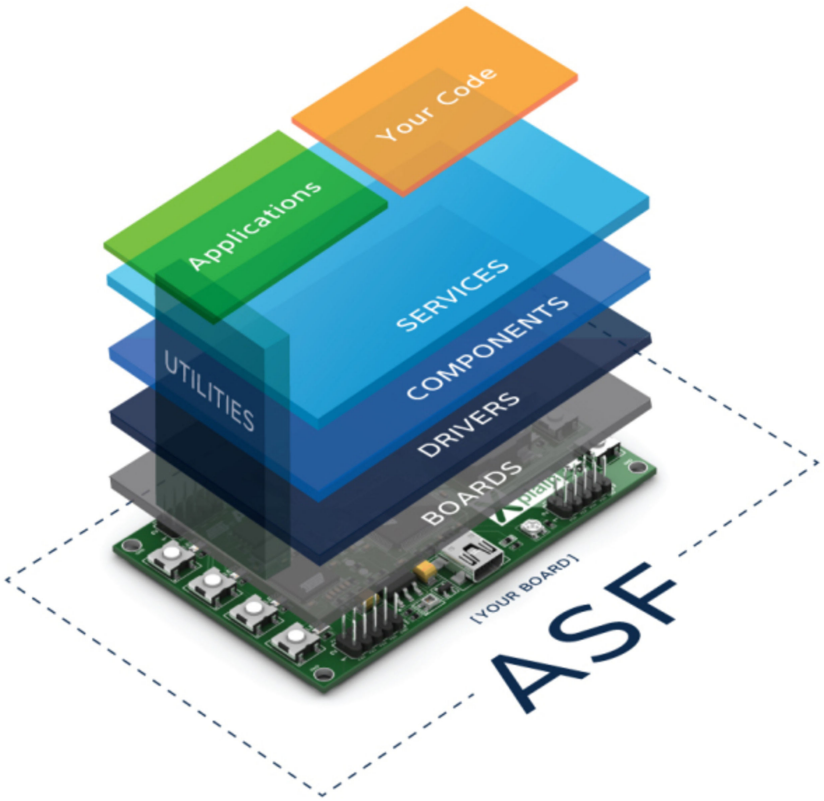
SMART ARM-based Microcontrollers

AT13526: ASF Manual (SAM C21)

APPLICATION NOTE

Preface

The Atmel® Software Framework (ASF) is a collection of free embedded software for Atmel microcontroller devices. It simplifies the usage of Atmel products, providing an abstraction to the hardware and high-value middle-ware. ASF is designed to be used for evaluation, prototyping, design, and production phases. ASF is integrated in the Atmel Studio IDE with a graphical user interface or available as a standalone package for several commercial and open source compilers. This document describes the API interfaces to the low level ASF module drivers of the device.



For more information on ASF, refer to the online documentation at http://www.atmel.com/asf.

Table of Contents

1. Software License

2. SAM Analog Comparator (AC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Analog Comparator functionality, for the comparison of analog voltages against a known reference voltage to determine its relative level. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- AC (Analog Comparator)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

2.1. Prerequisites

There are no prerequisites for this module.

2.2. Module Overview

The Analog Comparator module provides an interface for the comparison of one or more analog voltage inputs (sourced from external or internal inputs) against a known reference voltage, to determine if the unknown voltage is higher or lower than the reference. Additionally, window functions are provided so that two comparators can be connected together to determine if an input is below, inside, above, or outside the two reference points of the window.

Each comparator requires two analog input voltages, a positive and negative channel input. The result of the comparison is a binary `true` if the comparator's positive channel input is higher than the comparator's negative input channel, and `false` if otherwise.

2.2.1. Driver Feature Macro Definition

Driver feature macro	Supported devices
FEATURE_AC_HYSTERESIS_LEVEL	SAM L21/L22/C20/C21
FEATURE_AC_SYNCBUSY_SCHEME_VERSION_2	SAM L21/L22/C20/C21
FEATURE_AC_RUN_IN_STANDY_EACH_COMPARATOR	SAM L21/L22/C20/C21
FEATURE_AC_RUN_IN_STANDY_PAIR_COMPARATOR	SAM D20/L22/D21/D10/D11/R21/DAx

Note: The specific features are only available in the driver when the selected device supports those features.

2.2.2. Window Comparators and Comparator Pairs

Each comparator module contains one or more comparator pairs, a set of two distinct comparators which can be used independently or linked together for Window Comparator mode. In this latter mode, the two comparator units in a comparator pair are linked together to allow the module to detect if an input voltage is below, inside, above, or outside a window set by the upper and lower threshold voltages set by the two comparators. If not required, window comparison mode can be turned off and the two comparator units can be configured and used separately.

2.2.3. Positive and Negative Input MUXes

Each comparator unit requires two input voltages, a positive and a negative channel (note that these names refer to the logical operation that the unit performs, and both voltages should be above GND), which are then compared with one another. Both the positive and the negative channel inputs are connected to a pair of multiplexers (MUXes), which allows one of several possible inputs to be selected for each comparator channel.

The exact channels available for each comparator differ for the positive and the negative inputs, but the same MUX choices are available for all comparator units (i.e. all positive MUXes are identical, all negative MUXes are identical). This allows the user application to select which voltages are compared to one another.

When used in window mode, both comparators in the window pair should have their positive channel input MUXes configured to the same input channel, with the negative channel input MUXes used to set the lower and upper window bounds.

2.2.4. Output Filtering

The output of each comparator unit can either be used directly with no filtering (giving a lower latency signal, with potentially more noise around the comparison threshold) or be passed through a multiple stage digital majority filter. Several filter lengths are available, with the longer stages producing a more stable result, at the expense of a higher latency.

When output filtering is used in single shot mode, a single trigger of the comparator will automatically perform the required number of samples to produce a correctly filtered result.

2.2.5. Input Hysteresis

To prevent unwanted noise around the threshold where the comparator unit's positive and negative input channels are close in voltage to one another, an optional hysteresis can be used to widen the point at

which the output result flips. This mode will prevent a change in the comparison output unless the inputs cross one another beyond the hysteresis gap introduces by this mode.

2.2.6. Single Shot and Continuous Sampling Modes

Comparators can be configured to run in either Single Shot or Continuous sampling modes; when in Single Shot mode, the comparator will only perform a comparison (and any resulting filtering, see Output Filtering) when triggered via a software or event trigger. This mode improves the power efficiency of the system by only performing comparisons when actually required by the application.

For systems requiring a lower latency or more frequent comparisons, continuous mode will place the comparator into continuous sampling mode, which increases the module's power consumption, but decreases the latency between each comparison result by automatically performing a comparison on every cycle of the module's clock.

2.2.7. Events

Each comparator unit is capable of being triggered by both software and hardware triggers. Hardware input events allow for other peripherals to automatically trigger a comparison on demand - for example, a timer output event could be used to trigger comparisons at a desired regular interval.

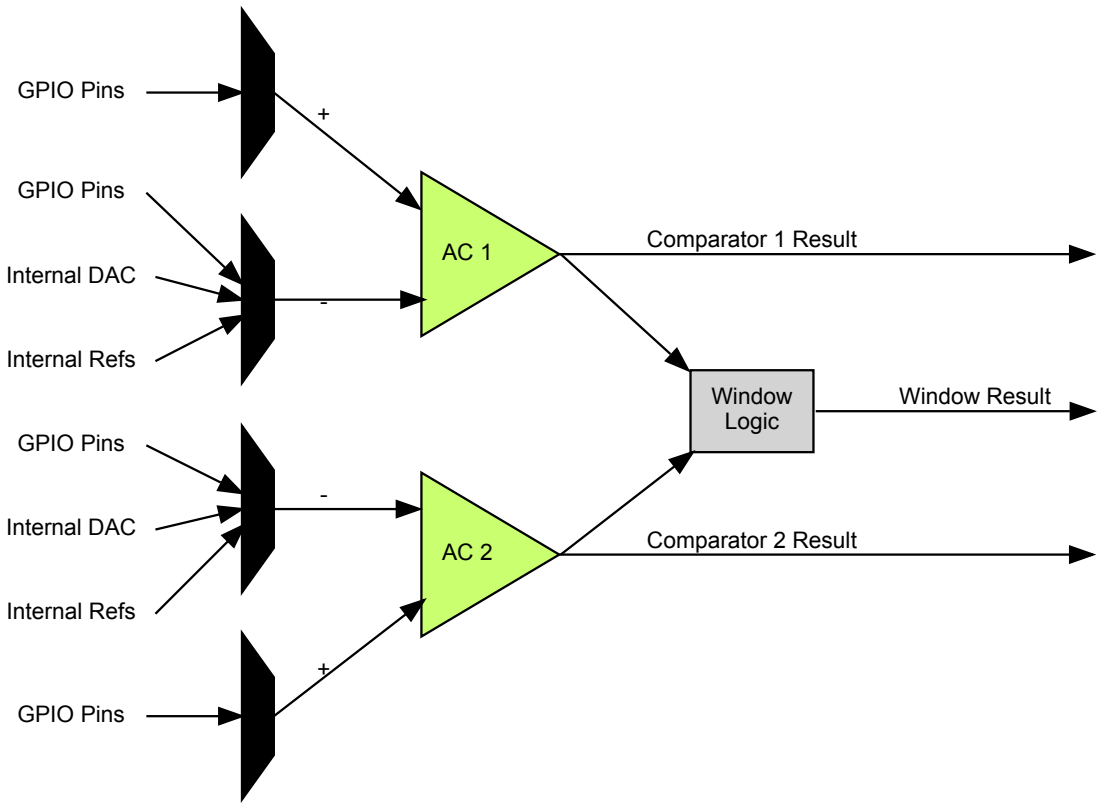
The module's output events can similarly be used to trigger other hardware modules each time a new comparison result is available. This scheme allows for reduced levels of CPU usage in an application and lowers the overall system response latency by directly triggering hardware peripherals from one another without requiring software intervention.

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

2.2.8. Physical Connection

Physically, the modules are interconnected within the device as shown in Figure 2-1.

Figure 2-1. Physical Connection



2.3. Special Considerations

The number of comparator pairs (and, thus, window comparators) within a single hardware instance of the Analog Comparator module is device-specific. Some devices will contain a single comparator pair, while others may have two pairs; refer to your device specific datasheet for details.

2.4. Extra Information

For extra information, see Extra Information for AC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

2.5. Examples

For a list of examples related to this driver, see Examples for AC Driver.

2.6. API Overview

2.6.1. Variable and Type Definitions

2.6.1.1. Type ac_callback_t

```
typedef void(* ac_callback_t )(struct ac_module *const module_inst)
```

Type definition for a AC module callback function.

2.6.2. Structure Definitions

2.6.2.1. Struct ac_chan_config

Configuration structure for a comparator channel, to configure the input and output settings of the comparator.

Table 2-1. Members

Type	Name	Description
bool	enable_hysteresis	When `true`, hysteresis mode is enabled on the comparator inputs
enum ac_chan_filter	filter	Filtering mode for the comparator output, when the comparator is used in a supported mode
enum ac_hysteresis_level	hysteresis_level	Hysteresis level of the comparator channel
enum ac_chan_interrupt_selection	interrupt_selection	Interrupt criteria for the comparator channel, to select the condition that will trigger a callback
enum ac_chan_neg_mux	negative_input	Input multiplexer selection for the comparator's negative input pin. Any internal reference source, such as a bandgap reference voltage or the DAC, must be configured and enabled prior to its use as a comparator input.
enum ac_chan_output	output_mode	Output mode of the comparator, whether it should be available for internal use, or asynchronously/ synchronously linked to a general-purpose input/ output (GPIO) pin
enum ac_chan_pos_mux	positive_input	Input multiplexer selection for the comparator's positive input pin
bool	run_in_standby	If `true`, the comparator will continue to sample during sleep mode when triggered

Type	Name	Description
enum ac_chan_sample_mode	sample_mode	Sampling mode of the comparator channel
uint8_t	vcc_scale_factor	Scaled VCC voltage division factor for the channel, when a comparator pin is connected to the V_{CC} voltage scalar input. The formular is: Vscale = Vdd * vcc_scale_factor / 64. If the V_{CC} voltage scalar is not selected as a comparator channel pin's input, this value will be ignored.

2.6.2.2. Struct ac_config

Configuration structure for a comparator channel, to configure the input and output settings of the comparator.

Table 2-2. Members

Type	Name	Description
enum gclk_generator	source_generator	Source generator for AC GCLK

2.6.2.3. Struct ac_events

Event flags for the Analog Comparator module. This is used to enable and disable events via ac_enable_events() and ac_disable_events().

Table 2-3. Members

Type	Name	Description
bool	generate_event_on_state[]	If `true`, an event will be generated when a comparator state changes
bool	generate_event_on_window[]	If `true`, an event will be generated when a comparator window state changes
bool	on_event_sample[]	If `true`, a comparator will be sampled each time an event is received

2.6.2.4. Struct ac_module

AC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

2.6.2.5. Struct ac_win_config

Table 2-4. Members

Type	Name	Description
enum ac_win_interrupt_selection	interrupt_selection	Interrupt criteria for the comparator window channel, to select the condition that will trigger a callback

2.6.3. Macro Definitions

2.6.3.1. Driver Feature Definition

Define AC driver feature set according to different device family.

Macro FEATURE_AC_HYSTERESIS_LEVEL

```
#define FEATURE_AC_HYSTERESIS_LEVEL
```

Setting of hysteresis level

Macro FEATURE_AC_SYNCBUSY_SCHEME_VERSION_2

```
#define FEATURE_AC_SYNCBUSY_SCHEME_VERSION_2
```

SYNCBUSY scheme version 2

Macro FEATURE_AC_RUN_IN_STANDY_EACH_COMPARATOR

```
#define FEATURE_AC_RUN_IN_STANDY_EACH_COMPARATOR
```

Run in standby feature for each comparator

2.6.3.2. AC Window Channel Status Flags

AC window channel status flags, returned by ac_win_get_status().

Macro AC_WIN_STATUS_UNKNOWN

```
#define AC_WIN_STATUS_UNKNOWN
```

Unknown output state; the comparator window channel was not ready.

Macro AC_WIN_STATUS_ABOVE

```
#define AC_WIN_STATUS_ABOVE
```

Window Comparator's input voltage is above the window

Macro AC_WIN_STATUS_INSIDE

```
#define AC_WIN_STATUS_INSIDE
```

Window Comparator's input voltage is inside the window

Macro AC_WIN_STATUS_BELOW

```
#define AC_WIN_STATUS_BELOW
```

Window Comparator's input voltage is below the window

Macro AC_WIN_STATUS_INTERRUPT_SET

```
#define AC_WIN_STATUS_INTERRUPT_SET
```

This state reflects the window interrupt flag. When the interrupt flag should be set is configured in ac_win_set_config(). This state needs to be cleared by the of ac_win_clear_status().

2.6.3.3. AC Channel Status Flags

AC channel status flags, returned by ac_chan_get_status().

Macro AC_CHAN_STATUS_UNKNOWN

```
#define AC_CHAN_STATUS_UNKNOWN
```

Unknown output state; the comparator channel was not ready.

Macro AC_CHAN_STATUS_NEG_ABOVE_POS

```
#define AC_CHAN_STATUS_NEG_ABOVE_POS
```

Comparator's negative input pin is higher in voltage than the positive input pin.

Macro AC_CHAN_STATUS_POS_ABOVE_NEG

```
#define AC_CHAN_STATUS_POS_ABOVE_NEG
```

Comparator's positive input pin is higher in voltage than the negative input pin.

Macro AC_CHAN_STATUS_INTERRUPT_SET

```
#define AC_CHAN_STATUS_INTERRUPT_SET
```

This state reflects the channel interrupt flag. When the interrupt flag should be set is configured in ac_chan_set_config(). This state needs to be cleared by the of ac_chan_clear_status().

2.6.4. Function Definitions

2.6.4.1. Configuration and Initialization

Function ac_reset()

Resets and disables the Analog Comparator driver.

```
enum status_code ac_reset(
        struct ac_module *const module_inst)
```

Resets and disables the Analog Comparator driver, resets the internal states and registers of the hardware module to their power-on defaults.

Table 2-5. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the AC software instance struct

Function ac_init()

Initializes and configures the Analog Comparator driver.

```
enum status_code ac_init(
        struct ac_module *const module_inst,
        Ac *const hw,
        struct ac_config *const config)
```

Initializes the Analog Comparator driver, configuring it to the user supplied configuration parameters, ready for use. This function should be called before enabling the Analog Comparator.

Note: Once called the Analog Comparator will not be running; to start the Analog Comparator call ac_enable() after configuring the module.

Table 2-6. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the AC software instance struct
[in]	hw	Pointer to the AC module instance
[in]	config	Pointer to the config struct, created by the user application

Function ac_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool ac_is_syncing(
        struct ac_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 2-7. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the AC software instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 2-8. Return Values

Return value	Description
false	If the module has completed synchronization
ture	If the module synchronization is ongoing

Function ac_get_config_defaults()

Initializes all members of an Analog Comparator configuration structure to safe defaults.

```
void ac_get_config_defaults(
        struct ac_config *const config)
```

Initializes all members of a given Analog Comparator configuration structure to safe known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- All comparator pairs disabled during sleep mode (if has this feature)
- Generator 0 is the default GCLK generator

Table 2-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function ac_enable()

Enables an Analog Comparator that was previously configured.

```
void ac_enable(
        struct ac_module *const module_inst)
```

Enables an Analog Comparator that was previously configured via a call to ac_init().

Table 2-10. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral

Function ac_disable()

Disables an Analog Comparator that was previously enabled.

```
void ac_disable(
        struct ac_module *const module_inst)
```

Disables an Analog Comparator that was previously started via a call to ac_enable().

Table 2-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral

Function ac_enable_events()

Enables an Analog Comparator event input or output.

```
void ac_enable_events(
        struct ac_module *const module_inst,
        struct ac_events *const events)
```

Enables one or more input or output events to or from the Analog Comparator module. See ac_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 2-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	events	Struct containing flags of events to enable

Function ac_disable_events()

Disables an Analog Comparator event input or output.

```
void ac_disable_events(
        struct ac_module *const module_inst,
        struct ac_events *const events)
```

Disables one or more input or output events to or from the Analog Comparator module. See ac_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 2-13. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	events	Struct containing flags of events to disable

2.6.4.2. Channel Configuration and Initialization

Function ac_chan_get_config_defaults()

Initializes all members of an Analog Comparator channel configuration structure to safe defaults.

```
void ac_chan_get_config_defaults(
        struct ac_chan_config *const config)
```

Initializes all members of an Analog Comparator channel configuration structure to safe defaults. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Continuous sampling mode
- Majority of five sample output filter
- Comparator disabled during sleep mode (if has this feature)
- Hysteresis enabled on the input pins
- Hysteresis level of 50mV if having this feature
- Internal comparator output mode
- Comparator pin multiplexer 0 selected as the positive input
- Scaled V_{CC} voltage selected as the negative input
- V_{CC} voltage scaler set for a division factor of two
- Channel interrupt set to occur when the compare threshold is passed

Table 2-14. Parameters

Data direction	Parameter name	Description
[out]	config	Channel configuration structure to initialize to default values

Function ac_chan_set_config()

Writes an Analog Comparator channel configuration to the hardware module.

```
enum status_code ac_chan_set_config(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel,
        struct ac_chan_config *const config)
```

Writes a given Analog Comparator channel configuration to the hardware module.

Table 2-15. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Analog Comparator channel to configure
[in]	config	Pointer to the channel configuration struct

Function ac_chan_enable()

Enables an Analog Comparator channel that was previously configured.

```
void ac_chan_enable(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

Enables an Analog Comparator channel that was previously configured via a call to ac_chan_set_config().

Table 2-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to enable

Function ac_chan_disable()

Disables an Analog Comparator channel that was previously enabled.

```
void ac_chan_disable(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

Stops an Analog Comparator channel that was previously started via a call to ac_chan_enable().

Table 2-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to disable

2.6.4.3. Channel Control

Function ac_chan_trigger_single_shot()

Triggers a comparison on a comparator that is configured in single shot mode.

```
void ac_chan_trigger_single_shot(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

Triggers a single conversion on a comparator configured to compare on demand (single shot mode) rather than continuously.

Table 2-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to trigger

Function ac_chan_is_ready()

Determines if a given comparator channel is ready for comparisons.

```
bool ac_chan_is_ready(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

Checks a comparator channel to see if the comparator is currently ready to begin comparisons.

Table 2-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to test

Returns

Comparator channel readiness state.

Function ac_chan_get_status()

Determines the output state of a comparator channel.

```
uint8_t ac_chan_get_status(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

Retrieves the last comparison value (after filtering) of a given comparator. If the comparator was not ready at the time of the check, the comparison result will be indicated as being unknown.

Table 2-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to test

Returns

Bit mask of comparator channel status flags.

Function ac_chan_clear_status()

Clears an interrupt status flag.

```
void ac_chan_clear_status(
        struct ac_module *const module_inst,
        const enum ac_chan_channel channel)
```

This function is used to clear the AC_CHAN_STATUS_INTERRUPT_SET flag it will clear the flag for the channel indicated by the channel argument.

Table 2-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	channel	Comparator channel to clear

2.6.4.4. Window Mode Configuration and Initialization

Function ac_win_get_config_defaults()

Initializes an Analog Comparator window configuration structure to defaults.

```
void ac_win_get_config_defaults(
        struct ac_win_config *const config)
```

Initializes a given Analog Comparator channel configuration structure to a set of known default values. This function should be called if window interrupts are needed and before ac_win_set_config().

The default configuration is as follows:

- Channel interrupt set to occur when the measurement is above the window

Table 2-22. Parameters

Data direction	Parameter name	Description
[out]	config	Window configuration structure to initialize to default values

Function ac_win_set_config()

Function used to setup interrupt selection of a window.

```
enum status_code ac_win_set_config(
        struct ac_module *const module_inst,
        enum ac_win_channel const win_channel,
        struct ac_win_config *const config)
```

This function is used to setup when an interrupt should occur for a given window.

Note: This must be done before enabling the channel.

Table 2-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to software instance struct
[in]	win_channel	Window channel to setup
[in]	config	Configuration for the given window channel

Table 2-24. Return Values

Return value	Description
STATUS_OK	Function exited successful
STATUS_ERR_INVALID_ARG	win_channel argument incorrect

Function ac_win_enable()

Enables an Analog Comparator window channel that was previously configured.

```
enum status_code ac_win_enable(
        struct ac_module *const module_inst,
        const enum ac_win_channel win_channel)
```

Enables and starts an Analog Comparator window channel.

Note: The comparator channels used by the window channel must be configured and enabled before calling this function. The two comparator channels forming each window comparator pair must have identical configurations other than the negative pin multiplexer setting.

Table 2-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator window channel to enable

Returns
Status of the window enable procedure.

Table 2-26. Return Values

Return value	Description
STATUS_OK	The window comparator was enabled
STATUS_ERR_IO	One or both comparators in the window comparator pair is disabled
STATUS_ERR_BAD_FORMAT	The comparator channels in the window pair were not configured correctly

Function ac_win_disable()

Disables an Analog Comparator window channel that was previously enabled.

```
void ac_win_disable(
        struct ac_module *const module_inst,
        const enum ac_win_channel win_channel)
```

Stops an Analog Comparator window channel that was previously started via a call to ac_win_enable().

Table 2-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator window channel to disable

2.6.4.5. Window Mode Control

Function ac_win_is_ready()

Determines if a given Window Comparator is ready for comparisons.

```
bool ac_win_is_ready(
        struct ac_module *const module_inst,
        const enum ac_win_channel win_channel)
```

Checks a Window Comparator to see if the both comparators used for window detection is currently ready to begin comparisons.

Table 2-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Window Comparator channel to test

Returns
Window Comparator channel readiness state.

Function ac_win_get_status()

Determines the state of a specified Window Comparator.

```
uint8_t ac_win_get_status(
        struct ac_module *const module_inst,
        const enum ac_win_channel win_channel)
```

Retrieves the current window detection state, indicating what the input signal is currently comparing to relative to the window boundaries.

Table 2-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Comparator Window channel to test

Returns
Bit mask of Analog Comparator window channel status flags.

Function ac_win_clear_status()

Clears an interrupt status flag.

```
void ac_win_clear_status(
        struct ac_module *const module_inst,
        const enum ac_win_channel win_channel)
```

This function is used to clear the AC_WIN_STATUS_INTERRUPT_SET flag it will clear the flag for the channel indicated by the win_channel argument.

Table 2-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Analog Comparator peripheral
[in]	win_channel	Window channel to clear

2.6.5. Enumeration Definitions

2.6.5.1. Enum ac_callback

Enum for possible callback types for the AC module.

Table 2-31. Members

Enum value	Description
AC_CALLBACK_COMPARATOR_0	Callback for comparator 0
AC_CALLBACK_COMPARATOR_1	Callback for comparator 1
AC_CALLBACK_WINDOW_0	Callback for window 0

2.6.5.2. Enum ac_chan_channel

Enum for the possible comparator channels.

Table 2-32. Members

Enum value	Description
AC_CHAN_CHANNEL_0	Comparator channel 0 (Pair 0, Comparator 0)
AC_CHAN_CHANNEL_1	Comparator channel 1 (Pair 0, Comparator 1)
AC_CHAN_CHANNEL_2	Comparator channel 2 (Pair 1, Comparator 0)
AC_CHAN_CHANNEL_3	Comparator channel 3 (Pair 1, Comparator 1)

2.6.5.3. Enum ac_chan_filter

Enum for the possible channel output filtering configurations of an Analog Comparator channel.

Table 2-33. Members

Enum value	Description
AC_CHAN_FILTER_NONE	No output filtering is performed on the comparator channel
AC_CHAN_FILTER_MAJORITY_3	Comparator channel output is passed through a Majority-of-Three filter
AC_CHAN_FILTER_MAJORITY_5	Comparator channel output is passed through a Majority-of-Five filter

2.6.5.4. Enum ac_chan_interrupt_selection

This enum is used to select when a channel interrupt should occur.

Table 2-34. Members

Enum value	Description
AC_CHAN_INTERRUPT_SELECTION_TOGGLE	An interrupt will be generated when the comparator level is passed
AC_CHAN_INTERRUPT_SELECTION_RISING	An interrupt will be generated when the measurement goes above the compare level
AC_CHAN_INTERRUPT_SELECTION_FALLING	An interrupt will be generated when the measurement goes below the compare level
AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE	An interrupt will be generated when a new measurement is complete. Interrupts will only be generated in single shot mode. This state needs to be cleared by the use of ac_chan_cleare_status()

2.6.5.5. Enum ac_chan_neg_mux

Enum for the possible channel negative pin input of an Analog Comparator channel.

Table 2-35. Members

Enum value	Description
AC_CHAN_NEG_MUX_PIN0	Negative comparator input is connected to physical AC input pin 0
AC_CHAN_NEG_MUX_PIN1	Negative comparator input is connected to physical AC input pin 1
AC_CHAN_NEG_MUX_PIN2	Negative comparator input is connected to physical AC input pin 2
AC_CHAN_NEG_MUX_PIN3	Negative comparator input is connected to physical AC input pin 3

Enum value	Description
AC_CHAN_NEG_MUX_GND	Negative comparator input is connected to the internal ground plane
AC_CHAN_NEG_MUX_SCALED_VCC	Negative comparator input is connected to the channel's internal V_{CC} plane voltage scalar
AC_CHAN_NEG_MUX_BANDGAP	Negative comparator input is connected to the internal band gap voltage reference
AC_CHAN_NEG_MUX_DAC0	For SAM D20/D21/D10/D11/R21/DA1: Negative comparator input is connected to the channel's internal DAC channel 0 output. For SAM L21/C20/C21: Negative comparator input is connected to the channel's internal DAC channel 0 output for Comparator 0 or OPAMP output for Comparator 1.

2.6.5.6. Enum ac_chan_output

Enum for the possible channel GPIO output routing configurations of an Analog Comparator channel.

Table 2-36. Members

Enum value	Description
AC_CHAN_OUTPUT_INTERNAL	Comparator channel output is not routed to a physical GPIO pin, and is used internally only
AC_CHAN_OUTPUT_ASYNCRONOUS	Comparator channel output is routed to its matching physical GPIO pin, via an asynchronous path
AC_CHAN_OUTPUT_SYNCHRONOUS	Comparator channel output is routed to its matching physical GPIO pin, via a synchronous path

2.6.5.7. Enum ac_chan_pos_mux

Enum for the possible channel positive pin input of an Analog Comparator channel.

Table 2-37. Members

Enum value	Description
AC_CHAN_POS_MUX_PIN0	Positive comparator input is connected to physical AC input pin 0
AC_CHAN_POS_MUX_PIN1	Positive comparator input is connected to physical AC input pin 1
AC_CHAN_POS_MUX_PIN2	Positive comparator input is connected to physical AC input pin 2
AC_CHAN_POS_MUX_PIN3	Positive comparator input is connected to physical AC input pin 3

2.6.5.8. Enum ac_chan_sample_mode

Enum for the possible channel sampling modes of an Analog Comparator channel.

Table 2-38. Members

Enum value	Description
AC_CHAN_MODE_CONTINUOUS	Continuous sampling mode; when the channel is enabled the comparator output is available for reading at any time
AC_CHAN_MODE_SINGLE_SHOT	Single shot mode; when used the comparator channel must be triggered to perform a comparison before reading the result

2.6.5.9. Enum ac_hysteresis_level

Enum for possible hysteresis level types for AC module.

Table 2-39. Members

Enum value	Description
AC_HYSTERESIS_LEVEL_50	Hysteresis level of 50mV
AC_HYSTERESIS_LEVEL_70	Hysteresis level of 70mV
AC_HYSTERESIS_LEVEL_90	Hysteresis level of 90mV
AC_HYSTERESIS_LEVEL_110	Hysteresis level of 110mV

2.6.5.10. Enum ac_win_channel

Enum for the possible window comparator channels.

Table 2-40. Members

Enum value	Description
AC_WIN_CHANNEL_0	Window channel 0 (Pair 0, Comparators 0 and 1)
AC_WIN_CHANNEL_1	Window channel 1 (Pair 1, Comparators 2 and 3)

2.6.5.11. Enum ac_win_interrupt_selection

This enum is used to select when a window interrupt should occur.

Table 2-41. Members

Enum value	Description
AC_WIN_INTERRUPT_SELECTION_ABOVE	Interrupt is generated when the compare value goes above the window
AC_WIN_INTERRUPT_SELECTION_INSIDE	Interrupt is generated when the compare value goes inside the window
AC_WIN_INTERRUPT_SELECTION_BELOW	Interrupt is generated when the compare value goes below the window
AC_WIN_INTERRUPT_SELECTION_OUTSIDE	Interrupt is generated when the compare value goes outside the window

2.7. Extra Information for AC Driver

2.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
AC	Analog Comparator
DAC	Digital-to-Analog Converter
MUX	Multiplexer

2.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

2.7.3. Errata

There are no errata related to this driver.

2.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

2.8. Examples for AC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Analog Comparator (AC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for AC - Basic
- Quick Start Guide for AC - Callback

2.8.1. Quick Start Guide for AC - Basic

In this use case, the Analog Comparator module is configured for:

- Comparator peripheral in manually triggered (e.g. "Single Shot" mode)
- One comparator channel connected to input MUX pin 0 and compared to a scaled $V_{CC}/2$ voltage

This use case sets up the Analog Comparator to compare an input voltage fed into a GPIO pin of the device against a scaled voltage of the microcontroller's V_{CC} power rail. The comparisons are made on-demand in single-shot mode, and the result stored into a local variable which is then output to the board LED to visually show the comparison state.

2.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
/* AC module software instance (must not go out of scope while in use) */
static struct ac_module ac_instance;

/* Comparator channel that will be used */
#define AC_COMPARATOR_CHANNEL   AC_CHAN_CHANNEL_0

void configure_ac(void)
{
    /* Create a new configuration structure for the Analog Comparator settings
    * and fill with the default module settings. */
    struct ac_config config_ac;
    ac_get_config_defaults(&config_ac);

    /* Alter any Analog Comparator configuration settings here if required */

    /* Initialize and enable the Analog Comparator with the user settings */
    ac_init(&ac_instance, AC, &config_ac);
}

void configure_ac_channel(void)
{
    /* Create a new configuration structure for the Analog Comparator channel
    * settings and fill with the default module channel settings. */
    struct ac_chan_config ac_chan_conf;
    ac_chan_get_config_defaults(&ac_chan_conf);

    /* Set the Analog Comparator channel configuration settings */
    ac_chan_conf.sample_mode      = AC_CHAN_MODE_SINGLE_SHOT;
    ac_chan_conf.positive_input   = AC_CHAN_POS_MUX_PIN0;
    ac_chan_conf.negative_input   = AC_CHAN_NEG_MUX_SCALED_VCC;
    ac_chan_conf.vcc_scale_factor = 32;

    /* Set up a pin as an AC channel input */
    struct system_pinmux_config ac0_pin_conf;
    system_pinmux_get_config_defaults(&ac0_pin_conf);
    ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    ac0_pin_conf.mux_position = CONF_AC_MUX;
    system_pinmux_pin_set_config(CONF_AC_PIN, &ac0_pin_conf);

    /* Initialize and enable the Analog Comparator channel with the user
    * settings */
    ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &ac_chan_conf);
    ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_ac();
configure_ac_channel();
ac_enable(&ac_instance);
```

Workflow

1. Create an AC device instance struct, which will be associated with an Analog Comparator peripheral hardware instance.

```
static struct ac_module ac_instance;
```

   Note: Device instance structures shall never go out of scope when in use.

2. Define a macro to select the comparator channel that will be sampled, for convenience.

```
#define AC_COMPARATOR_CHANNEL   AC_CHAN_CHANNEL_0
```

3. Create a new function `configure_ac()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac(void)
```

4. Create an Analog Comparator peripheral configuration structure that will be filled out to set the module configuration.

```
struct ac_config config_ac;
```

5. Fill the Analog Comparator peripheral configuration structure with the default module configuration values.

```
ac_get_config_defaults(&config_ac);
```

6. Initialize the Analog Comparator peripheral and associate it with the software instance structure that was defined previously.

```
ac_init(&ac_instance, AC, &config_ac);
```

7. Create a new function `configure_ac_channel()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac_channel(void)
```

8. Create an Analog Comparator channel configuration structure that will be filled out to set the channel configuration.

```
struct ac_chan_config ac_chan_conf;
```

9. Fill the Analog Comparator channel configuration structure with the default channel configuration values.

```
ac_chan_get_config_defaults(&ac_chan_conf);
```

10. Alter the channel configuration parameters to set the channel to one-shot mode, with the correct negative and positive MUX selections and the desired voltage scaler.

```
ac_chan_conf.sample_mode      = AC_CHAN_MODE_SINGLE_SHOT;
ac_chan_conf.positive_input   = AC_CHAN_POS_MUX_PIN0;
ac_chan_conf.negative_input   = AC_CHAN_NEG_MUX_SCALED_VCC;
ac_chan_conf.vcc_scale_factor = 32;
```

    Note: The voltage scalar formula is documented in description for ac_chan_config::vcc_scale_factor.

11. Configure the physical pin that will be routed to the AC module channel 0.

```
struct system_pinmux_config ac0_pin_conf;
system_pinmux_get_config_defaults(&ac0_pin_conf);
ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
```

```
ac0_pin_conf.mux_position = CONF_AC_MUX;
system_pinmux_pin_set_config(CONF_AC_PIN, &ac0_pin_conf);
```

12. Initialize the Analog Comparator channel and configure it with the desired settings.

```
ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL, &ac_chan_conf);
```

13. Enable the now initialized Analog Comparator channel.

```
ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
```

14. Enable the now initialized Analog Comparator peripheral.

```
ac_enable(&ac_instance);
```

2.8.1.2. Implementation

Code

Copy-paste the following code to your user application:

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);

uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;

while (true) {
    if (ac_chan_is_ready(&ac_instance, AC_COMPARATOR_CHANNEL)) {
        do {
            last_comparison = ac_chan_get_status(&ac_instance,
                    AC_COMPARATOR_CHANNEL);
        } while (last_comparison & AC_CHAN_STATUS_UNKNOWN);

        port_pin_set_output_level(LED_0_PIN,
                (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));

        ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
    }
}
```

Workflow

1. Trigger the first comparison on the comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

2. Create a local variable to maintain the current comparator state. Since no comparison has taken place, it is initialized to AC_CHAN_STATUS_UNKNOWN.

```
uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
```

3. Make the application loop infinitely, while performing triggered comparisons.

```
while (true) {
```

4. Check if the comparator is ready for the last triggered comparison result to be read.

```
if (ac_chan_is_ready(&ac_instance, AC_COMPARATOR_CHANNEL)) {
```

5. Read the comparator output state into the local variable for application use, re-trying until the comparison state is ready.

```
do {
    last_comparison = ac_chan_get_status(&ac_instance,
            AC_COMPARATOR_CHANNEL);
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

6. Set the board LED state to mirror the last comparison state.

```
port_pin_set_output_level(LED_0_PIN,
        (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
```

7. Trigger the next conversion on the Analog Comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

2.8.2. Quick Start Guide for AC - Callback

In this use case, the Analog Comparator module is configured for:

- Comparator peripheral in manually triggered (e.g. "Single Shot" mode)
- One comparator channel connected to input MUX pin 0 and compared to a scaled $V_{CC}/2$ voltage

This use case sets up the Analog Comparator to compare an input voltage fed into a GPIO pin of the device against a scaled voltage of the microcontroller's V_{CC} power rail. The comparisons are made on-demand in single-shot mode, and the result stored into a local variable which is then output to the board LED to visually show the comparison state.

2.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
/* AC module software instance (must not go out of scope while in use). */
static struct ac_module ac_instance;

/* Comparator channel that will be used. */
#define AC_COMPARATOR_CHANNEL   AC_CHAN_CHANNEL_0

void configure_ac(void)
{
    /* Create a new configuration structure for the Analog Comparator settings
    * and fill with the default module settings. */
    struct ac_config config_ac;
    ac_get_config_defaults(&config_ac);

    /* Alter any Analog Comparator configuration settings here if required. */

    /* Initialize and enable the Analog Comparator with the user settings. */
    ac_init(&ac_instance, AC, &config_ac);
}

void configure_ac_channel(void)
{
    /* Create a new configuration structure for the Analog Comparator channel
    * settings and fill with the default module channel settings. */
    struct ac_chan_config config_ac_chan;
    ac_chan_get_config_defaults(&config_ac_chan);

    /* Set the Analog Comparator channel configuration settings. */
    config_ac_chan.sample_mode          = AC_CHAN_MODE_SINGLE_SHOT;
    config_ac_chan.positive_input       = AC_CHAN_POS_MUX_PIN0;
    config_ac_chan.negative_input       = AC_CHAN_NEG_MUX_SCALED_VCC;
    config_ac_chan.vcc_scale_factor     = 32;
    config_ac_chan.interrupt_selection =
AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE;
```

```
    /* Set up a pin as an AC channel input. */
    struct system_pinmux_config ac0_pin_conf;
    system_pinmux_get_config_defaults(&ac0_pin_conf);
    ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    ac0_pin_conf.mux_position = CONF_AC_MUX;
    system_pinmux_pin_set_config(CONF_AC_PIN, &ac0_pin_conf);

    /* Initialize and enable the Analog Comparator channel with the user
    * settings. */
    ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL,
&config_ac_chan);
    ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
}

void callback_function_ac(struct ac_module *const module_inst)
{
    callback_status = true;
}

void configure_ac_callback(void)
{
    ac_register_callback(&ac_instance, callback_function_ac,
AC_CALLBACK_COMPARATOR_0);
    ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_ac();
configure_ac_channel();
configure_ac_callback();

ac_enable(&ac_instance);
```

Workflow

1. Create an AC device instance struct, which will be associated with an Analog Comparator peripheral hardware instance.

   ```
   static struct ac_module ac_instance;
   ```

   Note: Device instance structures shall never go out of scope when in use.
2. Define a macro to select the comparator channel that will be sampled, for convenience.

   ```
   #define AC_COMPARATOR_CHANNEL    AC_CHAN_CHANNEL_0
   ```
3. Create a new function `configure_ac()`, which will be used to configure the overall Analog Comparator peripheral.

   ```
   void configure_ac(void)
   {
   ```
4. Create an Analog Comparator peripheral configuration structure that will be filled out to set the module configuration.

   ```
   struct ac_config config_ac;
   ```

5. Fill the Analog Comparator peripheral configuration structure with the default module configuration values.

```
ac_get_config_defaults(&config_ac);
```

6. Initialize the Analog Comparator peripheral and associate it with the software instance structure that was defined previously.

```
ac_init(&ac_instance, AC, &config_ac);
```

7. Create a new function `configure_ac_channel()`, which will be used to configure the overall Analog Comparator peripheral.

```
void configure_ac_channel(void)
{
```

8. Create an Analog Comparator channel configuration structure that will be filled out to set the channel configuration.

```
struct ac_chan_config config_ac_chan;
```

9. Fill the Analog Comparator channel configuration structure with the default channel configuration values.

```
ac_chan_get_config_defaults(&config_ac_chan);
```

10. Alter the channel configuration parameters to set the channel to one-shot mode, with the correct negative and positive MUX selections and the desired voltage scaler.
Note: The voltage scalar formula is documented in description for ac_chan_config::vcc_scale_factor.

11. Select when the interrupt should occur. In this case an interrupt will occur at every finished conversion.

```
config_ac_chan.sample_mode          = AC_CHAN_MODE_SINGLE_SHOT;
config_ac_chan.positive_input       = AC_CHAN_POS_MUX_PIN0;
config_ac_chan.negative_input       = AC_CHAN_NEG_MUX_SCALED_VCC;
config_ac_chan.vcc_scale_factor     = 32;
config_ac_chan.interrupt_selection =
AC_CHAN_INTERRUPT_SELECTION_END_OF_COMPARE;
```

12. Configure the physical pin that will be routed to the AC module channel 0.

```
struct system_pinmux_config ac0_pin_conf;
system_pinmux_get_config_defaults(&ac0_pin_conf);
ac0_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
ac0_pin_conf.mux_position = CONF_AC_MUX;
system_pinmux_pin_set_config(CONF_AC_PIN, &ac0_pin_conf);
```

13. Initialize the Analog Comparator channel and configure it with the desired settings.

```
ac_chan_set_config(&ac_instance, AC_COMPARATOR_CHANNEL,
&config_ac_chan);
```

14. Enable the initialized Analog Comparator channel.

```
ac_chan_enable(&ac_instance, AC_COMPARATOR_CHANNEL);
```

15. Create a new callback function.

```
void callback_function_ac(struct ac_module *const module_inst)
{
    callback_status = true;
}
```

16. Create a callback status software flag.

```
bool volatile callback_status = false;
```

17. Let the callback function set the calback_status flag to true.

```
callback_status = true;
```

18. Create a new function `configure_ac_callback()`, which will be used to configure the callbacks.

```
void configure_ac_callback(void)
{
    ac_register_callback(&ac_instance, callback_function_ac,
AC_CALLBACK_COMPARATOR_0);
    ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
}
```

19. Register callback function.

```
ac_register_callback(&ac_instance, callback_function_ac,
AC_CALLBACK_COMPARATOR_0);
```

20. Enable the callbacks.

```
ac_enable_callback(&ac_instance, AC_CALLBACK_COMPARATOR_0);
```

21. Enable the now initialized Analog Comparator peripheral.

```
ac_enable(&ac_instance);
```

Note: This should not be done until after the AC is setup and ready to be used.

2.8.2.2. Implementation

Code

Copy-paste the following code to your user application:

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);

uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
port_pin_set_output_level(LED_0_PIN, true);
while (true) {
    if (callback_status == true) {
        do
        {
            last_comparison = ac_chan_get_status(&ac_instance,
                    AC_COMPARATOR_CHANNEL);
        } while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
        port_pin_set_output_level(LED_0_PIN,
                (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
        callback_status = false;
        ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
    }
}
```

Workflow

1. Trigger the first comparison on the comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

2. Create a local variable to maintain the current comparator state. Since no comparison has taken place, it is initialized to AC_CHAN_STATUS_UNKNOWN.

```
uint8_t last_comparison = AC_CHAN_STATUS_UNKNOWN;
```

3. Make the application loop infinitely, while performing triggered comparisons.

```
while (true) {
```

4. Check if a new comparison is complete.

```
if (callback_status == true) {
```

5. Check if the comparator is ready for the last triggered comparison result to be read.

```
do
{
    last_comparison = ac_chan_get_status(&ac_instance,
            AC_COMPARATOR_CHANNEL);
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

6. Read the comparator output state into the local variable for application use, re-trying until the comparison state is ready.

```
do
{
    last_comparison = ac_chan_get_status(&ac_instance,
            AC_COMPARATOR_CHANNEL);
} while (last_comparison & AC_CHAN_STATUS_UNKNOWN);
```

7. Set the board LED state to mirror the last comparison state.

```
port_pin_set_output_level(LED_0_PIN,
        (last_comparison & AC_CHAN_STATUS_NEG_ABOVE_POS));
```

8. After the interrupt is handled, set the software callback flag to false.

```
callback_status = false;
```

9. Trigger the next conversion on the Analog Comparator channel.

```
ac_chan_trigger_single_shot(&ac_instance, AC_COMPARATOR_CHANNEL);
```

3. SAM Analog-to-Digital Converter (ADC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Analog-to-Digital Converter functionality, for the conversion of analog voltages into a corresponding digital form. The following driver Application Programming Interface (API) modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- ADC (Analog-to-Digital Converter)

The following devices can use this module:

- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

3.1. Prerequisites

There are no prerequisites for this module.

3.2. Module Overview

This driver provides an interface for the Analog-to-Digital conversion functions on the device, to convert analog voltages to a corresponding digital value. The ADC has up to 12-bit resolution, and is capable of converting up to 1,000,000 samples per second (MSPS).

The ADC has a compare function for accurate monitoring of user defined thresholds with minimum software intervention required. The ADC may be configured for 8-, 10-, or 12-bit result, reducing the conversion time. ADC conversion results are provided left or right adjusted which eases calculation when the result is represented as a signed integer.

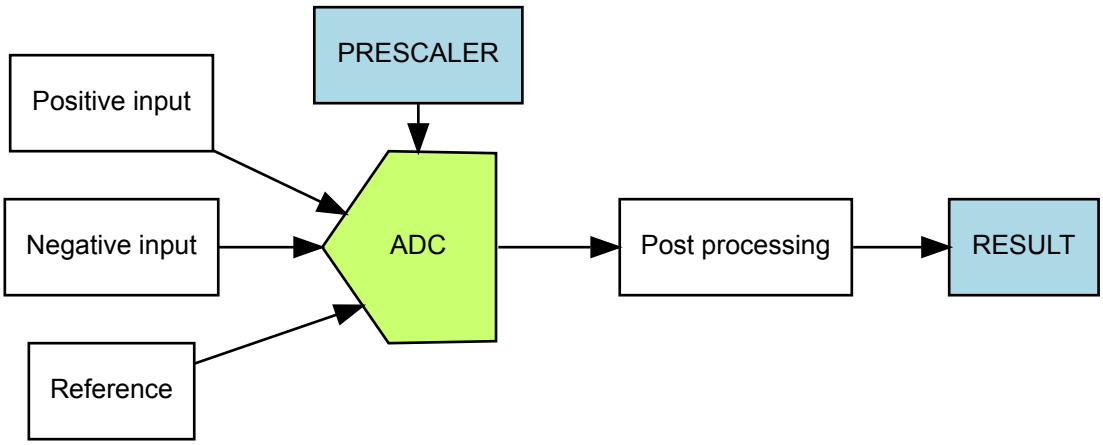
The input selection is flexible, and both single-ended and differential measurements can be made. For differential measurements, an optional gain stage is available to increase the dynamic range. In addition, several internal signal inputs are available. The ADC can provide both signed and unsigned results.

The ADC measurements can either be started by application software or an incoming event from another peripheral in the device, and both internal and external reference voltages can be selected.

Note: Internal references will be enabled by the driver, but not disabled. Any reference not used by the application should be disabled by the application.

A simplified block diagram of the ADC can be seen in Figure 3-1.

Figure 3-1. Module Overview



3.2.1. Sample Clock Prescaler

The ADC features a prescaler, which enables conversion at lower clock rates than the input Generic Clock to the ADC module. This feature can be used to lower the synchronization time of the digital interface to the ADC module via a high speed Generic Clock frequency, while still allowing the ADC sampling rate to be reduced.

3.2.2. ADC Resolution

The ADC supports full 8-, 10-, or 12-bit resolution. Hardware oversampling and decimation can be used to increase the effective resolution at the expense of throughput. Using oversampling and decimation mode the ADC resolution is increased from 12-bit to an effective 13-, 14-, 15-, or 16-bit. In these modes the conversion rate is reduced, as a greater number of samples is used to achieve the increased resolution. The available resolutions and effective conversion rate is listed in Table 3-1.

Table 3-1. Effective ADC Conversion Speed Using Oversampling

Resolution	Effective conversion rate
13-bit	Conversion rate divided by 4
14-bit	Conversion rate divided by 16
15-bit	Conversion rate divided by 64
16-bit	Conversion rate divided by 256

3.2.3. Conversion Modes

ADC conversions can be software triggered on demand by the user application, if continuous sampling is not required. It is also possible to configure the ADC in free running mode, where new conversions are started as soon as the previous conversion is completed, or configure the ADC to scan across a number of input pins (see Pin Scan).

3.2.4. Differential and Single-ended Conversion

The ADC has two conversion modes; differential and single-ended. When measuring signals where the positive input pin is always at a higher voltage than the negative input pin, the single-ended conversion mode should be used in order to achieve a full 12-bit output resolution.

If however the positive input pin voltage may drop below the negative input pin the signed differential mode should be used.

3.2.5. Sample Time

The sample time for each ADC conversion is configurable as a number of half prescaled ADC clock cycles (depending on the prescaler value), allowing the user application to achieve faster or slower sampling depending on the source impedance of the ADC input channels. For applications with high impedance inputs the sample time can be increased to give the ADC an adequate time to sample and convert the input channel.

The resulting sampling time is given by the following equation:

$$t_{SAMPLE} = (sample\_length + 1) \times \frac{ADC_{CLK}}{2}$$

3.2.6. Averaging

The ADC can be configured to trade conversion speed for accuracy by averaging multiple samples in hardware. This feature is suitable when operating in noisy conditions.

You can specify any number of samples to accumulate (up to 1024) and the divide ratio to use (up to divide by 128). To modify these settings the ADC_RESOLUTION_CUSTOM needs to be set as the resolution. When this is set the number of samples to accumulate and the division ratio can be set by the configuration struct members adc_config::accumulate_samples and adc_config::divide_result. When using this mode the ADC result register will be set to be 16-bit wide to accommodate the larger result sizes produced by the accumulator.

The effective ADC conversion rate will be reduced by a factor of the number of accumulated samples; however, the effective resolution will be increased according to Table 3-2.

Table 3-2. Effective ADC Resolution From Various Hardware Averaging Modes

Number of samples	Final result
1	12-bit
2	13-bit
4	14-bit
8	15-bit
16	16-bit
32	16-bit
64	16-bit
128	16-bit
256	16-bit
512	16-bit
1024	16-bit

3.2.7. Offset and Gain Correction

Inherent gain and offset errors affect the absolute accuracy of the ADC.

The offset error is defined as the deviation of the ADC's actual transfer function from ideal straight line at zero input voltage.

The gain error is defined as the deviation of the last output step's midpoint from the ideal straight line, after compensating for offset error.

The offset correction value is subtracted from the converted data before the result is ready. The gain correction value is multiplied with the offset corrected value.

The equation for both offset and gain error compensation is shown below:

$$ADC_{RESULT} = \left(VALUE_{CONV} + CORR_{OFFSET}\right) \times CORR_{GAIN}$$

When enabled, a given set of offset and gain correction values can be applied to the sampled data in hardware, giving a corrected stream of sample data to the user application at the cost of an increased sample latency.

In single conversion, a latency of 13 ADC Generic Clock cycles is added for the final sample result availability. As the correction time is always less than the propagation delay, in free running mode this latency appears only during the first conversion. After the first conversion is complete, future conversion results are available at the defined sampling rate.

3.2.8. Pin Scan

In pin scan mode, the first ADC conversion will begin from the configured positive channel, plus the requested starting offset. When the first conversion is completed, the next conversion will start at the next positive input channel and so on, until all requested pins to scan have been sampled and converted. SAM L21/L22 has automatic sequences feature instead of pin scan mode. In automatic sequence mode, all of 32 positives inputs can be included in a sequence. The sequence starts from the lowest input, and go to the next enabled input automatically.

Pin scanning gives a simple mechanism to sample a large number of physical input channel samples, using a single physical ADC channel.

3.2.9. Window Monitor

The ADC module window monitor function can be used to automatically compare the conversion result against a preconfigured pair of upper and lower threshold values.

The threshold values are evaluated differently, depending on whether differential or single-ended mode is selected. In differential mode, the upper and lower thresholds are evaluated as signed values for the comparison, while in single-ended mode the comparisons are made as a set of unsigned values.

The significant bits of the lower window monitor threshold and upper window monitor threshold values are user-configurable, and follow the overall ADC sampling bit precision set when the ADC is configured by the user application. For example, only the eight lower bits of the window threshold values will be compared to the sampled data whilst the ADC is configured in 8-bit mode. In addition, if using differential mode, the 8th bit will be considered as the sign bit even if bit 9 is zero.

3.2.10. Events

Event generation and event actions are configurable in the ADC.

The ADC has two actions that can be triggered upon event reception:

- Start conversion
- Flush pipeline and start conversion

The ADC can generate two events:

- Window monitor
- Result ready

If the event actions are enabled in the configuration, any incoming event will trigger the action.

If the window monitor event is enabled, an event will be generated when the configured window condition is detected.

If the result ready event is enabled, an event will be generated when a conversion is completed.

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

3.3. Special Considerations

An integrated analog temperature sensor is available for use with the ADC. The bandgap voltage, as well as the scaled I/O and core voltages can also be measured by the ADC. For internal ADC inputs, the internal source(s) may need to be manually enabled by the user application before they can be measured.

3.4. Extra Information

For extra information, see Extra Information for ADC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

3.5. Examples

For a list of examples related to this driver, see Examples for ADC Driver.

3.6. API Overview

3.6.1. Variable and Type Definitions

3.6.1.1. Type adc_callback_t

```
typedef void(* adc_callback_t )(struct adc_module *const module)
```

Type of the callback functions.

3.6.2. Structure Definitions

3.6.2.1. Struct adc_config

Configuration structure for an ADC instance. This structure should be initialized by the adc_get_config_defaults() function before being modified by the user application.

Table 3-3. Members

Type	Name	Description
enum adc_accumulate_samples	accumulate_samples	Number of ADC samples to accumulate when using the ADC_RESOLUTION_CUSTOM mode
enum adc_clock_prescaler	clock_prescaler	Clock prescaler
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
struct adc_correction_config	correction	Gain and offset correction configuration structure
bool	differential_mode	Enables differential mode if true
enum adc_divide_result	divide_result	Division ration when using the ADC_RESOLUTION_CUSTOM mode
enum adc_event_action	event_action	Event action to take on incoming event
bool	freerunning	Enables free running mode if true
bool	left_adjust	Left adjusted result
enum adc_negative_input	negative_input	Negative MUX input
bool	on_demand	ADC On demand control
enum adc_positive_input	positive_input	Positive MUX input
uint32_t	positive_input_sequence_mask_enable	Positive input enabled mask for conversion sequence. The sequence start from the lowest input, and go to the next enabled input automatically when the conversion is done. If no bits are set the sequence is disabled.
enum adc_reference	reference	Voltage reference

Type	Name	Description
bool	reference_compensation_enable	Enables reference buffer offset compensation if true. This will increase the accuracy of the gain stage, but decreases the input impedance; therefore the startup time of the reference must be increased.
enum adc_resolution	resolution	Result resolution
bool	run_in_standby	ADC run in standby control
uint8_t	sample_length	This value (0-63) control the ADC sampling time in number of half ADC prescaled clock cycles (depends of `ADC_PRESCALER` value), thus controlling the ADC input impedance. Sampling time is set according to the formula: Sample time = (sample_length+1) * (ADCclk / 2).
bool	sampling_time_compensation_enable	Enables sampling period offset compensation if true
struct adc_window_config	window	Window monitor configuration structure

3.6.2.2. Struct adc_correction_config

Gain and offset correction configuration structure. Part of the adc_config struct and will be initialized by adc_get_config_defaults.

Table 3-4. Members

Type	Name	Description
bool	correction_enable	Enables correction for gain and offset based on values of gain_correction and offset_correction if set to true
uint16_t	gain_correction	This value defines how the ADC conversion result is compensated for gain error before written to the result register. This is a fractional value, 1-bit integer plus an 11-bit fraction, therefore 1/2 <= gain_correction < 2. Valid `gain_correction` values ranges from `0b010000000000` to `0b111111111111`.
int16_t	offset_correction	This value defines how the ADC conversion result is compensated for offset error before written to the result register. This is a 12-bit value in two's complement format.

3.6.2.3. Struct adc_events

Event flags for the ADC module. This is used to enable and disable events via adc_enable_events() and adc_disable_events().

Table 3-5. Members

Type	Name	Description
bool	generate_event_on_conversion_done	Enable event generation on conversion done
bool	generate_event_on_window_monitor	Enable event generation on window monitor

3.6.2.4. Struct adc_module

ADC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

3.6.2.5. Struct adc_window_config

Window monitor configuration structure.

Table 3-6. Members

Type	Name	Description
int32_t	window_lower_value	Lower window value
enum adc_window_mode	window_mode	Selected window mode
int32_t	window_upper_value	Upper window value

3.6.3. Macro Definitions

3.6.3.1. Module Status Flags

ADC status flags, returned by adc_get_status() and cleared by adc_clear_status().

Macro ADC_STATUS_RESULT_READY

```
#define ADC_STATUS_RESULT_READY
```

ADC result ready.

Macro ADC_STATUS_WINDOW

```
#define ADC_STATUS_WINDOW
```

Window monitor match.

Macro ADC_STATUS_OVERRUN

```
#define ADC_STATUS_OVERRUN
```

ADC result overwritten before read.

3.6.3.2. Macro FEATURE_ADC_SUPPORT_MASTER_SLAVE

```
#define FEATURE_ADC_SUPPORT_MASTER_SLAVE
```

Output Driver Strength Selection feature support.

3.6.4. Function Definitions

3.6.4.1. Driver Initialization and Configuration

Function adc_init()

Initializes the ADC.

```
enum status_code adc_init(
        struct adc_module *const module_inst,
        Adc * hw,
        struct adc_config * config)
```

Initializes the ADC device struct and the hardware module based on the given configuration struct values.

Table 3-7. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the ADC software instance struct
[in]	hw	Pointer to the ADC module instance
[in]	config	Pointer to the configuration struct

Returns

Status of the initialization procedure.

Table 3-8. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_ERR_INVALID_ARG	Invalid argument(s) were provided
STATUS_BUSY	The module is busy with a reset operation
STATUS_ERR_DENIED	The module is enabled

Function adc_get_config_defaults()

Initializes an ADC configuration structure to defaults.

```
void adc_get_config_defaults(
        struct adc_config *const config)
```

Initializes a given ADC configuration struct to a set of known default values. This function should be called on any new instance of the configuration struct before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- Internal bandgap reference
- Div 2 clock prescaler
- 12-bit resolution
- Window monitor disabled

- Positive input on ADC PIN 1
- Negative input on Internal ground
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- ADC run in standby disabled
- ADC On demand disabled
- No sampling time compensation
- Disable the positive input sequense
- No reference compensation
- No gain/offset correction
- No added sampling time

Table 3-9. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration struct to initialize to default values

3.6.4.2. Status Management

Function adc_get_status()

Retrieves the current module status.

```
uint32_t adc_get_status(
        struct adc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 3-10. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Returns

Bitmask of `ADC_STATUS_*` flags.

Table 3-11. Return Values

Return value	Description
ADC_STATUS_RESULT_READY	ADC result is ready to be read
ADC_STATUS_WINDOW	ADC has detected a value inside the set window range
ADC_STATUS_OVERRUN	ADC result has overrun

Function adc_clear_status()

Clears a module status flag.

```
void adc_clear_status(
        struct adc_module *const module_inst,
        const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 3-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	status_flags	Bitmask of `ADC_STATUS_*` flags to clear

3.6.4.3. Enable, Disable, and Reset ADC Module, Start Conversion and Read Result

Function adc_enable()

Enables the ADC module.

```
enum status_code adc_enable(
        struct adc_module *const module_inst)
```

Enables an ADC module that has previously been configured. If any internal reference is selected it will be enabled.

Table 3-13. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_disable()

Disables the ADC module.

```
enum status_code adc_disable(
        struct adc_module *const module_inst)
```

Disables an ADC module that was previously enabled.

Table 3-14. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_reset()

Resets the ADC module.

```
enum status_code adc_reset(
        struct adc_module *const module_inst)
```

Resets an ADC module, clearing all module state, and registers to their default values.

Table 3-15. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_enable_events()

Enables an ADC event input or output.

```
void adc_enable_events(
        struct adc_module *const module_inst,
        struct adc_events *const events)
```

Enables one or more input or output events to or from the ADC module. See Struct adc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 3-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the ADC peripheral
[in]	events	Struct containing flags of events to enable

Function adc_disable_events()

Disables an ADC event input or output.

```
void adc_disable_events(
        struct adc_module *const module_inst,
        struct adc_events *const events)
```

Disables one or more input or output events to or from the ADC module. See Struct adc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 3-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the ADC peripheral
[in]	events	Struct containing flags of events to disable

Function adc_start_conversion()

Starts an ADC conversion.

```
void adc_start_conversion(
        struct adc_module *const module_inst)
```

Starts a new ADC conversion.

Table 3-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_read()

Reads the ADC result.

```
enum status_code adc_read(
        struct adc_module *const module_inst,
        uint16_t * result)
```

Reads the result from an ADC conversion that was previously started.

Table 3-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[out]	result	Pointer to store the result value in

Returns
Status of the ADC read request.

Table 3-20. Return Values

Return value	Description
STATUS_OK	The result was retrieved successfully
STATUS_BUSY	A conversion result was not ready
STATUS_ERR_OVERFLOW	The result register has been overwritten by the ADC module before the result was read by the software

3.6.4.4. Runtime Changes of ADC Module

Function adc_flush()

Flushes the ADC pipeline.

```
void adc_flush(
        struct adc_module *const module_inst)
```

Flushes the pipeline and restarts the ADC clock on the next peripheral clock edge. All conversions in progress will be lost. When flush is complete, the module will resume where it left off.

Table 3-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_set_window_mode()

Sets the ADC window mode.

```
void adc_set_window_mode(
        struct adc_module *const module_inst,
        const enum adc_window_mode window_mode,
        const int16_t window_lower_value,
        const int16_t window_upper_value)
```

Sets the ADC window mode to a given mode and value range.

Table 3-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	window_mode	Window monitor mode to set
[in]	window_lower_value	Lower window monitor threshold value
[in]	window_upper_value	Upper window monitor threshold value

Function adc_set_positive_input()

Sets positive ADC input pin.

```
void adc_set_positive_input(
        struct adc_module *const module_inst,
        const enum adc_positive_input positive_input)
```

Sets the positive ADC input pin selection.

Table 3-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	positive_input	Positive input pin

Function adc_set_negative_input()

Sets negative ADC input pin for differential mode.

```
void adc_set_negative_input(
        struct adc_module *const module_inst,
        const enum adc_negative_input negative_input)
```

Sets the negative ADC input pin, when the ADC is configured in differential mode.

Table 3-24. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	negative_input	Negative input pin

3.6.4.5. Enable and Disable Interrupts

Function adc_enable_interrupt()

Enable interrupt.

```
void adc_enable_interrupt(
        struct adc_module *const module_inst,
        enum adc_interrupt_flag interrupt)
```

Enable the given interrupt request from the ADC module.

Table 3-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	interrupt	Interrupt to enable

Function adc_disable_interrupt()

Disable interrupt.

```
void adc_disable_interrupt(
        struct adc_module *const module_inst,
        enum adc_interrupt_flag interrupt)
```

Disable the given interrupt request from the ADC module.

Table 3-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	interrupt	Interrupt to disable

3.6.4.6. Callback Management

Function adc_register_callback()

Registers a callback.

```
void adc_register_callback(
        struct adc_module *const module,
        adc_callback_t callback_func,
        enum adc_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note: The callback must be enabled for the interrupt handler to call it when the condition for the callback is met.

Table 3-27. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function adc_unregister_callback()

Unregisters a callback.

```
void adc_unregister_callback(
        struct adc_module * module,
        enum adc_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 3-28. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Function adc_enable_callback()

Enables callback.

```
void adc_enable_callback(
        struct adc_module *const module,
        enum adc_callback callback_type)
```

Enables the callback function registered by adc_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 3-29. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns
Status of the operation.

Table 3-30. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

Function adc_disable_callback()

Disables callback.

```
void adc_disable_callback(
        struct adc_module *const module,
        enum adc_callback callback_type)
```

Disables the callback function registered by the adc_register_callback.

Table 3-31. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to ADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns
Status of the operation.

Table 3-32. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

3.6.4.7. Job Management

Function adc_read_buffer_job()

Read multiple samples from ADC.

```
enum status_code adc_read_buffer_job(
        struct adc_module *const module_inst,
        uint16_t * buffer,
        uint16_t samples)
```

Read `samples` from the ADC into the `buffer`. If there is no hardware trigger defined (event action) the driver will retrigger the ADC conversion whenever a conversion is complete until `samples` has been acquired. To avoid jitter in the sampling frequency using an event trigger is advised.

Table 3-33. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	samples	Number of samples to acquire
[out]	buffer	Buffer to store the ADC samples

Returns
Status of the job start.

Table 3-34. Return Values

Return value	Description
STATUS_OK	The conversion job was started successfully and is in progress
STATUS_BUSY	The ADC is already busy with another job

Function adc_get_job_status()

Gets the status of a job.

```
enum status_code adc_get_job_status(
        struct adc_module * module_inst,
        enum adc_job_type type)
```

Gets the status of an ongoing or the last job.

Table 3-35. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	type	Type of to get status

Returns
Status of the job.

Function adc_abort_job()

Aborts an ongoing job.

```
void adc_abort_job(
        struct adc_module * module_inst,
        enum adc_job_type type)
```

Aborts an ongoing job.

Table 3-36. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	type	Type of job to abort

3.6.4.8. Positive Input Sequence

Function adc_enable_positive_input_sequence()

Enable positive input sequence mask for conversion.

```
void adc_enable_positive_input_sequence(
        struct adc_module *const module_inst,
        uint32_t positive_input_sequence_mask_enable)
```

The sequence start from the lowest input, and go to the next enabled input automatically when the conversion is done. If no bits are set the sequence is disabled.

Table 3-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[in]	eanble_seq_mask	Sequence mask

Function adc_disable_positive_input_sequence()

Disable positive input in the sequence.

```
void adc_disable_positive_input_sequence(
        struct adc_module *const module_inst)
```

Disable positive input in the sequence.

Table 3-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct

Function adc_get_sequence_status()

Get ADC sequence status.

```
void adc_get_sequence_status(
        struct adc_module *const module_inst,
        bool * is_sequence_busy,
        uint8_t * sequence_state)
```

Check if a sequence is done and get last conversion done in the sequence.

Table 3-39. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the ADC software instance struct
[out]	is_sequence_busy	Sequence busy status
[out]	sequence_state	This value identifies the last conversion done in the sequence

3.6.4.9. Function adc_set_master_slave_mode()

Set ADC master and slave mode.

```
void adc_set_master_slave_mode(
        struct adc_module *const master_inst,
        struct adc_module *const slave_inst,
        enum adc_dual_mode_trigger_selection dualsel)
```

Enable ADC module Master-Slave Operation and select dual mode trigger.

Table 3-40. Parameters

Data direction	Parameter name	Description
[in]	master_inst	Pointer to the master ADC software instance struct
[in]	slave_inst	Pointer to the slave ADC software instance struct
[in]	dualsel	Dual mode trigger selection

3.6.5. Enumeration Definitions

3.6.5.1. Enum adc_accumulate_samples

Enum for the possible numbers of ADC samples to accumulate. This setting is only used when the ADC_RESOLUTION_CUSTOM resolution setting is used.

Table 3-41. Members

Enum value	Description
ADC_ACCUMULATE_DISABLE	No averaging
ADC_ACCUMULATE_SAMPLES_2	Average 2 samples
ADC_ACCUMULATE_SAMPLES_4	Average 4 samples
ADC_ACCUMULATE_SAMPLES_8	Average 8 samples
ADC_ACCUMULATE_SAMPLES_16	Average 16 samples
ADC_ACCUMULATE_SAMPLES_32	Average 32 samples
ADC_ACCUMULATE_SAMPLES_64	Average 64 samples
ADC_ACCUMULATE_SAMPLES_128	Average 128 samples
ADC_ACCUMULATE_SAMPLES_256	Average 256 samples
ADC_ACCUMULATE_SAMPLES_512	Average 512 samples
ADC_ACCUMULATE_SAMPLES_1024	Average 1024 samples

3.6.5.2. Enum adc_callback

Callback types for ADC callback driver.

Table 3-42. Members

Enum value	Description
ADC_CALLBACK_READ_BUFFER	Callback for buffer received
ADC_CALLBACK_WINDOW	Callback when window is hit
ADC_CALLBACK_ERROR	Callback for error

3.6.5.3. Enum adc_clock_prescaler

Enum for the possible clock prescaler values for the ADC.

Table 3-43. Members

Enum value	Description
ADC_CLOCK_PRESCALER_DIV2	ADC clock division factor 2
ADC_CLOCK_PRESCALER_DIV4	ADC clock division factor 4
ADC_CLOCK_PRESCALER_DIV8	ADC clock division factor 8

Enum value	Description
ADC_CLOCK_PRESCALER_DIV16	ADC clock division factor 16
ADC_CLOCK_PRESCALER_DIV32	ADC clock division factor 32
ADC_CLOCK_PRESCALER_DIV64	ADC clock division factor 64
ADC_CLOCK_PRESCALER_DIV128	ADC clock division factor 128
ADC_CLOCK_PRESCALER_DIV256	ADC clock division factor 256

3.6.5.4. Enum adc_divide_result

Enum for the possible division factors to use when accumulating multiple samples. To keep the same resolution for the averaged result and the actual input value, the division factor must be equal to the number of samples accumulated. This setting is only used when the ADC_RESOLUTION_CUSTOM resolution setting is used.

Table 3-44. Members

Enum value	Description
ADC_DIVIDE_RESULT_DISABLE	Don't divide result register after accumulation
ADC_DIVIDE_RESULT_2	Divide result register by 2 after accumulation
ADC_DIVIDE_RESULT_4	Divide result register by 4 after accumulation
ADC_DIVIDE_RESULT_8	Divide result register by 8 after accumulation
ADC_DIVIDE_RESULT_16	Divide result register by 16 after accumulation
ADC_DIVIDE_RESULT_32	Divide result register by 32 after accumulation
ADC_DIVIDE_RESULT_64	Divide result register by 64 after accumulation
ADC_DIVIDE_RESULT_128	Divide result register by 128 after accumulation

3.6.5.5. Enum adc_dual_mode_trigger_selection

Enum for the trigger selection in dual mode.

Table 3-45. Members

Enum value	Description
ADC_DUAL_MODE_BOTH	Start event or software trigger will start a conversion on both ADCs
ADC_DUAL_MODE_INTERLEAVE	START event or software trigger will alternatingly start a conversion on ADC0 and ADC1

3.6.5.6. Enum adc_event_action

Enum for the possible actions to take on an incoming event.

Table 3-46. Members

Enum value	Description
ADC_EVENT_ACTION_DISABLED	Event action disabled
ADC_EVENT_ACTION_FLUSH_START_CONV	Flush ADC and start conversion
ADC_EVENT_ACTION_START_CONV	Start conversion

3.6.5.7. Enum adc_interrupt_flag

Enum for the possible ADC interrupt flags.

Table 3-47. Members

Enum value	Description
ADC_INTERRUPT_RESULT_READY	ADC result ready
ADC_INTERRUPT_WINDOW	Window monitor match
ADC_INTERRUPT_OVERRUN	ADC result overwritten before read

3.6.5.8. Enum adc_job_type

Enum for the possible types of ADC asynchronous jobs that may be issued to the driver.

Table 3-48. Members

Enum value	Description
ADC_JOB_READ_BUFFER	Asynchronous ADC read into a user provided buffer

3.6.5.9. Enum adc_negative_input

Enum for the possible negative MUX input selections for the ADC.

Table 3-49. Members

Enum value	Description
ADC_NEGATIVE_INPUT_PIN0	ADC0 pin
ADC_NEGATIVE_INPUT_PIN1	ADC1 pin
ADC_NEGATIVE_INPUT_PIN2	ADC2 pin
ADC_NEGATIVE_INPUT_PIN3	ADC3 pin
ADC_NEGATIVE_INPUT_PIN4	ADC4 pin
ADC_NEGATIVE_INPUT_PIN5	ADC5 pin
ADC_NEGATIVE_INPUT_PIN6	ADC6 pin
ADC_NEGATIVE_INPUT_PIN7	ADC7 pin
ADC_NEGATIVE_INPUT_GND	Internal ground

3.6.5.10. Enum adc_oversampling_and_decimation

Enum for the possible numbers of bits resolution can be increased by when using oversampling and decimation.

Table 3-50. Members

Enum value	Description
ADC_OVERSAMPLING_AND_DECIMATION_DISABLE	Don't use oversampling and decimation mode
ADC_OVERSAMPLING_AND_DECIMATION_1BIT	1-bit resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_2BIT	2-bit resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_3BIT	3-bit resolution increase
ADC_OVERSAMPLING_AND_DECIMATION_4BIT	4-bit resolution increase

3.6.5.11. Enum adc_positive_input

Enum for the possible positive MUX input selections for the ADC.

Table 3-51. Members

Enum value	Description
ADC_POSITIVE_INPUT_PIN0	ADC0 pin
ADC_POSITIVE_INPUT_PIN1	ADC1 pin
ADC_POSITIVE_INPUT_PIN2	ADC2 pin
ADC_POSITIVE_INPUT_PIN3	ADC3 pin
ADC_POSITIVE_INPUT_PIN4	ADC4 pin
ADC_POSITIVE_INPUT_PIN5	ADC5 pin
ADC_POSITIVE_INPUT_PIN6	ADC6 pin
ADC_POSITIVE_INPUT_PIN7	ADC7 pin
ADC_POSITIVE_INPUT_PIN8	ADC8 pin
ADC_POSITIVE_INPUT_PIN9	ADC9 pin
ADC_POSITIVE_INPUT_PIN10	ADC10 pin
ADC_POSITIVE_INPUT_PIN11	ADC11 pin
ADC_POSITIVE_INPUT_PIN12	ADC12 pin
ADC_POSITIVE_INPUT_PIN13	ADC13 pin
ADC_POSITIVE_INPUT_PIN14	ADC14 pin
ADC_POSITIVE_INPUT_PIN15	ADC15 pin

Enum value	Description
ADC_POSITIVE_INPUT_PIN16	ADC16 pin
ADC_POSITIVE_INPUT_PIN17	ADC17 pin
ADC_POSITIVE_INPUT_PIN18	ADC18 pin
ADC_POSITIVE_INPUT_PIN19	ADC19 pin
ADC_POSITIVE_INPUT_PIN20	ADC20 pin.
ADC_POSITIVE_INPUT_PIN21	ADC21 pin
ADC_POSITIVE_INPUT_PIN22	ADC22 pin
ADC_POSITIVE_INPUT_PIN23	ADC23 pin
ADC_POSITIVE_INPUT_TEMP	Temperature reference.
ADC_POSITIVE_INPUT_BANDGAP	Bandgap voltage
ADC_POSITIVE_INPUT_SCALEDCOREVCC	1/4 scaled core supply
ADC_POSITIVE_INPUT_SCALEDIOVCC	1/4 scaled I/O supply
ADC_POSITIVE_INPUT_DAC	DAC input

3.6.5.12. Enum adc_reference

Enum for the possible reference voltages for the ADC.

Table 3-52. Members

Enum value	Description
ADC_REFERENCE_INTREF	Internal Bandgap Reference
ADC_REFERENCE_INTVCC0	1/1.48V_{CC} reference
ADC_REFERENCE_INTVCC1	1/2V_{CC} (only for internal V_{CC} > 2.1V)
ADC_REFERENCE_AREFA	External reference A
ADC_REFERENCE_INTVCC2	VDDANA

3.6.5.13. Enum adc_resolution

Enum for the possible resolution values for the ADC.

Table 3-53. Members

Enum value	Description
ADC_RESOLUTION_12BIT	ADC 12-bit resolution
ADC_RESOLUTION_16BIT	ADC 16-bit resolution using oversampling and decimation
ADC_RESOLUTION_10BIT	ADC 10-bit resolution

Enum value	Description
ADC_RESOLUTION_8BIT	ADC 8-bit resolution
ADC_RESOLUTION_13BIT	ADC 13-bit resolution using oversampling and decimation
ADC_RESOLUTION_14BIT	ADC 14-bit resolution using oversampling and decimation
ADC_RESOLUTION_15BIT	ADC 15-bit resolution using oversampling and decimation
ADC_RESOLUTION_CUSTOM	ADC 16-bit result register for use with averaging. When using this mode the ADC result register will be set to 16-bit wide, and the number of samples to accumulate and the division factor is configured by the adc_config::accumulate_samples and adc_config::divide_result members in the configuration struct.

3.6.5.14. Enum adc_window_mode

Enum for the possible window monitor modes for the ADC.

Table 3-54. Members

Enum value	Description
ADC_WINDOW_MODE_DISABLE	No window mode
ADC_WINDOW_MODE_ABOVE_LOWER	RESULT > WINLT
ADC_WINDOW_MODE_BELOW_UPPER	RESULT < WINUT
ADC_WINDOW_MODE_BETWEEN	WINLT < RESULT < WINUT
ADC_WINDOW_MODE_BETWEEN_INVERTED	!(WINLT < RESULT < WINUT)

3.7. Extra Information for ADC Driver

3.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

3.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

3.7.3. Errata

There are no errata related to this driver.

3.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

3.8. Examples for ADC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Analog-to-Digital Converter (ADC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for ADC - Basic
- Quick Start Guide for ADC - Callback
- Quick Start Guide for Using DMA with ADC/DAC

3.8.1. Quick Start Guide for ADC - Basic

In this use case, the ADC will be configured with the following settings:

- 1V from internal bandgap reference
- Div 4 clock prescaler
- 12-bit resolution
- Window monitor disabled
- No gain
- Positive input on ADC PIN x (depend on default configuration)
- Negative input to GND (single ended)
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

3.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct adc_module adc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;
    adc_get_config_defaults(&config_adc);

#if (SAMC21)
    adc_init(&adc_instance, ADC1, &config_adc);
#else
    adc_init(&adc_instance, ADC, &config_adc);
#endif

    adc_enable(&adc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();
```

Workflow

1. Create a module software instance structure for the ADC module to store the ADC driver state while in use.

   ```
   struct adc_module adc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the ADC module.
   1. Create an ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

      ```
      struct adc_config config_adc;
      ```
   2. Initialize the ADC configuration struct with the module's default values.

      ```
      adc_get_config_defaults(&config_adc);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   3. Set ADC configurations.

      ```
      #if (SAMC21)
          adc_init(&adc_instance, ADC1, &config_adc);
      #else
          adc_init(&adc_instance, ADC, &config_adc);
      #endif
      ```

4. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

3.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
adc_start_conversion(&adc_instance);

uint16_t result;

do {
    /* Wait for conversion to be done and read out result */
} while (adc_read(&adc_instance, &result) == STATUS_BUSY);

while (1) {
    /* Infinite loop */
}
```

Workflow

1. Start conversion.

```
adc_start_conversion(&adc_instance);
```

2. Wait until conversion is done and read result.

```
uint16_t result;

do {
    /* Wait for conversion to be done and read out result */
} while (adc_read(&adc_instance, &result) == STATUS_BUSY);
```

3. Enter an infinite loop once the conversion is complete.

```
while (1) {
    /* Infinite loop */
}
```

3.8.2. Quick Start Guide for ADC - Callback

In this use case, the ADC will convert 128 samples using interrupt driven conversion. When all samples have been sampled, a callback will be called that signals the main application that conversion is complete.

The ADC will be set up as follows:

- V_{CC} /2 as reference
- Div 8 clock prescaler
- 12-bit resolution
- Window monitor disabled
- 1/2 gain
- Positive input on ADC PIN 0
- Negative input to GND (single ended)
- Averaging disabled
- Oversampling disabled
- Right adjust data

- Single-ended mode
- Free running disabled
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

3.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct adc_module adc_instance;
```

```
#define ADC_SAMPLES 128
uint16_t adc_result_buffer[ADC_SAMPLES];
```

Callback function:

```
volatile bool adc_read_done = false;

void adc_complete_callback(
        struct adc_module *const module)
{
    adc_read_done = true;
}
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;
    adc_get_config_defaults(&config_adc);

#if (!SAML21) && (!SAML22) && (!SAMC21) && (!SAMR30)
    config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
#endif
    config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV8;
    config_adc.reference       = ADC_REFERENCE_INTVCC1;
#if (SAMC21)
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN5;
#else
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN6;
#endif
    config_adc.resolution      = ADC_RESOLUTION_12BIT;

#if (SAMC21)
    adc_init(&adc_instance, ADC1, &config_adc);
#else
    adc_init(&adc_instance, ADC, &config_adc);
#endif

    adc_enable(&adc_instance);
}
```

```
void configure_adc_callbacks(void)
{
    adc_register_callback(&adc_instance,
            adc_complete_callback, ADC_CALLBACK_READ_BUFFER);
    adc_enable_callback(&adc_instance, ADC_CALLBACK_READ_BUFFER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();
configure_adc_callbacks();
```

Workflow

1. Create a module software instance structure for the ADC module to store the ADC driver state while in use.

   ```
   struct adc_module adc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a buffer for the ADC samples to be stored in by the driver asynchronously.

   ```
   #define ADC_SAMPLES 128
   uint16_t adc_result_buffer[ADC_SAMPLES];
   ```
3. Create a callback function that will be called each time the ADC completes an asynchronous read job.

   ```
   volatile bool adc_read_done = false;

   void adc_complete_callback(
           struct adc_module *const module)
   {
       adc_read_done = true;
   }
   ```
4. Configure the ADC module.
   1. Create an ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

      ```
      struct adc_config config_adc;
      ```
   2. Initialize the ADC configuration struct with the module's default values.

      ```
      adc_get_config_defaults(&config_adc);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   3. Change the ADC module configuration to suit the application.

      ```
      #if (!SAML21) && (!SAML22) && (!SAMC21) && (!SAMR30)
          config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
      #endif
          config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV8;
          config_adc.reference       = ADC_REFERENCE_INTVCC1;
      #if (SAMC21)
          config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN5;
      #else
          config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN6;
      ```

```
#endif
    config_adc.resolution      = ADC_RESOLUTION_12BIT;
```

4. Set ADC configurations.

```
#if (SAMC21)
    adc_init(&adc_instance, ADC1, &config_adc);
#else
    adc_init(&adc_instance, ADC, &config_adc);
#endif
```

5. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

5. Register and enable the ADC Read Buffer Complete callback handler.
    1. Register the user-provided Read Buffer Complete callback function with the driver, so that it will be run when an asynchronous buffer read job completes.

```
adc_register_callback(&adc_instance,
        adc_complete_callback, ADC_CALLBACK_READ_BUFFER);
```

    2. Enable the Read Buffer Complete callback so that it will generate callbacks.

```
adc_enable_callback(&adc_instance, ADC_CALLBACK_READ_BUFFER);
```

3.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

adc_read_buffer_job(&adc_instance, adc_result_buffer, ADC_SAMPLES);

while (adc_read_done == false) {
    /* Wait for asynchronous ADC read to complete */
}

while (1) {
    /* Infinite loop */
}
```

Workflow

1. Enable global interrupts, so that callbacks can be generated by the driver.

```
system_interrupt_enable_global();
```

2. Start an asynchronous ADC conversion, to store ADC samples into the global buffer and generate a callback when complete.

```
adc_read_buffer_job(&adc_instance, adc_result_buffer, ADC_SAMPLES);
```

3. Wait until the asynchronous conversion is complete.

```
while (adc_read_done == false) {
    /* Wait for asynchronous ADC read to complete */
}
```

4. Enter an infinite loop once the conversion is complete.

```
while (1) {
    /* Infinite loop */
}
```

3.8.3. Quick Start Guide for Using DMA with ADC/DAC

The supported board list:

- SAM D21 Xplained Pro
- SAM D11 Xplained Pro
- SAM L21 Xplained Pro
- SAM DA1 Xplained Pro
- SAM C21 Xplained Pro

This quick start will convert an analog input signal from AIN4 and output the converted value to DAC on PA2. The data between ADC and DAC with be transferred through DMA instead of a CPU intervene.

The ADC will be configured with the following settings:

- 1/2 VDDANA
- Div 16 clock prescaler
- 10-bit resolution
- Window monitor disabled
- No gain
- Positive input on ADC AIN4
- Averaging disabled
- Oversampling disabled
- Right adjust data
- Single-ended mode
- Free running enable
- All events (input and generation) disabled
- Sleep operation disabled
- No reference compensation
- No gain/offset correction
- No added sampling time
- Pin scan mode disabled

The DAC will be configured with the following settings:

- Analog V_{CC} as reference
- Internal output disabled
- Drive the DAC output to PA2
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode

The DMA will be configured with the following settings:

- Move data from peripheral to peripheral
- Using ADC result ready trigger
- Using DMA priority level 0
- Beat transfer will be triggered on each trigger
- Loopback descriptor for DAC conversion

3.8.3.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct dac_module dac_instance;
```

```
struct adc_module adc_instance;
```

```
struct dma_resource example_resource;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;
```

Copy-paste the following setup code to your user application:

```
void configure_adc(void)
{
    struct adc_config config_adc;

    adc_get_config_defaults(&config_adc);

#if !(SAML21)
#if !(SAMC21)
    config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
#endif
    config_adc.resolution      = ADC_RESOLUTION_10BIT;
#endif
    config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV16;
    config_adc.reference       = ADC_REFERENCE_INTVCC1;
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
    config_adc.freerunning     = true;
    config_adc.left_adjust     = false;

#if (SAMC21)
    adc_init(&adc_instance, ADC1, &config_adc);
#else
    adc_init(&adc_instance, ADC, &config_adc);
#endif

    adc_enable(&adc_instance);
}

void configure_dac(void)
{
    struct dac_config config_dac;

    dac_get_config_defaults(&config_dac);

#if (SAML21)
    config_dac.reference = DAC_REFERENCE_INTREF;
#else
    config_dac.reference = DAC_REFERENCE_AVCC;
#endif

    dac_init(&dac_instance, DAC, &config_dac);

}

void configure_dac_channel(void)
{
    struct dac_chan_config config_dac_chan;

    dac_chan_get_config_defaults(&config_dac_chan);
```

```
    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}

void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

#if (SAMC21)
    config.peripheral_trigger = ADC1_DMAC_ID_RESRDY;
#else
    config.peripheral_trigger = ADC_DMAC_ID_RESRDY;
#endif
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(resource, &config);
}

void setup_transfer_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = 1000;
    descriptor_config.source_address = (uint32_t)(&adc_instance.hw-
>RESULT.reg);
#if (SAML21)
    descriptor_config.destination_address = (uint32_t)(&dac_instance.hw-
>DATA[DAC_CHANNEL_0].reg);
#else
    descriptor_config.destination_address = (uint32_t)(&dac_instance.hw-
>DATA.reg);
#endif
    descriptor_config.next_descriptor_address = (uint32_t)descriptor;

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_adc();

configure_dac();

configure_dac_channel();

dac_enable(&dac_instance);

configure_dma_resource(&example_resource);

setup_transfer_descriptor(&example_descriptor);

dma_add_descriptor(&example_resource, &example_descriptor);
```

Workflow

Configure the ADC

1. Create a module software instance structure for the ADC module to store the ADC driver state while it is in use.

```
struct adc_module adc_instance;
```

Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the ADC module.
    1. Create an ADC module configuration struct, which can be filled out to adjust the configuration of a physical ADC peripheral.

```
struct adc_config config_adc;
```

    2. Initialize the ADC configuration struct with the module's default values.

```
adc_get_config_defaults(&config_adc);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    3. Set extra configurations.

```
#if !(SAML21)
#if !(SAMC21)
    config_adc.gain_factor     = ADC_GAIN_FACTOR_DIV2;
#endif
    config_adc.resolution      = ADC_RESOLUTION_10BIT;
#endif
    config_adc.clock_prescaler = ADC_CLOCK_PRESCALER_DIV16;
    config_adc.reference       = ADC_REFERENCE_INTVCC1;
    config_adc.positive_input  = ADC_POSITIVE_INPUT_PIN4;
    config_adc.freerunning     = true;
    config_adc.left_adjust     = false;
```

    4. Set ADC configurations.

```
#if (SAMC21)
    adc_init(&adc_instance, ADC1, &config_adc);
#else
    adc_init(&adc_instance, ADC, &config_adc);
#endif
```

    5. Enable the ADC module so that conversions can be made.

```
adc_enable(&adc_instance);
```

Configure the DAC

1. Create a module software instance structure for the DAC module to store the DAC driver state while it is in use.

```
struct dac_module dac_instance;
```

Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the DAC module.

1. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

```
struct dac_config config_dac;
```

2. Initialize the DAC configuration struct with the module's default values.

```
dac_get_config_defaults(&config_dac);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra DAC configurations.

```
#if (SAML21)
    config_dac.reference = DAC_REFERENCE_INTREF;
#else
    config_dac.reference = DAC_REFERENCE_AVCC;
#endif
```

4. Set DAC configurations to DAC instance.

```
dac_init(&dac_instance, DAC, &config_dac);
```

5. Enable the DAC module so that channels can be configured.

```
dac_enable(&dac_instance);
```

3. Configure the DAC channel.
    1. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

    2. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    3. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
&config_dac_chan);
```

    4. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

Configure the DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra configurations for the DMA resource. ADC_DMAC_ID_RESRDY trigger causes a beat transfer in this example.

```
#if (SAMC21)
    config.peripheral_trigger = ADC1_DMAC_ID_RESRDY;
#else
    config.peripheral_trigger = ADC_DMAC_ID_RESRDY;
#endif
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = 1000;
descriptor_config.source_address = (uint32_t)(&adc_instance.hw-
>RESULT.reg);
#if (SAML21)
    descriptor_config.destination_address = (uint32_t)
(&dac_instance.hw->DATA[DAC_CHANNEL_0].reg);
#else
    descriptor_config.destination_address = (uint32_t)
(&dac_instance.hw->DATA.reg);
#endif
    descriptor_config.next_descriptor_address = (uint32_t)descriptor;
```

8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

9. Add DMA descriptor to DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

3.8.3.2. Use Case

Code

Copy-paste the following code to your user application:

```
adc_start_conversion(&adc_instance);

dma_start_transfer_job(&example_resource);

while (true) {
}
```

Workflow

1. Start ADC conversion.

```
adc_start_conversion(&adc_instance);
```

2. Start the transfer job.

```
dma_start_transfer_job(&example_resource);
```

3. Enter endless loop.

```
while (true) {
}
```

4. SAM Brown Out Detector (BOD) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Brown Out Detector (BOD) modules, to detect and respond to under-voltage events and take an appropriate action.

The following peripherals are used by this module:

- SUPC (Supply Controller)

The following devices can use this module:

- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

4.1. Prerequisites

There are no prerequisites for this module.

4.2. Module Overview

The SAM devices contain a number of Brown Out Detector (BOD) modules. Each BOD monitors the supply voltage for any dips that go below the set threshold for the module. In case of a BOD detection the BOD will either reset the system or raise a hardware interrupt so that a safe power-down sequence can be attempted.

4.3. Special Considerations

The time between a BOD interrupt being raised and a failure of the processor to continue executing (in the case of a core power failure) is system specific; care must be taken that all critical BOD detection events can complete within the amount of time available.

4.4. Extra Information

For extra information, see Extra Information for BOD Driver. This includes:

4.5. Examples

For a list of examples related to this driver, see Examples for BOD Driver.

4.6. API Overview

4.6.1. Structure Definitions

4.6.1.1. Struct bodvdd_config

Configuration structure for a BODVDD module.

Table 4-1. Members

Type	Name	Description
enum bodvdd_action	action	Action to perform when a low power detection is made
bool	hysteresis	If `true`, enables detection hysteresis
uint8_t	level	BODVDD level to trigger at when monitors VDD except in backup sleep mode
enum bodvdd_mode_in_active	mode_in_active	BODVDD configuration in active mode
enum bodvdd_mode_in_standby	mode_in_standby	BODVDD configuration in backup sleep mode
enum bodvdd_prescale	prescaler	Input sampler clock prescaler factor, to reduce the 1kHz clock from the ULP32K to lower the sampling rate of the BODVDD
bool	run_in_standby	If `true`, the BODVDD is kept enabled and sampled during standby

4.6.2. Function Definitions

4.6.2.1. Configuration and Initialization

Function bodvdd_get_config_defaults()

Get default BODVDD configuration.

```
void bodvdd_get_config_defaults(
        struct bodvdd_config *const conf)
```

The default BODVDD configuration is:

- Clock prescaler set to divide the input clock by two
- Continuous in active mode
- Continuous in standby mode
- Reset on BODVDD detect
- Hysteresis enabled
- BODVDD level 42 on V_{DD}
- BODVDD kept enabled during standby

Table 4-2. Parameters

Data direction	Parameter name	Description
[out]	conf	BODVDD configuration struct to set to default settings

Function bodvdd_set_config()

Configure a Brown Out Detector module.

```
enum status_code bodvdd_set_config(
        struct bodvdd_config *const conf)
```

Configures a given BOD module with the settings stored in the given configuration structure.

Table 4-3. Parameters

Data direction	Parameter name	Description
[in]	conf	Configuration settings to use for the specified BODVDD

Table 4-4. Return Values

Return value	Description
STATUS_OK	Operation completed successfully
STATUS_ERR_INVALID_ARG	An invalid BOD was supplied
STATUS_ERR_INVALID_OPTION	The requested BOD level was outside the acceptable range

Function bodvdd_enable()

Enables a configured BODVDD module.

```
enum status_code bodvdd_enable( void )
```

Enables the BODVDD module that has been previously configured.

Returns
Error code indicating the status of the enable operation.

Table 4-5. Return Values

Return value	Description
STATUS_OK	If the BODVDD was successfully enabled

Function bodvdd_disable()

Disables an enabled BODVDD module.

```
enum status_code bodvdd_disable( void )
```

Disables the BODVDD module that was previously enabled.

Returns
Error code indicating the status of the disable operation.

Table 4-6. Return Values

Return value	Description
STATUS_OK	If the BODVDD was successfully disabled

Function bodvdd_is_detected()

Checks if the BODVDD low voltage detection has occurred.

```
bool bodvdd_is_detected( void )
```

Determines if the BODVDD has detected a voltage lower than its configured threshold.

Returns
Detection status of the BODVDD.

Table 4-7. Return Values

Return value	Description
true	If the BODVDD has detected a low voltage condition
false	If the BODVDD has not detected a low voltage condition

Function bodvdd_clear_detected()

Clears the low voltage detection state of the BODVDD.

```
void bodvdd_clear_detected( void )
```

Clears the low voltage condition of the BODVDD module, so that new low voltage conditions can be detected.

4.6.3. Enumeration Definitions

4.6.3.1. Enum bodvdd_action

List of possible BODVDD actions when a BODVDD module detects a brown-out condition.

Table 4-8. Members

Enum value	Description
BODVDD_ACTION_NONE	A BODVDD detect will do nothing, and the BODVDD state must be polled
BODVDD_ACTION_RESET	A BODVDD detect will reset the device
BODVDD_ACTION_INTERRUPT	A BODVDD detect will fire an interrupt
BODVDD_ACTION_BACKUP	A BODVDD detect will put the device in backup sleep mode

4.6.3.2. Enum bodvdd_mode_in_active

List of possible BODVDD module voltage sampling modes in active sleep mode.

Table 4-9. Members

Enum value	Description
BODVDD_ACTCFG_CONTINUOUS	BODVDD will sample the supply line continuously
BODVDD_ACTCFG_SAMPLED	BODVDD will use the BODVDD sampling clock (1kHz) to sample the supply line

4.6.3.3. Enum bodvdd_mode_in_standby

List of possible BODVDD module voltage sampling modes in standby sleep mode.

Table 4-10. Members

Enum value	Description
BODVDD_STDBYCFG_CONTINUOUS	BODVDD will sample the supply line continuously
BODVDD_STDBYCFG_SAMPLED	BODVDD will use the BODVDD sampling clock (1kHz) to sample the supply line

4.6.3.4. Enum bodvdd_prescale

List of possible BODVDD controller prescaler values, to reduce the sampling speed of a BODVDD to lower the power consumption.

Table 4-11. Members

Enum value	Description
BODVDD_PRESCALE_DIV_2	Divide input prescaler clock by 2
BODVDD_PRESCALE_DIV_4	Divide input prescaler clock by 4
BODVDD_PRESCALE_DIV_8	Divide input prescaler clock by 8
BODVDD_PRESCALE_DIV_16	Divide input prescaler clock by 16
BODVDD_PRESCALE_DIV_32	Divide input prescaler clock by 32
BODVDD_PRESCALE_DIV_64	Divide input prescaler clock by 64
BODVDD_PRESCALE_DIV_128	Divide input prescaler clock by 128
BODVDD_PRESCALE_DIV_256	Divide input prescaler clock by 256
BODVDD_PRESCALE_DIV_512	Divide input prescaler clock by 512
BODVDD_PRESCALE_DIV_1024	Divide input prescaler clock by 1024
BODVDD_PRESCALE_DIV_2048	Divide input prescaler clock by 2048
BODVDD_PRESCALE_DIV_4096	Divide input prescaler clock by 4096
BODVDD_PRESCALE_DIV_8192	Divide input prescaler clock by 8192
BODVDD_PRESCALE_DIV_16384	Divide input prescaler clock by 16384

Enum value	Description
BODVDD_PRESCALE_DIV_32768	Divide input prescaler clock by 32768
BODVDD_PRESCALE_DIV_65536	Divide input prescaler clock by 65536

4.7. Extra Information for BOD Driver

4.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Definition
BOD	Brown Out Detector

4.7.2. Dependencies

This driver has the following dependencies:

- None

4.7.3. Errata

There are no errata related to this driver.

4.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

4.8. Examples for BOD Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Brown Out Detector (BOD) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for BOD - Basic
- Application Use Case for BOD - Application

4.8.1. Quick Start Guide for BOD - Basic

In this use case, the BODVDD will be configured with the following settings:

- Continuous sampling mode
- Prescaler setting of 2
- Reset action on low voltage detect

4.8.1.1. Quick Start

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
static void configure_bodvdd(void)
{
    struct bodvdd_config config_bodvdd;
    bodvdd_get_config_defaults(&config_bodvdd);

    bodvdd_set_config(&config_bodvdd);

    bodvdd_enable();
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_bodvdd();
```

Workflow

1. Create a BODVDD module configuration struct, which can be filled out to adjust the configuration of a physical BOD peripheral.

   ```
   struct bodvdd_config config_bodvdd;
   ```

2. Initialize the BODVDD configuration struct with the module's default values.

   ```
   bodvdd_get_config_defaults(&config_bodvdd);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Configure the BODVDD module with the desired settings.

   ```
   bodvdd_set_config(&config_bodvdd);
   ```

4. Enable the BODVDD module so that it will monitor the power supply voltage.

   ```
   bodvdd_enable();
   ```

4.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop so that the BOD can continue to monitor the supply voltage level.

   ```
   while (true) {
       /* Infinite loop */
   }
   ```

4.8.2. Application Use Case for BOD - Application

The preferred method of setting BODVDD levels and settings is trough the fuses. When it is desirable to set it in software, see the below use case.

In this use case, a new BODVDD level might be set in SW if the clock settings are adjusted after a battery has charged to a higher level. When the battery discharges, the chip will reset when the battery level is below the SW BODVDD level. Now the chip will run at a lower clock rate and the BODVDD level from fuse. The chip should always measure the voltage before adjusting the frequency up.

5. SAM Configurable Custom Logic (CCL) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Configurable Custom Logic functionality.

The following peripheral is used by this module:

- CCL (Configurable Custom Logic)

The following devices can use this module:

- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

5.1. Prerequisites

There are no prerequisites for this module.

5.2. Module Overview

This driver provides an interface for the Configurable Custom Logic functions on the device.

The Configurable Custom Logic (CCL) contains programmable logic which can be connected to the device pins, events, or internal peripherals.

Each LUT consists of three inputs, a truth table and optional synchronizer, filter and edge detector. Each LUT can generate an output as a user programmable logic expression with three inputs.

The output can be combinatorially generated from the inputs, or filtered to remove spike. An optional sequential module can be enabled. The inputs of sequential module are individually controlled by two independent, adjacent LUT(LUT0/LUT1, LUT2/LUT3 etc.) outputs, enabling complex waveform generation.

5.3. Special Considerations

There are no special considerations for this module.

5.4. Extra Information

For extra information, see Extra Information for CCL Driver. This includes:

- Acronyms
- Dependencies

- Errata
- Module History

5.5. Examples

For a list of examples related to this driver, see Examples for CCL Driver.

5.6. API Overview

5.6.1. Structure Definitions

5.6.1.1. Struct ccl_config

Configuration structure for CCL module.

Table 5-1. Members

Type	Name	Description
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
bool	run_in_standby	If `true`, the GCLK_CCL clock will not stop in standby sleep mode

5.6.1.2. Struct ccl_lut_config

Configuration structure for CCL LUT 0 to 3.

Table 5-2. Members

Type	Name	Description
bool	edge_selection_enable	If `true`, Edge detector is enabled
bool	event_input_enable	If `true`, LUT incoming event is enabled
bool	event_input_inverted_enable	If `true`, incoming event is inverted
bool	event_output_enable	If `true`, LUT event output is enabled
enum ccl_lut_filter_sel	filter_sel	Selection of the LUT output filter options
enum ccl_lut_input_src_sel	input0_src_sel	Selection of the input0 source
enum ccl_lut_input_src_sel	input1_src_sel	Selection of the input1 source
enum ccl_lut_input_src_sel	input2_src_sel	Selection of the input2 source
uint8_t	truth_table_value	The value of truth logic as a function of inputs IN[2:0]

5.6.2. Function Definitions

5.6.2.1. Initialize and Reset CCL Module

Function ccl_init()

Initializes CCL module.

```
void ccl_init(
        struct ccl_config *const config)
```

Resets all registers in the MODULE to their initial state, and then enable the module.

Function ccl_get_config_defaults()

Initializes all members of a CCL configuration structure to safe defaults.

```
void ccl_get_config_defaults(
        struct ccl_config *const config)
```

Initializes all members of a given Configurable Custom Logic configuration structure to safe and known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- GCLK_CLL will be stopped in standby sleep mode
- Generator 0 is the default GCLK generator

Table 5-3. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function ccl_module_reset()

Resets CCL module.

```
void ccl_module_reset( void )
```

Resets all registers in the MODULE to their initial state, and the CCL will be disabled.

5.6.2.2. Enable and Disable CCL Module

Function ccl_module_enable()

Enables CCL module.

```
void ccl_module_enable( void )
```

Enable the peripheral.

Function ccl_module_disable()

Disables CCL module.

```
void ccl_module_disable( void )
```

Disables the peripheral.

5.6.2.3. Configure LUT

Function ccl_seq_config()

Writes sequential selection to the hardware module.

```
enum status_code ccl_seq_config(
        const enum ccl_seq_id number,
        const enum ccl_seq_selection seq_selection)
```

Writes a given sequential selection configuration to the hardware module.

Note: This function can only be used when the CCL module is disabled.

Table 5-4. Parameters

Data direction	Parameter name	Description
[in]	seq_selection	Enum for the sequential selection configuration
[in]	number	SEQ unit number to config

Function ccl_lut_get_config_defaults()

Initializes all members of LUT configuration structure to safe defaults.

```
void ccl_lut_get_config_defaults(
        struct ccl_lut_config *const config)
```

Initializes all members of LUT configuration structure to safe defaults. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Truth table value is 0x00
- LUT event output is disabled
- LUT incoming event is disabled
- LUT incoming event is not inverted
- The input IN[2:0] source is masked
- The edge detector is disabled
- The LUT output filter is disabled

Table 5-5. Parameters

Data direction	Parameter name	Description
[out]	config	LUT configuration structure to initialize to default values

Function ccl_lut_set_config()

Writes LUT configuration to the hardware module.

```
enum status_code ccl_lut_set_config(
        const enum ccl_lut_id number,
        struct ccl_lut_config *const config)
```

Writes a given LUT configuration to the hardware module.

Note: This function can only be used when the CCL module is disabled.

Table 5-6. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to the LUT configuration struct
[in]	number	LUT number to config

5.6.2.4. Enable and Disable LUT

Function ccl_lut_enable()

Enables an LUT that was previously configured.

```
void ccl_lut_enable(
        const enum ccl_lut_id number)
```

Enables an LUT that was previously configured via a call to ccl_lut_set_config function.

Table 5-7. Parameters

Data direction	Parameter name	Description
[in]	number	LUT number to enable

Function ccl_lut_disable()

Disables an LUT that was previously enabled.

```
void ccl_lut_disable(
        const enum ccl_lut_id number)
```

Disables an LUT that was previously enabled via a call to ccl_lut_enable().

Table 5-8. Parameters

Data direction	Parameter name	Description
[in]	number	LUT number to enable

5.6.3. Enumeration Definitions

5.6.3.1. Enum ccl_lut_filter_sel

Enum for the LUT output filter options.

Table 5-9. Members

Enum value	Description
CCL_LUT_FILTER_DISABLE	Filter disabled
CCL_LUT_FILTER_SYNC	Synchronizer enabled
CCL_LUT_FILTER_ENABLE	Filter enabled

5.6.3.2. Enum ccl_lut_id

Table 5-10. Members

Enum value	Description
CCL_LUT_0	CCL LUT 0
CCL_LUT_1	CCL LUT 1
CCL_LUT_2	CCL LUT 2
CCL_LUT_3	CCL LUT 3

5.6.3.3. Enum ccl_lut_input_src_sel

Enum for the LUT Input source selection.

Table 5-11. Members

Enum value	Description
CCL_LUT_INPUT_SRC_MASK	Masked input
CCL_LUT_INPUT_SRC_FEEDBACK	Feedback input source
CCL_LUT_INPUT_SRC_LINK	Linked LUT input source
CCL_LUT_INPUT_SRC_EVENT	Event input source
CCL_LUT_INPUT_SRC_IO	I/O pin input source
CCL_LUT_INPUT_SRC_AC	AC input source
CCL_LUT_INPUT_SRC_TC	TC input source
CCL_LUT_INPUT_SRC_ALTTC	Alternative TC input source
CCL_LUT_INPUT_SRC_TCC	TCC input source
CCL_LUT_INPUT_SRC_SERCOM	SERCOM input source

5.6.3.4. Enum ccl_seq_id

Table 5-12. Members

Enum value	Description
CCL_SEQ_0	CCL SEQ 0
CCL_SEQ_1	CCL SEQ 1

5.6.3.5. Enum ccl_seq_selection

Enum for the sequential selection configuration.

Table 5-13. Members

Enum value	Description
CCL_SEQ_DISABLED	Sequential logic is disabled
CCL_SEQ_D_FLIP_FLOP	D flip flop
CCL_SEQ_JK_FLIP_FLOP	JK flip flop
CCL_SEQ_D_LATCH	D latch
CCL_SEQ_RS_LATCH	RS latch

5.7. Extra Information for CCL Driver

5.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
CCL	Configurable Custom Logic

5.7.2. Dependencies

This driver has no dependencies.

5.7.3. Errata

There are no errata related to this driver.

5.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

5.8. Examples for CCL Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Configurable Custom Logic (CCL) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for CCL - Basic

5.8.1. Quick Start Guide for CCL - Basic

In this use case, the LUT0 and LUT1 input source is configured as I/O pin. The LUT0 and LUT1 pair is connected to internal sequential logic, which is configured as D flip flop mode.

5.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_ccl(void)
{
    struct ccl_config conf;

    ccl_get_config_defaults(&conf);

    ccl_init(&conf);
}

void configure_ccl_lut0(void)
{
    struct ccl_lut_config conf;

    ccl_lut_get_config_defaults(&conf);

    conf.truth_table_value = 0x02;
    conf.input0_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.input1_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.input2_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.filter_sel = CCL_LUTCTRL_FILTSEL_FILTER;

    struct system_pinmux_config lut0_input_pin0_conf, lut0_input_pin1_conf,
lut0_input_pin2_conf;
    system_pinmux_get_config_defaults(&lut0_input_pin0_conf);
    system_pinmux_get_config_defaults(&lut0_input_pin1_conf);
    system_pinmux_get_config_defaults(&lut0_input_pin2_conf);
    lut0_input_pin0_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut0_input_pin0_conf.mux_position = CCL_LUT0_IN0_MUX;
    lut0_input_pin1_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut0_input_pin1_conf.mux_position = CCL_LUT0_IN1_MUX;
    lut0_input_pin2_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut0_input_pin2_conf.mux_position = CCL_LUT0_IN2_MUX;
    system_pinmux_pin_set_config(CCL_LUT0_IN0_PIN, &lut0_input_pin0_conf);
    system_pinmux_pin_set_config(CCL_LUT0_IN1_PIN, &lut0_input_pin1_conf);
    system_pinmux_pin_set_config(CCL_LUT0_IN2_PIN, &lut0_input_pin2_conf);
    struct system_pinmux_config lut0_out_pin_conf;
    system_pinmux_get_config_defaults(&lut0_out_pin_conf);
    lut0_out_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_OUTPUT;
    lut0_out_pin_conf.mux_position = CCL_LUT0_OUT_MUX;
    system_pinmux_pin_set_config(CCL_LUT0_OUT_PIN, &lut0_out_pin_conf);

    ccl_lut_set_config(CCL_LUT_0, &conf);
}

void configure_ccl_lut1(void)
{
    struct ccl_lut_config conf;

    ccl_lut_get_config_defaults(&conf);

    conf.truth_table_value = 0x02;
```

```
    conf.input0_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.input1_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.input2_src_sel = CCL_LUT_INPUT_SRC_IO;
    conf.filter_sel = CCL_LUTCTRL_FILTSEL_FILTER;

    struct system_pinmux_config lut1_input_pin0_conf, lut1_input_pin1_conf,
lut1_input_pin2_conf;
    system_pinmux_get_config_defaults(&lut1_input_pin0_conf);
    system_pinmux_get_config_defaults(&lut1_input_pin1_conf);
    system_pinmux_get_config_defaults(&lut1_input_pin2_conf);
    lut1_input_pin0_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut1_input_pin0_conf.mux_position = CCL_LUT1_IN0_MUX;
    lut1_input_pin1_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut1_input_pin1_conf.mux_position = CCL_LUT1_IN1_MUX;
    lut1_input_pin2_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
    lut1_input_pin2_conf.mux_position = CCL_LUT1_IN2_MUX;
    system_pinmux_pin_set_config(CCL_LUT1_IN0_PIN, &lut1_input_pin0_conf);
    system_pinmux_pin_set_config(CCL_LUT1_IN1_PIN, &lut1_input_pin1_conf);
    system_pinmux_pin_set_config(CCL_LUT1_IN2_MUX, &lut1_input_pin2_conf);
    struct system_pinmux_config lut1_out_pin_conf;
    system_pinmux_get_config_defaults(&lut1_out_pin_conf);
    lut1_out_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_OUTPUT;
    lut1_out_pin_conf.mux_position = CCL_LUT1_OUT_MUX;
    system_pinmux_pin_set_config(CCL_LUT1_OUT_PIN, &lut1_out_pin_conf);

    ccl_lut_set_config(CCL_LUT_1, &conf);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_ccl();
configure_ccl_lut0();
configure_ccl_lut1();
ccl_seq_config(CCL_SEQ_0, CCL_SEQ_D_FLIP_FLOP);
```

```
ccl_lut_enable(CCL_LUT_0);
ccl_lut_enable(CCL_LUT_1);
ccl_module_enable();
```

Workflow

1. Creates a CCL configuration struct, which can be filled out to adjust the configuration of CCL.

   ```
   struct ccl_config conf;
   ```

2. Settings and fill the CCL configuration struct with the default settings.

   ```
   ccl_get_config_defaults(&conf);
   ```

3. Initializes CCL module.

   ```
   ccl_init(&conf);
   ```

4. Creates a LUT configuration struct, which can be filled out to adjust the configuration of LUT0.

   ```
   struct ccl_lut_config conf;
   ```

   1. Fill the LUT0 configuration struct with the default settings.

      ```
      ccl_lut_get_config_defaults(&conf);
      ```

5. Adjust the LUT0 configuration struct.

   ```
   conf.truth_table_value = 0x02;
   conf.input0_src_sel = CCL_LUT_INPUT_SRC_IO;
   ```

```
conf.input1_src_sel = CCL_LUT_INPUT_SRC_IO;
conf.input2_src_sel = CCL_LUT_INPUT_SRC_IO;
conf.filter_sel = CCL_LUTCTRL_FILTSEL_FILTER;
```

6. Set up LUT0 input and output pin.

```
struct system_pinmux_config lut0_input_pin0_conf, lut0_input_pin1_conf,
lut0_input_pin2_conf;
system_pinmux_get_config_defaults(&lut0_input_pin0_conf);
system_pinmux_get_config_defaults(&lut0_input_pin1_conf);
system_pinmux_get_config_defaults(&lut0_input_pin2_conf);
lut0_input_pin0_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut0_input_pin0_conf.mux_position = CCL_LUT0_IN0_MUX;
lut0_input_pin1_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut0_input_pin1_conf.mux_position = CCL_LUT0_IN1_MUX;
lut0_input_pin2_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut0_input_pin2_conf.mux_position = CCL_LUT0_IN2_MUX;
system_pinmux_pin_set_config(CCL_LUT0_IN0_PIN, &lut0_input_pin0_conf);
system_pinmux_pin_set_config(CCL_LUT0_IN1_PIN, &lut0_input_pin1_conf);
system_pinmux_pin_set_config(CCL_LUT0_IN2_PIN, &lut0_input_pin2_conf);
struct system_pinmux_config lut0_out_pin_conf;
system_pinmux_get_config_defaults(&lut0_out_pin_conf);
lut0_out_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_OUTPUT;
lut0_out_pin_conf.mux_position = CCL_LUT0_OUT_MUX;
system_pinmux_pin_set_config(CCL_LUT0_OUT_PIN, &lut0_out_pin_conf);
```

7. Writes LUT0 configuration to the hardware module.

```
ccl_lut_set_config(CCL_LUT_0, &conf);
```

8. Creates a LUT configuration struct, which can be filled out to adjust the configuration of LUT1.

```
struct ccl_lut_config conf;
```

   1. Fill the LUT1 configuration struct with the default settings.

```
ccl_lut_get_config_defaults(&conf);
```

9. Adjust the LUT1 configuration struct.

```
conf.truth_table_value = 0x02;
conf.input0_src_sel = CCL_LUT_INPUT_SRC_IO;
conf.input1_src_sel = CCL_LUT_INPUT_SRC_IO;
conf.input2_src_sel = CCL_LUT_INPUT_SRC_IO;
conf.filter_sel = CCL_LUTCTRL_FILTSEL_FILTER;
```

10. Set up LUT1 input and output pin.

```
struct system_pinmux_config lut1_input_pin0_conf, lut1_input_pin1_conf,
lut1_input_pin2_conf;
system_pinmux_get_config_defaults(&lut1_input_pin0_conf);
system_pinmux_get_config_defaults(&lut1_input_pin1_conf);
system_pinmux_get_config_defaults(&lut1_input_pin2_conf);
lut1_input_pin0_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut1_input_pin0_conf.mux_position = CCL_LUT1_IN0_MUX;
lut1_input_pin1_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut1_input_pin1_conf.mux_position = CCL_LUT1_IN1_MUX;
lut1_input_pin2_conf.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
lut1_input_pin2_conf.mux_position = CCL_LUT1_IN2_MUX;
system_pinmux_pin_set_config(CCL_LUT1_IN0_PIN, &lut1_input_pin0_conf);
system_pinmux_pin_set_config(CCL_LUT1_IN1_PIN, &lut1_input_pin1_conf);
system_pinmux_pin_set_config(CCL_LUT1_IN2_MUX, &lut1_input_pin2_conf);
struct system_pinmux_config lut1_out_pin_conf;
system_pinmux_get_config_defaults(&lut1_out_pin_conf);
lut1_out_pin_conf.direction    = SYSTEM_PINMUX_PIN_DIR_OUTPUT;
```

```
lut1_out_pin_conf.mux_position = CCL_LUT1_OUT_MUX;
system_pinmux_pin_set_config(CCL_LUT1_OUT_PIN, &lut1_out_pin_conf);
```

11. Writes LUT1 configuration to the hardware module.

```
ccl_lut_set_config(CCL_LUT_1, &conf);
```

12. Configure the sequential logic with the D flip flop mode.

```
ccl_seq_config(CCL_SEQ_0, CCL_SEQ_D_FLIP_FLOP);
```

5.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
     /* Do nothing */
}
```

6. SAM Digital-to-Analog (DAC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the conversion of digital values to analog voltage. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- DAC (Digital-to-Analog Converter)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM D10/D11
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C21

The outline of this documentation is as follows:

6.1. Prerequisites

There are no prerequisites for this module.

6.2. Module Overview

The Digital-to-Analog converter converts a digital value to analog voltage. The SAM DAC module has one channel with 10-bit resolution, and is capable of converting up to 350k samples per second (ksps).

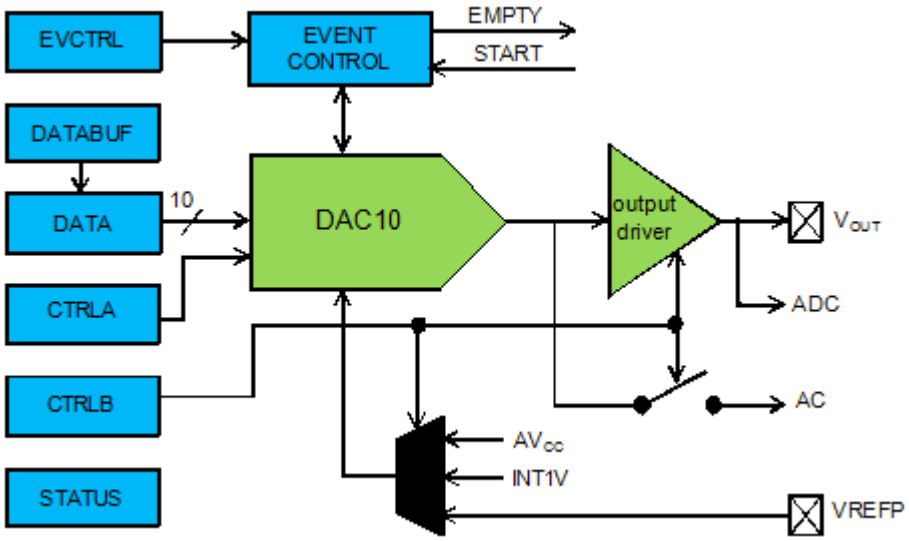
A common use of DAC is to generate audio signals by connecting the DAC output to a speaker, or to generate a reference voltage; either for an external circuit or an internal peripheral such as the Analog Comparator.

After being set up, the DAC will convert new digital values written to the conversion data register (DATA) to an analog value either on the VOUT pin of the device, or internally for use as an input to the AC, ADC, and other analog modules.

Writing the DATA register will start a new conversion. It is also possible to trigger the conversion from the event system.

A simplified block diagram of the DAC can be seen in Figure 6-1.

Figure 6-1. DAC Block Diagram



6.2.1. Conversion Range

The conversion range is between GND and the selected voltage reference. Available voltage references are:

- AVCC voltage reference
- Internal 1V reference (INT1V)
- External voltage reference (AREF)

Note: Internal references will be enabled by the driver, but not disabled. Any reference not used by the application should be disabled by the application.

The output voltage from a DAC channel is given as:

$$V_{OUT} = \frac{DATA}{0x3FF} \times VREF$$

6.2.2. Conversion

The digital value written to the conversion data register (DATA) will be converted to an analog value. Writing the DATA register will start a new conversion. It is also possible to write the conversion data to the DATABUF register, the writing of the DATA register can then be triggered from the event system, which will load the value from DATABUF to DATA.

6.2.3. Analog Output

The analog output value can be output to either the VOUT pin or internally, but not both at the same time.

6.2.3.1. External Output

The output buffer must be enabled in order to drive the DAC output to the VOUT pin. Due to the output buffer, the DAC has high drive strength, and is capable of driving both resistive and capacitive loads, as well as loads which combine both.

6.2.3.2. Internal Output

The analog value can be internally available for use as input to the AC or ADC modules.

6.2.4. Events

Events generation and event actions are configurable in the DAC. The DAC has one event line input and one event output: *Start Conversion* and *Data Buffer Empty*.

If the Start Conversion input event is enabled in the module configuration, an incoming event will load data from the data buffer to the data register and start a new conversion. This method synchronizes conversions with external events (such as those from a timer module) and ensures regular and fixed conversion intervals.

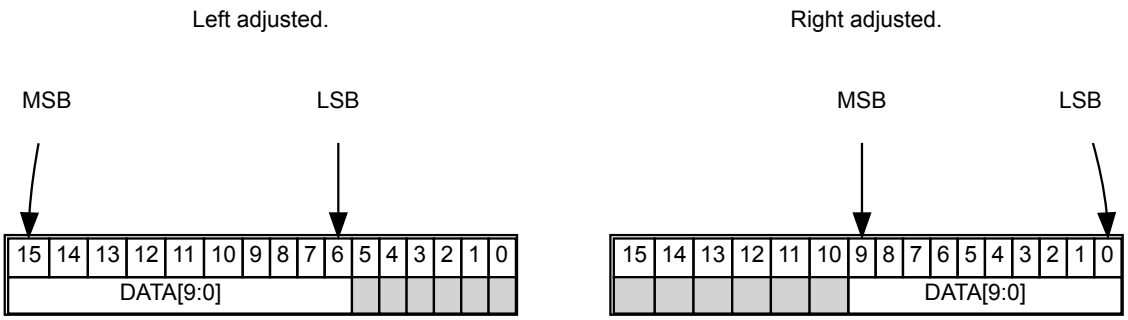
If the Data Buffer Empty output event is enabled in the module configuration, events will be generated when the DAC data buffer register becomes empty and new data can be loaded to the buffer.

Note: The connection of events between modules requires the use of the event driver to route output event of one module to the input event of another. For more information on event routing, refer to the documentation SAM Event System (EVENTS) Driver.

6.2.5. Left and Right Adjusted Values

The 10-bit input value to the DAC is contained in a 16-bit register. This can be configured to be either left or right adjusted. In Figure 6-2 both options are shown, and the position of the most (MSB) and the least (LSB) significant bits are indicated. The unused bits should always be written to zero.

Figure 6-2. Left and Right Adjusted Values



6.2.6. Clock Sources

The clock for the DAC interface (CLK_DAC) is generated by the Power Manager. This clock is turned on by default, and can be enabled and disabled in the Power Manager.

Additionally, an asynchronous clock source (GCLK_DAC) is required. These clocks are normally disabled by default. The selected clock source must be enabled in the Power Manager before it can be used by the DAC. The DAC core operates asynchronously from the user interface and peripheral bus. As a consequence, the DAC needs two clock cycles of both CLK_DAC and GCLK_DAC to synchronize the values written to some of the control and data registers. The oscillator source for the GCLK_DAC clock is selected in the System Control Interface (SCIF).

6.3. Special Considerations

6.3.1. Output Driver

The DAC can only do conversions in Active or Idle modes. However, if the output buffer is enabled it will draw current even if the system is in sleep mode. Therefore, always make sure that the output buffer is not enabled when it is not needed, to ensure minimum power consumption.

6.3.2. Conversion Time

DAC conversion time is approximately 2.85µs. The user must ensure that new data is not written to the DAC before the last conversion is complete. Conversions should be triggered by a periodic event from a Timer/Counter or another peripheral.

6.4. Extra Information

For extra information, see Extra Information for DAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

6.5. Examples

For a list of examples related to this driver, see Examples for DAC Driver.

6.6. API Overview

6.6.1. Variable and Type Definitions

6.6.1.1. Type dac_callback_t

```
typedef void(* dac_callback_t )(uint8_t channel)
```

Type definition for a DAC module callback function.

6.6.2. Structure Definitions

6.6.2.1. Struct dac_chan_config

Configuration for a DAC channel. This structure should be initialized by the dac_chan_get_config_defaults() function before being modified by the user application.

6.6.2.2. Struct dac_config

Configuration structure for a DAC instance. This structure should be initialized by the dac_get_config_defaults() function before being modified by the user application.

Table 6-1. Members

Type	Name	Description
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
bool	left_adjust	Left adjusted data
enum dac_output	output	Select DAC output
enum dac_reference	reference	Reference voltage
bool	run_in_standby	The DAC behaves as in normal mode when the chip enters STANDBY sleep mode
bool	voltage_pump_disable	Voltage pump disable

6.6.2.3. Struct dac_events

Event flags for the DAC module. This is used to enable and disable events via dac_enable_events() and dac_disable_events().

Table 6-2. Members

Type	Name	Description
bool	generate_event_on_buffer_empty	Enable event generation on data buffer empty
bool	on_event_start_conversion	Start a new DAC conversion

6.6.2.4. Struct dac_module

DAC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

6.6.3. Macro Definitions

6.6.3.1. DAC Status Flags

DAC status flags, returned by dac_get_status() and cleared by dac_clear_status().

Macro DAC_STATUS_CHANNEL_0_EMPTY

```
#define DAC_STATUS_CHANNEL_0_EMPTY
```

Data Buffer Empty Channel 0 - Set when data is transferred from DATABUF to DATA by a start conversion event and DATABUF is ready for new data.

Macro DAC_STATUS_CHANNEL_0_UNDERRUN

```
#define DAC_STATUS_CHANNEL_0_UNDERRUN
```

Under-run Channel 0 - Set when a start conversion event occurs when DATABUF is empty.

6.6.3.2. Macro DAC_TIMEOUT

```
#define DAC_TIMEOUT
```

Define DAC features set according to different device families.

6.6.4. Function Definitions

6.6.4.1. Configuration and Initialization

Function dac_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool dac_is_syncing(
        struct dac_module *const dev_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 6-3. Parameters

Data direction	Parameter name	Description
[in]	dev_inst	Pointer to the DAC software instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 6-4. Return Values

Return value	Description
true	If the module synchronization is ongoing
false	If the module has completed synchronization

Function dac_get_config_defaults()

Initializes a DAC configuration structure to defaults.

```
void dac_get_config_defaults(
        struct dac_config *const config)
```

Initializes a given DAC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- 1V from internal bandgap reference
- Drive the DAC output to the VOUT pin
- Right adjust data
- GCLK generator 0 (GCLK main) clock source
- The output buffer is disabled when the chip enters STANDBY sleep mode

Table 6-5. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function dac_init()

Initialize the DAC device struct.

```
enum status_code dac_init(
        struct dac_module *const dev_inst,
        Dac *const module,
        struct dac_config *const config)
```

Use this function to initialize the Digital to Analog Converter. Resets the underlying hardware module and configures it.

Note: The DAC channel must be configured separately.

Table 6-6. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the DAC software instance struct
[in]	module	Pointer to the DAC module instance
[in]	config	Pointer to the config struct, created by the user application

Returns
Status of initialization.

Table 6-7. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting

Function dac_reset()

Resets the DAC module.

```
void dac_reset(
        struct dac_module *const dev_inst)
```

This function will reset the DAC module to its power on default values and disable it.

Table 6-8. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_enable()

Enable the DAC module.

```
void dac_enable(
        struct dac_module *const dev_inst)
```

Enables the DAC interface and the selected output. If any internal reference is selected it will be enabled.

Table 6-9. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_disable()

Disable the DAC module.

```
void dac_disable(
        struct dac_module *const dev_inst)
```

Disables the DAC interface and the output buffer.

Table 6-10. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct

Function dac_enable_events()

Enables a DAC event input or output.

```
void dac_enable_events(
        struct dac_module *const module_inst,
        struct dac_events *const events)
```

Enables one or more input or output events to or from the DAC module. See dac_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 6-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the DAC peripheral
[in]	events	Struct containing flags of events to enable

Function dac_disable_events()

Disables a DAC event input or output.

```
void dac_disable_events(
        struct dac_module *const module_inst,
        struct dac_events *const events)
```

Disables one or more input or output events to or from the DAC module. See dac_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 6-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the DAC peripheral
[in]	events	Struct containing flags of events to disable

6.6.4.2. Configuration and Initialization (Channel)

Function dac_chan_get_config_defaults()

Initializes a DAC channel configuration structure to defaults.

```
void dac_chan_get_config_defaults(
        struct dac_chan_config *const config)
```

Initializes a given DAC channel configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Start Conversion Event Input enabled
- Start Data Buffer Empty Event Output disabled

Table 6-13. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function dac_chan_set_config()

Writes a DAC channel configuration to the hardware module.

```
void dac_chan_set_config(
        struct dac_module *const dev_inst,
        const enum dac_channel channel,
        struct dac_chan_config *const config)
```

Writes a given channel configuration to the hardware module.

Note: The DAC device instance structure must be initialized before calling this function.

Table 6-14. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to configure
[in]	config	Pointer to the configuration struct

Function dac_chan_enable()

Enable a DAC channel.

```
void dac_chan_enable(
        struct dac_module *const dev_inst,
        enum dac_channel channel)
```

Enables the selected DAC channel.

Table 6-15. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to enable

Function dac_chan_disable()

Disable a DAC channel.

```
void dac_chan_disable(
        struct dac_module *const dev_inst,
        enum dac_channel channel)
```

Disables the selected DAC channel.

Table 6-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Channel to disable

6.6.4.3. Channel Data Management

Function dac_chan_write()

Write to the DAC.

```
enum status_code dac_chan_write(
        struct dac_module *const dev_inst,
        enum dac_channel channel,
        const uint16_t data)
```

Note: To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 6-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	data	Conversion data

Returns
Status of the operation.

Table 6-18. Return Values

Return value	Description
STATUS_OK	If the data was written

Function dac_chan_write_buffer_wait()

Write to the DAC.

```
enum status_code dac_chan_write_buffer_wait(
        struct dac_module *const module_inst,
        enum dac_channel channel,
        uint16_t * buffer,
        uint32_t length)
```

Note: To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 6-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	buffer	Pointer to the digital data write buffer to be converted
[in]	length	Length of the write buffer

Returns
Status of the operation.

Table 6-20. Return Values

Return value	Description
STATUS_OK	If the data was written or no data conversion required
STATUS_ERR_UNSUPPORTED_DEV	The DAC is not configured as using event trigger
STATUS_BUSY	The DAC is busy to convert

6.6.4.4. Status Management

Function dac_get_status()

Retrieves the current module status.

```
uint32_t dac_get_status(
        struct dac_module *const module_inst)
```

Checks the status of the module and returns it as a bitmask of status flags.

Table 6-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct

Returns
Bitmask of status flags.

Table 6-22. Return Values

Return value	Description
DAC_STATUS_CHANNEL_0_EMPTY	Data has been transferred from DATABUF to DATA by a start conversion event and DATABUF is ready for new data
DAC_STATUS_CHANNEL_0_UNDERRUN	A start conversion event has occurred when DATABUF is empty

Function dac_clear_status()

Clears a module status flag.

```
void dac_clear_status(
        struct dac_module *const module_inst,
        uint32_t status_flags)
```

Clears the given status flag of the module.

Table 6-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	status_flags	Bit mask of status flags to clear

6.6.4.5. Callback Configuration and Initialization

Function dac_chan_write_buffer_job()

Convert a specific number digital data to analog through DAC.

```
enum status_code dac_chan_write_buffer_job(
        struct dac_module *const module_inst,
        const enum dac_channel channel,
        uint16_t * buffer,
        uint32_t buffer_size)
```

Note: To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 6-24. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	buffer	Pointer to the digital data write buffer to be converted
[in]	length	Size of the write buffer

Returns
Status of the operation.

Table 6-25. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode
STATUS_BUSY	The DAC is busy to accept new job

Function dac_chan_write_job()

Convert one digital data job.

```
enum status_code dac_chan_write_job(
        struct dac_module *const module_inst,
        const enum dac_channel channel,
        uint16_t data)
```

Note: To be event triggered, the enable_start_on_event must be enabled in the configuration.

Table 6-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software device struct
[in]	channel	DAC channel to write to
[in]	data	Digital data to be converted

Returns
Status of the operation.

Table 6-27. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode
STATUS_BUSY	The DAC is busy to accept new job

Function dac_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code dac_register_callback(
        struct dac_module *const module,
        const enum dac_channel channel,
        const dac_callback_t callback,
        const enum dac_callback type)
```

Registers an asynchronous callback with the DAC driver, fired when a callback condition occurs.

Table 6-28. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the DAC software instance struct
[in]	callback	Pointer to the callback function to register
[in]	channel	Logical channel to register callback function
[in]	type	Type of callback function to register

Returns
Status of the registration operation.

Table 6-29. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode

Function dac_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code dac_unregister_callback(
        struct dac_module *const module,
        const enum dac_channel channel,
        const enum dac_callback type)
```

Unregisters an asynchronous callback with the DAC driver, removing it from the internal callback registration table.

Table 6-30. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Logical channel to unregister callback function
[in]	type	Type of callback function to unregister

Returns
Status of the de-registration operation.

Table 6-31. Return Values

Return value	Description
STATUS_OK	The callback was unregistered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode

6.6.4.6. Callback Enabling and Disabling (Channel)

Function dac_chan_enable_callback()

Enables asynchronous callback generation for a given channel and type.

```
enum status_code dac_chan_enable_callback(
        struct dac_module *const module,
        const enum dac_channel channel,
        const enum dac_callback type)
```

Enables asynchronous callbacks for a given logical DAC channel and type. This must be called before a DAC channel will generate callback events.

Table 6-32. Parameters

Data direction	Parameter name	Description
[in, out]	dac_module	Pointer to the DAC software instance struct
[in]	channel	Logical channel to enable callback function
[in]	type	Type of callback function callbacks to enable

Returns

Status of the callback enable operation.

Table 6-33. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode

Function dac_chan_disable_callback()

Disables asynchronous callback generation for a given channel and type.

```
enum status_code dac_chan_disable_callback(
        struct dac_module *const module,
        const enum dac_channel channel,
        const enum dac_callback type)
```

Disables asynchronous callbacks for a given logical DAC channel and type.

Table 6-34. Parameters

Data direction	Parameter name	Description
[in, out]	dac_module	Pointer to the DAC software instance struct
[in]	channel	Logical channel to disable callback function
[in]	type	Type of callback function callbacks to disable

Returns
Status of the callback disable operation.

Table 6-35. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully
STATUS_ERR_UNSUPPORTED_DEV	If a callback that requires event driven mode was specified with a DAC instance configured in non-event mode

Function dac_chan_get_job_status()

Gets the status of a job.

```
enum status_code dac_chan_get_job_status(
        struct dac_module * module_inst,
        const enum dac_channel channel)
```

Gets the status of an ongoing or the last job.

Table 6-36. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Logical channel to enable callback function

Returns
Status of the job.

Function dac_chan_abort_job()

Aborts an ongoing job.

```
void dac_chan_abort_job(
        struct dac_module * module_inst,
        const enum dac_channel channel)
```

Aborts an ongoing job.

Table 6-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	Logical channel to enable callback function

6.6.4.7. Configuration and Initialization (Channel)

Function dac_chan_enable_output_buffer()

Enable the output buffer.

```
void dac_chan_enable_output_buffer(
        struct dac_module *const dev_inst,
        const enum dac_channel channel)
```

Enables the output buffer and drives the DAC output to the VOUT pin.

Table 6-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	DAC channel to alter

Function dac_chan_disable_output_buffer()

Disable the output buffer.

```
void dac_chan_disable_output_buffer(
        struct dac_module *const dev_inst,
        const enum dac_channel channel)
```

Disables the output buffer.

Note: The output buffer(s) should be disabled when a channel's output is not currently needed, as it will draw current even if the system is in sleep mode.

Table 6-39. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the DAC software instance struct
[in]	channel	DAC channel to alter

6.6.5. Enumeration Definitions

6.6.5.1. Enum dac_callback

Enum for the possible callback types for the DAC module.

Table 6-40. Members

Enum value	Description
DAC_CALLBACK_DATA_EMPTY	Callback type for when a DAC channel data empty condition occurs (requires event triggered mode)
DAC_CALLBACK_DATA_UNDERRUN	Callback type for when a DAC channel data underrun condition occurs (requires event triggered mode)
DAC_CALLBACK_TRANSFER_COMPLETE	Callback type for when a DAC channel write buffer job complete (requires event triggered mode)

6.6.5.2. Enum dac_channel

Enum for the DAC channel selection.

Table 6-41. Members

Enum value	Description
DAC_CHANNEL_0	DAC output channel 0

6.6.5.3. Enum dac_output

Enum for the DAC output selection.

Table 6-42. Members

Enum value	Description
DAC_OUTPUT_EXTERNAL	DAC output to VOUT pin
DAC_OUTPUT_INTERNAL	DAC output as internal reference
DAC_OUTPUT_NONE	No output

6.6.5.4. Enum dac_reference

Enum for the possible reference voltages for the DAC.

Table 6-43. Members

Enum value	Description
DAC_REFERENCE_INT1V	1V from the internal band-gap reference
DAC_REFERENCE_AVCC	Analog V_{CC} as reference
DAC_REFERENCE_AREF	External reference on AREF

6.7. Extra Information for DAC Driver

6.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
ADC	Analog-to-Digital Converter
AC	Analog Comparator
DAC	Digital-to-Analog Converter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

6.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

6.7.3. Errata

There are no errata related to this driver.

6.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add configuration for using 14-bit hardware dithering (SAMC21 support)
Added new configuration parameters `databuf_protection_bypass`, `voltage_pump_disable`. Added new callback functions `dac_chan_write_buffer_wait`, `dac_chan_write_buffer_job`, `dac_chan_write_job`, `dac_get_job_status`, `dac_abort_job` and new callback type `DAC_CALLBACK_TRANSFER_COMPLETE` for DAC conversion job
Initial Release

6.8. Examples for DAC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Digital-to-Analog (DAC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for DAC - Basic
- Quick Start Guide for DAC - Callback

6.8.1. Quick Start Guide for DAC - Basic

In this use case, the DAC will be configured with the following settings:

- Analog V_{CC} as reference
- Internal output disabled
- Drive the DAC output to the V_{OUT} pin
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode

6.8.1.1. Quick Start

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct dac_module dac_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_dac(void)
{
    struct dac_config config_dac;
    dac_get_config_defaults(&config_dac);

    dac_init(&dac_instance, DAC, &config_dac);
}

void configure_dac_channel(void)
{
    struct dac_chan_config config_dac_chan;
    dac_chan_get_config_defaults(&config_dac_chan);

    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0, &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_dac();
configure_dac_channel();
```

Workflow

1. Create a module software instance structure for the DAC module to store the DAC driver state while in use.

   ```
   struct dac_module dac_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the DAC module.
   1. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

      ```
      struct dac_config config_dac;
      ```
   2. Initialize the DAC configuration struct with the module's default values.

      ```
      dac_get_config_defaults(&config_dac);
      ```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Configure the DAC channel.
    1. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

    2. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    3. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
&config_dac_chan);
```

    4. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

4. Enable the DAC module.

```
dac_enable(&dac_instance);
```

6.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
uint16_t i = 0;

while (1) {
    dac_chan_write(&dac_instance, DAC_CHANNEL_0, i);

    if (++i == 0x3FF) {
        i = 0;
    }
}
```

Workflow

1. Create a temporary variable to track the current DAC output value.

```
uint16_t i = 0;
```

2. Enter an infinite loop to continuously output new conversion values to the DAC.

```
while (1) {
```

3. Write the next conversion value to the DAC, so that it will be output on the device's DAC analog output pin.

```
dac_chan_write(&dac_instance, DAC_CHANNEL_0, i);
```

4. Increment and wrap the DAC output conversion value, so that a ramp pattern will be generated.

```
if (++i == 0x3FF) {
    i = 0;
}
```

6.8.2. Quick Start Guide for DAC - Callback

In this use case, the DAC will convert 16 samples using interrupt driven conversion. When all samples have been sampled, a callback will be called that signals the main application that conversion is compete.

The DAC will be set up as follows:

- Analog V_{CC} as reference
- Internal output disabled
- Drive the DAC output to the V_{OUT} pin
- Right adjust data
- The output buffer is disabled when the chip enters STANDBY sleep mode
- DAC conversion is started with RTC overflow event

6.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use case.

Code

Add to the main application source file, outside of any functions:

```
#define DATA_LENGTH (16)
```

```
struct dac_module dac_instance;
```

```
struct rtc_module rtc_instance;
```

```
struct events_resource event_dac;
```

```
static volatile bool transfer_is_done = false;
```

```
static uint16_t dac_data[DATA_LENGTH];
```

Callback function:

```
void dac_callback(uint8_t channel)
{
    UNUSED(channel);

    transfer_is_done = true;
}
```

Copy-paste the following setup code to your user application:

```
void configure_rtc_count(void)
{
    struct rtc_count_events  rtc_event;

    struct rtc_count_config config_rtc_count;

    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
#ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
    config_rtc_count.continuously_update = true;
#endif
```

```
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_event.generate_event_on_overflow = true;

    rtc_count_enable_events(&rtc_instance, &rtc_event);

    rtc_count_enable(&rtc_instance);
}
```

```
void configure_dac(void)
{
    struct dac_config config_dac;

    dac_get_config_defaults(&config_dac);

#if (SAML21)
    dac_instance.start_on_event[DAC_CHANNEL_0] = true;
#else
    dac_instance.start_on_event = true;
#endif

    dac_init(&dac_instance, DAC, &config_dac);

    struct dac_events events =
#if (SAML21)
        { .on_event_chan0_start_conversion = true };
#else
        { .on_event_start_conversion = true };
#endif

    dac_enable_events(&dac_instance, &events);
}
```

```
void configure_dac_channel(void)
{
    struct dac_chan_config config_dac_chan;

    dac_chan_get_config_defaults(&config_dac_chan);

    dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
            &config_dac_chan);

    dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
}
```

Define a data length variables and add to user application (typically the start of `main()`):

```
uint32_t i;
```

Add to user application initialization (typically the start of `main()`):

```
configure_rtc_count();

rtc_count_set_period(&rtc_instance, 1);

configure_dac();

configure_dac_channel();

dac_enable(&dac_instance);

configure_event_resource();

dac_register_callback(&dac_instance, DAC_CHANNEL_0,
        dac_callback,DAC_CALLBACK_TRANSFER_COMPLETE);
```

```
dac_chan_enable_callback(&dac_instance, DAC_CHANNEL_0,
        DAC_CALLBACK_TRANSFER_COMPLETE);

for (i = 0;i < DATA_LENGTH;i++) {
    dac_data[i] = 0xfff * i;
}
```

Workflow

1. Create a module software instance structure for the DAC module to store the DAC driver state while in use.

   ```
   struct dac_module dac_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. RTC module is used as the event trigger for DAC in this case, create a module software instance structure for the RTC module to store the RTC driver state.

   ```
   struct rtc_module rtc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
3. Create a buffer for the DAC samples to be converted by the driver.

   ```
   static uint16_t dac_data[DATA_LENGTH];
   ```
4. Create a callback function that will be called when DAC completes convert job.

   ```
   void dac_callback(uint8_t channel)
   {
       UNUSED(channel);

       transfer_is_done = true;
   }
   ```
5. Configure the DAC module.
   1. Create a DAC module configuration struct, which can be filled out to adjust the configuration of a physical DAC peripheral.

      ```
      struct dac_config config_dac;
      ```
   2. Initialize the DAC configuration struct with the module's default values.

      ```
      dac_get_config_defaults(&config_dac);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   3. Configure the DAC module with starting conversion on event.

      ```
      #if (SAML21)
          dac_instance.start_on_event[DAC_CHANNEL_0] = true;
      #else
          dac_instance.start_on_event = true;
      #endif
      ```
   4. Initialize the DAC module.

      ```
      dac_init(&dac_instance, DAC, &config_dac);
      ```

5. Enable DAC start on conversion mode.

```
struct dac_events events =
#if (SAML21)
        { .on_event_chan0_start_conversion = true };
#else
        { .on_event_start_conversion = true };
#endif
```

6. Enable DAC event.

```
dac_enable_events(&dac_instance, &events);
```

6. Configure the DAC channel.
    1. Create a DAC channel configuration struct, which can be filled out to adjust the configuration of a physical DAC output channel.

```
struct dac_chan_config config_dac_chan;
```

    2. Initialize the DAC channel configuration struct with the module's default values.

```
dac_chan_get_config_defaults(&config_dac_chan);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    3. Configure the DAC channel with the desired channel settings.

```
dac_chan_set_config(&dac_instance, DAC_CHANNEL_0,
        &config_dac_chan);
```

    4. Enable the DAC channel so that it can output a voltage.

```
dac_chan_enable(&dac_instance, DAC_CHANNEL_0);
```

7. Enable DAC module.

```
dac_enable(&dac_instance);
```

8. Configure the RTC module.
    1. Create an RTC module event struct, which can be filled out to adjust the configuration of a physical RTC peripheral.

```
struct rtc_count_events  rtc_event;
```

    2. Create an RTC module configuration struct, which can be filled out to adjust the configuration of a physical RTC peripheral.

```
struct rtc_count_config config_rtc_count;
```

    3. Initialize the RTC configuration struct with the module's default values.

```
rtc_count_get_config_defaults(&config_rtc_count);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    4. Change the RTC module configuration to suit the application.

```
config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
#ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
    config_rtc_count.continuously_update = true;
#endif
```

5. Initialize the RTC module.

```
rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
```

6. Configure the RTC module with overflow event.

```
rtc_event.generate_event_on_overflow = true;
```

7. Enable RTC module overflow event.

```
rtc_count_enable_events(&rtc_instance, &rtc_event);
```

8. Enable RTC module.

```
rtc_count_enable(&rtc_instance);
```

9. Configure the Event resource.
    1. Create an event resource config struct, which can be filled out to adjust the configuration of a physical event peripheral.

```
struct events_config event_config;
```

    2. Initialize the event configuration struct with the module's default values.

```
events_get_config_defaults(&event_config);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    3. Change the event module configuration to suit the application.

```
event_config.generator      = EVSYS_ID_GEN_RTC_OVF;
event_config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
event_config.path           = EVENTS_PATH_ASYNCHRONOUS;
event_config.clock_source   = GCLK_GENERATOR_0;
```

    4. Allocate the event resource.

```
events_allocate(&event_dac, &event_config);
```

    5. Attach the event resource with user DAC start.

```
#if (SAML21)
    events_attach_user(&event_dac, EVSYS_ID_USER_DAC_START_0);
#else
    events_attach_user(&event_dac, EVSYS_ID_USER_DAC_START);
#endif
```

10. Register and enable the DAC Write Buffer Complete callback handler.
    1. Register the user-provided Write Buffer Complete callback function with the driver, so that it will be run when an asynchronous buffer write job completes.

```
dac_register_callback(&dac_instance, DAC_CHANNEL_0,
        dac_callback,DAC_CALLBACK_TRANSFER_COMPLETE);
```

    2. Enable the Read Buffer Complete callback so that it will generate callbacks.

```
dac_chan_enable_callback(&dac_instance, DAC_CHANNEL_0,
        DAC_CALLBACK_TRANSFER_COMPLETE);
```

6.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
dac_chan_write_buffer_job(&dac_instance, DAC_CHANNEL_0,
        dac_data, DATA_LENGTH);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (1) {
}
```

Workflow

1. Start a DAC conversion and generate a callback when complete.

```
dac_chan_write_buffer_job(&dac_instance, DAC_CHANNEL_0,
        dac_data, DATA_LENGTH);
```

2. Wait until the conversion is complete.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

3. Enter an infinite loop once the conversion is complete.

```
while (1) {
}
```

7. SAM Direct Memory Access Controller (DMAC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the Direct Memory Access Controller(DMAC) module within the device. The DMAC can transfer data between memories and peripherals, and thus off-load these tasks from the CPU. The module supports peripheral to peripheral, peripheral to memory, memory to peripheral, and memory to memory transfers.

The following peripheral is used by the DMAC Driver:

- DMAC (Direct Memory Access Controller)

The following devices can use this module:

- Atmel | SMART SAM D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

7.1. Prerequisites

There are no prerequisites for this module.

7.2. Module Overview

SAM devices with DMAC enables high data transfer rates with minimum CPU intervention and frees up CPU time. With access to all peripherals, the DMAC can handle automatic transfer of data to/from modules. It supports static and incremental addressing for both source and destination.

The DMAC when used with Event System or peripheral triggers, provides a considerable advantage by reducing the power consumption and performing data transfer in the background. For example, if the ADC is configured to generate an event, it can trigger the DMAC to transfer the data into another peripheral or SRAM. The CPU can remain in sleep during this time to reduce the power consumption.

Device	Dma channel number
SAM D21/R21/C20/C21	12
SAM D09/D10/D11	6
SAM L21,SAMR30	16

The DMA channel operation can be suspended at any time by software, by events from event system, or after selectable descriptor execution. The operation can be resumed by software or by events from the event system. The DMAC driver for SAM supports four types of transfers such as peripheral to peripheral, peripheral to memory, memory to peripheral, and memory to memory.

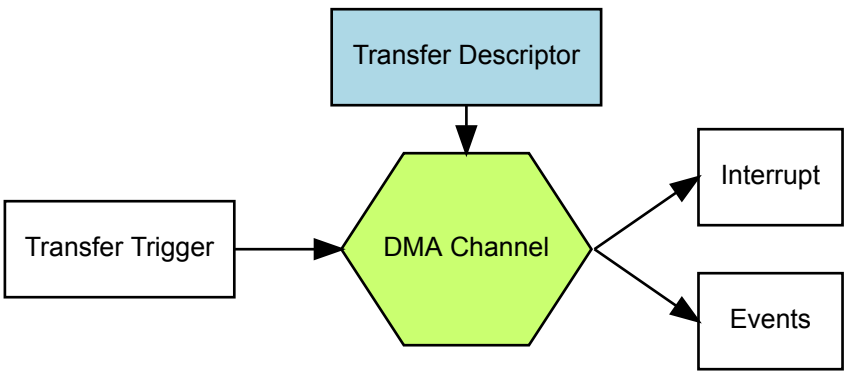
The basic transfer unit is a beat, which is defined as a single bus access. There can be multiple beats in a single block transfer and multiple block transfers in a DMA transaction. DMA transfer is based on descriptors, which holds transfer properties such as the source and destination addresses, transfer counter, and other additional transfer control information. The descriptors can be static or linked. When static, a single block transfer is performed. When linked, a number of transfer descriptors can be used to enable multiple block transfers within a single DMA transaction.

The implementation of the DMA driver is based on the idea that the DMA channel is a finite resource of entities with the same abilities. A DMA channel resource is able to move a defined set of data from a source address to destination address triggered by a transfer trigger. On the SAM devices there are 12 DMA resources available for allocation. Each of these DMA resources can trigger interrupt callback routines and peripheral events. The other main features are:

- Selectable transfer trigger source
  - Software
  - Event System
  - Peripheral
- Event input and output is supported for the four lower channels
- Four level channel priority
- Optional interrupt generation on transfer complete, channel error, or channel suspend
- Supports multi-buffer or circular buffer mode by linking multiple descriptors
- Beat size configurable as 8-bit, 16-bit, or 32-bit

A simplified block diagram of the DMA Resource can be seen in Figure 7-1.

Figure 7-1. Module Overview



7.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_DMA_CHANNEL_STANDBY	SAM L21/L22/C20/C21/R30

Note: The specific features are only available in the driver when the selected device supports those features.

7.2.2. Terminology Used in DMAC Transfers

Name	Description
Beat	It is a single bus access by the DMAC. Configurable as 8-bit, 16-bit, or 32-bit.
Burst	It is a transfer of n-beats (n=1,4,8,16). For the DMAC module in SAM, the burst size is one beat. Arbitration takes place each time a burst transfer is completed.
Block transfer	A single block transfer is a configurable number of (1 to 64k) beat transfers

7.2.3. DMA Channels

The DMAC in each device consists of several DMA channels, which along with the transfer descriptors defines the data transfer properties.

- The transfer control descriptor defines the source and destination addresses, source and destination address increment settings, the block transfer count, and event output condition selection
- Dedicated channel registers control the peripheral trigger source, trigger mode settings, event input actions, and channel priority level settings

With a successful DMA resource allocation, a dedicated DMA channel will be assigned. The channel will be occupied until the DMA resource is freed. A DMA resource handle is used to identify the specific DMA resource. When there are multiple channels with active requests, the arbiter prioritizes the channels requesting access to the bus.

7.2.4. DMA Triggers

DMA transfer can be started only when a DMA transfer request is acknowledged/granted by the arbiter. A transfer request can be triggered from software, peripheral, or an event. There are dedicated source trigger selections for each DMA channel usage.

7.2.5. DMA Transfer Descriptor

The transfer descriptor resides in the SRAM and defines these channel properties.

Field name	Field width
Descriptor Next Address	32 bits
Destination Address	32 bits
Source Address	32 bits

Field name	Field width
Block Transfer Counter	16 bits
Block Transfer Control	16 bits

Before starting a transfer, at least one descriptor should be configured. After a successful allocation of a DMA channel, the transfer descriptor can be added with a call to dma_add_descriptor(). If there is a transfer descriptor already allocated to the DMA resource, the descriptor will be linked to the next descriptor address.

7.2.6. DMA Interrupts/Events

Both an interrupt callback and an peripheral event can be triggered by the DMA transfer. Three types of callbacks are supported by the DMA driver: transfer complete, channel suspend, and transfer error. Each of these callback types can be registered and enabled for each channel independently through the DMA driver API.

The DMAC module can also generate events on transfer complete. Event generation is enabled through the DMA channel, event channel configuration, and event user multiplexing is done through the events driver.

The DMAC can generate events in the below cases:

- When a block transfer is complete
- When each beat transfer within a block transfer is complete

7.3. Special Considerations

There are no special considerations for this module.

7.4. Extra Information

For extra information, see Extra Information for DMAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

7.5. Examples

For a list of examples related to this driver, see Examples for DMAC Driver.

7.6. API Overview

7.6.1. Variable and Type Definitions

7.6.1.1. Type dma_callback_t

```
typedef void(* dma_callback_t )(struct dma_resource *const resource)
```

Type definition for a DMA resource callback function.

7.6.1.2. Variable descriptor_section

```
DmacDescriptor descriptor_section
```

ExInitial description section.

7.6.1.3. Variable g_chan_interrupt_flag

```
uint8_t g_chan_interrupt_flag
```

7.6.2. Structure Definitions

7.6.2.1. Struct dma_descriptor_config

DMA transfer descriptor configuration. When the source or destination address increment is enabled, the addresses stored into the configuration structure must correspond to the end of the transfer.

Table 7-1. Members

Type	Name	Description
enum dma_beat_size	beat_size	Beat size is configurable as 8-bit, 16-bit, or 32-bit
enum dma_block_action	block_action	Action taken when a block transfer is completed
uint16_t	block_transfer_count	It is the number of beats in a block. This count value is decremented by one after each beat data transfer.
bool	descriptor_valid	Descriptor valid flag used to identify whether a descriptor is valid or not
uint32_t	destination_address	Transfer destination address
bool	dst_increment_enable	Used for enabling the destination address increment
enum dma_event_output_selection	event_output_selection	This is used to generate an event on specific transfer action in a channel. Supported only in four lower channels.
uint32_t	next_descriptor_address	Set to zero for static descriptors. This must have a valid memory address for linked descriptors.
uint32_t	source_address	Transfer source address

Type	Name	Description
bool	src_increment_enable	Used for enabling the source address increment
enum dma_step_selection	step_selection	This bit selects whether the source or destination address is using the step size settings
enum dma_address_increment_stepsize	step_size	The step size for source/destination address increment. The next address is calculated as next_addr = addr + (2^step_size * beat size).

7.6.2.2. Struct dma_events_config

Configurations for DMA events.

Table 7-2. Members

Type	Name	Description
bool	event_output_enable	Enable DMA event output
enum dma_event_input_action	input_action	Event input actions

7.6.2.3. Struct dma_resource

Structure for DMA transfer resource.

Table 7-3. Members

Type	Name	Description
dma_callback_t	callback[]	Array of callback functions for DMA transfer job
uint8_t	callback_enable	Bit mask for enabled callbacks
uint8_t	channel_id	Allocated DMA channel ID
DmacDescriptor *	descriptor	DMA transfer descriptor
enum status_code	job_status	Status of the last job
uint32_t	transfered_size	Transferred data size

7.6.2.4. Struct dma_resource_config

DMA configurations for transfer.

Table 7-4. Members

Type	Name	Description
struct dma_events_config	event_config	DMA events configurations
uint8_t	peripheral_trigger	DMA peripheral trigger index

Type	Name	Description
enum dma_priority_level	priority	DMA transfer priority
bool	run_in_standby	Keep DMA channel enabled in standby sleep mode if true
enum dma_transfer_trigger_action	trigger_action	DMA trigger action

7.6.3. Macro Definitions

7.6.3.1. Macro DMA_INVALID_CHANNEL

```
#define DMA_INVALID_CHANNEL
```

DMA invalid channel number.

7.6.3.2. Macro FEATURE_DMA_CHANNEL_STANDBY

```
#define FEATURE_DMA_CHANNEL_STANDBY
```

7.6.4. Function Definitions

7.6.4.1. Function dma_abort_job()

Abort a DMA transfer.

```
void dma_abort_job(
        struct dma_resource * resource)
```

This function will abort a DMA transfer. The DMA channel used for the DMA resource will be disabled. The block transfer count will also be calculated and written to the DMA resource structure.

Note: The DMA resource will not be freed after calling this function. The function dma_free() can be used to free an allocated resource.

Table 7-5. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

7.6.4.2. Function dma_add_descriptor()

Add a DMA transfer descriptor to a DMA resource.

```
enum status_code dma_add_descriptor(
        struct dma_resource * resource,
        DmacDescriptor * descriptor)
```

This function will add a DMA transfer descriptor to a DMA resource. If there was a transfer descriptor already allocated to the DMA resource, the descriptor will be linked to the next descriptor address.

Table 7-6. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	descriptor	Pointer to the transfer descriptor

Table 7-7. Return Values

Return value	Description
STATUS_OK	The descriptor is added to the DMA resource
STATUS_BUSY	The DMA resource was busy and the descriptor is not added

7.6.4.3. Function dma_allocate()

Allocate a DMA with configurations.

```
enum status_code dma_allocate(
        struct dma_resource * resource,
        struct dma_resource_config * config)
```

This function will allocate a proper channel for a DMA transfer request.

Table 7-8. Parameters

Data direction	Parameter name	Description
[in, out]	dma_resource	Pointer to a DMA resource instance
[in]	transfer_config	Configurations of the DMA transfer

Returns
Status of the allocation procedure.

Table 7-9. Return Values

Return value	Description
STATUS_OK	The DMA resource was allocated successfully
STATUS_ERR_NOT_FOUND	DMA resource allocation failed

7.6.4.4. Function dma_descriptor_create()

Create a DMA transfer descriptor with configurations.

```
void dma_descriptor_create(
        DmacDescriptor * descriptor,
        struct dma_descriptor_config * config)
```

This function will set the transfer configurations to the DMA transfer descriptor.

Table 7-10. Parameters

Data direction	Parameter name	Description
[in]	descriptor	Pointer to the DMA transfer descriptor
[in]	config	Pointer to the descriptor configuration structure

7.6.4.5. Function dma_descriptor_get_config_defaults()

Initializes DMA transfer configuration with predefined default values.

```
void dma_descriptor_get_config_defaults(
        struct dma_descriptor_config * config)
```

This function will initialize a given DMA descriptor configuration structure to a set of known default values. This function should be called on any new instance of the configuration structure before being modified by the user application.

The default configuration is as follows:

- Set the descriptor as valid
- Disable event output
- No block action
- Set beat size as byte
- Enable source increment
- Enable destination increment
- Step size is applied to the destination address
- Address increment is beat size multiplied by 1
- Default transfer size is set to 0
- Default source address is set to NULL
- Default destination address is set to NULL
- Default next descriptor not available

Table 7-11. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to the configuration

7.6.4.6. Function dma_disable_callback()

Disable a callback function for a dedicated DMA resource.

```
void dma_disable_callback(
        struct dma_resource * resource,
        enum dma_callback_type type)
```

Table 7-12. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

7.6.4.7. Function dma_enable_callback()

Enable a callback function for a dedicated DMA resource.

```
void dma_enable_callback(
        struct dma_resource * resource,
        enum dma_callback_type type)
```

Table 7-13. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

7.6.4.8. Function dma_free()

Free an allocated DMA resource.

```
enum status_code dma_free(
        struct dma_resource * resource)
```

This function will free an allocated DMA resource.

Table 7-14. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

Returns
Status of the free procedure.

Table 7-15. Return Values

Return value	Description
STATUS_OK	The DMA resource was freed successfully
STATUS_BUSY	The DMA resource was busy and can't be freed
STATUS_ERR_NOT_INITIALIZED	DMA resource was not initialized

7.6.4.9. Function dma_get_config_defaults()

Initializes config with predefined default values.

```
void dma_get_config_defaults(
        struct dma_resource_config * config)
```

This function will initialize a given DMA configuration structure to a set of known default values. This function should be called on any new instance of the configuration structure before being modified by the user application.

The default configuration is as follows:

- Software trigger is used as the transfer trigger
- Priority level 0
- Only software/event trigger

- Requires a trigger for each transaction
- No event input /output
- DMA channel is disabled during sleep mode (if has the feature)

Table 7-16. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to the configuration

7.6.4.10. Function dma_get_job_status()

Get DMA resource status.

```
enum status_code dma_get_job_status(
        struct dma_resource * resource)
```

Table 7-17. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

Returns
Status of the DMA resource.

7.6.4.11. Function dma_is_busy()

Check if the given DMA resource is busy.

```
bool dma_is_busy(
        struct dma_resource * resource)
```

Table 7-18. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

Returns
Status which indicates whether the DMA resource is busy.

Table 7-19. Return Values

Return value	Description
true	The DMA resource has an on-going transfer
false	The DMA resource is not busy

7.6.4.12. Function dma_register_callback()

Register a callback function for a dedicated DMA resource.

```
void dma_register_callback(
        struct dma_resource * resource,
        dma_callback_t callback,
        enum dma_callback_type type)
```

There are three types of callback functions, which can be registered:

- Callback for transfer complete
- Callback for transfer error
- Callback for channel suspend

Table 7-20. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	callback	Pointer to the callback function
[in]	type	Callback function type

7.6.4.13. Function dma_reset_descriptor()

Reset DMA descriptor.

```
void dma_reset_descriptor(
        struct dma_resource * resource)
```

This function will clear the DESCADDR register of an allocated DMA resource.

7.6.4.14. Function dma_resume_job()

Resume a suspended DMA transfer.

```
void dma_resume_job(
        struct dma_resource * resource)
```

This function try to resume a suspended transfer of a DMA resource.

Table 7-21. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

7.6.4.15. Function dma_start_transfer_job()

Start a DMA transfer.

```
enum status_code dma_start_transfer_job(
        struct dma_resource * resource)
```

This function will start a DMA transfer through an allocated DMA resource.

Table 7-22. Parameters

Data direction	Parameter name	Description
[in, out]	resource	Pointer to the DMA resource

Returns
Status of the transfer start procedure.

Table 7-23. Return Values

Return value	Description
STATUS_OK	The transfer was started successfully
STATUS_BUSY	The DMA resource was busy and the transfer was not started
STATUS_ERR_INVALID_ARG	Transfer size is 0 and transfer was not started

7.6.4.16. Function dma_suspend_job()

Suspend a DMA transfer.

```
void dma_suspend_job(
        struct dma_resource * resource)
```

This function will request to suspend the transfer of the DMA resource. The channel is kept enabled, can receive transfer triggers (the transfer pending bit will be set), but will be removed from the arbitration scheme. The channel operation can be resumed by calling dma_resume_job().

Note: This function sets the command to suspend the DMA channel associated with a DMA resource. The channel suspend interrupt flag indicates whether the transfer is truly suspended.

Table 7-24. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

7.6.4.17. Function dma_trigger_transfer()

Will set a software trigger for resource.

```
void dma_trigger_transfer(
        struct dma_resource * resource)
```

This function is used to set a software trigger on the DMA channel associated with resource. If a trigger is already pending no new trigger will be generated for the channel.

Table 7-25. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource

7.6.4.18. Function dma_unregister_callback()

Unregister a callback function for a dedicated DMA resource.

```
void dma_unregister_callback(
        struct dma_resource * resource,
        enum dma_callback_type type)
```

There are three types of callback functions:

- Callback for transfer complete
- Callback for transfer error
- Callback for channel suspend

The application can unregister any of the callback functions which are already registered and are no longer needed.

Table 7-26. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to the DMA resource
[in]	type	Callback function type

7.6.4.19. Function dma_update_descriptor()

Update DMA descriptor.

```
void dma_update_descriptor(
        struct dma_resource * resource,
        DmacDescriptor * descriptor)
```

This function can update the descriptor of an allocated DMA resource.

7.6.5. Enumeration Definitions

7.6.5.1. Enum dma_address_increment_stepsize

Address increment step size. These bits select the address increment step size. The setting apply to source or destination address, depending on STEPSEL setting.

Table 7-27. Members

Enum value	Description
DMA_ADDRESS_INCREMENT_STEP_SIZE_1	The address is incremented by (beat size * 1).
DMA_ADDRESS_INCREMENT_STEP_SIZE_2	The address is incremented by (beat size * 2).
DMA_ADDRESS_INCREMENT_STEP_SIZE_4	The address is incremented by (beat size * 4).
DMA_ADDRESS_INCREMENT_STEP_SIZE_8	The address is incremented by (beat size * 8).
DMA_ADDRESS_INCREMENT_STEP_SIZE_16	The address is incremented by (beat size * 16).
DMA_ADDRESS_INCREMENT_STEP_SIZE_32	The address is incremented by (beat size * 32).
DMA_ADDRESS_INCREMENT_STEP_SIZE_64	The address is incremented by (beat size * 64).
DMA_ADDRESS_INCREMENT_STEP_SIZE_128	The address is incremented by (beat size * 128).

7.6.5.2. Enum dma_beat_size

The basic transfer unit in DMAC is a beat, which is defined as a single bus access. Its size is configurable and applies to both read and write.

Table 7-28. Members

Enum value	Description
DMA_BEAT_SIZE_BYTE	8-bit access.
DMA_BEAT_SIZE_HWORD	16-bit access.
DMA_BEAT_SIZE_WORD	32-bit access.

7.6.5.3. Enum dma_block_action

Block action definitions.

Table 7-29. Members

Enum value	Description
DMA_BLOCK_ACTION_NOACT	No action.
DMA_BLOCK_ACTION_INT	Channel in normal operation and sets transfer complete interrupt flag after block transfer.
DMA_BLOCK_ACTION_SUSPEND	Trigger channel suspend after block transfer and sets channel suspend interrupt flag once the channel is suspended.
DMA_BLOCK_ACTION_BOTH	Sets transfer complete interrupt flag after a block transfer and trigger channel suspend. The channel suspend interrupt flag will be set once the channel is suspended.

7.6.5.4. Enum dma_callback_type

Callback types for DMA callback driver.

Table 7-30. Members

Enum value	Description
DMA_CALLBACK_TRANSFER_ERROR	Callback for any of transfer errors. A transfer error is flagged if a bus error is detected during an AHB access or when the DMAC fetches an invalid descriptor.
DMA_CALLBACK_TRANSFER_DONE	Callback for transfer complete.
DMA_CALLBACK_CHANNEL_SUSPEND	Callback for channel suspend.
DMA_CALLBACK_N	Number of available callbacks.

7.6.5.5. Enum dma_event_input_action

DMA input actions.

Table 7-31. Members

Enum value	Description
DMA_EVENT_INPUT_NOACT	No action.
DMA_EVENT_INPUT_TRIG	Normal transfer and periodic transfer trigger.

Enum value	Description
DMA_EVENT_INPUT_CTRIG	Conditional transfer trigger.
DMA_EVENT_INPUT_CBLOCK	Conditional block transfer.
DMA_EVENT_INPUT_SUSPEND	Channel suspend operation.
DMA_EVENT_INPUT_RESUME	Channel resume operation.
DMA_EVENT_INPUT_SSKIP	Skip next block suspend action.

7.6.5.6. Enum dma_event_output_selection

Event output selection.

Table 7-32. Members

Enum value	Description
DMA_EVENT_OUTPUT_DISABLE	Event generation disable.
DMA_EVENT_OUTPUT_BLOCK	Event strobe when block transfer complete.
DMA_EVENT_OUTPUT_RESERVED	Event output reserved.
DMA_EVENT_OUTPUT_BEAT	Event strobe when beat transfer complete.

7.6.5.7. Enum dma_priority_level

DMA priority level.

Table 7-33. Members

Enum value	Description
DMA_PRIORITY_LEVEL_0	Priority level 0.
DMA_PRIORITY_LEVEL_1	Priority level 1.
DMA_PRIORITY_LEVEL_2	Priority level 2.
DMA_PRIORITY_LEVEL_3	Priority level 3.

7.6.5.8. Enum dma_step_selection

DMA step selection. This bit determines whether the step size setting is applied to source or destination address.

Table 7-34. Members

Enum value	Description
DMA_STEPSEL_DST	Step size settings apply to the destination address.
DMA_STEPSEL_SRC	Step size settings apply to the source address.

7.6.5.9. Enum dma_transfer_trigger_action

DMA trigger action type.

Table 7-35. Members

Enum value	Description
DMA_TRIGGER_ACTION_BLOCK	Perform a block transfer when triggered.
DMA_TRIGGER_ACTION_BEAT	Perform a beat transfer when triggered.
DMA_TRIGGER_ACTION_TRANSACTION	Perform a transaction when triggered.

7.7. Extra Information for DMAC Driver

7.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
DMA	Direct Memory Access
DMAC	Direct Memory Access Controller
CPU	Central Processing Unit

7.7.2. Dependencies

This driver has the following dependencies:

- System Clock Driver

7.7.3. Errata

There are no errata related to this driver.

7.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add SAM C21 support
Add SAM L21 support
Add SAM R30 support
Initial Release

7.8. Examples for DMAC Driver

This is a list of the available Quick Start Guides (QSGs) and example applications for SAM Direct Memory Access Controller (DMAC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for Memory to Memory Data Transfer Using DMAC

Note: More DMA usage examples are available in peripheral QSGs. A quick start guide for TC/TCC shows the usage of DMA event trigger; SERCOM SPI/USART/I^2C has example for DMA transfer from peripheral to memory or from memory to peripheral; ADC/DAC shows peripheral to peripheral transfer.

7.8.1. Quick Start Guide for Memory to Memory Data Transfer Using DMAC

The supported board list:

- SAM D21 Xplained Pro
- SAM R21 Xplained Pro
- SAM D11 Xplained Pro
- SAM L21 Xplained Pro
- SAM L22 Xplained Pro
- SAM DA1 Xplained Pro

In this use case, the DMAC is configured for:

- Moving data from memory to memory
- Using software trigger
- Using DMA priority level 0
- Transaction as DMA trigger action
- No action on input events
- Output event not enabled

7.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
#define DATA_LENGTH (512)

static uint8_t source_memory[DATA_LENGTH];

static uint8_t destination_memory[DATA_LENGTH];

static volatile bool transfer_is_done = false;

COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;

static void transfer_done(struct dma_resource* const resource )
{
    transfer_is_done = true;
}

static void configure_dma_resource(struct dma_resource *resource)
```

```
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor(DmacDescriptor *descriptor )
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = sizeof(source_memory);
    descriptor_config.source_address = (uint32_t)source_memory +
        sizeof(source_memory);
    descriptor_config.destination_address = (uint32_t)destination_memory +
        sizeof(source_memory);

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add the below section to user application initialization (typically the start of `main()`):

```
configure_dma_resource(&example_resource);

setup_transfer_descriptor(&example_descriptor);

dma_add_descriptor(&example_resource, &example_descriptor);

dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);

for (uint32_t i = 0; i < DATA_LENGTH; i++) {
    source_memory[i] = i;
}
```

Workflow

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

   ```
   struct dma_resource_config config;
   ```

2. Initialize the DMA resource configuration struct with the module's default values.

   ```
   dma_get_config_defaults(&config);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Allocate a DMA resource with the configurations.

   ```
   dma_allocate(resource, &config);
   ```

4. Declare a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

   ```
   struct dma_descriptor_config descriptor_config;
   ```

5. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

6. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address. In this example, we have enabled the source and destination address increment. The source and destination addresses to be stored into descriptor_config must correspond to the end of the transfer.

```
descriptor_config.block_transfer_count = sizeof(source_memory);
descriptor_config.source_address = (uint32_t)source_memory +
    sizeof(source_memory);
descriptor_config.destination_address = (uint32_t)destination_memory +
    sizeof(source_memory);
```

7. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

9. Register a callback to indicate transfer status.

```
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
```

10. Set the transfer done flag in the registered callback function.

```
static void transfer_done(struct dma_resource* const resource )
{
    transfer_is_done = true;
}
```

11. Enable the registered callbacks.

```
dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);
```

7.8.1.2. Use Case

Code

Add the following code at the start of `main()`:

```
struct dma_resource example_resource;
```

Copy the following code to your user application:

```
dma_start_transfer_job(&example_resource);

dma_trigger_transfer(&example_resource);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (true) {
    /* Nothing to do */
}
```

Workflow

1. Start the DMA transfer job with the allocated DMA resource and transfer descriptor.

```
dma_start_transfer_job(&example_resource);
```

2. Set the software trigger for the DMA channel. This can be done before or after the DMA job is started. Note that all transfers needs a trigger to start.

```
dma_trigger_transfer(&example_resource);
```

3. Waiting for the setting of the transfer done flag.

```
while (!transfer_is_done) {
     /* Wait for transfer done */
}
```

8. SAM Divide and Square Root Accelerator (DIVAS) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Divide and Square Root Accelerator functionality.

The following peripherals are used by this module:

- DIVAS (Divide and Square Root Accelerator)

The following devices can use this module:

- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

8.1. Prerequisites

There are no prerequisites for this module.

8.2. Module Overview

This driver provides an interface for the Divide and Square Root Accelerator on the device.

The DIVAS is a programmable 32-bit signed or unsigned hardware divider and a 32-bit unsigned square root hardware engine. When running signed division, both the input and the result will be in two's complement format. The result of signed division is that the remainder has the same sign as the dividend and the quotient is negative if the dividend and divisor have opposite signs. When the square root input register is programmed, the square root function starts and the result will be stored in the Remainder register.

There are two ways to calculate the results:

- Call the DIVAS API
- Overload "/" and "%" operation
  Note: Square root operation can't implement overload operation.

8.2.1. Overload Operation

The operation is implemented automatically by EABI (Enhanced Application Binary Interface). EABI is a standard calling convention, which is defined by ARM. The four functions interface can implement division and mod operation in EABI.

The following prototypes for EABI division operation in ICCARM tool chain:

```
int __aeabi_idiv(int numerator, int denominator);
unsigned __aeabi_uidiv(unsigned numerator, unsigned denominator);
__value_in_regs idiv_return __aeabi_idivmod( int numerator, int denominator);
__value_in_regs uidiv_return __aeabi_uidivmod( unsigned numerator,
                                               unsigned denominator);
```

The following prototypes for EABI division operation in GNUC tool chain:

```
int __aeabi_idiv(int numerator, int denominator);
unsigned __aeabi_uidiv(unsigned numerator, unsigned denominator);
uint64_t __aeabi_idivmod( int numerator, int denominator);
uint64_t uidiv_return __aeabi_uidivmod( unsigned numerator,
                                        unsigned denominator);
```

No matter what kind of tool chain, by using DIVAS module in the four functions body, the user can transparently access the DIVAS module when writing normal C code. For example:

```
void division(int32_t b, int32_t c)
{
    int32_t a;
    a = b / c;
    return a;
}
```

Similarly, the user can use the "a = b % c;" symbol to implement the operation with DIVAS, and needn't to care about the internal operation process.

8.2.2. Operand Size

- Divide: The DIVAS can perform 32-bit signed and unsigned division.
- Square Root: The DIVAS can perform 32-bit unsigned division.

8.2.3. Signed Division

When the signed flag is one, both the input and the result will be in two's complement format. The result of signed division is that the remainder has the same sign as the dividend and the quotient is negative if the dividend and divisor have opposite signs.
Note: When the maximum negative number is divided by the minimum negative number, the resulting quotient overflows the signed integer range and will return the maximum negative number with no indication of the overflow. This occurs for 0x80000000 / 0xFFFFFFFF in 32-bit operation and 0x8000 / 0xFFFF in 16-bit operation.

8.2.4. Divide By Zero

A divide by zero will cause a fault if the DIVISOR is programmed to zero. The result is that the quotient is zero and the reminder is equal to the dividend.

8.2.5. Unsigned Square Root

When the square root input register is programmed, the square root function starts and the result will be stored in the Result and Remainder registers.
Note: The square root function can't overload.

8.3. Special Considerations

There are no special considerations for this module.

8.4. Extra Information

For extra information, see Extra Information for DIVAS Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

8.5. Examples

For a list of examples related to this driver, see Examples for DIVAS Driver.

8.6. API Overview

8.6.1. Structure Definitions

8.6.1.1. Struct idiv_return

DIVAS signed division operator output data structure.

Table 8-1. Members

Type	Name	Description
int32_t	quotient	Signed division operator result: quotient
int32_t	remainder	Signed division operator result: remainder

8.6.1.2. Struct uidiv_return

DIVAS unsigned division operator output data structure.

Table 8-2. Members

Type	Name	Description
uint32_t	quotient	Unsigned division operator result: quotient
uint32_t	remainder	Unsigned division operator result: remainder

8.6.2. Function Definitions

8.6.2.1. Call the DIVAS API Operation

In this mode, the way that directly call the DIVAS API implement division or mod operation.

Function divas_idiv()

Signed division operation.

```
int32_t divas_idiv(
        int32_t numerator,
        int32_t denominator)
```

Run the signed division operation and return the quotient.

Table 8-3. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the signed division operation
[in]	denominator	The divisor of the signed division operation

Returns
The quotient of the DIVAS signed division operation.

Function divas_uidiv()

Unsigned division operation.

```
uint32_t divas_uidiv(
        uint32_t numerator,
        uint32_t denominator)
```

Run the unsigned division operation and return the results.

Table 8-4. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the unsigned division operation
[in]	denominator	The divisor of the unsigned division operation

Returns
The quotient of the DIVAS unsigned division operation.

Function divas_idivmod()

Signed division remainder operation.

```
int32_t divas_idivmod(
        int32_t numerator,
        int32_t denominator)
```

Run the signed division operation and return the remainder.

Table 8-5. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the signed division operation
[in]	denominator	The divisor of the signed division operation

Returns
The remainder of the DIVAS signed division operation.

Function divas_uidivmod()

Unsigned division remainder operation.

```
uint32_t divas_uidivmod(
        uint32_t numerator,
        uint32_t denominator)
```

Run the unsigned division operation and return the remainder.

Table 8-6. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the unsigned division operation
[in]	denominator	The divisor of the unsigned division operation

Returns
The remainder of the DIVAS unsigned division operation.

Function divas_sqrt()

Square root operation.

```
uint32_t divas_sqrt(
        uint32_t radicand)
```

Run the square root operation and return the results.

Table 8-7. Parameters

Data direction	Parameter name	Description
[in]	radicand	The radicand of the square root operation

Returns
The result of the DIVAS square root operation.

8.6.2.2. DIVAS Overload '/' and '%' Operation

In this mode, the user can transparently access the DIVAS module when writing normal C code. E.g. "a = b / c;" or "a = b % c;" will be translated to a subroutine call, which uses the DIVAS.

Function __aeabi_idiv()

Signed division operation overload.

```
int32_t __aeabi_idiv(
        int32_t numerator,
        int32_t denominator)
```

Run the signed division operation and return the results.

Table 8-8. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the signed division operation
[in]	denominator	The divisor of the signed division operation

Returns
The quotient of the DIVAS signed division operation.

Function __aeabi_uidiv()

Unsigned division operation overload.

```
uint32_t __aeabi_uidiv(
        uint32_t numerator,
        uint32_t denominator)
```

Run the unsigned division operation and return the results.

Table 8-9. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the unsigned division operation
[in]	denominator	The divisor of the unsigned division operation

Returns
The quotient of the DIVAS unsigned division operation.

Function __aeabi_idivmod()

Signed division remainder operation overload.

```
uint64_t __aeabi_idivmod(
        int32_t numerator,
        int32_t denominator)
```

Run the signed division operation and return the remainder.

Table 8-10. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the signed division operation
[in]	denominator	The divisor of the signed division operation

Returns
The remainder of the DIVAS signed division operation.

Function __aeabi_uidivmod()

Unsigned division remainder operation overload.

```
uint64_t __aeabi_uidivmod(
        uint32_t numerator,
        uint32_t denominator)
```

Run the unsigned division operation and return the remainder.

Table 8-11. Parameters

Data direction	Parameter name	Description
[in]	numerator	The dividend of the unsigned division operation
[in]	denominator	The divisor of the unsigned division operation

Returns
The remainder of the DIVAS unsigned division operation.

8.6.2.3. Function divas_disable_dlz()

Disables DIVAS leading zero optimization.

```
void divas_disable_dlz( void )
```

Disable leading zero optimization from the Divide and Square Root Accelerator module. When leading zero optimization is disable, 16-bit division completes in 8 cycles and 32-bit division completes in 16 cycles.

8.6.2.4. Function divas_enable_dlz()

Enables DIVAS leading zero optimization.

```
void divas_enable_dlz( void )
```

Enable leading zero optimization from the Divide and Square Root Accelerator module. When leading zero optimization is enable, 16-bit division completes in 2-8 cycles and 32-bit division completes in 2-16 cycles.

8.7. Extra Information for DIVAS Driver

8.7.1. Acronyms

Acronym	Description
DIVAS	Divide and Square Root Accelerator
EABI	Enhanced Application Binary Interface

8.7.2. Dependencies

This driver has no dependencies.

8.7.3. Errata

There are no errata related to this driver.

8.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

8.8. Examples for DIVAS Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Divide and Square Root Accelerator (DIVAS) Driver. QSGs are simple examples with step-by-step instructions to

configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for DIVAS - No Overload
- Quick Start Guide for DIVAS - Overload

8.8.1. Quick Start Guide for DIVAS - No Overload

In this use case, the Divide and Square Root Accelerator (DIVAS) module is used.

This use case will calculate the data in No Overload mode. If all the calculation results are the same as the desired results, the board LED will be lighted. Otherwise, the board LED will be flashing. The variable "result" can indicate which calculation is wrong.

8.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application source file, outside any function:

The signed and unsigned dividend:

```
#define BUF_LEN 8

const int32_t numerator_s[BUF_LEN] = {
    2046, 415, 26, 1, -1, -255, -3798, -65535};

const int32_t excepted_s[BUF_LEN] = {
    2046, 207, 8, 0, 0, -42, -542, -8191};

const int32_t excepted_s_m[BUF_LEN] = {
    0, 1, 2, 1, -1, -3, -4, -7};

const uint32_t numerator_u[BUF_LEN] = {
    0x00000001,
    0x0000005A,
    0x000007AB,
    0x00006ABC,
    0x0004567D,
    0x0093846E,
    0x20781945,
    0x7FFFFFFF,
};

const uint32_t excepted_u[BUF_LEN] = {
    0x00000001,
    0x0000002d,
    0x0000028E,
    0x00001AAF,
    0x0000DE19,
    0x00189612,
    0x04A37153,
    0x0FFFFFFF,
};

const uint32_t excepted_u_m[BUF_LEN] = {
    0, 0, 1, 0, 0, 2, 0, 7};

const uint32_t excepted_r[BUF_LEN] = {
```

```
    0x00000001,
    0x00000009,
    0x0000002C,
    0x000000A5,
    0x00000215,
    0x00000C25,
    0x00005B2B,
    0x0000B504,
};

static int32_t result_s[BUF_LEN], result_s_m[BUF_LEN];
static uint32_t result_u[BUF_LEN], result_u_m[BUF_LEN];
static uint32_t result_r[BUF_LEN];
static uint8_t result = 0;
```

Copy-paste the following function code to your user application:

```
static void signed_division(void)
{
    int32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_s[i];
        denominator = i + 1;
        result_s[i] = divas_idiv(numerator, denominator);
        if(result_s[i] != excepted_s[i]) {
            result |= 0x01;
        }
    }
}

static void unsigned_division(void)
{
    uint32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_u[i];
        denominator = i + 1;
        result_u[i] = divas_uidiv(numerator, denominator);
        if(result_u[i] != excepted_u[i]) {
            result |= 0x02;
        }
    }
}

static void signed_division_mod(void)
{
    int32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_s[i];
        denominator = i + 1;
        result_s_m[i] = divas_idivmod(numerator, denominator);
        if(result_s_m[i] != excepted_s_m[i]) {
            result |= 0x04;
        }
    }
}

static void unsigned_division_mod(void)
```

```
{
    uint32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_u[i];
        denominator = i + 1;
        result_u_m[i] = divas_uidivmod(numerator, denominator);
        if(result_u_m[i] != excepted_u_m[i]) {
            result |= 0x08;
        }
    }
}

static void squart_root(void)
{
    uint32_t operator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        operator = numerator_u[i];
        result_r[i] = divas_sqrt(operator);
        if(result_r[i] != excepted_r[i]) {
            result |= 0x10;
        }
    }
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
```

8.8.1.2. Implementation

Code

Copy-paste the following code to your user application:

```
signed_division();
unsigned_division();
signed_division_mod();
unsigned_division_mod();
squart_root();

while (true) {
    if(result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 50000;
        while(delay--) {
        }
    } else {
        port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
    }
}
```

Workflow

1. Signed division calculation.

   ```
   signed_division();
   ```

2. Unsigned division calculation.

```
unsigned_division();
```

3. Signed reminder calculation.

```
signed_division_mod();
```

4. Unsigned reminder calculation.

```
unsigned_division_mod();
```

5. Square root calculation.

```
squart_root();
```

6. Infinite loop.

```
while (true) {
    if(result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 50000;
        while(delay--) {
        }
    } else {
        port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
    }
}
```

8.8.2. Quick Start Guide for DIVAS - Overload

In this use case, the Divide and Square Root Accelerator (DIVAS) module is used.

This use case will calculate the data in overload mode. If all the calculation results are the same as the desired results, the board LED will be lighted. Otherwise, the board LED will be flashing. The variable "result" can indicate which calculation is wrong.

8.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application source file, outside any function:

The signed and unsigned dividend:

```
#define BUF_LEN 8

const int32_t numerator_s[BUF_LEN] = {
    2046, 415, 26, 1, -1, -255, -3798, -65535};

const int32_t excepted_s[BUF_LEN] = {
    2046, 207, 8, 0, 0, -42, -542, -8191};

const int32_t excepted_s_m[BUF_LEN] = {
    0, 1, 2, 1, -1, -3, -4, -7};

const uint32_t numerator_u[BUF_LEN] = {
    0x00000001,
    0x0000005A,
    0x000007AB,
```

```
    0x00006ABC,
    0x0004567D,
    0x0093846E,
    0x20781945,
    0x7FFFFFFF,
};

const uint32_t excepted_u[BUF_LEN] = {
    0x00000001,
    0x0000002d,
    0x0000028E,
    0x00001AAF,
    0x0000DE19,
    0x00189612,
    0x04A37153,
    0x0FFFFFFF,
};

const uint32_t excepted_u_m[BUF_LEN] = {
    0, 0, 1, 0, 0, 2, 0, 7};

const uint32_t excepted_r[BUF_LEN] = {
    0x00000001,
    0x00000009,
    0x0000002C,
    0x000000A5,
    0x00000215,
    0x00000C25,
    0x00005B2B,
    0x0000B504,
};

static int32_t result_s[BUF_LEN], result_s_m[BUF_LEN];
static uint32_t result_u[BUF_LEN], result_u_m[BUF_LEN];
static uint32_t result_r[BUF_LEN];
static uint8_t result = 0;
```

Copy-paste the following function code to your user application:

```
static void signed_division(void)
{
    int32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_s[i];
        denominator = i + 1;
        result_s[i] = numerator / denominator;
        if(result_s[i] != excepted_s[i]) {
            result |= 0x01;
        }
    }
}

static void unsigned_division(void)
{
    uint32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_u[i];
        denominator = i + 1;
        result_u[i] = numerator / denominator;
```

```
        if(result_u[i] != excepted_u[i]) {
            result |= 0x02;
        }
    }
}

static void signed_division_mod(void)
{
    int32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_s[i];
        denominator = i + 1;
        result_s_m[i] = numerator % denominator;
        if(result_s_m[i] != excepted_s_m[i]) {
            result |= 0x04;
        }
    }
}

static void unsigned_division_mod(void)
{
    uint32_t numerator, denominator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        numerator = numerator_u[i];
        denominator = i + 1;
        result_u_m[i] = numerator % denominator;
        if(result_u_m[i] != excepted_u_m[i]) {
            result |= 0x08;
        }
    }
}

static void squart_root(void)
{
    uint32_t operator;
    uint8_t i;

    for (i = 0; i < BUF_LEN; i++) {
        operator = numerator_u[i];
        result_r[i] = divas_sqrt(operator);
        if(result_r[i] != excepted_r[i]) {
            result |= 0x10;
        }
    }
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
```

8.8.2.2. Implementation

Code

Copy-paste the following code to your user application:

```
signed_division();
unsigned_division();
signed_division_mod();
```

```
unsigned_division_mod();
squart_root();

while (true) {
    if(result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 50000;
        while(delay--) {
        }
    } else {
        port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
    }
}
```

Workflow

1. Signed division calculation.

   ```
   signed_division();
   ```

2. Unsigned division calculation.

   ```
   unsigned_division();
   ```

3. Signed reminder calculation.

   ```
   signed_division_mod();
   ```

4. Unsigned reminder calculation.

   ```
   unsigned_division_mod();
   ```

5. Square root calculation.

   ```
   squart_root();
   ```

6. Infinite loop.

   ```
   while (true) {
       if(result) {
           port_pin_toggle_output_level(LED_0_PIN);
           /* Add a short delay to see LED toggle */
           volatile uint32_t delay = 50000;
           while(delay--) {
           }
       } else {
           port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
       }
   }
   ```

9. SAM Event System (EVENTS) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's peripheral event resources and users within the device, including enabling and disabling of peripheral source selection and synchronization of clock domains between various modules. The following API modes is covered by this manual:

- Polled API
- Interrupt hook API

The following peripheral is used by this module:

- EVSYS (Event System Management)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

9.1. Prerequisites

There are no prerequisites for this module.

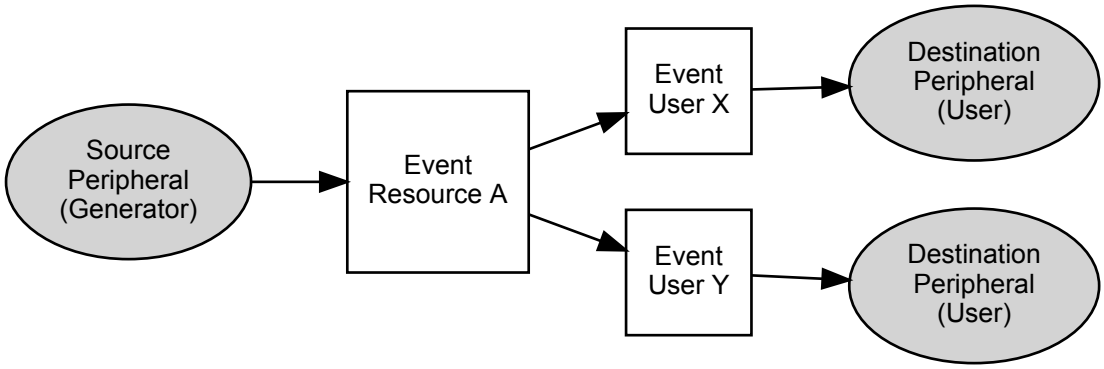
9.2. Module Overview

Peripherals within the SAM devices are capable of generating two types of actions in response to given stimulus; set a register flag for later intervention by the CPU (using interrupt or polling methods), or generate event signals, which can be internally routed directly to other peripherals within the device. The use of events allows for direct actions to be performed in one peripheral in response to a stimulus in another without CPU intervention. This can lower the overall power consumption of the system if the CPU is able to remain in sleep modes for longer periods (SleepWalking), and lowers the latency of the system response.

The event system is comprised of a number of freely configurable Event resources, plus a number of fixed Event Users. Each Event resource can be configured to select the input peripheral that will generate the events signal, as well as the synchronization path and edge detection mode. The fixed-function Event Users, connected to peripherals within the device, can then subscribe to an Event resource in a one-to-

many relationship in order to receive events as they are generated. An overview of the event system chain is shown in Figure 9-1.

Figure 9-1. Module Overview



There are many different events that can be routed in the device, which can then trigger many different actions. For example, an Analog Comparator module could be configured to generate an event when the input signal rises above the compare threshold, which then triggers a Timer Counter module to capture the current count value for later use.

9.2.1. Event Channels

The Event module in each device consists of several channels, which can be freely linked to an event generator (i.e. a peripheral within the device that is capable of generating events). Each channel can be individually configured to select the generator peripheral, signal path, and edge detection applied to the input event signal, before being passed to any event user(s).

Event channels can support multiple users within the device in a standardized manner. When an Event User is linked to an Event Channel, the channel will automatically handshake with all attached users to ensure that all modules correctly receive and acknowledge the event.

9.2.2. Event Users

Event Users are able to subscribe to an Event Channel, once it has been configured. Each Event User consists of a fixed connection to one of the peripherals within the device (for example, an ADC module, or Timer module) and is capable of being connected to a single Event Channel.

9.2.3. Edge Detection

For asynchronous events, edge detection on the event input is not possible, and the event signal must be passed directly between the event generator and event user. For synchronous and re-synchronous events, the input signal from the event generator must pass through an edge detection unit, so that only the rising, falling, or both edges of the event signal triggers an action in the event user.

9.2.4. Path Selection

The event system in the SAM devices supports three signal path types from the event generator to Event Users: asynchronous, synchronous, and re-synchronous events.

9.2.4.1. Asynchronous Paths

Asynchronous event paths allow for an asynchronous connection between the event generator and Event Users, when the source and destination peripherals share the same Generic Clock channel. In this mode the event is propagated between the source and destination directly to reduce the event latency, thus no edge detection is possible. The asynchronous event chain is shown in Figure 9-2.

Figure 9-2. Asynchronous Paths

Note: Identically shaped borders in the diagram indicate a shared generic clock channel.

9.2.4.2. Synchronous Paths

The Synchronous event path should be used when edge detection or interrupts from the event channel are required, and the source event generator and the event channel shares the same Generic Clock channel. The synchronous event chain is shown in Figure 9-3.

Not all peripherals support Synchronous event paths; refer to the device datasheet.

Figure 9-3. Synchronous Paths

Note: Identically shaped borders in the diagram indicate a shared generic clock channel.

9.2.4.3. Re-synchronous Paths

Re-synchronous event paths are a special form of synchronous events, where when edge detection or interrupts from the event channel are required, but the event generator and the event channel use different Generic Clock channels. The re-synchronous path allows the Event System to synchronize the incoming event signal from the Event Generator to the clock of the Event System module to avoid missed events, at the cost of a higher latency due to the re-synchronization process. The re-synchronous event chain is shown in Figure 9-4.

Not all peripherals support re-synchronous event paths; refer to the device datasheet.

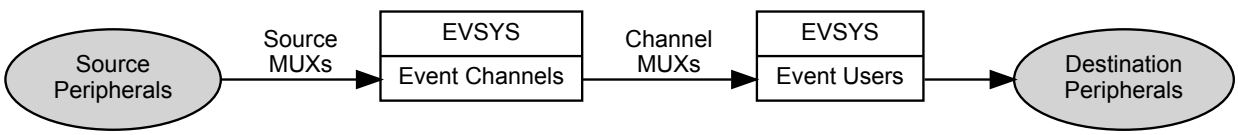
Figure 9-4. Re-synchronous Paths

Note: Identically shaped borders in the diagram indicate a shared generic clock channel.

9.2.5. Physical Connection

Figure 9-5 shows how this module is interconnected within the device.

Figure 9-5. Physical Connection



9.2.6. Configuring Events

For SAM devices, several steps are required to properly configure an event chain, so that hardware peripherals can respond to events generated by each other, as listed below.

9.2.6.1. Source Peripheral

1. The source peripheral (that will generate events) must be configured and enabled.
2. The source peripheral (that will generate events) must have an output event enabled.

9.2.6.2. Event System

1. An event system channel must be allocated and configured with the correct source peripheral selected as the channel's event generator.
2. The event system user must be configured and enabled, and attached to # event channel previously allocated.

9.2.6.3. Destination Peripheral

1. The destination peripheral (that will receive events) must be configured and enabled.
2. The destination peripheral (that will receive events) must have an input event enabled.

9.3. Special Considerations

There are no special considerations for this module.

9.4. Extra Information

For extra information, see Extra Information for EVENTS Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

9.5. Examples

For a list of examples related to this driver, see Examples for EVENTS Driver.

9.6. API Overview

9.6.1. Variable and Type Definitions

9.6.1.1. Type events_interrupt_hook

```
typedef void(* events_interrupt_hook )(struct events_resource *resource)
```

9.6.2. Structure Definitions

9.6.2.1. Struct events_config

This event configuration struct is used to configure each of the channels.

Table 9-1. Members

Type	Name	Description
uint8_t	clock_source	Clock source for the event channel
enum events_edge_detect	edge_detect	Select edge detection mode
uint8_t	generator	Set event generator for the channel
enum events_path_selection	path	Select events channel path

9.6.2.2. Struct events_hook

Event hook structure.

Table 9-2. Members

Type	Name	Description
events_interrupt_hook	hook_func	Event hook function
struct events_hook *	next	Next event hook
struct events_resource *	resource	Event resource

9.6.2.3. Struct events_resource

Event resource structure.

Note: The fields in this structure should not be altered by the user application; they are reserved for driver internals only.

9.6.3. Macro Definitions

9.6.3.1. Macro EVSYS_ID_GEN_NONE

```
#define EVSYS_ID_GEN_NONE
```

Use this to disable any peripheral event input to a channel. This can be useful if you only want to use a channel for software generated events. Definition for no generator selection.

9.6.4. Function Definitions

9.6.4.1. Function events_ack_interrupt()

Acknowledge an interrupt source.

```
enum status_code events_ack_interrupt(
        struct events_resource * resource,
        enum events_interrupt_source source)
```

Acknowledge an interrupt source so the interrupt state is cleared in hardware.

Table 9-3. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns
Status of the interrupt source.

Table 9-4. Return Values

Return value	Description
STATUS_OK	Interrupt source was acknowledged successfully

9.6.4.2. Function events_add_hook()

Insert hook into the event drivers interrupt hook queue.

```
enum status_code events_add_hook(
        struct events_resource * resource,
        struct events_hook * hook)
```

Inserts a hook into the event drivers interrupt hook queue.

Table 9-5. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	hook	Pointer to an events_hook struct instance

Returns
Status of the insertion procedure.

Table 9-6. Return Values

Return value	Description
STATUS_OK	Insertion of hook went successful

9.6.4.3. Function events_allocate()

Allocate an event channel and set configuration.

```
enum status_code events_allocate(
        struct events_resource * resource,
        struct events_config * config)
```

Allocates an event channel from the event channel pool and sets the channel configuration.

Table 9-7. Parameters

Data direction	Parameter name	Description
[out]	resource	Pointer to a events_resource struct instance
[in]	config	Pointer to a events_config struct

Returns
Status of the configuration procedure.

Table 9-8. Return Values

Return value	Description
STATUS_OK	Allocation and configuration went successful
STATUS_ERR_NOT_FOUND	No free event channel found

9.6.4.4. Function events_attach_user()

Attach user to the event channel.

```
enum status_code events_attach_user(
        struct events_resource * resource,
        uint8_t user_id)
```

Attach a user peripheral to the event channel to receive events.

Table 9-9. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	user_id	A number identifying the user peripheral found in the device header file

Returns
Status of the user attach procedure.

Table 9-10. Return Values

Return value	Description
STATUS_OK	No errors detected when attaching the event user

9.6.4.5. Function events_create_hook()

Initializes an interrupt hook for insertion in the event interrupt hook queue.

```
enum status_code events_create_hook(
        struct events_hook * hook,
        events_interrupt_hook hook_func)
```

Initializes a hook structure so it is ready for insertion in the interrupt hook queue.

Table 9-11. Parameters

Data direction	Parameter name	Description
[out]	hook	Pointer to an events_hook struct instance
[in]	hook_func	Pointer to a function containing the interrupt hook code

Returns
Status of the hook creation procedure.

Table 9-12. Return Values

Return value	Description
STATUS_OK	Creation and initialization of interrupt hook went successful

9.6.4.6. Function events_del_hook()

Remove hook from the event drivers interrupt hook queue.

```
enum status_code events_del_hook(
        struct events_resource * resource,
        struct events_hook * hook)
```

Removes a hook from the event drivers interrupt hook queue.

Table 9-13. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	hook	Pointer to an events_hook struct instance

Returns
Status of the removal procedure.

Table 9-14. Return Values

Return value	Description
STATUS_OK	Removal of hook went successful
STATUS_ERR_NO_MEMORY	There are no hooks instances in the event driver interrupt hook list
STATUS_ERR_NOT_FOUND	Interrupt hook not found in the event drivers interrupt hook list

9.6.4.7. Function events_detach_user()

Detach a user peripheral from the event channel.

```
enum status_code events_detach_user(
        struct events_resource * resource,
        uint8_t user_id)
```

Deattach a user peripheral from the event channels so it does not receive any more events.

Table 9-15. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an event_resource struct instance
[in]	user_id	A number identifying the user peripheral found in the device header file

Returns
Status of the user detach procedure.

Table 9-16. Return Values

Return value	Description
STATUS_OK	No errors detected when detaching the event user

9.6.4.8. Function events_disable_interrupt_source()

Disable interrupt source.

```
enum status_code events_disable_interrupt_source(
        struct events_resource * resource,
        enum events_interrupt_source source)
```

Disable an interrupt source so can trigger execution of an interrupt hook.

Table 9-17. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns
Status of the interrupt source enable procedure.

Table 9-18. Return Values

Return value	Description
STATUS_OK	Enabling of the interrupt source went successful
STATUS_ERR_INVALID_ARG	Interrupt source does not exist

9.6.4.9. Function events_enable_interrupt_source()

Enable interrupt source.

```
enum status_code events_enable_interrupt_source(
        struct events_resource * resource,
        enum events_interrupt_source source)
```

Enable an interrupt source so can trigger execution of an interrupt hook.

Table 9-19. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns
Status of the interrupt source enable procedure.

Table 9-20. Return Values

Return value	Description
STATUS_OK	Enabling of the interrupt source was successful
STATUS_ERR_INVALID_ARG	Interrupt source does not exist

9.6.4.10. Function events_get_config_defaults()

Initializes an event configurations struct to defaults.

```
void events_get_config_defaults(
        struct events_config * config)
```

Initailizes an event configuration struct to predefined safe default settings.

Table 9-21. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to an instance of struct events_config

9.6.4.11. Function events_get_free_channels()

Get the number of free channels.

```
uint8_t events_get_free_channels( void )
```

Get the number of allocatable channels in the events system resource pool.

Returns
The number of free channels in the event system.

9.6.4.12. Function events_is_busy()

Check if a channel is busy.

```
bool events_is_busy(
        struct events_resource * resource)
```

Check if a channel is busy, a channel stays busy until all users connected to the channel has handled an event.

Table 9-22. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to a events_resource struct instance

Returns
Status of the channels busy state.

Table 9-23. Return Values

Return value	Description
true	One or more users connected to the channel has not handled the last event
false	All users are ready to handle new events

9.6.4.13. Function events_is_detected()

Check if an event is detected on the event channel.

```
bool events_is_detected(
        struct events_resource * resource)
```

Check if an event has been detected on the channel.

Note: This function will clear the event detected interrupt flag.

Table 9-24. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns
Status of the event detection interrupt flag.

Table 9-25. Return Values

Return value	Description
true	Event has been detected
false	Event has not been detected

9.6.4.14. Function events_is_interrupt_set()

Check if interrupt source is set.

```
bool events_is_interrupt_set(
        struct events_resource * resource,
        enum events_interrupt_source source)
```

Check if an interrupt source is set and should be processed.

Table 9-26. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct instance
[in]	source	One of the members in the events_interrupt_source enumerator

Returns
Status of the interrupt source.

Table 9-27. Return Values

Return value	Description
true	Interrupt source is set
false	Interrupt source is not set

9.6.4.15. Function events_is_overrun()

Check if there has been an overrun situation on this channel.

```
bool events_is_overrun(
        struct events_resource * resource)
```

Note: This function will clear the event overrun detected interrupt flag.

Table 9-28. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns
Status of the event overrun interrupt flag.

Table 9-29. Return Values

Return value	Description
true	Event overrun has been detected
false	Event overrun has not been detected

9.6.4.16. Function events_is_users_ready()

Check if all users connected to the channel are ready.

```
bool events_is_users_ready(
        struct events_resource * resource)
```

Check if all users connected to the channel are ready to handle incoming events.

Table 9-30. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns
The ready status of users connected to an event channel.

Table 9-31. Return Values

Return value	Description
true	All the users connected to the event channel are ready to handle incoming events
false	One or more users connected to the event channel are not ready to handle incoming events

9.6.4.17. Function events_release()

Release allocated channel back the the resource pool.

```
enum status_code events_release(
        struct events_resource * resource)
```

Release an allocated channel back to the resource pool to make it available for other purposes.

Table 9-32. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns
Status of the channel release procedure.

Table 9-33. Return Values

Return value	Description
STATUS_OK	No error was detected when the channel was released
STATUS_BUSY	One or more event users have not processed the last event
STATUS_ERR_NOT_INITIALIZED	Channel not allocated, and can therefore not be released

9.6.4.18. Function events_trigger()

Trigger software event.

```
enum status_code events_trigger(
        struct events_resource * resource)
```

Trigger an event by software.

Note: Software event works on either a synchronous path or resynchronized path, and edge detection must be configured to rising-edge detection.

Table 9-34. Parameters

Data direction	Parameter name	Description
[in]	resource	Pointer to an events_resource struct

Returns
Status of the event software procedure.

Table 9-35. Return Values

Return value	Description
STATUS_OK	No error was detected when the software tigger signal was issued
STATUS_ERR_UNSUPPORTED_DEV	If the channel path is asynchronous and/or the edge detection is not set to RISING

9.6.5. Enumeration Definitions

9.6.5.1. Enum events_edge_detect

Event channel edge detect setting.

Table 9-36. Members

Enum value	Description
EVENTS_EDGE_DETECT_NONE	No event output
EVENTS_EDGE_DETECT_RISING	Event on rising edge
EVENTS_EDGE_DETECT_FALLING	Event on falling edge
EVENTS_EDGE_DETECT_BOTH	Event on both edges

9.6.5.2. Enum events_interrupt_source

Interrupt source selector definitions.

Table 9-37. Members

Enum value	Description
EVENTS_INTERRUPT_OVERRUN	Overrun in event channel detected interrupt
EVENTS_INTERRUPT_DETECT	Event signal propagation in event channel detected interrupt

9.6.5.3. Enum events_path_selection

Event channel path selection.

Table 9-38. Members

Enum value	Description
EVENTS_PATH_SYNCHRONOUS	Select the synchronous path for this event channel
EVENTS_PATH_RESYNCHRONIZED	Select the resynchronizer path for this event channel
EVENTS_PATH_ASYNCHRONOUS	Select the asynchronous path for this event channel

9.7. Extra Information for EVENTS Driver

9.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
CPU	Central Processing Unit
MUX	Multiplexer

9.7.2. Dependencies

This driver has the following dependencies:

- System Clock Driver

9.7.3. Errata

There are no errata related to this driver.

9.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Fix a bug in internal function `_events_find_bit_position()`
Rewrite of events driver
Initial Release

9.8. Examples for EVENTS Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Event System (EVENTS) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for EVENTS - Basic
- Quick Start Guide for EVENTS - Interrupt Hooks

9.8.1. Quick Start Guide for EVENTS - Basic

In this use case, the EVENT module is configured for:

- Synchronous event path with rising edge detection on the input
- One user attached to the configured event channel
- No hardware event generator attached to the channel

This use case allocates an event channel. This channel is not connected to any hardware event generator, events are software triggered. One user is connected to the allocated and configured event channel.

9.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D20 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_MCX_0
#define CONF_EVENT_USER         EVSYS_ID_USER_TC3_EVU
```

- SAM D21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_MCX_0
#define CONF_EVENT_USER         EVSYS_ID_USER_TC3_EVU
```

- SAM R21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_MCX_0
#define CONF_EVENT_USER         EVSYS_ID_USER_TC3_EVU
```

- SAM D11 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC2_MCX_0
#define CONF_EVENT_USER         EVSYS_ID_USER_TC1_EVU
```

- SAM L21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_NONE
#define CONF_EVENT_USER         EVSYS_ID_USER_PORT_EV_0
```

- SAM L22 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_NONE
#define CONF_EVENT_USER         EVSYS_ID_USER_PORT_EV_0
```

- SAM DA1 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_MCX_0
#define CONF_EVENT_USER         EVSYS_ID_USER_TC3_EVU
```

- SAM C21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_NONE
#define CONF_EVENT_USER         EVSYS_ID_USER_PORT_EV_0
```

Copy-paste the following setup code to your user application:

```
static void configure_event_channel(struct events_resource *resource)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = CONF_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;
```

```
    events_allocate(resource, &config);
}

static void configure_event_user(struct events_resource *resource)
{
    events_attach_user(resource, CONF_EVENT_USER);
}
```

Create an event resource struct and add to user application (typically the start of `main()`):

```
struct events_resource example_event;
```

Add to user application initialization (typically the start of `main()`):

```
configure_event_channel(&example_event);
configure_event_user(&example_event);
```

Workflow

1. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

   ```
   struct events_config config;
   ```

2. Initialize the event channel configuration struct with the module's default values.

   ```
   events_get_config_defaults(&config);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request that the channel is to be attached to the specified event generator, that rising edges of the event signal is to be detected on the channel, and that the synchronous event path is to be used.

   ```
   config.generator      = CONF_EVENT_GENERATOR;
   config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
   config.path           = EVENTS_PATH_SYNCHRONOUS;
   config.clock_source   = GCLK_GENERATOR_0;
   ```

4. Allocate and configure the channel using the configuration structure.

   ```
   events_allocate(resource, &config);
   ```

   Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

5. Attach a user to the channel.

   ```
   events_attach_user(resource, CONF_EVENT_USER);
   ```

9.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};

events_trigger(&example_event);

while (true) {
```

```
    /* Nothing to do */
}
```

Workflow

1. Wait for the event channel to become ready to accept a new event trigger.

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};
```

2. Perform a software event trigger on the configured event channel.

```
events_trigger(&example_event);
```

9.8.2. Quick Start Guide for EVENTS - Interrupt Hooks

In this use case, the EVENT module is configured for:

- Synchronous event path with rising edge detection
- TC4 as event generator on the allocated event channel (TC0 is used for SAM L22)
- One event channel user attached
- An event interrupt hook is used to execute some code when an event is detected

In this use case TC is used as event generator, generating events on overflow. One user attached, counting events on the channel. To be able to execute some code when an event is detected, an interrupt hook is used. The interrupt hook will also count the number of events detected and toggle a LED on the board each time an event is detected.

Note: Because this example is showing how to set up an interrupt hook there is no user attached to the user.

9.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use case.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D20 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_TC0_EVU
```

```
#define CONF_TC_MODULE TC4
```

- SAM D21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC4
```

- SAM R21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC4
```

- SAM D11 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC2_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC2
```

- SAM L21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC4
```

- SAM L22 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC0_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC0
```

- SAM DA1 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC4
```

- SAM C21 Xplained Pro:

```
#define CONF_EVENT_GENERATOR    EVSYS_ID_GEN_TC4_OVF
#define CONF_EVENT_USER         EVSYS_ID_USER_DMAC_CH_0
```

```
#define CONF_TC_MODULE TC4
```

Copy-paste the following setup code to your user application:

```
static volatile uint32_t event_count = 0;

void event_counter(struct events_resource *resource);

static void configure_event_channel(struct events_resource *resource)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = CONF_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;

    events_allocate(resource, &config);
}
```

```
static void configure_event_user(struct events_resource *resource)
{
    events_attach_user(resource, CONF_EVENT_USER);
}

static void configure_tc(struct tc_module *tc_instance)
{
    struct tc_config config_tc;
    struct tc_events config_events;

    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_8BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_FREQ;
    config_tc.clock_source    = GCLK_GENERATOR_1;
    config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV64;

    tc_init(tc_instance, CONF_TC_MODULE, &config_tc);

    config_events.generate_event_on_overflow = true;
    tc_enable_events(tc_instance, &config_events);

    tc_enable(tc_instance);

}

static void configure_event_interrupt(struct events_resource *resource,
        struct events_hook *hook)
{
    events_create_hook(hook, event_counter);

    events_add_hook(resource, hook);
    events_enable_interrupt_source(resource, EVENTS_INTERRUPT_DETECT);
}


void event_counter(struct events_resource *resource)
{
    if(events_is_interrupt_set(resource, EVENTS_INTERRUPT_DETECT)) {
        port_pin_toggle_output_level(LED_0_PIN);

        event_count++;
        events_ack_interrupt(resource, EVENTS_INTERRUPT_DETECT);

    }
}
```

Add to user application initialization (typically the start of `main()`):

```
struct tc_module       tc_instance;
struct events_resource example_event;
struct events_hook     hook;

system_init();
system_interrupt_enable_global();

configure_event_channel(&example_event);
configure_event_user(&example_event);
configure_event_interrupt(&example_event, &hook);
configure_tc(&tc_instance);
```

Workflow

1. Create an event channel configuration structure instance which will contain the configuration for the event.

```
struct events_config config;
```

2. Initialize the event channel configuration struct with safe default values.
   Note: This shall always be performed before using the configuration struct to ensure that all members are initialized to known default values.

```
events_get_config_defaults(&config);
```

3. Adjust the configuration structure:
   - Use EXAMPLE_EVENT_GENRATOR as event generator
   - Detect events on rising edge
   - Use the synchronous event path
   - Use GCLK Generator 0 as event channel clock source

```
config.generator      = CONF_EVENT_GENERATOR;
config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
config.path           = EVENTS_PATH_SYNCHRONOUS;
config.clock_source   = GCLK_GENERATOR_0;
```

4. Allocate and configure the channel using the configuration structure.

```
events_allocate(resource, &config);
```

5. Make sure there is no user attached. To attach a user, change the value of EXAMPLE_EVENT_USER to the correct peripheral ID.

```
events_attach_user(resource, CONF_EVENT_USER);
```

6. Create config_tc and config_events configuration structure instances.

```
struct tc_config config_tc;
struct tc_events config_events;
```

7. Initialize the TC module configuration structure with safe default values.
   Note: This function shall always be called on new configuration structure instances to make sure that all structure members are initialized.

```
tc_get_config_defaults(&config_tc);
```

8. Adjust the config_tc structure:
   - Set counter size to 8-bit
   - Set wave generation mode to normal frequency generation
   - Use GCLK generator 1 to as TC module clock source
   - Prescale the input clock with 64

```
config_tc.counter_size    = TC_COUNTER_SIZE_8BIT;
config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_FREQ;
config_tc.clock_source    = GCLK_GENERATOR_1;
config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV64;
```

9. Initialize, configure, and assosiate the tc_instance handle with the TC hardware pointed to by TC_MODULE.

```
tc_init(tc_instance, CONF_TC_MODULE, &config_tc);
```

10. Adjust the config_events structure to enable event generation on overflow in the timer and then enable the event configuration.

```
config_events.generate_event_on_overflow = true;
tc_enable_events(tc_instance, &config_events);
```

11. Enable the timer/counter module.

```
tc_enable(tc_instance);
```

12. Create a new interrupt hook and use the function event_counter as hook code.

```
events_create_hook(hook, event_counter);
```

13. Add the newly created hook to the interrupt hook queue and enable the event detected interrupt.

```
events_add_hook(resource, hook);
events_enable_interrupt_source(resource, EVENTS_INTERRUPT_DETECT);
```

14. Example interrupt hook code. If the hook was triggered by an event detected interrupt on the event channel this code will toggle the LED on the Xplained PRO board and increase the value of the event_count variable. The interrupt is then acknowledged.

```
void event_counter(struct events_resource *resource)
{
    if(events_is_interrupt_set(resource, EVENTS_INTERRUPT_DETECT)) {
        port_pin_toggle_output_level(LED_0_PIN);

        event_count++;
        events_ack_interrupt(resource, EVENTS_INTERRUPT_DETECT);

    }
}
```

9.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};

tc_start_counter(&tc_instance);

while (true) {
    /* Nothing to do */
}
```

Workflow

1. Wait for the event channel to become ready.

```
while (events_is_busy(&example_event)) {
    /* Wait for channel */
};
```

2. Start the timer/counter.

```
tc_start_counter(&tc_instance);
```

10. SAM External Interrupt (EXTINT) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of external interrupts generated by the physical device pins, including edge detection. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- EIC (External Interrupt Controller)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

10.1. Prerequisites

There are no prerequisites for this module.

10.2. Module Overview

The External Interrupt (EXTINT) module provides a method of asynchronously detecting rising edge, falling edge, or specific level detection on individual I/O pins of a device. This detection can then be used to trigger a software interrupt or event, or polled for later use if required. External interrupts can also optionally be used to automatically wake up the device from sleep mode, allowing the device to conserve power while still being able to react to an external stimulus in a timely manner.

10.2.1. Logical Channels

The External Interrupt module contains a number of logical channels, each of which is capable of being individually configured for a given pin routing, detection mode, and filtering/wake up characteristics.

Each individual logical external interrupt channel may be routed to a single physical device I/O pin in order to detect a particular edge or level of the incoming signal.

10.2.2. NMI Channels

One or more Non Maskable Interrupt (NMI) channels are provided within each physical External Interrupt Controller module, allowing a single physical pin of the device to fire a single NMI interrupt in response to a particular edge or level stimulus. An NMI cannot, as the name suggests, be disabled in firmware and will take precedence over any in-progress interrupt sources.

NMIs can be used to implement critical device features such as forced software reset or other functionality where the action should be executed in preference to all other running code with a minimum amount of latency.

10.2.3. Input Filtering and Detection

To reduce the possibility of noise or other transient signals causing unwanted device wake-ups, interrupts, and/or events via an external interrupt channel. A hardware signal filter can be enabled on individual channels. This filter provides a Majority-of-Three voter filter on the incoming signal, so that the input state is considered to be the majority vote of three subsequent samples of the pin input buffer. The possible sampled input and resulting filtered output when the filter is enabled is shown in Table 10-1.

Table 10-1. Sampled Input and Resulting Filtered Output

Input Sample 1	Input Sample 2	Input Sample 3	Filtered Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

10.2.4. Events and Interrupts

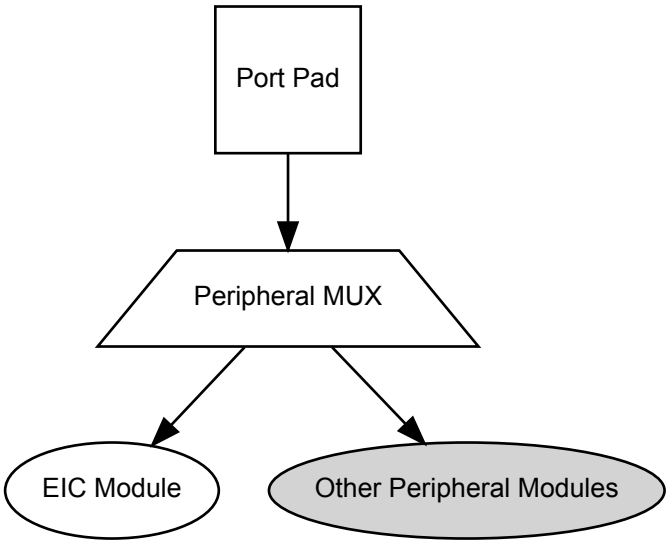
Channel detection states may be polled inside the application for synchronous detection, or events and interrupts may be used for asynchronous behavior. Each channel can be configured to give an asynchronous hardware event (which may in turn trigger actions in other hardware modules) or an asynchronous software interrupt.

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

10.2.5. Physical Connection

Figure 10-1 shows how this module is interconnected within the device.

Figure 10-1. Physical Connection



10.3. Special Considerations

Not all devices support disabling of the NMI channel(s) detection mode - see your device datasheet.

10.4. Extra Information

For extra information, see Extra Information for EXTINT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

10.5. Examples

For a list of examples related to this driver, see Examples for EXTINT Driver.

10.6. API Overview

10.6.1. Variable and Type Definitions

10.6.1.1. Type extint_callback_t

```
typedef void(* extint_callback_t )(void)
```

Type definition for an EXTINT module callback function

10.6.2. Structure Definitions

10.6.2.1. Struct extint_chan_conf

Configuration structure for the edge detection mode of an external interrupt channel.

Table 10-2. Members

Type	Name	Description
enum extint_detect	detection_criteria	Edge detection mode to use
bool	filter_input_signal	Filter the raw input signal to prevent noise from triggering an interrupt accidentally, using a three sample majority filter
uint32_t	gpio_pin	GPIO pin the NMI should be connected to
uint32_t	gpio_pin_mux	MUX position the GPIO pin should be configured to
enum extint_pull	gpio_pin_pull	Internal pull to enable on the input pin
bool	wake_if_sleeping	Wake up the device if the channel interrupt fires during sleep mode

10.6.2.2. Struct extint_events

Event flags for the extint_enable_events() and extint_disable_events().

Table 10-3. Members

Type	Name	Description
bool	generate_event_on_detect[]	If `true`, an event will be generated when an external interrupt channel detection state changes

10.6.2.3. Struct extint_nmi_conf

Configuration structure for the edge detection mode of an external interrupt NMI channel.

Table 10-4. Members

Type	Name	Description
enum extint_detect	detection_criteria	Edge detection mode to use. Not all devices support all possible detection modes for NMIs.
bool	filter_input_signal	Filter the raw input signal to prevent noise from triggering an interrupt accidentally, using a three sample majority filter
uint32_t	gpio_pin	GPIO pin the NMI should be connected to
uint32_t	gpio_pin_mux	MUX position the GPIO pin should be configured to
enum extint_pull	gpio_pin_pull	Internal pull to enable on the input pin

10.6.3. Macro Definitions

10.6.3.1. Macro EIC_NUMBER_OF_INTERRUPTS

```
#define EIC_NUMBER_OF_INTERRUPTS
```

10.6.3.2. Macro EXTINT_CLK_GCLK

```
#define EXTINT_CLK_GCLK
```

The EIC is clocked by GCLK_EIC.

10.6.3.3. Macro EXTINT_CLK_ULP32K

```
#define EXTINT_CLK_ULP32K
```

The EIC is clocked by CLK_ULP32K.

10.6.4. Function Definitions

10.6.4.1. Event Management

Function extint_enable_events()

Enables an External Interrupt event output.

```
void extint_enable_events(
        struct extint_events *const events)
```

Enables one or more output events from the External Interrupt module. See here for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 10-5. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to enable

Function extint_disable_events()

Disables an External Interrupt event output.

```
void extint_disable_events(
        struct extint_events *const events)
```

Disables one or more output events from the External Interrupt module. See here for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 10-6. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to disable

10.6.4.2. Configuration and Initialization (Channel)

Function extint_chan_get_config_defaults()

Initializes an External Interrupt channel configuration structure to defaults.

```
void extint_chan_get_config_defaults(
        struct extint_chan_conf *const config)
```

Initializes a given External Interrupt channel configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Wake the device if an edge detection occurs whilst in sleep
- Input filtering disabled
- Internal pull-up enabled
- Detect falling edges of a signal

Table 10-7. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function extint_chan_set_config()

Writes an External Interrupt channel configuration to the hardware module.

```
void extint_chan_set_config(
        const uint8_t channel,
        const struct extint_chan_conf *const config)
```

Writes out a given configuration of an External Interrupt channel configuration to the hardware module. If the channel is already configured, the new configuration will replace the existing one.

Table 10-8. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel to configure
[in]	config	Configuration settings for the channel

10.6.4.3. Configuration and Initialization (NMI)

Function extint_nmi_get_config_defaults()

Initializes an External Interrupt NMI channel configuration structure to defaults.

```
void extint_nmi_get_config_defaults(
        struct extint_nmi_conf *const config)
```

Initializes a given External Interrupt NMI channel configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Input filtering disabled

- Detect falling edges of a signal
- Asynchronous edge detection is disabled

Table 10-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function extint_nmi_set_config()

Writes an External Interrupt NMI channel configuration to the hardware module.

```
enum status_code extint_nmi_set_config(
        const uint8_t nmi_channel,
        const struct extint_nmi_conf *const config)
```

Writes out a given configuration of an External Interrupt NMI channel configuration to the hardware module. If the channel is already configured, the new configuration will replace the existing one.

Table 10-10. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel to configure
[in]	config	Configuration settings for the channel

Returns
Status code indicating the success or failure of the request.

Table 10-11. Return Values

Return value	Description
STATUS_OK	Configuration succeeded
STATUS_ERR_PIN_MUX_INVALID	An invalid pinmux value was supplied
STATUS_ERR_BAD_FORMAT	An invalid detection mode was requested

10.6.4.4. Detection testing and clearing (channel)

Function extint_chan_is_detected()

Retrieves the edge detection state of a configured channel.

```
bool extint_chan_is_detected(
        const uint8_t channel)
```

Reads the current state of a configured channel, and determines if the detection criteria of the channel has been met.

Table 10-12. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel index to check

Returns
Status of the requested channel's edge detection state.

Table 10-13. Return Values

Return value	Description
true	If the channel's edge/level detection criteria was met
false	If the channel has not detected its configured criteria

Function extint_chan_clear_detected()

Clears the edge detection state of a configured channel.

```
void extint_chan_clear_detected(
        const uint8_t channel)
```

Clears the current state of a configured channel, readying it for the next level or edge detection.

Table 10-14. Parameters

Data direction	Parameter name	Description
[in]	channel	External Interrupt channel index to check

10.6.4.5. Detection Testing and Clearing (NMI)

Function extint_nmi_is_detected()

Retrieves the edge detection state of a configured NMI channel.

```
bool extint_nmi_is_detected(
        const uint8_t nmi_channel)
```

Reads the current state of a configured NMI channel, and determines if the detection criteria of the NMI channel has been met.

Table 10-15. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel index to check

Returns
Status of the requested NMI channel's edge detection state.

Table 10-16. Return Values

Return value	Description
true	If the NMI channel's edge/level detection criteria was met
false	If the NMI channel has not detected its configured criteria

Function extint_nmi_clear_detected()

Clears the edge detection state of a configured NMI channel.

```
void extint_nmi_clear_detected(
        const uint8_t nmi_channel)
```

Clears the current state of a configured NMI channel, readying it for the next level or edge detection.

Table 10-17. Parameters

Data direction	Parameter name	Description
[in]	nmi_channel	External Interrupt NMI channel index to check

10.6.4.6. Callback Configuration and Initialization

Function extint_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code extint_register_callback(
        const extint_callback_t callback,
        const uint8_t channel,
        const enum extint_callback_type type)
```

Registers an asynchronous callback with the EXTINT driver, fired when a channel detects the configured channel detection criteria (e.g. edge or level). Callbacks are fired once for each detected channel.

Note: NMI channel callbacks cannot be registered via this function; the device's NMI interrupt should be hooked directly in the user application and the NMI flags manually cleared via extint_nmi_clear_detected().

Table 10-18. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to register
[in]	channel	Logical channel to register callback for
[in]	type	Type of callback function to register

Returns

Status of the registration operation.

Table 10-19. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied
STATUS_ERR_ALREADY_INITIALIZED	Callback function has been registered, need unregister first

Function extint_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code extint_unregister_callback(
        const extint_callback_t callback,
        const uint8_t channel,
        const enum extint_callback_type type)
```

Unregisters an asynchronous callback with the EXTINT driver, removing it from the internal callback registration table.

Table 10-20. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to unregister
[in]	channel	Logical channel to unregister callback for
[in]	type	Type of callback function to unregister

Returns
Status of the de-registration operation.

Table 10-21. Return Values

Return value	Description
STATUS_OK	The callback was unregistered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied
STATUS_ERR_BAD_ADDRESS	No matching entry was found in the registration table

Function extint_get_current_channel()

Find what channel caused the callback.

```
uint8_t extint_get_current_channel( void )
```

Can be used in an EXTINT callback function to find what channel caused the callback in case the same callback is used by multiple channels.

Returns
Channel number.

10.6.4.7. Callback Enabling and Disabling (Channel)

Function extint_chan_enable_callback()

Enables asynchronous callback generation for a given channel and type.

```
enum status_code extint_chan_enable_callback(
        const uint8_t channel,
        const enum extint_callback_type type)
```

Enables asynchronous callbacks for a given logical external interrupt channel and type. This must be called before an external interrupt channel will generate callback events.

Table 10-22. Parameters

Data direction	Parameter name	Description
[in]	channel	Logical channel to enable callback generation for
[in]	type	Type of callback function callbacks to enable

Returns
Status of the callback enable operation.

Table 10-23. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

Function extint_chan_disable_callback()

Disables asynchronous callback generation for a given channel and type.

```
enum status_code extint_chan_disable_callback(
        const uint8_t channel,
        const enum extint_callback_type type)
```

Disables asynchronous callbacks for a given logical external interrupt channel and type.

Table 10-24. Parameters

Data direction	Parameter name	Description
[in]	channel	Logical channel to disable callback generation for
[in]	type	Type of callback function callbacks to disable

Returns
Status of the callback disable operation.

Table 10-25. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

10.6.5. Enumeration Definitions

10.6.5.1. Callback Configuration and Initialization

Enum extint_callback_type

Enum for the possible callback types for the EXTINT module.

Table 10-26. Members

Enum value	Description
EXTINT_CALLBACK_TYPE_DETECT	Callback type for when an external interrupt detects the configured channel criteria (i.e. edge or level detection)

10.6.5.2. Enum extint_detect

Enum for the possible signal edge detection modes of the External Interrupt Controller module.

Table 10-27. Members

Enum value	Description
EXTINT_DETECT_NONE	No edge detection. Not allowed as a NMI detection mode on some devices.
EXTINT_DETECT_RISING	Detect rising signal edges
EXTINT_DETECT_FALLING	Detect falling signal edges
EXTINT_DETECT_BOTH	Detect both signal edges
EXTINT_DETECT_HIGH	Detect high signal levels
EXTINT_DETECT_LOW	Detect low signal levels

10.6.5.3. Enum extint_pull

Enum for the possible pin internal pull configurations.

Note: Disabling the internal pull resistor is not recommended if the driver is used in interrupt (callback) mode, due the possibility of floating inputs generating continuous interrupts.

Table 10-28. Members

Enum value	Description
EXTINT_PULL_UP	Internal pull-up resistor is enabled on the pin
EXTINT_PULL_DOWN	Internal pull-down resistor is enabled on the pin
EXTINT_PULL_NONE	Internal pull resistor is disconnected from the pin

10.7. Extra Information for EXTINT Driver

10.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
EIC	External Interrupt Controller
MUX	Multiplexer
NMI	Non-Maskable Interrupt

10.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

10.7.3. Errata

There are no errata related to this driver.

10.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
• Driver updated to follow driver type convention • Removed `extint_reset`(), `extint_disable`() and `extint_enable()` functions. Added internal function `_system_extint_init`(). • Added configuration EXTINT_CLOCK_SOURCE in conf_extint.h • Removed configuration EXTINT_CALLBACKS_MAX in conf_extint.h, and added channel parameter in the register functions `extint_register_callback`() and `extint_unregister_callback`()
Updated interrupt handler to clear interrupt flag before calling callback function
Updated initialization function to also enable the digital interface clock to the module if it is disabled
Initial Release

10.8. Examples for EXTINT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM External Interrupt (EXTINT) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for EXTINT - Basic
- Quick Start Guide for EXTINT - Callback

10.8.1. Quick Start Guide for EXTINT - Basic

The supported board list:

- SAM D20 Xplained Pro
- SAM D21 Xplained Pro
- SAM R21 Xplained Pro
- SAM L21 Xplained Pro
- SAM L22 Xplained Pro
- SAM DA1 Xplained Pro
- SAM C21 Xplained Pro

In this use case, the EXTINT module is configured for:

- External interrupt channel connected to the board LED is used
- External interrupt channel is configured to detect both input signal edges

This use case configures a physical I/O pin of the device so that it is routed to a logical External Interrupt Controller channel to detect rising and falling edges of the incoming signal.

When the board button is pressed, the board LED will light up. When the board button is released, the LED will turn off.

10.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_extint_channel(void)
{
    struct extint_chan_conf config_extint_chan;
    extint_chan_get_config_defaults(&config_extint_chan);

    config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
    config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
    config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
    config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
    extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_extint_channel();
```

Workflow

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

   ```
   struct extint_chan_conf config_extint_chan;
   ```

2. Initialize the channel configuration struct with the module's default values.

   ```
   extint_chan_get_config_defaults(&config_extint_chan);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
```

10.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    if (extint_chan_is_detected(BUTTON_0_EIC_LINE)) {

        // Do something in response to EXTINT edge detection
        bool button_pin_state = port_pin_get_input_level(BUTTON_0_PIN);
        port_pin_set_output_level(LED_0_PIN, button_pin_state);

        extint_chan_clear_detected(BUTTON_0_EIC_LINE);
    }
}
```

Workflow

1. Read in the current external interrupt channel state to see if an edge has been detected.

```
if (extint_chan_is_detected(BUTTON_0_EIC_LINE)) {
```

2. Read in the new physical button state and mirror it on the board LED.

```
// Do something in response to EXTINT edge detection
bool button_pin_state = port_pin_get_input_level(BUTTON_0_PIN);
port_pin_set_output_level(LED_0_PIN, button_pin_state);
```

3. Clear the detection state of the external interrupt channel so that it is ready to detect a future falling edge.

```
extint_chan_clear_detected(BUTTON_0_EIC_LINE);
```

10.8.2. Quick Start Guide for EXTINT - Callback

The supported board list:

- SAM D20 Xplained Pro
- SAM D21 Xplained Pro
- SAM R21 Xplained Pro
- SAM L21 Xplained Pro
- SAM L22 Xplained Pro
- SAM DA1 Xplained Pro
- SAM C21 Xplained Pro

In this use case, the EXTINT module is configured for:

- External interrupt channel connected to the board LED is used

- External interrupt channel is configured to detect both input signal edges
- Callbacks are used to handle detections from the External Interrupt

This use case configures a physical I/O pin of the device so that it is routed to a logical External Interrupt Controller channel to detect rising and falling edges of the incoming signal. A callback function is used to handle detection events from the External Interrupt module asynchronously.

When the board button is pressed, the board LED will light up. When the board button is released, the LED will turn off.

10.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_extint_channel(void)
{
    struct extint_chan_conf config_extint_chan;
    extint_chan_get_config_defaults(&config_extint_chan);

    config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
    config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
    config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
    config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
    extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
}

void configure_extint_callbacks(void)
{
    extint_register_callback(extint_detection_callback,
            BUTTON_0_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(BUTTON_0_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}

void extint_detection_callback(void)
{
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
    port_pin_set_output_level(LED_0_PIN, pin_state);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_extint_channel();
configure_extint_callbacks();

system_interrupt_enable_global();
```

Workflow

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

   ```
   struct extint_chan_conf config_extint_chan;
   ```

2. Initialize the channel configuration struct with the module's default values.

   ```
   extint_chan_get_config_defaults(&config_extint_chan);
   ```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config_extint_chan.gpio_pin           = BUTTON_0_EIC_PIN;
config_extint_chan.gpio_pin_mux       = BUTTON_0_EIC_MUX;
config_extint_chan.gpio_pin_pull      = EXTINT_PULL_UP;
config_extint_chan.detection_criteria = EXTINT_DETECT_BOTH;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(BUTTON_0_EIC_LINE, &config_extint_chan);
```

5. Register a callback function `extint_handler()` to handle detections from the External Interrupt controller.

```
extint_register_callback(extint_detection_callback,
        BUTTON_0_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

6. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(BUTTON_0_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

7. Define the EXTINT callback that will be fired when a detection event occurs. For this example, a LED will mirror the new button state on each detection edge.

```
void extint_detection_callback(void)
{
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
    port_pin_set_output_level(LED_0_PIN, pin_state);
}
```

10.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Do nothing - EXTINT will fire callback asynchronously */
}
```

Workflow

1. External interrupt events from the driver are detected asynchronously; no special application `main()` code is required.

11. SAM Frequency Meter (FREQM) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Frequency Meter functionality.

The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- FREQM (Frequency Meter)

The following devices can use this module:

- Atmel | SMART SAM L22
- Atmel | SMART SAM C20
- Atmel | SMART SAM C21

The outline of this documentation is as follows:

11.1. Prerequisites

There are no prerequisites for this module.

11.2. Module Overview

The module accurately measures the frequency of a clock by comparing it to a known reference clock as soon as the FREQM is enabled. Two generic clocks are used by the FREQM. The frequency of the measured clock is:

$$f_{CLK\_MSR} = \frac{VALUE}{REFNUM} \times f_{CLK\_REF}$$

Ratio can be measured with 24-bit accuracy.

The FREQM has one interrupt source, which generates when a frequency measurement is done. It can be used to wake up the device from sleep modes.

This driver provides an interface for the FREQM functions on the device.

11.3. Special Considerations

There are no special considerations for this module.

11.4. Extra Information

For extra information see Extra Information for FREQM Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

11.5. Examples

For a list of examples related to this driver, see Examples for FREQM Driver.

11.6. API Overview

11.6.1. Variable and Type Definitions

11.6.1.1. Type freqm_callback_t

```
typedef void(* freqm_callback_t )(void)
```

Type definition for a FREQM module callback function.

11.6.1.2. Variable _freqm_instance

```
struct freqm_module * _freqm_instance
```

11.6.2. Structure Definitions

11.6.2.1. Struct freqm_config

Configuration structure for a Frequency Meter.

Table 11-1. Members

Type	Name	Description
enum gclk_generator	msr_clock_source	GCLK source select for measurement
uint16_t	ref_clock_circles	Measurement duration in number of reference clock cycles. Range 1~255
enum gclk_generator	ref_clock_source	GCLK source select for reference

11.6.2.2. Struct freqm_module

FREQM software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

11.6.3. Function Definitions

11.6.3.1. Driver Initialization and Configuration

Function freqm_init()

Initializes a hardware FREQM module instance.

```
enum status_code freqm_init(
        struct freqm_module *const module_inst,
        Freqm *const hw,
        struct freqm_config *const config)
```

Enables the clock and initializes the FREQM module, based on the given configuration values.

Table 11-2. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the FREQM hardware module
[in]	config	Pointer to the FREQM configuration options struct

Returns

Status of the initialization procedure.

Table 11-3. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully

Function freqm_get_config_defaults()

Initializes all members of a FREQM configuration structure to safe defaults.

```
void freqm_get_config_defaults(
        struct freqm_config *const config)
```

Initializes all members of a given Frequency Meter configuration structure to safe known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Measurement clock source is GCLK0
- Reference clock source is GCLK1
- Frequency Meter Reference Clock Cycles 127

Table 11-4. Parameters

Data direction	Parameter name	Description
[in]	config	Configuration structure to initialize to default values

Function freqm_enable()

Enables a FREQM that was previously configured.

```
void freqm_enable(
        struct freqm_module *const module_inst)
```

Enables Frequency Meter that was previously configured via a call to freqm_init().

Table 11-5. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Frequency Meter peripheral

Function freqm_disable()

Disables a FREQM that was previously enabled.

```
void freqm_disable(
        struct freqm_module *const module_inst)
```

Disables Frequency Meter that was previously started via a call to freqm_enable().

Table 11-6. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the Frequency Meter peripheral

11.6.3.2. Read FREQM Result

Function freqm_start_measure()

Start a manual measurement process.

```
void freqm_start_measure(
        struct freqm_module *const module)
```

Table 11-7. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the FREQM software instance struct

Function freqm_clear_overflow()

Clears module overflow flag.

```
void freqm_clear_overflow(
        struct freqm_module *const module)
```

Clears the overflow flag of the module.

Table 11-8. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the FREQM software instance struct

Function freqm_get_result_value()

Read the measurement data result.

```
enum freqm_status freqm_get_result_value(
        struct freqm_module *const module_inst,
        uint32_t * result)
```

Reads the measurement data result.

Table 11-9. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the FREQM software instance struct
[out]	result	Pointer to store the result value in

Note: If overflow occurred, configure faster reference clock or reduce reference clock cycles.

Returns
Status of the FREQM read request.

Table 11-10. Return Values

Return value	Description
FREQM_STATUS_MEASURE_DONE	Measurement result was retrieved successfully
FREQM_STATUS_MEASURE_BUSY	Measurement result was not ready
FREQM_STATUS_CNT_OVERFLOW	Measurement result was overflow

11.6.3.3. Callback Configuration and Initialization

Function freqm_register_callback()

Registers a callback.

```
enum status_code freqm_register_callback(
        struct freqm_module *const module,
        freqm_callback_t callback_func,
        enum freqm_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note: The callback must be enabled by freqm_enable_callback, in order for the interrupt handler to call it when the conditions for the callback type is met.

Table 11-11. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to FREQM software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Table 11-12. Return Values

Return value	Description
STATUS_OK	The function exited successfully

Function freqm_unregister_callback()

Unregisters a callback.

```
enum status_code freqm_unregister_callback(
        struct freqm_module * module,
        enum freqm_callback callback_type)
```

Unregisters a callback function implemented by the user. The callback should be disabled before it is unregistered.

Table 11-13. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to FREQM software instance struct
[in]	callback_type	Callback type given by an enum

Table 11-14. Return Values

Return value	Description
STATUS_OK	The function exited successfully

11.6.3.4. Callback Enabling and Disabling

Function freqm_enable_callback()

Enable an FREQM callback.

```
enum status_code freqm_enable_callback(
        struct freqm_module *const module,
        const enum freqm_callback_type type)
```

Table 11-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	type	Callback source type

Returns
Status of the callback enable operation.

Table 11-16. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

Function freqm_disable_callback()

Disable an FREQM callback.

```
enum status_code freqm_disable_callback(
        struct freqm_module *const module,
        const enum freqm_callback_type type)
```

Table 11-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	type	Callback source type

Returns
Status of the callback enable operation.

Table 11-18. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

11.6.3.5. Function freqm_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool freqm_is_syncing( void )
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns
Synchronization status of the underlying hardware module(s).

Table 11-19. Return Values

Return value	Description
false	If the module has completed synchronization
true	If the module synchronization is ongoing

11.6.4. Enumeration Definitions

11.6.4.1. Enum freqm_callback

Enum for possible callback types for the FREQM module.

Table 11-20. Members

Enum value	Description
FREQM_CALLBACK_DONE	Callback for measurement done

11.6.4.2. Enum freqm_callback_type

FREQM callback type.

Table 11-21. Members

Enum value	Description
FREQM_CALLBACK_MEASURE_DONE	Measurement done callback.

11.6.4.3. Enum freqm_status

Enum for the possible status types for the FREQM module.

Table 11-22. Members

Enum value	Description
FREQM_STATUS_MEASURE_DONE	FREQM measurement is finish
FREQM_STATUS_MEASURE_BUSY	FREQM measurement is ongoing or not
FREQM_STATUS_CNT_OVERFLOW	FREQM sticky count value overflow

11.7. Extra Information for FREQM Driver

11.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
FREQM	Frequency Meter

11.7.2. Dependencies

This driver has no dependencies.

11.7.3. Errata

There are no errata related to this driver.

11.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

11.8. Examples for FREQM Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Frequency Meter (FREQM) Driver. QSGs are simple examples with step-by-step instructions to configure and use

this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for FREQM - Basic
- Quick Start Guide for FREQM - Callback

11.8.1. Quick Start Guide for FREQM - Basic

In this use case, the Frequency Meter (FREQM) module is configured for:

- The FREQM peripheral will not be stopped in standby sleep mode.

This use case will read measurement data in polling mode repeatly. After reading a data, the board LED will be toggled.

11.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
/* FREQM module software instance (must not go out of scope while in use) */
static struct freqm_module freqm_instance;

void configure_freqm(void)
{
     /* Create a new configuration structure for the FREQM settings
     * and fill with the default module settings. */
     struct freqm_config config_freqm;
     freqm_get_config_defaults(&config_freqm);

     /* Alter any FREQM configuration settings here if required */

     /* Initialize FREQM with the user settings */
     freqm_init(&freqm_instance, FREQM, &config_freqm);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_freqm();
freqm_enable(&freqm_instance);
```

Workflow

1. Create an FREQM device instance struct, which will be associated with a FREQM peripheral hardware instance.

   ```
   static struct freqm_module freqm_instance;
   ```

   Note: Device instance structures shall **never** go out of scope when in use.
2. Create a new function `configure_freqm()`, which will be used to configure the overall FREQM peripheral.

   ```
   void configure_freqm(void)
   ```
3. Create an FREQM peripheral configuration structure that will be filled out to set the module configuration.

   ```
   struct freqm_config config_freqm;
   ```

4. Fill the FREQM peripheral configuration structure with the default module configuration values.

```
freqm_get_config_defaults(&config_freqm);
```

5. Initialize the FREQM peripheral and associate it with the software instance structure that was defined previously.

```
freqm_init(&freqm_instance, FREQM, &config_freqm);
```

6. Enable the now initialized FREQM peripheral.

```
freqm_enable(&freqm_instance);
```

11.8.1.2. Implementation

Code

Copy-paste the following code to your user application:

```
uint32_t measure_result;
enum freqm_status status;

freqm_start_measure(&freqm_instance);
while ((status = freqm_get_result_value(&freqm_instance, &measure_result))
        == FREQM_STATUS_MEASURE_BUSY) {
};
switch(status) {
    case FREQM_STATUS_MEASURE_DONE:
        LED_On(LED_0_PIN);
        while (true) {
        }
    case FREQM_STATUS_CNT_OVERFLOW:
        freqm_clear_overflow(&freqm_instance);
        while (true) {
            LED_Toggle(LED_0_PIN);
            volatile uint32_t delay = 50000;
            while(delay--) {
            }
        }
    default:
        Assert(false);
        break;
}
```

Workflow

1. Start FREQM measurement and wait until measure done then read result data.

```
freqm_start_measure(&freqm_instance);
while ((status = freqm_get_result_value(&freqm_instance,
&measure_result))
        == FREQM_STATUS_MEASURE_BUSY) {
};
```

2. The board LED is on to indicate a measurement data is read.

```
case FREQM_STATUS_MEASURE_DONE:
    LED_On(LED_0_PIN);
    while (true) {
    }
```

3. The board LED is toggle to indicate measurement is overflow.

```
case FREQM_STATUS_CNT_OVERFLOW:
     freqm_clear_overflow(&freqm_instance);
     while (true) {
          LED_Toggle(LED_0_PIN);
          volatile uint32_t delay = 50000;
          while(delay--) {
          }
     }
```

11.8.2. Quick Start Guide for FREQM - Callback

In this use case, the Frequency Meter (FREQM) module is configured for:

- The FREQM peripheral will not be stopped in standby sleep mode.

This use case will read measurement data in interrupt mode repeatly. After reading specific size of buffer data, the board LED will be toggled.

11.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
bool volatile freqm_read_done = false;

void configure_freqm(void);
void configure_freqm_callback(void);
void freqm_complete_callback(void);

/* FREQM module software instance (must not go out of scope while in use) */
static struct freqm_module freqm_instance;

void configure_freqm(void)
{
     /* Create a new configuration structure for the FREQM settings
     * and fill with the default module settings. */
     struct freqm_config config_freqm;
     freqm_get_config_defaults(&config_freqm);
     config_freqm.ref_clock_circles = 255;

     /* Alter any FREQM configuration settings here if required */

     /* Initialize FREQM with the user settings */
     freqm_init(&freqm_instance, FREQM, &config_freqm);
}

void freqm_complete_callback(void)
{
     freqm_read_done = true;
}

void configure_freqm_callback(void)
{
     freqm_register_callback(&freqm_instance, freqm_complete_callback,
               FREQM_CALLBACK_MEASURE_DONE);
     freqm_enable_callback(&freqm_instance, FREQM_CALLBACK_MEASURE_DONE);
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_freqm();
configure_freqm_callback();

freqm_enable(&freqm_instance);
```

Workflow

1. Create an FREQM device instance struct, which will be associated with an FREQM peripheral hardware instance.

   ```
   static struct freqm_module freqm_instance;
   ```

   Note: Device instance structures shall **never** go out of scope when in use.
2. Create a new function `configure_freqm()`, which will be used to configure the overall FREQM peripheral.

   ```
   void configure_freqm(void)
   ```
3. Create an FREQM peripheral configuration structure that will be filled out to set the module configuration.

   ```
   struct freqm_config config_freqm;
   ```
4. Fill the FREQM peripheral configuration structure with the default module configuration values.

   ```
   freqm_get_config_defaults(&config_freqm);
   config_freqm.ref_clock_circles = 255;
   ```
5. Initialize the FREQM peripheral and associate it with the software instance structure that was defined previously.

   ```
   freqm_init(&freqm_instance, FREQM, &config_freqm);
   ```
6. Create a new callback function.

   ```
   void freqm_complete_callback(void)
   {
       freqm_read_done = true;
   }
   ```
7. Create a callback status software flag.

   ```
   bool volatile freqm_read_done = false;
   ```
8. Let the callback function set the flag to true when read job done.

   ```
   freqm_read_done = true;
   ```
9. Create a new function `configure_freqm_callback()`, which will be used to configure the callbacks.

   ```
   void configure_freqm_callback(void)
   {
       freqm_register_callback(&freqm_instance, freqm_complete_callback,
               FREQM_CALLBACK_MEASURE_DONE);
       freqm_enable_callback(&freqm_instance,
   FREQM_CALLBACK_MEASURE_DONE);
   }
   ```

10. Register callback function.

```
freqm_register_callback(&freqm_instance, freqm_complete_callback,
        FREQM_CALLBACK_MEASURE_DONE);
```

11. Enable the callbacks.

```
freqm_enable_callback(&freqm_instance, FREQM_CALLBACK_MEASURE_DONE);
```

12. Enable the now initialized FREQM peripheral.

```
freqm_enable(&freqm_instance);
```

Note: This should not be done until after the FREQM is setup and ready to be used.

11.8.2.2. Implementation

Code

Copy-paste the following code to your user application:

```
uint32_t measure_result;
enum freqm_status status;
freqm_start_measure(&freqm_instance);

while (!freqm_read_done) {
}
status = freqm_get_result_value(&freqm_instance, &measure_result);
switch(status) {
    case FREQM_STATUS_MEASURE_DONE:
        LED_On(LED_0_PIN);
        while (true) {
        }
    case FREQM_STATUS_CNT_OVERFLOW:
        freqm_clear_overflow(&freqm_instance);
        while (true) {
            LED_Toggle(LED_0_PIN);
            volatile uint32_t delay = 50000;
            while(delay--) {
            }
        }
    default:
        Assert(false);
        break;
}
```

Workflow

1. Start an asynchronous FREQM read job, to store measurement data into the global buffer and generate a callback when complete.

```
freqm_start_measure(&freqm_instance);
```

2. Wait until the asynchronous read job is complete.

```
while (!freqm_read_done) {
}
status = freqm_get_result_value(&freqm_instance, &measure_result);
```

3. The board LED on to indicate measurement data read.

```
case FREQM_STATUS_MEASURE_DONE:
    LED_On(LED_0_PIN);
    while (true) {
    }
```

4. The board LED toggled to indicate measurement overflow occous.

```
case FREQM_STATUS_CNT_OVERFLOW:
     freqm_clear_overflow(&freqm_instance);
     while (true) {
          LED_Toggle(LED_0_PIN);
          volatile uint32_t delay = 50000;
          while(delay--) {
          }
     }
```

12. SAM Non-Volatile Memory (NVM) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of non-volatile memories within the device, for partitioning, erasing, reading, and writing of data.

The following peripheral is used by this module:

- NVM (Non-Volatile Memory)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

12.1. Prerequisites

There are no prerequisites for this module.

12.2. Module Overview

The Non-Volatile Memory (NVM) module provides an interface to the device's Non-Volatile Memory controller, so that memory pages can be written, read, erased, and reconfigured in a standardized manner.

12.2.1. Driver Feature Macro Definition

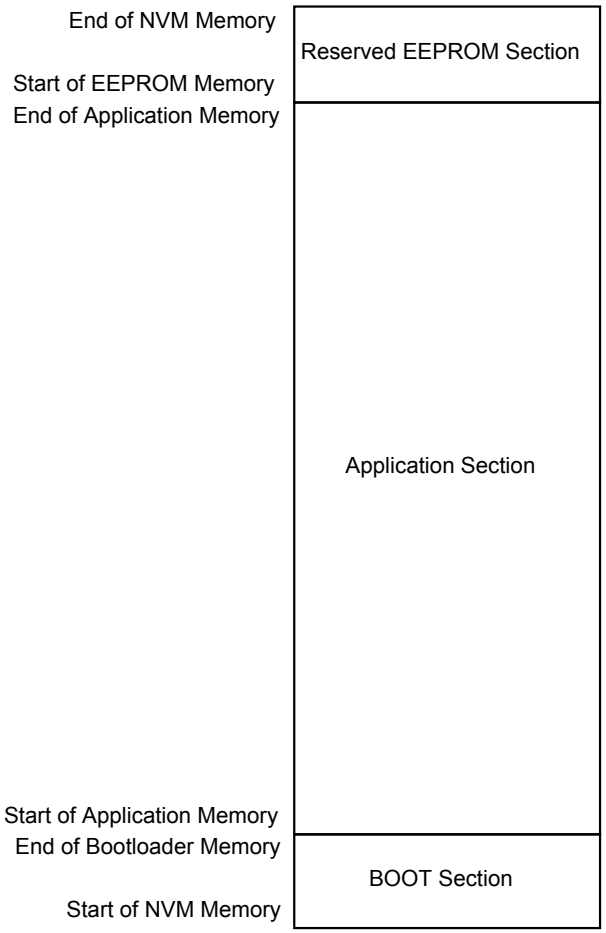
Driver feature macro	Supported devices
FEATURE_NVM_RWWEE	SAM L21/L22, SAM D21-64K, SAM DA1, SAM C20/C21, SAM R30
FEATURE_BOD12	SAM L21, SAMR30

Note: The specific features are only available in the driver when the selected device supports those features.

12.2.2. Memory Regions

The NVM memory space of the SAM devices is divided into two sections: a Main Array section, and an Auxiliary space section. The Main Array space can be configured to have an (emulated) EEPROM and/or boot loader section. The memory layout with the EEPROM and bootloader partitions is shown in Figure 12-1.

Figure 12-1. Memory Regions



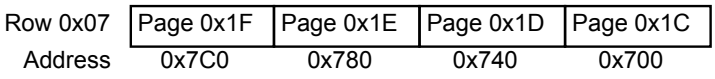
The Main Array is divided into rows and pages, where each row contains four pages. The size of each page may vary from 8-1024 bytes dependent of the device. Device specific parameters such as the page size and total number of pages in the NVM memory space are available via the nvm_get_parameters() function.

An NVM page number and address can be computed via the following equations:

$$PageNum = (RowNum \times 4) + PagePosInRow$$
$$PageAddr = PageNum \times PageSize$$

Figure 12-2 shows an example of the memory page and address values associated with logical row 7 of the NVM memory space.

Figure 12-2. Memory Regions



12.2.3. Region Lock Bits

As mentioned in Memory Regions, the main block of the NVM memory is divided into a number of individually addressable pages. These pages are grouped into 16 equal sized regions, where each region can be locked separately issuing an NVM_COMMAND_LOCK_REGION command or by writing the LOCK bits in the User Row. Rows reserved for the EEPROM section are not affected by the lock bits or commands.

Note: By using the NVM_COMMAND_LOCK_REGION or NVM_COMMAND_UNLOCK_REGION commands the settings will remain in effect until the next device reset. By changing the default lock setting for the regions, the auxiliary space must to be written, however the adjusted configuration will not take effect until the next device reset.

Note: If the Security Bit is set, the auxiliary space cannot be written to. Clearing of the security bit can only be performed by a full chip erase.

12.2.4. Read/Write

Reading from the NVM memory can be performed using direct addressing into the NVM memory space, or by calling the nvm_read_buffer() function.

Writing to the NVM memory must be performed by the nvm_write_buffer() function - additionally, a manual page program command must be issued if the NVM controller is configured in manual page writing mode.

Before a page can be updated, the associated NVM memory row must be erased first via the nvm_erase_row() function. Writing to a non-erased page will result in corrupt data being stored in the NVM memory space.

12.3. Special Considerations

12.3.1. Page Erasure

The granularity of an erase is per row, while the granularity of a write is per page. Thus, if the user application is modifying only one page of a row, the remaining pages in the row must be buffered and the row erased, as an erase is mandatory before writing to a page.

12.3.2. Clocks

The user must ensure that the driver is configured with a proper number of wait states when the CPU is running at high frequencies.

12.3.3. Security Bit

The User Row in the Auxiliary Space cannot be read or written when the Security Bit is set. The Security Bit can be set by using passing NVM_COMMAND_SET_SECURITY_BIT to the nvm_execute_command() function, or it will be set if one tries to access a locked region. See Region Lock Bits.

The Security Bit can only be cleared by performing a chip erase.

12.4. Extra Information

For extra information, see Extra Information for NVM Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

12.5. Examples

For a list of examples related to this driver, see Examples for NVM Driver.

12.6. API Overview

12.6.1. Structure Definitions

12.6.1.1. Struct nvm_config

Configuration structure for the NVM controller within the device.

Table 12-1. Members

Type	Name	Description
enum nvm_cache_readmode	cache_readmode	Select the mode for how the cache will pre-fetch data from the flash
bool	disable_cache	Setting this to true will disable the pre-fetch cache in front of the NVM controller
bool	manual_page_write	Manual write mode; if enabled, pages loaded into the NVM buffer will not be written until a separate write command is issued. If disabled, writing to the last byte in the NVM page buffer will trigger an automatic write. **Note:** If a partial page is to be written, a manual write command must be executed in either mode.
enum nvm_sleep_power_mode	sleep_power_mode	Power reduction mode during device sleep
uint8_t	wait_states	Number of wait states to insert when reading from flash, to prevent invalid data from being read at high clock frequencies

12.6.1.2. Struct nvm_fusebits

This structure contain the layout of the first 64 bits of the user row which contain the fuse settings.

Table 12-2. Members

Type	Name	Description
enum nvm_bod12_action	bod12_action	BOD12 Action at power on
bool	bod12_enable	BOD12 Enable at power on
bool	bod12_hysteresis	
uint8_t	bod12_level	BOD12 Threshold level at power on
enum nvm_bod33_action	bod33_action	BOD33 Action at power on
bool	bod33_enable	BOD33 Enable at power on
bool	bod33_hysteresis	
uint8_t	bod33_level	BOD33 Threshold level at power on
enum nvm_bootloader_size	bootloader_size	Bootloader size
enum nvm_eeprom_emulator_size	eeprom_size	EEPROM emulation area size
uint16_t	lockbits	NVM Lock bits
bool	wdt_always_on	WDT Always-on at power on
enum nvm_wdt_early_warning_offset	wdt_early_warning_offset	WDT Early warning interrupt time offset at power on
bool	wdt_enable	WDT Enable at power on
uint8_t	wdt_timeout_period	WDT Period at power on
bool	wdt_window_mode_enable_at_poweron	WDT Window mode enabled at power on
enum nvm_wdt_window_timeout	wdt_window_timeout	WDT Window mode time-out at power on

12.6.1.3. Struct nvm_parameters

Structure containing the memory layout parameters of the NVM module.

Table 12-3. Members

Type	Name	Description
uint32_t	bootloader_number_of_pages	Size of the Bootloader memory section configured in the NVM auxiliary memory space
uint32_t	eeprom_number_of_pages	Size of the emulated EEPROM memory section configured in the NVM auxiliary memory space
uint16_t	nvm_number_of_pages	Number of pages in the main array
uint8_t	page_size	Number of bytes per page
uint16_t	rww_eeprom_number_of_pages	Number of pages in read while write EEPROM (RWWEE) emulation area

12.6.2. Macro Definitions

12.6.2.1. Driver Feature Definition

Define NVM features set according to the different device families.

Macro FEATURE_NVM_RWWEE

```
#define FEATURE_NVM_RWWEE
```

Read while write EEPROM emulation feature.

Macro FEATURE_BOD12

```
#define FEATURE_BOD12
```

Brown-out detector internal to the voltage regulator for VDDCORE.

12.6.3. Function Definitions

12.6.3.1. Configuration and Initialization

Function nvm_get_config_defaults()

Initializes an NVM controller configuration structure to defaults.

```
void nvm_get_config_defaults(
        struct nvm_config *const config)
```

Initializes a given NVM controller configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Power reduction mode enabled after sleep mode until first NVM access
- Automatic page write mode disabled
- Number of FLASH wait states left unchanged

Table 12-4. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function nvm_set_config()

Sets the up the NVM hardware module based on the configuration.

```
enum status_code nvm_set_config(
        const struct nvm_config *const config)
```

Writes a given configuration of an NVM controller configuration to the hardware module, and initializes the internal device struct.

Table 12-5. Parameters

Data direction	Parameter name	Description
[in]	config	Configuration settings for the NVM controller

Note: The security bit must be cleared in order successfully use this function. This can only be done by a chip erase.

Returns

Status of the configuration procedure.

Table 12-6. Return Values

Return value	Description
STATUS_OK	If the initialization was a success
STATUS_BUSY	If the module was busy when the operation was attempted
STATUS_ERR_IO	If the security bit has been set, preventing the EEPROM and/or auxiliary space configuration from being altered

Function nvm_is_ready()

Checks if the NVM controller is ready to accept a new command.

```
bool nvm_is_ready( void )
```

Checks the NVM controller to determine if it is currently busy execution an operation, or ready for a new command.

Returns

Busy state of the NVM controller.

Table 12-7. Return Values

Return value	Description
true	If the hardware module is ready for a new command
false	If the hardware module is busy executing a command

12.6.3.2. NVM Access Management

Function nvm_get_parameters()

Reads the parameters of the NVM controller.

```
void nvm_get_parameters(
        struct nvm_parameters *const parameters)
```

Retrieves the page size, number of pages, and other configuration settings of the NVM region.

Table 12-8. Parameters

Data direction	Parameter name	Description
[out]	parameters	Parameter structure, which holds page size and number of pages in the NVM memory

Function nvm_write_buffer()

Writes a number of bytes to a page in the NVM memory region.

```
enum status_code nvm_write_buffer(
        const uint32_t destination_address,
        const uint8_t * buffer,
        uint16_t length)
```

Writes from a buffer to a given page address in the NVM memory.

Table 12-9. Parameters

Data direction	Parameter name	Description
[in]	destination_address	Destination page address to write to
[in]	buffer	Pointer to buffer where the data to write is stored
[in]	length	Number of bytes in the page to write

Note: If writing to a page that has previously been written to, the page's row should be erased (via nvm_erase_row()) before attempting to write new data to the page.

Note: For SAM D21 RWW devices, see `SAMD21_64K`, command `NVM_COMMAND_RWWEE_WRITE_PAGE` must be executed before any other commands after writing a page, refer to errata 13588.

Note: If manual write mode is enabled, the write command must be executed after this function, otherwise the data will not write to NVM from page buffer.

Returns
Status of the attempt to write a page.

Table 12-10. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted

Return value	Description
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region or not aligned to the start of a page
STATUS_ERR_INVALID_ARG	The supplied write length was invalid

Function nvm_read_buffer()

Reads a number of bytes from a page in the NVM memory region.

```
enum status_code nvm_read_buffer(
        const uint32_t source_address,
        uint8_t *const buffer,
        uint16_t length)
```

Reads a given number of bytes from a given page address in the NVM memory space into a buffer.

Table 12-11. Parameters

Data direction	Parameter name	Description
[in]	source_address	Source page address to read from
[out]	buffer	Pointer to a buffer where the content of the read page will be stored
[in]	length	Number of bytes in the page to read

Returns
Status of the page read attempt.

Table 12-12. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region or not aligned to the start of a page
STATUS_ERR_INVALID_ARG	The supplied read length was invalid

Function nvm_update_buffer()

Updates an arbitrary section of a page with new data.

```
enum status_code nvm_update_buffer(
        const uint32_t destination_address,
        uint8_t *const buffer,
        uint16_t offset,
        uint16_t length)
```

Writes from a buffer to a given page in the NVM memory, retaining any unmodified data already stored in the page.

Note: If manual write mode is enable, the write command must be executed after this function, otherwise the data will not write to NVM from page buffer.

Warning: This routine is unsafe if data integrity is critical; a system reset during the update process will result in up to one row of data being lost. If corruption must be avoided in all circumstances (including power loss or system reset) this function should not be used.

Table 12-13. Parameters

Data direction	Parameter name	Description
[in]	destination_address	Destination page address to write to
[in]	buffer	Pointer to buffer where the data to write is stored
[in]	offset	Number of bytes to offset the data write in the page
[in]	length	Number of bytes in the page to update

Returns
Status of the attempt to update a page.

Table 12-14. Return Values

Return value	Description
STATUS_OK	Requested NVM memory page was successfully read
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested address was outside the acceptable range of the NVM memory region
STATUS_ERR_INVALID_ARG	The supplied length and offset was invalid

Function nvm_erase_row()

Erases a row in the NVM memory space.

```
enum status_code nvm_erase_row(
        const uint32_t row_address)
```

Erases a given row in the NVM memory region.

Table 12-15. Parameters

Data direction	Parameter name	Description
[in]	row_address	Address of the row to erase

Returns
Status of the NVM row erase attempt.

Table 12-16. Return Values

Return value	Description
STATUS_OK	Requested NVM memory row was successfully erased
STATUS_BUSY	NVM controller was busy when the operation was attempted
STATUS_ERR_BAD_ADDRESS	The requested row address was outside the acceptable range of the NVM memory region or not aligned to the start of a row
STATUS_ABORTED	NVM erased error

Function nvm_execute_command()

Executes a command on the NVM controller.

```
enum status_code nvm_execute_command(
        const enum nvm_command command,
        const uint32_t address,
        const uint32_t parameter)
```

Executes an asynchronous command on the NVM controller, to perform a requested action such as an NVM page read or write operation.

Note: The function will return before the execution of the given command is completed.

Table 12-17. Parameters

Data direction	Parameter name	Description
[in]	command	Command to issue to the NVM controller
[in]	address	Address to pass to the NVM controller in NVM memory space
[in]	parameter	Parameter to pass to the NVM controller, not used for this driver

Returns

Status of the attempt to execute a command.

Table 12-18. Return Values

Return value	Description
STATUS_OK	If the command was accepted and execution is now in progress
STATUS_BUSY	If the NVM controller was already busy executing a command when the new command was issued
STATUS_ERR_IO	If the command was invalid due to memory or security locking
STATUS_ERR_INVALID_ARG	If the given command was invalid or unsupported
STATUS_ERR_BAD_ADDRESS	If the given address was invalid

Function nvm_get_fuses()

Get fuses from user row.

```
enum status_code nvm_get_fuses(
        struct nvm_fusebits * fusebits)
```

Read out the fuse settings from the user row.

Table 12-19. Parameters

Data direction	Parameter name	Description
[in]	fusebits	Pointer to a 64-bit wide memory buffer of type struct nvm_fusebits

Returns
Status of read fuses attempt.

Table 12-20. Return Values

Return value	Description
STATUS_OK	This function will always return STATUS_OK

Function nvm_set_fuses()

Set fuses from user row.

```
enum status_code nvm_set_fuses(
        struct nvm_fusebits * fb)
```

Set fuse settings from the user row.

Note: When writing to the user row, the values do not get loaded by the other modules on the device until a device reset occurs.

Table 12-21. Parameters

Data direction	Parameter name	Description
[in]	fusebits	Pointer to a 64-bit wide memory buffer of type struct nvm_fusebits

Returns
Status of read fuses attempt.

Table 12-22. Return Values

Return value	Description
STATUS_OK	This function will always return STATUS_OK
STATUS_BUSY	If the NVM controller was already busy executing a command when the new command was issued
STATUS_ERR_IO	If the command was invalid due to memory or security locking
STATUS_ERR_INVALID_ARG	If the given command was invalid or unsupported
STATUS_ERR_BAD_ADDRESS	If the given address was invalid

Function nvm_is_page_locked()

Checks whether the page region is locked.

```
bool nvm_is_page_locked(
        uint16_t page_number)
```

Extracts the region to which the given page belongs and checks whether that region is locked.

Table 12-23. Parameters

Data direction	Parameter name	Description
[in]	page_number	Page number to be checked

Returns
Page lock status.

Table 12-24. Return Values

Return value	Description
true	Page is locked
false	Page is not locked

Function nvm_get_error()

Retrieves the error code of the last issued NVM operation.

```
enum nvm_error nvm_get_error( void )
```

Retrieves the error code from the last executed NVM operation. Once retrieved, any error state flags in the controller are cleared.

Note: The nvm_is_ready() function is an exception. Thus, errors retrieved after running this function should be valid for the function executed before nvm_is_ready().

Returns
Error caused by the last NVM operation.

Table 12-25. Return Values

Return value	Description
NVM_ERROR_NONE	No error occurred in the last NVM operation
NVM_ERROR_LOCK	The last NVM operation attempted to access a locked region
NVM_ERROR_PROG	An invalid NVM command was issued

12.6.4. Enumeration Definitions

12.6.4.1. Enum nvm_bod12_action

What action should be triggered when BOD12 is detected.

Table 12-26. Members

Enum value	Description
NVM_BOD12_ACTION_NONE	No action
NVM_BOD12_ACTION_RESET	The BOD12 generates a reset
NVM_BOD12_ACTION_INTERRUPT	The BOD12 generates an interrupt

12.6.4.2. Enum nvm_bod33_action

What action should be triggered when BOD33 is detected.

Table 12-27. Members

Enum value	Description
NVM_BOD33_ACTION_NONE	No action
NVM_BOD33_ACTION_RESET	The BOD33 generates a reset
NVM_BOD33_ACTION_INTERRUPT	The BOD33 generates an interrupt

12.6.4.3. Enum nvm_bootloader_size

Available bootloader protection sizes in kilobytes.

Table 12-28. Members

Enum value	Description
NVM_BOOTLOADER_SIZE_128	Boot Loader Size is 32768 bytes
NVM_BOOTLOADER_SIZE_64	Boot Loader Size is 16384 bytes
NVM_BOOTLOADER_SIZE_32	Boot Loader Size is 8192 bytes
NVM_BOOTLOADER_SIZE_16	Boot Loader Size is 4096 bytes
NVM_BOOTLOADER_SIZE_8	Boot Loader Size is 2048 bytes
NVM_BOOTLOADER_SIZE_4	Boot Loader Size is 1024 bytes
NVM_BOOTLOADER_SIZE_2	Boot Loader Size is 512 bytes
NVM_BOOTLOADER_SIZE_0	Boot Loader Size is 0 bytes

12.6.4.4. Enum nvm_cache_readmode

Control how the NVM cache prefetch data from flash.

Table 12-29. Members

Enum value	Description
NVM_CACHE_READMODE_NO_MISS_PENALTY	The NVM Controller (cache system) does not insert wait states on a cache miss. Gives the best system performance.
NVM_CACHE_READMODE_LOW_POWER	Reduces power consumption of the cache system, but inserts a wait state each time there is a cache miss
NVM_CACHE_READMODE_DETERMINISTIC	The cache system ensures that a cache hit or miss takes the same amount of time, determined by the number of programmed flash wait states

12.6.4.5. Enum nvm_command

Table 12-30. Members

Enum value	Description
NVM_COMMAND_ERASE_ROW	Erases the addressed memory row
NVM_COMMAND_WRITE_PAGE	Write the contents of the page buffer to the addressed memory page
NVM_COMMAND_ERASE_AUX_ROW	Erases the addressed auxiliary memory row. **Note:** This command can only be given when the security bit is not set.
NVM_COMMAND_WRITE_AUX_ROW	Write the contents of the page buffer to the addressed auxiliary memory row. **Note:** This command can only be given when the security bit is not set.
NVM_COMMAND_LOCK_REGION	Locks the addressed memory region, preventing further modifications until the region is unlocked or the device is erased
NVM_COMMAND_UNLOCK_REGION	Unlocks the addressed memory region, allowing the region contents to be modified
NVM_COMMAND_PAGE_BUFFER_CLEAR	Clears the page buffer of the NVM controller, resetting the contents to all zero values
NVM_COMMAND_SET_SECURITY_BIT	Sets the device security bit, disallowing the changing of lock bits and auxiliary row data until a chip erase has been performed
NVM_COMMAND_ENTER_LOW_POWER_MODE	Enter power reduction mode in the NVM controller to reduce the power consumption of the system

Enum value	Description
NVM_COMMAND_EXIT_LOW_POWER_MODE	Exit power reduction mode in the NVM controller to allow other NVM commands to be issued
NVM_COMMAND_RWWEE_ERASE_ROW	Read while write (RWW) EEPROM area erase row
NVM_COMMAND_RWWEE_WRITE_PAGE	RWW EEPROM write page

12.6.4.6. Enum nvm_eeprom_emulator_size

Available space in flash dedicated for EEPROM emulator in bytes.

Table 12-31. Members

Enum value	Description
NVM_EEPROM_EMULATOR_SIZE_16384	EEPROM Size for EEPROM emulation is 16384 bytes
NVM_EEPROM_EMULATOR_SIZE_8192	EEPROM Size for EEPROM emulation is 8192 bytes
NVM_EEPROM_EMULATOR_SIZE_4096	EEPROM Size for EEPROM emulation is 4096 bytes
NVM_EEPROM_EMULATOR_SIZE_2048	EEPROM Size for EEPROM emulation is 2048 bytes
NVM_EEPROM_EMULATOR_SIZE_1024	EEPROM Size for EEPROM emulation is 1024 bytes
NVM_EEPROM_EMULATOR_SIZE_512	EEPROM Size for EEPROM emulation is 512 bytes
NVM_EEPROM_EMULATOR_SIZE_256	EEPROM Size for EEPROM emulation is 256 bytes
NVM_EEPROM_EMULATOR_SIZE_0	EEPROM Size for EEPROM emulation is 0 bytes

12.6.4.7. Enum nvm_error

Possible NVM controller error codes, which can be returned by the NVM controller after a command is issued.

Table 12-32. Members

Enum value	Description
NVM_ERROR_NONE	No errors
NVM_ERROR_LOCK	Lock error, a locked region was attempted accessed
NVM_ERROR_PROG	Program error, invalid command was executed

12.6.4.8. Enum nvm_sleep_power_mode

Power reduction modes of the NVM controller, to conserve power while the device is in sleep.

Table 12-33. Members

Enum value	Description
NVM_SLEEP_POWER_MODE_WAKEONACCESS	NVM controller exits low-power mode on first access after sleep
NVM_SLEEP_POWER_MODE_WAKEUPINSTANT	NVM controller exits low-power mode when the device exits sleep mode
NVM_SLEEP_POWER_MODE_ALWAYS_AWAKE	Power reduction mode in the NVM controller disabled

12.6.4.9. Enum nvm_wdt_early_warning_offset

This setting determine how many GCLK_WDT cycles before a watchdog time-out period an early warning interrupt should be triggered.

Table 12-34. Members

Enum value	Description
NVM_WDT_EARLY_WARNING_OFFSET_8	8 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_16	16 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_32	32 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_64	64 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_128	128 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_256	256 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_512	512 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_1024	1024 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_2048	2048 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_4096	4096 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_8192	8192 clock cycles
NVM_WDT_EARLY_WARNING_OFFSET_16384	16384 clock cycles

12.6.4.10. Enum nvm_wdt_window_timeout

Window mode time-out period in clock cycles.

Table 12-35. Members

Enum value	Description
NVM_WDT_WINDOW_TIMEOUT_PERIOD_8	8 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_16	16 clock cycles

Enum value	Description
NVM_WDT_WINDOW_TIMEOUT_PERIOD_32	32 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_64	64 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_128	128 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_256	256 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_512	512 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_1024	1024 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_2048	2048 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_4096	4096 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_8192	8192 clock cycles
NVM_WDT_WINDOW_TIMEOUT_PERIOD_16384	16384 clock cycles

12.7. Extra Information for NVM Driver

12.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
NVM	Non-Volatile Memory
EEPROM	Electrically Erasable Programmable Read-Only Memory

12.7.2. Dependencies

This driver has the following dependencies:

- None

12.7.3. Errata

There are no errata related to this driver.

12.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Removed BOD12 reference, removed nvm_set_fuses() API
Added functions to read/write fuse settings

Changelog
Added support for NVM cache configuration
Updated initialization function to also enable the digital interface clock to the module if it is disabled
Initial Release

12.8. Examples for NVM Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Non-Volatile Memory (NVM) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for NVM - Basic

12.8.1. Quick Start Guide for NVM - Basic

In this use case, the NVM module is configured for:

- Power reduction mode enabled after sleep mode until first NVM access
- Automatic page write commands issued to commit data as pages are written to the internal buffer
- Zero wait states when reading FLASH memory
- No memory space for the EEPROM
- No protected bootloader section

This use case sets up the NVM controller to write a page of data to flash, and then read it back into the same buffer.

12.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_nvm(void)
{
    struct nvm_config config_nvm;

    nvm_get_config_defaults(&config_nvm);

    config_nvm.manual_page_write = false;

    nvm_set_config(&config_nvm);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_nvm();
```

Workflow

1. Create an NVM module configuration struct, which can be filled out to adjust the configuration of the NVM controller.

```
struct nvm_config config_nvm;
```

2. Initialize the NVM configuration struct with the module's default values.

```
nvm_get_config_defaults(&config_nvm);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Enable automatic page write mode. The new data will be written to NVM automaticly.

```
config_nvm.manual_page_write = false;
```

Note: If automatic page write mode is disabled, the data will not write to NVM until the NVM write command has been invoked. For safe use of the NVM module, disable automatic page write mode and use write command to commit data is recommended.

4. Configure NVM controller with the created configuration struct settings.

```
nvm_set_config(&config_nvm);
```

12.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t page_buffer[NVMCTRL_PAGE_SIZE];

for (uint32_t i = 0; i < NVMCTRL_PAGE_SIZE; i++) {
    page_buffer[i] = i;
}

enum status_code error_code;

do
{
    error_code = nvm_erase_row(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);

do
{
    error_code = nvm_write_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);

do
{
    error_code = nvm_read_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Workflow

1. Set up a buffer, one NVM page in size, to hold data to read or write into NVM memory.

```
uint8_t page_buffer[NVMCTRL_PAGE_SIZE];
```

2. Fill the buffer with a pattern of data.

```
for (uint32_t i = 0; i < NVMCTRL_PAGE_SIZE; i++) {
    page_buffer[i] = i;
}
```

3. Create a variable to hold the error status from the called NVM functions.

```
enum status_code error_code;
```

4. Erase a page of NVM data. As the NVM could be busy initializing or completing a previous operation, a loop is used to retry the command while the NVM controller is busy.

```
do
{
    error_code = nvm_erase_row(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Note: This must be performed before writing new data into an NVM page.

5. Write the data buffer to the previously erased page of the NVM.

```
do
{
    error_code = nvm_write_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

Note: The new data will be written to NVM memory automatically, as the NVM controller is configured in automatic page write mode.

6. Read back the written page of page from the NVM into the buffer.

```
do
{
    error_code = nvm_read_buffer(
            100 * NVMCTRL_ROW_PAGES * NVMCTRL_PAGE_SIZE,
            page_buffer, NVMCTRL_PAGE_SIZE);
} while (error_code == STATUS_BUSY);
```

13. SAM Peripheral Access Controller (PAC) Driver

This driver for Atmel® | SMART ARM®-based microcontroller provides an interface for the locking and unlocking of peripheral registers within the device. When a peripheral is locked, accidental writes to the peripheral will be blocked and a CPU exception will be raised.

The following peripherals are used by this module:

- PAC (Peripheral Access Controller)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

13.1. Prerequisites

There are no prerequisites for this module.

13.2. Module Overview

The SAM devices are fitted with a Peripheral Access Controller (PAC) that can be used to lock and unlock write access to a peripheral's registers (see Non-Writable Registers). Locking a peripheral minimizes the risk of unintended configuration changes to a peripheral as a consequence of Run-away Code or use of a Faulty Module Pointer.

Physically, the PAC restricts write access through the AHB bus to registers used by the peripheral, making the register non-writable. PAC locking of modules should be implemented in configuration critical applications where avoiding unintended peripheral configuration changes are to be regarded in the highest of priorities.

All interrupt must be disabled while a peripheral is unlocked to make sure correct lock/unlock scheme is upheld.

13.2.1. Locking Scheme

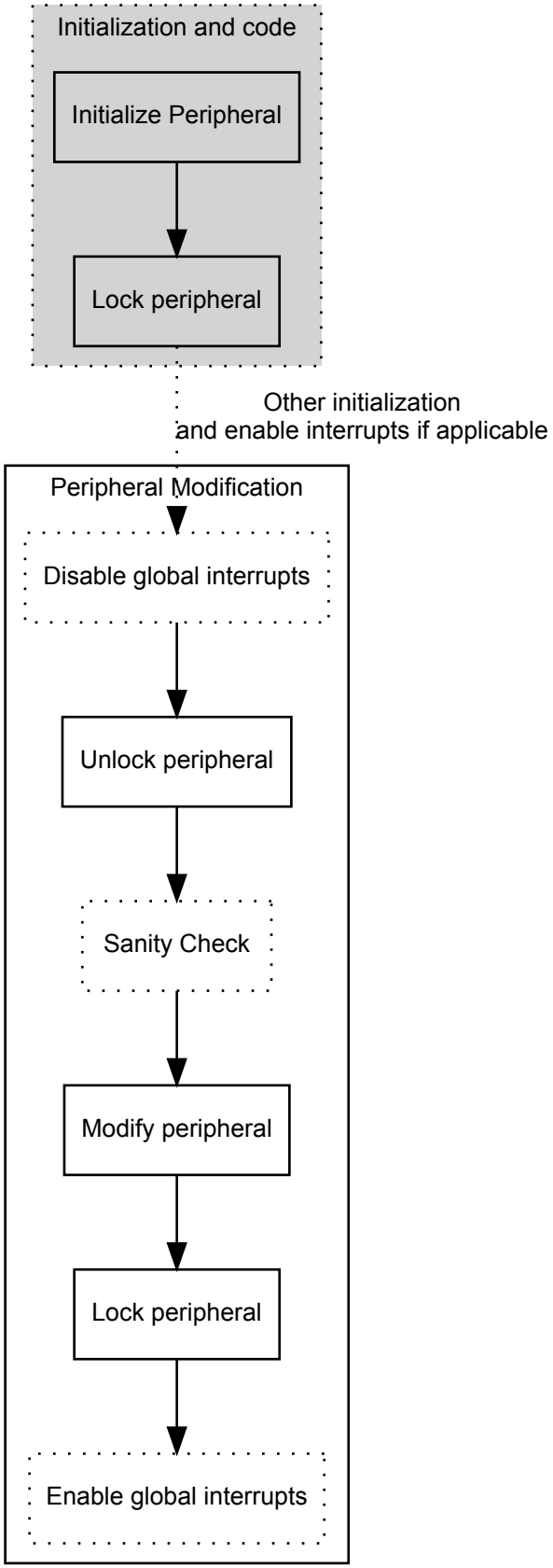
The module has a built in safety feature requiring that an already locked peripheral is not relocked, and that already unlocked peripherals are not unlocked again. Attempting to unlock and already unlocked peripheral, or attempting to lock a peripheral that is currently locked will generate a CPU exception. This implies that the implementer must keep strict control over the peripheral's lock-state before modifying

them. With this added safety, the probability of stopping runaway code increases as the program pointer can be caught inside the exception handler, and necessary countermeasures can be initiated. The implementer should also consider using sanity checks after an unlock has been performed to further increase the security.

13.2.2. Recommended Implementation

A recommended implementation of the PAC can be seen in Figure 13-1.

Figure 13-1. Recommended Implementation



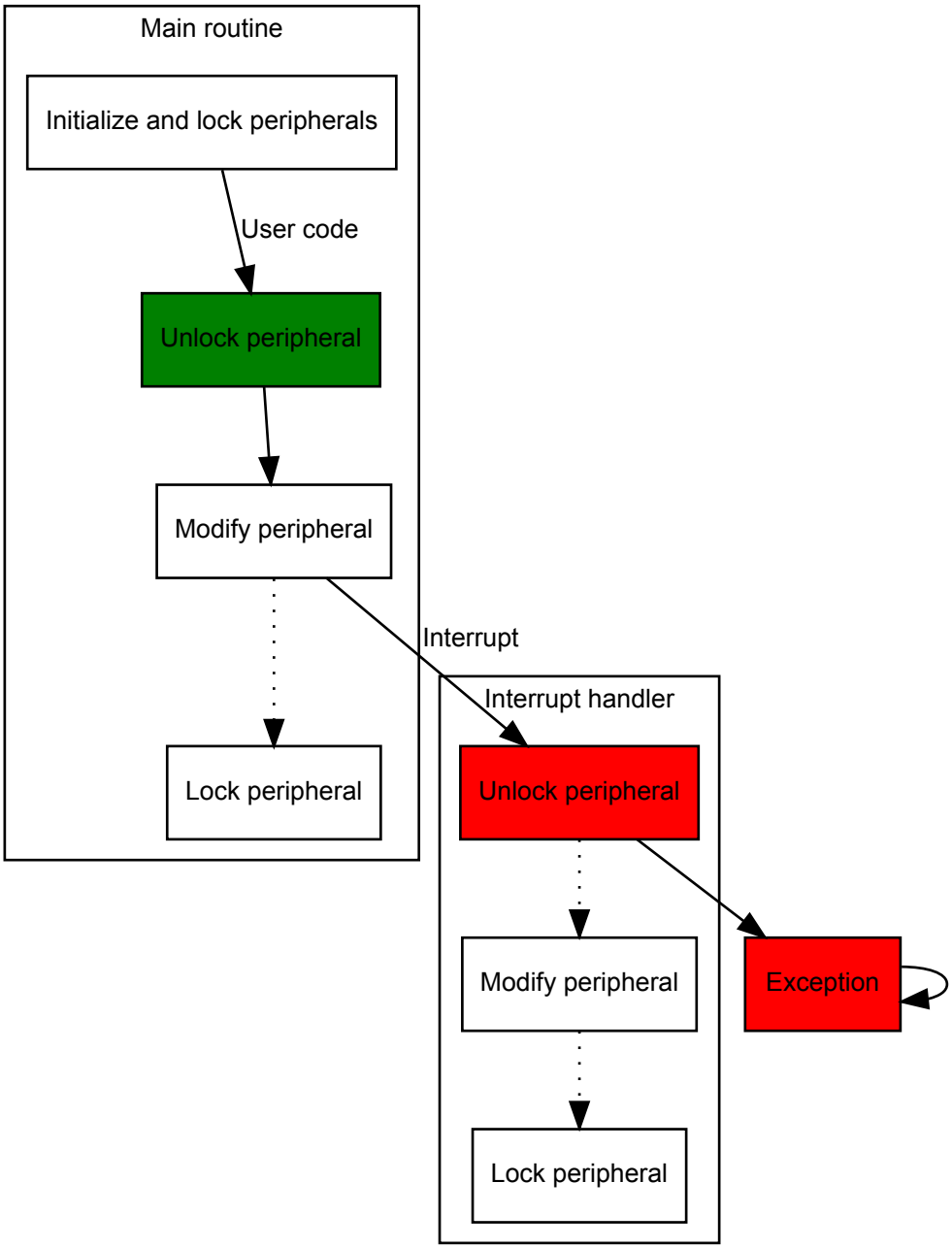
13.2.3. Why Disable Interrupts

Global interrupts must be disabled while a peripheral is unlocked as an interrupt handler would not know the current state of the peripheral lock. If the interrupt tries to alter the lock state, it can cause an exception as it potentially tries to unlock an already unlocked peripheral. Reading current lock state is to be avoided as it removes the security provided by the PAC (Reading Lock State).

Note: Global interrupts should also be disabled when a peripheral is unlocked inside an interrupt handler.

An example to illustrate the potential hazard of not disabling interrupts is shown in Figure 13-2.

Figure 13-2. Why Disable Interrupts



13.2.4. Run-away Code

Run-away code can be caused by the MCU being operated outside its specification, faulty code, or EMI issues. If a runaway code occurs, it is favorable to catch the issue as soon as possible. With a correct implementation of the PAC, the runaway code can potentially be stopped.

A graphical example showing how a PAC implementation will behave for different circumstances of runaway code in shown in Figure 13-3 and Figure 13-4.

Figure 13-3. Run-away Code

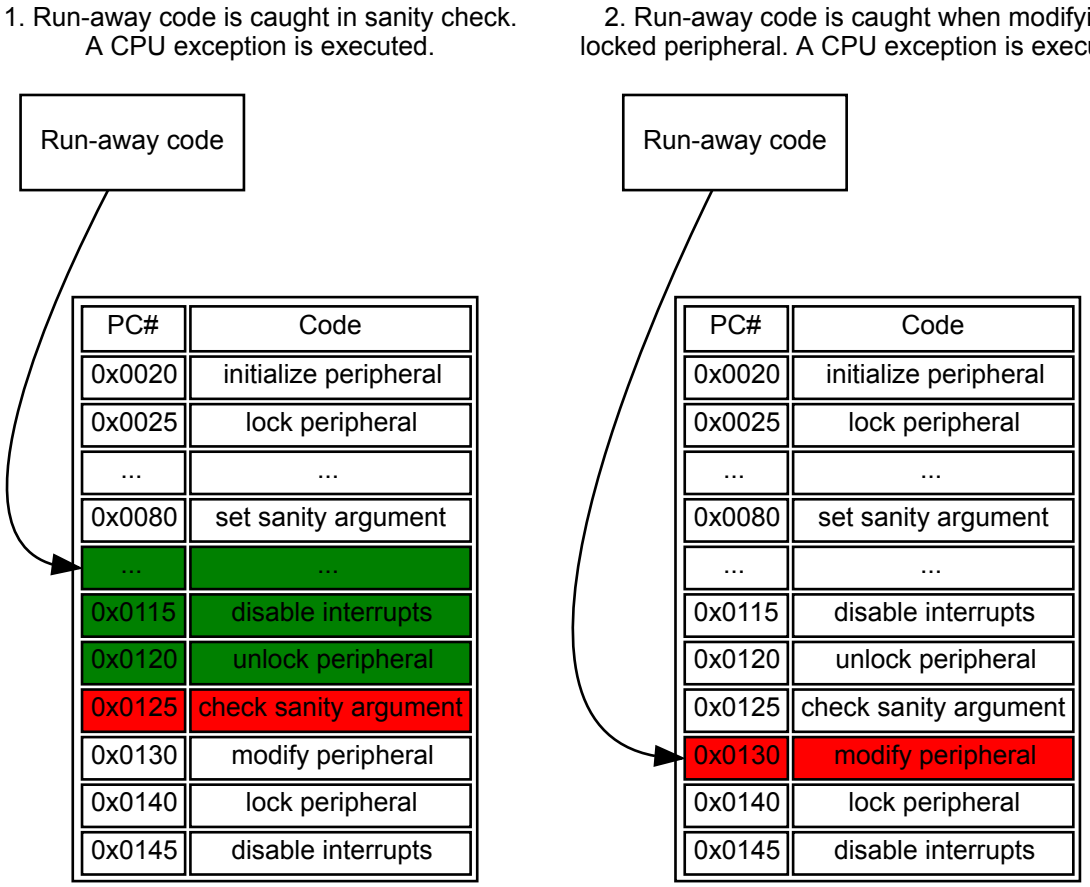
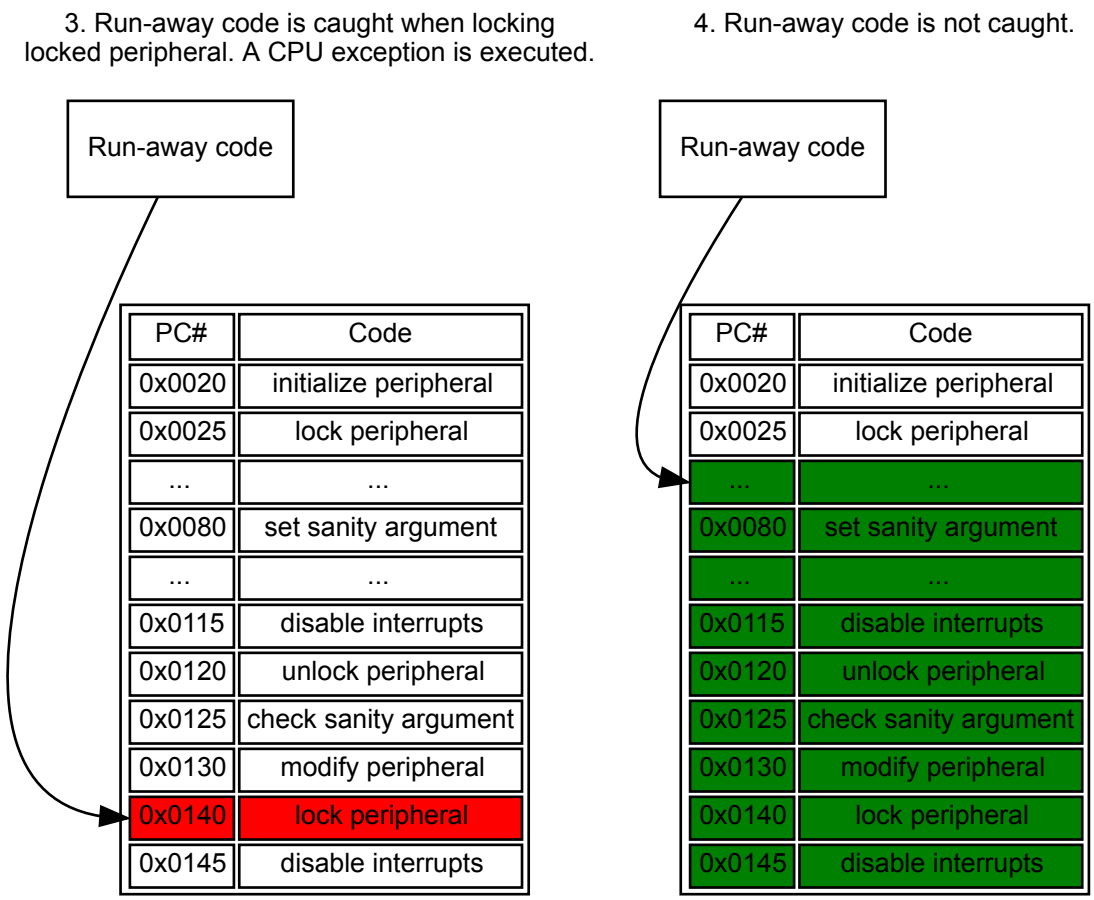


Figure 13-4. Run-away Code



In the example, green indicates that the command is allowed, red indicates where the runaway code will be caught, and the arrow where the runaway code enters the application. In special circumstances, like example 4 above, the runaway code will not be caught. However, the protection scheme will greatly enhance peripheral configuration security from being affected by runaway code.

13.2.4.1. Key-Argument

To protect the module functions against runaway code themselves, a key is required as one of the input arguments. The key-argument will make sure that runaway code entering the function without a function call will be rejected before inflicting any damage. The argument is simply set to be the bitwise inverse of the module flag, i.e.

```
system_peripheral_<lock_state>(SYSTEM_PERIPHERAL_<module>,
        ~SYSTEM_PERIPHERAL_<module>);
```

Where the lock state can be either lock or unlock, and module refer to the peripheral that is to be locked/unlocked.

13.2.5. Faulty Module Pointer

The PAC also protects the application from user errors such as the use of incorrect module pointers in function arguments, given that the module is locked. It is therefore recommended that any unused peripheral is locked during application initialization.

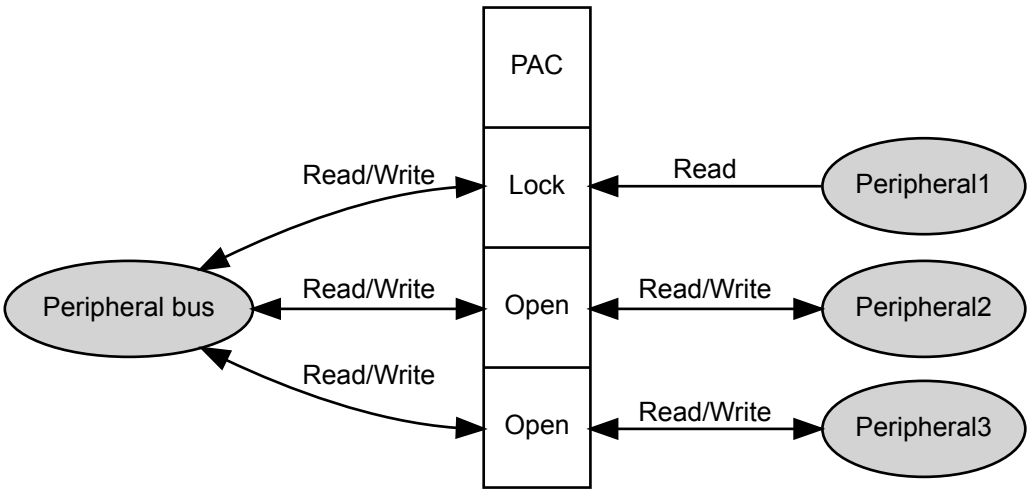
13.2.6. Use of __no_inline

Using the function attribute `__no_inline` will ensure that there will only be one copy of each functions in the PAC driver API in the application. This will lower the likelihood that runaway code will hit any of these functions.

13.2.7. Physical Connection

Figure 13-5 shows how this module is interconnected within the device.

Figure 13-5. Physical Connection



13.3. Special Considerations

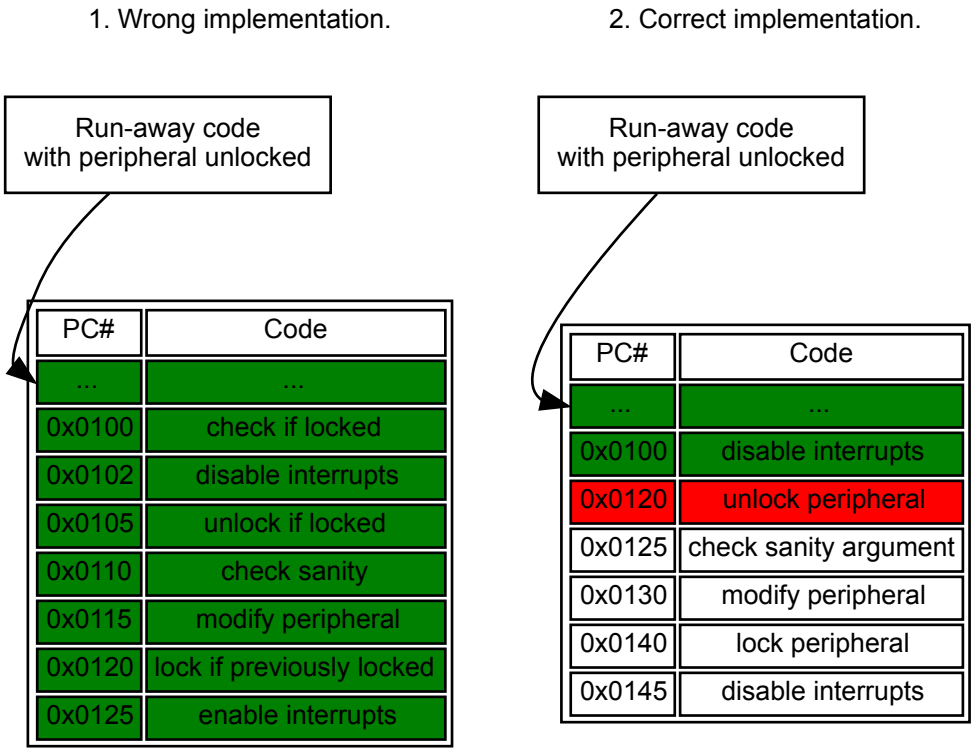
13.3.1. Non-Writable Registers

Not all registers in a given peripheral can be set non-writable. Which registers this applies to is showed in List of Non-Write Protected Registers and the peripheral's subsection "Register Access Protection" in the device datasheet.

13.3.2. Reading Lock State

Reading the state of the peripheral lock is to be avoided as it greatly compromises the protection initially provided by the PAC. If a lock/unlock is implemented conditionally, there is a risk that eventual errors are not caught in the protection scheme. Examples indicating the issue are shown in Figure 13-6.

Figure 13-6. Reading Lock State



In the left figure above, one can see the runaway code continues as all illegal operations are conditional. On the right side figure, the runaway code is caught as it tries to unlock the peripheral.

13.4. Extra Information

For extra information, see Extra Information for PAC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

13.5. Examples

For a list of examples related to this driver, see Examples for PAC Driver.

13.6. API Overview

13.6.1. Macro Definitions

13.6.1.1. Macro SYSTEM_PERIPHERAL_ID

```
#define SYSTEM_PERIPHERAL_ID(peripheral)
```

Retrieves the ID of a specified peripheral name, giving its peripheral bus location.

Table 13-1. Parameters

Data direction	Parameter name	Description
[in]	peripheral	Name of the peripheral instance

13.6.2. Function Definitions

13.6.2.1. Peripheral Lock and Unlock

Function system_peripheral_lock()

Lock a given peripheral's control registers.

```
__no_inline enum status_code system_peripheral_lock(
        const uint32_t peripheral_id,
        const uint32_t key)
```

Locks a given peripheral's control registers, to deny write access to the peripheral to prevent accidental changes to the module's configuration.

Warning: Locking an already locked peripheral will cause a CPU exception, and terminate program execution.

Table 13-2. Parameters

Data direction	Parameter name	Description
[in]	peripheral_id	ID for the peripheral to be locked, sourced via the SYSTEM_PERIPHERAL_ID macro
[in]	key	Bitwise inverse of peripheral ID, used as key to reduce the chance of accidental locking. See Key-Argument

Returns
Status of the peripheral lock procedure.

Table 13-3. Return Values

Return value	Description
STATUS_OK	If the peripheral was successfully locked
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied

Function system_peripheral_unlock()

Unlock a given peripheral's control registers.

```
__no_inline enum status_code system_peripheral_unlock(
        const uint32_t peripheral_id,
        const uint32_t key)
```

Unlocks a given peripheral's control registers, allowing write access to the peripheral so that changes can be made to the module's configuration.

Warning: Unlocking an already locked peripheral will cause a CUP exception, and terminate program execution.

Table 13-4. Parameters

Data direction	Parameter name	Description
[in]	peripheral_id	ID for the peripheral to be unlocked, sourced via the SYSTEM_PERIPHERAL_ID macro
[in]	key	Bitwise inverse of peripheral ID, used as key to reduce the chance of accidental unlocking. See Key-Argument

Returns

Status of the peripheral unlock procedure.

Table 13-5. Return Values

Return value	Description
STATUS_OK	If the peripheral was successfully locked
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied

13.6.2.2. APIs available for SAM L21/L22/C20/C21.

Function system_peripheral_lock_always()

Lock a given peripheral's control registers until hardware reset.

```
__no_inline enum status_code system_peripheral_lock_always(
        const uint32_t peripheral_id,
        const uint32_t key)
```

Locks a given peripheral's control registers, to deny write access to the peripheral to prevent accidental changes to the module's configuration. After lock, the only way to unlock is hardware reset.

Warning: Locking an already locked peripheral will cause a CPU exception, and terminate program execution.

Table 13-6. Parameters

Data direction	Parameter name	Description
[in]	peripheral_id	ID for the peripheral to be locked, sourced via the SYSTEM_PERIPHERAL_ID macro
[in]	key	Bitwise inverse of peripheral ID, used as key to reduce the chance of accidental locking. See Key-Argument

Returns

Status of the peripheral lock procedure.

Table 13-7. Return Values

Return value	Description
STATUS_OK	If the peripheral was successfully locked
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied

Function system_pac_enable_interrupt()

Enable PAC interrupt.

```
void system_pac_enable_interrupt( void )
```

Enable PAC interrupt so can trigger execution on peripheral access error, see SYSTEM_Handler().

Function system_pac_disable_interrupt()

Disable PAC interrupt.

```
void system_pac_disable_interrupt( void )
```

Disable PAC interrupt on peripheral access error.

Function system_pac_enable_event()

Enable PAC event output.

```
void system_pac_enable_event( void )
```

Enable PAC event output on peripheral access error.

Function system_pac_disable_event()

Disable PAC event output.

```
void system_pac_disable_event( void )
```

Disable PAC event output on peripheral access error.

13.7. Extra Information for PAC Driver

13.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
AC	Analog Comparator
ADC	Analog-to-Digital Converter
EVSYS	Event System
NMI	Non-Maskable Interrupt
NVMCTRL	Non-Volatile Memory Controller

Acronym	Description
PAC	Peripheral Access Controller
PM	Power Manager
RTC	Real-Time Counter
SERCOM	Serial Communication Interface
SYSCTRL	System Controller
TC	Timer/Counter
WDT	Watch Dog Timer

13.7.2. Dependencies

This driver has the following dependencies:

- None

13.7.3. Errata

There are no errata related to this driver.

13.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

13.8. Examples for PAC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Peripheral Access Controller (PAC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for PAC - Basic

13.8.1. Quick Start Guide for PAC - Basic

In this use case, the peripheral-lock will be used to lock and unlock the PORT peripheral access, and show how to implement the PAC module when the PORT registers needs to be altered. The PORT will be set up as follows:

- One pin in input mode, with pull-up and falling edge-detect
- One pin in output mode

13.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void config_port_pins(void)
{
    struct port_config pin_conf;

    port_get_config_defaults(&pin_conf);

    pin_conf.direction  = PORT_PIN_DIR_INPUT;
    pin_conf.input_pull = PORT_PIN_PULL_UP;
    port_pin_set_config(BUTTON_0_PIN, &pin_conf);

    pin_conf.direction = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LED_0_PIN, &pin_conf);
}
```

Add to user application initialization (typically the start of `main()`):

```
config_port_pins();
```

13.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_init();

config_port_pins();

system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

#if(SAML21)|| (SAML22) || (SAMC21) || defined(__DOXYGEN__)
    system_pac_enable_interrupt();
#endif
    system_interrupt_enable_global();

while (port_pin_get_input_level(BUTTON_0_PIN)) {
    /* Wait for button press */
}

system_interrupt_enter_critical_section();

system_peripheral_unlock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

port_pin_toggle_output_level(LED_0_PIN);

system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));

system_interrupt_leave_critical_section();

while (1) {
    /* Do nothing */
}
```

Workflow

1. Configure some GPIO port pins for input and output.

```
config_port_pins();
```

2. Lock peripheral access for the PORT module; attempting to update the module while it is in a protected state will cause a CPU exception. For SAM D20/D21/D10/D11/R21/DA0/DA1, it is Hard Fault exception; For SAM L21/C21, it is system exception, see SYSTEM_Handler().

```
system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

3. Enable global interrupts.

```
#if (SAML21) || (SAML22) || (SAMC21) || defined(__DOXYGEN__)
    system_pac_enable_interrupt();
#endif
    system_interrupt_enable_global();
```

4. Loop to wait for a button press before continuing.

```
while (port_pin_get_input_level(BUTTON_0_PIN)) {
    /* Wait for button press */
}
```

5. Enter a critical section, so that the PAC module can be unlocked safely and the peripheral manipulated without the possibility of an interrupt modifying the protected module's state.

```
system_interrupt_enter_critical_section();
```

6. Unlock the PORT peripheral registers.

```
system_peripheral_unlock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

7. Toggle pin 11, and clear edge detect flag.

```
port_pin_toggle_output_level(LED_0_PIN);
```

8. Lock the PORT peripheral registers.

```
system_peripheral_lock(SYSTEM_PERIPHERAL_ID(PORT),
        ~SYSTEM_PERIPHERAL_ID(PORT));
```

9. Exit the critical section to allow interrupts to function normally again.

```
system_interrupt_leave_critical_section();
```

10. Enter an infinite while loop once the module state has been modified successfully.

```
while (1) {
    /* Do nothing */
}
```

13.9. List of Non-Write Protected Registers

Look in device datasheet peripheral's subsection "Register Access Protection" to see which is actually available for your device.

Module	Non-write protected register
AC	INTFLAG
	STATUSA
	STATUSB
	STATUSC
ADC	INTFLAG
	STATUS
	RESULT
EVSYS	INTFLAG
	CHSTATUS
NVMCTRL	INTFLAG
	STATUS
PM	INTFLAG
PORT	N/A
RTC	INTFLAG
	READREQ
	STATUS
SYSCTRL	INTFLAG
SERCOM	INTFALG
	STATUS
	DATA
TC	INTFLAG
	STATUS
WDT	INTFLAG

Module	Non-write protected register
	STATUS
	(CLEAR)

14. SAM Port (PORT) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's General Purpose Input/Output (GPIO) pin functionality, for manual pin state reading and writing.

The following peripheral is used by this module:

- PORT (GPIO Management)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

14.1. Prerequisites

There are no prerequisites for this module.

14.2. Module Overview

The device GPIO (PORT) module provides an interface between the user application logic and external hardware peripherals, when general pin state manipulation is required. This driver provides an easy-to-use interface to the physical pin input samplers and output drivers, so that pins can be read from or written to for general purpose external hardware control.

14.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_PORT_INPUT_EVENT	SAM L21/L22/C20/C21/R30

Note: The specific features are only available in the driver when the selected device supports those features.

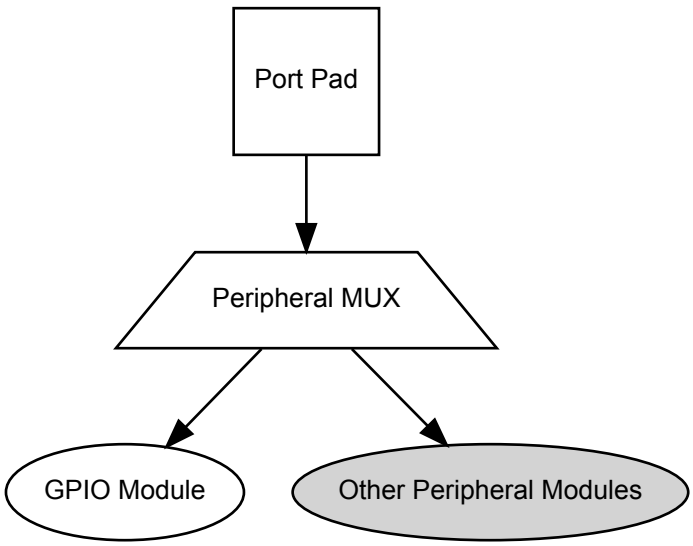
14.2.2. Physical and Logical GPIO Pins

SAM devices use two naming conventions for the I/O pins in the device; one physical and one logical. Each physical pin on a device package is assigned both a physical port and pin identifier (e.g. "PORTA. 0") as well as a monotonically incrementing logical GPIO number (e.g. "GPIO0"). While the former is used to map physical pins to their physical internal device module counterparts, for simplicity the design of this driver uses the logical GPIO numbers instead.

14.2.3. Physical Connection

Figure 14-1 shows how this module is interconnected within the device.

Figure 14-1. Physical Connection



14.3. Special Considerations

The SAM port pin input sampler can be disabled when the pin is configured in pure output mode to save power; reading the pin state of a pin configured in output-only mode will read the logical output state that was last set.

14.4. Extra Information

For extra information, see Extra Information for PORT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

14.5. Examples

For a list of examples related to this driver, see Examples for PORT Driver.

14.6. API Overview

14.6.1. Structure Definitions

14.6.1.1. Struct port_config

Configuration structure for a port pin instance. This structure should be initialized by the port_get_config_defaults() function before being modified by the user application.

Table 14-1. Members

Type	Name	Description
enum port_pin_dir	direction	Port buffer input/output direction
enum port_pin_pull	input_pull	Port pull-up/pull-down for input pins
bool	powersave	Enable lowest possible powerstate on the pin **Note:** All other configurations will be ignored, the pin will be disabled.

14.6.1.2. Struct port_input_event_config

Configuration structure for a port input event.

Table 14-2. Members

Type	Name	Description
enum port_input_event_action	action	Port input event action
uint8_t	gpio_pin	GPIO pin

14.6.2. Macro Definitions

14.6.2.1. Driver Feature Definition

Define port features set according to different device family.

Macro FEATURE_PORT_INPUT_EVENT

```
#define FEATURE_PORT_INPUT_EVENT
```

Event input control feature support for PORT group.

14.6.2.2. PORT Alias Macros

Macro PORTA

```
#define PORTA
```

Convenience definition for GPIO module group A on the device (if available).

Macro PORTB

```
#define PORTB
```

Convenience definition for GPIO module group B on the device (if available).

Macro PORTC

```
#define PORTC
```

Convenience definition for GPIO module group C on the device (if available).

Macro PORTD

```
#define PORTD
```

Convenience definition for GPIO module group D on the device (if available).

14.6.3. Function Definitions

14.6.3.1. State Reading/Writing (Physical Group Orientated)

Function port_get_group_from_gpio_pin()

Retrieves the PORT module group instance from a given GPIO pin number.

```
PortGroup * port_get_group_from_gpio_pin(
        const uint8_t gpio_pin)
```

Retrieves the PORT module group instance associated with a given logical GPIO pin number.

Table 14-3. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to convert

Returns
Base address of the associated PORT module.

Function port_group_get_input_level()

Retrieves the state of a group of port pins that are configured as inputs.

```
uint32_t port_group_get_input_level(
        const PortGroup *const port,
        const uint32_t mask)
```

Reads the current logic level of a port module's pins and returns the current levels as a bitmask.

Table 14-4. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to read from
[in]	mask	Mask of the port pin(s) to read

Returns
Status of the port pin(s) input buffers.

Function port_group_get_output_level()

Retrieves the state of a group of port pins that are configured as outputs.

```
uint32_t port_group_get_output_level(
        const PortGroup *const port,
        const uint32_t mask)
```

Reads the current logical output level of a port module's pins and returns the current levels as a bitmask.

Table 14-5. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to read from
[in]	mask	Mask of the port pin(s) to read

Returns

Status of the port pin(s) output buffers.

Function port_group_set_output_level()

Sets the state of a group of port pins that are configured as outputs.

```
void port_group_set_output_level(
        PortGroup *const port,
        const uint32_t mask,
        const uint32_t level_mask)
```

Sets the current output level of a port module's pins to a given logic level.

Table 14-6. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to
[in]	mask	Mask of the port pin(s) to change
[in]	level_mask	Mask of the port level(s) to set

Function port_group_toggle_output_level()

Toggles the state of a group of port pins that are configured as an outputs.

```
void port_group_toggle_output_level(
        PortGroup *const port,
        const uint32_t mask)
```

Toggles the current output levels of a port module's pins.

Table 14-7. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to
[in]	mask	Mask of the port pin(s) to toggle

14.6.3.2. Configuration and Initialization

Function port_get_config_defaults()

Initializes a Port pin/group configuration structure to defaults.

```
void port_get_config_defaults(
        struct port_config *const config)
```

Initializes a given Port pin/group configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Input mode with internal pull-up enabled

Table 14-8. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function port_pin_set_config()

Writes a Port pin configuration to the hardware module.

```
void port_pin_set_config(
        const uint8_t gpio_pin,
        const struct port_config *const config)
```

Writes out a given configuration of a Port pin configuration to the hardware module.

Note: If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 14-9. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure
[in]	config	Configuration settings for the pin

Function port_group_set_config()

Writes a Port group configuration group to the hardware module.

```
void port_group_set_config(
        PortGroup *const port,
        const uint32_t mask,
        const struct port_config *const config)
```

Writes out a given configuration of a Port group configuration to the hardware module.

Note: If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 14-10. Parameters

Data direction	Parameter name	Description
[out]	port	Base of the PORT module to write to
[in]	mask	Mask of the port pin(s) to configure
[in]	config	Configuration settings for the pin group

14.6.3.3. State Reading/Writing (Logical Pin Orientated)

Function port_pin_get_input_level()

Retrieves the state of a port pin that is configured as an input.

```
bool port_pin_get_input_level(
        const uint8_t gpio_pin)
```

Reads the current logic level of a port pin and returns the current level as a Boolean value.

Table 14-11. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to read

Returns
Status of the port pin's input buffer.

Function port_pin_get_output_level()

Retrieves the state of a port pin that is configured as an output.

```
bool port_pin_get_output_level(
        const uint8_t gpio_pin)
```

Reads the current logical output level of a port pin and returns the current level as a Boolean value.

Table 14-12. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to read

Returns
Status of the port pin's output buffer.

Function port_pin_set_output_level()

Sets the state of a port pin that is configured as an output.

```
void port_pin_set_output_level(
        const uint8_t gpio_pin,
        const bool level)
```

Sets the current output level of a port pin to a given logic level.

Table 14-13. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to write to
[in]	level	Logical level to set the given pin to

Function port_pin_toggle_output_level()

Toggles the state of a port pin that is configured as an output.

```
void port_pin_toggle_output_level(
        const uint8_t gpio_pin)
```

Toggles the current output level of a port pin.

Table 14-14. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to toggle

14.6.3.4. Port Input Event

Function port_enable_input_event()

Enable the port event input.

```
enum status_code port_enable_input_event(
        const uint8_t gpio_pin,
        const enum port_input_event n)
```

Enable the port event input with the given pin and event.

Table 14-15. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin
[in]	n	Port input event

Table 14-16. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid parameter
STATUS_OK	Successfully

Function port_disable_input_event()

Disable the port event input.

```
enum status_code port_disable_input_event(
        const uint8_t gpio_pin,
        const enum port_input_event n)
```

Disable the port event input with the given pin and event.

Table 14-17. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin
[in]	gpio_pin	Port input event

Table 14-18. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid parameter
STATUS_OK	Successfully

Function port_input_event_get_config_defaults()

Retrieve the default configuration for port input event.

```
void port_input_event_get_config_defaults(
        struct port_input_event_config *const config)
```

Fills a configuration structure with the default configuration for port input event:

- Event output to pin
- Event action to be executed on PIN 0

Table 14-19. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function port_input_event_set_config()

Configure port input event.

```
enum status_code port_input_event_set_config(
        const enum port_input_event n,
        struct port_input_event_config *const config)
```

Configures port input event with the given configuration settings.

Table 14-20. Parameters

Data direction	Parameter name	Description
[in]	config	Port input even configuration structure containing the new config

Table 14-21. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid parameter
STATUS_OK	Successfully

14.6.4. Enumeration Definitions

14.6.4.1. Enum port_input_event

List of port input events.

Table 14-22. Members

Enum value	Description
PORT_INPUT_EVENT_0	Port input event 0
PORT_INPUT_EVENT_1	Port input event 1
PORT_INPUT_EVENT_2	Port input event 2
PORT_INPUT_EVENT_3	Port input event 3

14.6.4.2. Enum port_input_event_action

List of port input events action on pin.

Table 14-23. Members

Enum value	Description
PORT_INPUT_EVENT_ACTION_OUT	Event out to pin
PORT_INPUT_EVENT_ACTION_SET	Set output register of pin on event
PORT_INPUT_EVENT_ACTION_CLR	Clear output register pin on event
PORT_INPUT_EVENT_ACTION_TGL	Toggle output register pin on event

14.6.4.3. Enum port_pin_dir

Enum for the possible pin direction settings of the port pin configuration structure, to indicate the direction the pin should use.

Table 14-24. Members

Enum value	Description
PORT_PIN_DIR_INPUT	The pin's input buffer should be enabled, so that the pin state can be read
PORT_PIN_DIR_OUTPUT	The pin's output buffer should be enabled, so that the pin state can be set
PORT_PIN_DIR_OUTPUT_WTH_READBACK	The pin's output and input buffers should be enabled, so that the pin state can be set and read back

14.6.4.4. Enum port_pin_pull

Enum for the possible pin pull settings of the port pin configuration structure, to indicate the type of logic level pull the pin should use.

Table 14-25. Members

Enum value	Description
PORT_PIN_PULL_NONE	No logical pull should be applied to the pin
PORT_PIN_PULL_UP	Pin should be pulled up when idle
PORT_PIN_PULL_DOWN	Pin should be pulled down when idle

14.7. Extra Information for PORT Driver

14.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
GPIO	General Purpose Input/Output
MUX	Multiplexer

14.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

14.7.3. Errata

There are no errata related to this driver.

14.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added input event feature
Initial release

14.8. Examples for PORT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Port (PORT) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for PORT - Basic

14.8.1. Quick Start Guide for PORT - Basic

In this use case, the PORT module is configured for:

- One pin in input mode, with pull-up enabled
- One pin in output mode

This use case sets up the PORT to read the current state of a GPIO pin set as an input, and mirrors the opposite logical state on a pin configured as an output.

14.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_port_pins(void)
{
    struct port_config config_port_pin;
    port_get_config_defaults(&config_port_pin);

    config_port_pin.direction  = PORT_PIN_DIR_INPUT;
    config_port_pin.input_pull = PORT_PIN_PULL_UP;
    port_pin_set_config(BUTTON_0_PIN, &config_port_pin);

    config_port_pin.direction = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LED_0_PIN, &config_port_pin);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_port_pins();
```

Workflow

1. Create a PORT module pin configuration struct, which can be filled out to adjust the configuration of a single port pin.

   ```
   struct port_config config_port_pin;
   ```

2. Initialize the pin configuration struct with the module's default values.

   ```
   port_get_config_defaults(&config_port_pin);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request an input pin.

   ```
   config_port_pin.direction  = PORT_PIN_DIR_INPUT;
   config_port_pin.input_pull = PORT_PIN_PULL_UP;
   ```

4. Configure push button pin with the initialized pin configuration struct, to enable the input sampler on the pin.

   ```
   port_pin_set_config(BUTTON_0_PIN, &config_port_pin);
   ```

5. Adjust the configuration struct to request an output pin.

   ```
   config_port_pin.direction = PORT_PIN_DIR_OUTPUT;
   ```

Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Configure LED pin with the initialized pin configuration struct, to enable the output driver on the pin.

```
port_pin_set_config(LED_0_PIN, &config_port_pin);
```

14.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);

    port_pin_set_output_level(LED_0_PIN, !pin_state);
}
```

Workflow

1. Read in the current input sampler state of push button pin, which has been configured as an input in the use-case setup code.

```
bool pin_state = port_pin_get_input_level(BUTTON_0_PIN);
```

2. Write the inverted pin level state to LED pin, which has been configured as an output in the use-case setup code.

```
port_pin_set_output_level(LED_0_PIN, !pin_state);
```

15. SAM RTC Count (RTC COUNT) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Real Time Clock functionality in Count operating mode, for the configuration and retrieval of the current RTC counter value. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- RTC (Real Time Clock)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

15.1. Prerequisites

There are no prerequisites for this module.

15.2. Module Overview

The RTC module in the SAM devices is a 32-bit counter, with a 10-bit programmable prescaler. Typically, the RTC clock is run continuously, including in the device's low-power sleep modes, to track the current time and date information. The RTC can be used as a source to wake up the system at a scheduled time or periodically using the alarm functions.

In this driver, the RTC is operated in Count mode. This allows for an easy integration of an asynchronous counter into a user application, which is capable of operating while the device is in sleep mode.

Whilst operating in Count mode, the RTC features:

- 16-bit counter mode
  - Selectable counter period
  - Up to six configurable compare values

- 32-bit counter mode
  - Clear counter value on match
  - Up to four configurable compare values

15.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_RTC_PERIODIC_INT	SAM L21/L22/C20/C21/R30
FEATURE_RTC_PRESCALER_OFF	SAM L21/L22/C20/C21/R30
FEATURE_RTC_CLOCK_SELECTION	SAM L21/L22/C20/C21/R30
FEATURE_RTC_GENERAL_PURPOSE_REG	SAM L21/L22/R30
FEATURE_RTC_CONTINUOUSLY_UPDATED	SAM D20, SAM D21, SAM R21, SAM D10, SAM D11, SAM DA1
FEATURE_RTC_TAMPER_DETECTION	SAM L22

Note: The specific features are only available in the driver when the selected device supports those features.

15.3. Compare and Overflow

The RTC can be used with up to 4/6 compare values (depending on selected operation mode). These compare values will trigger on match with the current RTC counter value, and can be set up to trigger an interrupt, event, or both. The RTC can also be configured to clear the counter value on compare match in 32-bit mode, resetting the count value back to zero.

If the RTC is operated without the Clear on Match option enabled, or in 16-bit mode, the RTC counter value will instead be cleared on overflow once the maximum count value has been reached:

$$COUNT_{MAX} = 2^{32} - 1$$

for 32-bit counter mode, and

$$COUNT_{MAX} = 2^{16} - 1$$

for 16-bit counter mode.

When running in 16-bit mode, the overflow value is selectable with a period value. The counter overflow will then occur when the counter value reaches the specified period value.

15.3.1. Periodic Events

The RTC can generate events at periodic intervals, allowing for direct peripheral actions without CPU intervention. The periodic events can be generated on the upper eight bits of the RTC prescaler, and will be generated on the rising edge transition of the specified bit. The resulting periodic frequency can be calculated by the following formula:

$$f_{PERIODIC} = \frac{f_{ASY}}{2^{n+3}}$$

Where

f_{ASY}
refers to the *asynchronous* clock is set up in the RTC module configuration. The **n** parameter is the event source generator index of the RTC module. If the asynchronous clock is operated at the recommended frequency of 1KHz, the formula results in the values shown in Table 15-1.

Table 15-1. RTC Event Frequencies for Each Prescaler Bit Using a 1KHz Clock

n	Periodic event
7	1Hz
6	2Hz
5	4Hz
4	8Hz
3	16Hz
2	32Hz
1	64Hz
0	128Hz

Note: The connection of events between modules requires the use of the SAM Event System (EVENTS) Driver to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

15.3.2. Digital Frequency Correction

The RTC module contains Digital Frequency Correction logic to compensate for inaccurate source clock frequencies which would otherwise result in skewed time measurements. The correction scheme requires that at least two bits in the RTC module prescaler are reserved by the correction logic. As a result of this implementation, frequency correction is only available when the RTC is running from a 1Hz reference clock.

The correction procedure is implemented by subtracting or adding a single cycle from the RTC prescaler every 1024 RTC GCLK cycles. The adjustment is applied the specified number of time (maximum 127) over 976 of these periods. The corresponding correction in PPM will be given by:

$$Correction(PPM) = \frac{VALUE}{999424}10^6$$

The RTC clock will tick faster if provided with a positive correction value, and slower when given a negative correction value.

15.3.3. RTC Tamper Detect

see RTC Tamper Detect

15.4. Special Considerations

15.4.1. Clock Setup

15.4.1.1. SAM D20/D21/R21/D10/D11/DA1 Clock Setup

The RTC is typically clocked by a specialized GCLK generator that has a smaller prescaler than the others. By default the RTC clock is on, selected to use the internal 32KHz RC-oscillator with a prescaler of 32, giving a resulting clock frequency of 1KHz to the RTC. When the internal RTC prescaler is set to 1024, this yields an end-frequency of 1Hz.

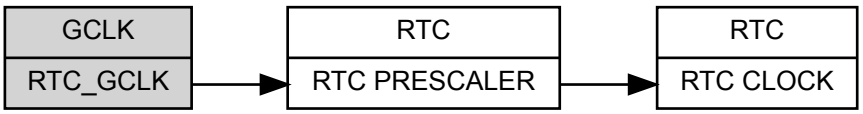
The implementer also has the option to set other end-frequencies. Table 15-2 lists the available RTC frequencies for each possible GCLK and RTC input prescaler options.

Table 15-2. RTC Output Frequencies from Allowable Input Clocks

End-frequency	GCLK prescaler	RTC prescaler
32KHz	1	1
1KHz	32	1
1Hz	32	1024

The overall RTC module clocking scheme is shown in Figure 15-1.

Figure 15-1. SAM D20/D21/R21/D10/D11/DA1 Clock Setup



15.4.1.2. SAM L21/C20/C21/R30 Clock Setup

The RTC clock can be selected from OSC32K, XOSC32K, or OSCULP32K, and a 32KHz or 1KHz oscillator clock frequency is required. This clock must be configured and enabled in the 32KHz oscillator controller before using the RTC.

The table below lists the available RTC clock Table 15-3.

Table 15-3. RTC Clocks Source

RTC clock frequency	Clock source	Description
1.024KHz	ULP1K	1.024KHz from 32KHz internal ULP oscillator
32.768KHz	ULP32K	32.768KHz from 32KHz internal ULP oscillator
1.024KHz	OSC1K	1.024KHz from 32KHz internal oscillator
32.768KHz	OSC32K	32.768KHz from 32KHz internal oscillator
1.024KHz	XOSC1K	1.024KHz from 32KHz internal oscillator
32.768KHz	XOSC32K	32.768KHz from 32KHz external crystal oscillator

15.5. Extra Information

For extra information, see Extra Information for RTC COUNT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

15.6. Examples

For a list of examples related to this driver, see Examples for RTC (COUNT) Driver.

15.7. API Overview

15.7.1. Structure Definitions

15.7.1.1. Struct rtc_count_config

Configuration structure for the RTC instance. This structure should be initialized using the rtc_count_get_config_defaults() before any user configurations are set.

Table 15-4. Members

Type	Name	Description
bool	clear_on_match	If true, clears the counter value on compare match. Only available whilst running in 32-bit mode
uint32_t	compare_values[]	Array of Compare values. Not all Compare values are available in 32-bit mode
enum rtc_count_mode	mode	Select the operation mode of the RTC
enum rtc_count_prescaler	prescaler	Input clock prescaler for the RTC module

15.7.1.2. Struct rtc_count_events

Event flags for the rtc_count_enable_events() and rtc_count_disable_events().

Table 15-5. Members

Type	Name	Description
bool	generate_event_on_compare[]	Generate an output event on a compare channel match against the RTC count
bool	generate_event_on_overflow	Generate an output event on each overflow of the RTC count
bool	generate_event_on_periodic[]	Generate an output event periodically at a binary division of the RTC counter frequency

Type	Name	Description
bool	generate_event_on_tamper	Generate an output event on every tamper input
bool	on_event_to_tamper	Tamper input event and capture the COUNT value

15.7.1.3. Struct rtc_tamper_config

The configuration structure for the RTC tamper. This structure should be initialized using the rtc_tamper_get_config_defaults() before any user configurations are set.

Table 15-6. Members

Type	Name	Description
enum rtc_tamper_active_layer_freq_divider	actl_freq_div	Active layer frequency
bool	bkup_reset_on_tamper	Backup register reset on tamper enable
enum rtc_tamper_debounce_freq_divider	deb_freq_div	Debounce frequency
enum rtc_tamper_debounce_seq	deb_seq	Debounce sequential
bool	dma_tamper_enable	DMA on tamper enable
bool	gp0_enable	General Purpose 0/1 Enable
bool	gp_reset_on_tamper	GP register reset on tamper enable
struct rtc_tamper_input_config	in_cfg[]	Tamper IN configuration

15.7.1.4. Struct rtc_tamper_input_config

The configuration structure for tamper INn.

Table 15-7. Members

Type	Name	Description
enum rtc_tamper_input_action	action	Tamper input action
bool	debounce_enable	Debounce enable
enum rtc_tamper_level_sel	level	Tamper level select

15.7.2. Macro Definitions

15.7.2.1. Driver Feature Definition

Define port features set according to different device family.

Macro FEATURE_RTC_PERIODIC_INT

```
#define FEATURE_RTC_PERIODIC_INT
```

RTC periodic interval interrupt.

Macro FEATURE_RTC_PRESCALER_OFF

```
#define FEATURE_RTC_PRESCALER_OFF
```

RTC prescaler is off.

Macro FEATURE_RTC_CLOCK_SELECTION

```
#define FEATURE_RTC_CLOCK_SELECTION
```

RTC clock selection.

Macro FEATURE_RTC_GENERAL_PURPOSE_REG

```
#define FEATURE_RTC_GENERAL_PURPOSE_REG
```

General purpose registers.

Macro FEATURE_RTC_TAMPER_DETECTION

```
#define FEATURE_RTC_TAMPER_DETECTION
```

RTC tamper detection.

15.7.2.2. Macro RTC_TAMPER_DETECT_EVT

```
#define RTC_TAMPER_DETECT_EVT
```

RTC tamper input event detection bitmask.

15.7.2.3. Macro RTC_TAMPER_DETECT_ID0

```
#define RTC_TAMPER_DETECT_ID0
```

RTC tamper ID0 detection bitmask.

15.7.2.4. Macro RTC_TAMPER_DETECT_ID1

```
#define RTC_TAMPER_DETECT_ID1
```

RTC tamper ID1 detection bitmask.

15.7.2.5. Macro RTC_TAMPER_DETECT_ID2

```
#define RTC_TAMPER_DETECT_ID2
```

RTC tamper ID2 detection bitmask.

15.7.2.6. Macro RTC_TAMPER_DETECT_ID3

```
#define RTC_TAMPER_DETECT_ID3
```

RTC tamper ID3 detection bitmask.

15.7.2.7. Macro RTC_TAMPER_DETECT_ID4

```
#define RTC_TAMPER_DETECT_ID4
```

RTC tamper ID4 detection bitmask.

15.7.3. Function Definitions

15.7.3.1. Configuration and Initialization

Function rtc_count_get_config_defaults()

Gets the RTC default configurations.

```
void rtc_count_get_config_defaults(
        struct rtc_count_config *const config)
```

Initializes the configuration structure to default values. This function should be called at the start of any RTC initialization.

The default configuration is:

- Input clock divided by a factor of 1024
- RTC in 32-bit mode
- Clear on compare match off
- Continuously sync count register off
- No event source on
- All compare values equal 0
- Count read synchronization is enabled for SAM L22

Table 15-8. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values

Function rtc_count_reset()

Resets the RTC module. Resets the RTC to hardware defaults.

```
void rtc_count_reset(
        struct rtc_module *const module)
```

Table 15-9. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_count_enable()

Enables the RTC module.

```
void rtc_count_enable(
        struct rtc_module *const module)
```

Enables the RTC module once it has been configured, ready for use. Most module configuration parameters cannot be altered while the module is enabled.

Table 15-10. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_disable()

Disables the RTC module.

```
void rtc_count_disable(
        struct rtc_module *const module)
```

Disables the RTC module.

Table 15-11. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_init()

Initializes the RTC module with given configurations.

```
enum status_code rtc_count_init(
        struct rtc_module *const module,
        Rtc *const hw,
        const struct rtc_count_config *const config)
```

Initializes the module, setting up all given configurations to provide the desired functionality of the RTC.

Table 15-12. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the configuration structure

Returns

Status of the initialization procedure.

Table 15-13. Return Values

Return value	Description
STATUS_OK	If the initialization was run stressfully
STATUS_ERR_INVALID_ARG	If invalid argument(s) were given

Function rtc_count_frequency_correction()

Calibrate for too-slow or too-fast oscillator.

```
enum status_code rtc_count_frequency_correction(
        struct rtc_module *const module,
        const int8_t value)
```

When used, the RTC will compensate for an inaccurate oscillator. The RTC module will add or subtract cycles from the RTC prescaler to adjust the frequency in approximately 1 PPM steps. The provided correction value should be between 0 and 127, allowing for a maximum 127 PPM correction.

If no correction is needed, set value to zero.

Note: Can only be used when the RTC is operated in 1Hz.

Table 15-14. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	value	Ranging from -127 to 127 used for the correction

Returns
Status of the calibration procedure.

Table 15-15. Return Values

Return value	Description
STATUS_OK	If calibration was executed correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

15.7.3.2. Count and Compare Value Management

Function rtc_count_set_count()

Set the current count value to desired value.

```
enum status_code rtc_count_set_count(
        struct rtc_module *const module,
        const uint32_t count_value)
```

Sets the value of the counter to the specified value.

Table 15-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	count_value	The value to be set in count register

Returns
Status of setting the register.

Table 15-17. Return Values

Return value	Description
STATUS_OK	If everything was executed correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

Function rtc_count_get_count()

Get the current count value.

```
uint32_t rtc_count_get_count(
        struct rtc_module *const module)
```

Table 15-18. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Returns the current count value.

Returns
The current counter value as a 32-bit unsigned integer.

Function rtc_count_set_compare()

Set the compare value for the specified compare.

```
enum status_code rtc_count_set_compare(
        struct rtc_module *const module,
        const uint32_t comp_value,
        const enum rtc_count_compare comp_index)
```

Sets the value specified by the implementer to the requested compare.

Note: Compare 4 and 5 are only available in 16-bit mode.

Table 15-19. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_value	The value to be written to the compare
[in]	comp_index	Index of the compare to set

Returns
Status indicating if compare was successfully set.

Table 15-20. Return Values

Return value	Description
STATUS_OK	If compare was successfully set
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode

Function rtc_count_get_compare()

Get the current compare value of specified compare.

```
enum status_code rtc_count_get_compare(
        struct rtc_module *const module,
        uint32_t *const comp_value,
        const enum rtc_count_compare comp_index)
```

Retrieves the current value of the specified compare.

Note: Compare 4 and 5 are only available in 16-bit mode.

Table 15-21. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	comp_value	Pointer to 32-bit integer that will be populated with the current compare value
[in]	comp_index	Index of compare to check

Returns
Status of the reading procedure.

Table 15-22. Return Values

Return value	Description
STATUS_OK	If the value was read correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode

Function rtc_count_set_period()

Set the given value to the period.

```
enum status_code rtc_count_set_period(
        struct rtc_module *const module,
        uint16_t period_value)
```

Sets the given value to the period.

Note: Only available in 16-bit mode.

Table 15-23. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	period_value	The value to set to the period

Returns
Status of setting the period value.

Table 15-24. Return Values

Return value	Description
STATUS_OK	If the period was set correctly
STATUS_ERR_UNSUPPORTED_DEV	If module is not operated in 16-bit mode

Function rtc_count_get_period()

Retrieves the value of period.

```
enum status_code rtc_count_get_period(
        struct rtc_module *const module,
        uint16_t *const period_value)
```

Retrieves the value of the period for the 16-bit mode counter.

Note: Only available in 16-bit mode.

Table 15-25. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	period_value	Pointer to value for return argument

Returns
Status of getting the period value.

Table 15-26. Return Values

Return value	Description
STATUS_OK	If the period value was read correctly
STATUS_ERR_UNSUPPORTED_DEV	If incorrect mode was set

15.7.3.3. Status Management

Function rtc_count_is_overflow()

Check if an RTC overflow has occurred.

```
bool rtc_count_is_overflow(
        struct rtc_module *const module)
```

Checks the overflow flag in the RTC. The flag is set when there is an overflow in the clock.

Table 15-27. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Returns
Overflow state of the RTC module.

Table 15-28. Return Values

Return value	Description
true	If the RTC count value has overflowed
false	If the RTC count value has not overflowed

Function rtc_count_clear_overflow()

Clears the RTC overflow flag.

```
void rtc_count_clear_overflow(
        struct rtc_module *const module)
```

Clears the RTC module counter overflow flag, so that new overflow conditions can be detected.

Table 15-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module

Function rtc_count_is_periodic_interval()

Check if an RTC periodic interval interrupt has occurred.

```
bool rtc_count_is_periodic_interval(
        struct rtc_module *const module,
        enum rtc_count_periodic_interval n)
```

Checks the periodic interval flag in the RTC.

Table 15-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	n	RTC periodic interval interrupt

Returns
Periodic interval interrupt state of the RTC module.

Table 15-31. Return Values

Return value	Description
true	RTC periodic interval interrupt occurs
false	RTC periodic interval interrupt doesn't occur

Function rtc_count_clear_periodic_interval()

Clears the RTC periodic interval flag.

```
void rtc_count_clear_periodic_interval(
        struct rtc_module *const module,
        enum rtc_count_periodic_interval n)
```

Clears the RTC module counter periodic interval flag, so that new periodic interval conditions can be detected.

Table 15-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	n	RTC periodic interval interrupt

Function rtc_count_is_compare_match()

Check if RTC compare match has occurred.

```
bool rtc_count_is_compare_match(
        struct rtc_module *const module,
        const enum rtc_count_compare comp_index)
```

Checks the compare flag to see if a match has occurred. The compare flag is set when there is a compare match between counter and the compare.

Note: Compare 4 and 5 are only available in 16-bit mode.

Table 15-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_index	Index of compare to check current flag

Function rtc_count_clear_compare_match()

Clears RTC compare match flag.

```
enum status_code rtc_count_clear_compare_match(
        struct rtc_module *const module,
        const enum rtc_count_compare comp_index)
```

Clears the compare flag. The compare flag is set when there is a compare match between the counter and the compare.

Note: Compare 4 and 5 are only available in 16-bit mode.

Table 15-34. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	comp_index	Index of compare to check current flag

Returns

Status indicating if flag was successfully cleared.

Table 15-35. Return Values

Return value	Description
STATUS_OK	If flag was successfully cleared
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_BAD_FORMAT	If the module was not initialized in a mode

15.7.3.4. Event Management

Function rtc_count_enable_events()

Enables an RTC event output.

```
void rtc_count_enable_events(
        struct rtc_module *const module,
        struct rtc_count_events *const events)
```

Enables one or more output events from the RTC module. See rtc_count_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 15-36. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	events	Struct containing flags of events to enable

Function rtc_count_disable_events()

Disables an RTC event output.

```
void rtc_count_disable_events(
        struct rtc_module *const module,
        struct rtc_count_events *const events)
```

Disabled one or more output events from the RTC module. See rtc_count_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 15-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	events	Struct containing flags of events to disable

15.7.3.5. RTC General Purpose Registers

Function rtc_write_general_purpose_reg()

Write a value into general purpose register.

```
void rtc_write_general_purpose_reg(
        struct rtc_module *const module,
```

```
        const uint8_t index,
        uint32_t value)
```

Table 15-38. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	n	General purpose type
[in]	index	General purpose register index (0..3)

Function rtc_read_general_purpose_reg()

Read the value from general purpose register.

```
uint32_t rtc_read_general_purpose_reg(
        struct rtc_module *const module,
        const uint8_t index)
```

Table 15-39. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	index	General purpose register index (0..3)

Returns
Value of general purpose register.

15.7.3.6. Callbacks

Function rtc_count_register_callback()

Registers callback for the specified callback type.

```
enum status_code rtc_count_register_callback(
        struct rtc_module *const module,
        rtc_count_callback_t callback,
        enum rtc_count_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the rtc_count_enable_callback function must be used.

Table 15-40. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Returns
Status of registering callback.

Table 15-41. Return Values

Return value	Description
STATUS_OK	Registering was done successfully
STATUS_ERR_INVALID_ARG	If trying to register a callback not available

Function rtc_count_unregister_callback()

Unregisters callback for the specified callback type.

```
enum status_code rtc_count_unregister_callback(
        struct rtc_module *const module,
        enum rtc_count_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 15-42. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Specifies the callback type to unregister

Returns

Status of unregistering callback.

Table 15-43. Return Values

Return value	Description
STATUS_OK	Unregistering was done successfully
STATUS_ERR_INVALID_ARG	If trying to unregister a callback not available

Function rtc_count_enable_callback()

Enables callback.

```
void rtc_count_enable_callback(
        struct rtc_module *const module,
        enum rtc_count_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 15-44. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to enable

Function rtc_count_disable_callback()

Disables callback.

```
void rtc_count_disable_callback(
        struct rtc_module *const module,
        enum rtc_count_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 15-45. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to disable

15.7.3.7. RTC Tamper Detection

Function rtc_tamper_get_config_defaults()

Gets the RTC tamper default configurations.

```
void rtc_tamper_get_config_defaults(
        struct rtc_tamper_config *const config)
```

Initializes the configuration structure to default values.

The default configuration is as follows:

- Disable backup register reset on tamper
- Disable GP register reset on tamper
- Active layer clock divided by a factor of 8
- Debounce clock divided by a factor of 8
- Detect edge on INn with synchronous stability debouncing
- Disable DMA on tamper
- Enable GP register
- Disable debouce, detect on falling edge and no action on INn

Table 15-46. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values.

Function rtc_tamper_set_config()

```
enum status_code rtc_tamper_set_config(
        struct rtc_module *const module,
        struct rtc_tamper_config *const tamper_cfg)
```

Function rtc_tamper_get_detect_flag()

Retrieves the RTC tamper detection status.

```
uint32_t rtc_tamper_get_detect_flag(
        struct rtc_module *const module)
```

Retrieves the detection status of each input pin and the input event.

Table 15-47. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the RTC software instance struct

Returns
Bitmask of detection flags.

Table 15-48. Return Values

Return value	Description
RTC_TAMPER_DETECT_ID0	Tamper condition on IN0 has been detected
RTC_TAMPER_DETECT_ID1	Tamper condition on IN1 has been detected
RTC_TAMPER_DETECT_ID2	Tamper condition on IN2 has been detected
RTC_TAMPER_DETECT_ID3	Tamper condition on IN3 has been detected
RTC_TAMPER_DETECT_ID4	Tamper condition on IN4 has been detected
RTC_TAMPER_DETECT_EVT	Tamper input event has been detected

Function rtc_tamper_clear_detect_flag()

Clears RTC tamper detection flag.

```
void rtc_tamper_clear_detect_flag(
        struct rtc_module *const module,
        const uint32_t detect_flags)
```

Clears the given detection flag of the module.

Table 15-49. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the TC software instance struct
[in]	detect_flags	Bitmask of detection flags

15.7.3.8. Function rtc_tamper_get_stamp()

Get the tamper stamp value.

```
uint32_t rtc_tamper_get_stamp(
        struct rtc_module *const module)
```

Table 15-50. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Returns
The current tamper stamp value as a 32-bit unsigned integer.

15.7.4. Enumeration Definitions

15.7.4.1. Enum rtc_clock_sel

Table 15-51. Members

Enum value	Description
RTC_CLOCK_SELECTION_ULP1K	1.024KHz from 32KHz internal ULP oscillator
RTC_CLOCK_SELECTION_ULP32K	32.768KHz from 32KHz internal ULP oscillator
RTC_CLOCK_SELECTION_OSC1K	1.024KHz from 32KHz internal oscillator
RTC_CLOCK_SELECTION_OSC32K	32.768KHz from 32KHz internal oscillator
RTC_CLOCK_SELECTION_XOSC1K	1.024KHz from 32KHz external oscillator
RTC_CLOCK_SELECTION_XOSC32K	32.768KHz from 32.768KHz external crystal oscillator

15.7.4.2. Enum rtc_count_callback

The available callback types for the RTC count module.

Table 15-52. Members

Enum value	Description
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_0	Callback for Periodic Interval 0 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_1	Callback for Periodic Interval 1 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_2	Callback for Periodic Interval 2 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_3	Callback for Periodic Interval 3 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_4	Callback for Periodic Interval 4 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_5	Callback for Periodic Interval 5 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_6	Callback for Periodic Interval 6 Interrupt
RTC_COUNT_CALLBACK_PERIODIC_INTERVAL_7	Callback for Periodic Interval 7 Interrupt
RTC_COUNT_CALLBACK_COMPARE_0	Callback for compare channel 0
RTC_COUNT_CALLBACK_COMPARE_1	Callback for compare channel 1
RTC_COUNT_CALLBACK_COMPARE_2	Callback for compare channel 2
RTC_COUNT_CALLBACK_COMPARE_3	Callback for compare channel 3
RTC_COUNT_CALLBACK_COMPARE_4	Callback for compare channel 4
RTC_COUNT_CALLBACK_COMPARE_5	Callback for compare channel 5
RTC_COUNT_CALLBACK_TAMPER	Callback for tamper
RTC_COUNT_CALLBACK_OVERFLOW	Callback for overflow

15.7.4.3. Enum rtc_count_compare

Note: Not all compare channels are available in all devices and modes.

Table 15-53. Members

Enum value	Description
RTC_COUNT_COMPARE_0	Compare channel 0
RTC_COUNT_COMPARE_1	Compare channel 1
RTC_COUNT_COMPARE_2	Compare channel 2
RTC_COUNT_COMPARE_3	Compare channel 3
RTC_COUNT_COMPARE_4	Compare channel 4
RTC_COUNT_COMPARE_5	Compare channel 5

15.7.4.4. Enum rtc_count_mode

RTC Count operating modes, to select the counting width and associated module operation.

Table 15-54. Members

Enum value	Description
RTC_COUNT_MODE_16BIT	RTC Count module operates in 16-bit mode
RTC_COUNT_MODE_32BIT	RTC Count module operates in 32-bit mode

15.7.4.5. Enum rtc_count_periodic_interval

Table 15-55. Members

Enum value	Description
RTC_COUNT_PERIODIC_INTERVAL_0	Periodic interval 0
RTC_COUNT_PERIODIC_INTERVAL_1	Periodic interval 1
RTC_COUNT_PERIODIC_INTERVAL_2	Periodic interval 2
RTC_COUNT_PERIODIC_INTERVAL_3	Periodic interval 3
RTC_COUNT_PERIODIC_INTERVAL_4	Periodic interval 4
RTC_COUNT_PERIODIC_INTERVAL_5	Periodic interval 5
RTC_COUNT_PERIODIC_INTERVAL_6	Periodic interval 6
RTC_COUNT_PERIODIC_INTERVAL_7	Periodic interval 7

15.7.4.6. Enum rtc_count_prescaler

The available input clock prescaler values for the RTC count module.

Table 15-56. Members

Enum value	Description
RTC_COUNT_PRESCALER_OFF	RTC prescaler is off, and the input clock frequency is prescaled by a factor of 1
RTC_COUNT_PRESCALER_DIV_1	RTC input clock frequency is prescaled by a factor of 1
RTC_COUNT_PRESCALER_DIV_2	RTC input clock frequency is prescaled by a factor of 2
RTC_COUNT_PRESCALER_DIV_4	RTC input clock frequency is prescaled by a factor of 4
RTC_COUNT_PRESCALER_DIV_8	RTC input clock frequency is prescaled by a factor of 8
RTC_COUNT_PRESCALER_DIV_16	RTC input clock frequency is prescaled by a factor of 16
RTC_COUNT_PRESCALER_DIV_32	RTC input clock frequency is prescaled by a factor of 32
RTC_COUNT_PRESCALER_DIV_64	RTC input clock frequency is prescaled by a factor of 64
RTC_COUNT_PRESCALER_DIV_128	RTC input clock frequency is prescaled by a factor of 128
RTC_COUNT_PRESCALER_DIV_256	RTC input clock frequency is prescaled by a factor of 256
RTC_COUNT_PRESCALER_DIV_512	RTC input clock frequency is prescaled by a factor of 512
RTC_COUNT_PRESCALER_DIV_1024	RTC input clock frequency is prescaled by a factor of 1024

15.7.4.7. Enum rtc_tamper_active_layer_freq_divider

The available prescaler factor for the RTC clock output used during active layer protection.

Table 15-57. Members

Enum value	Description
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_2	RTC active layer frequency is prescaled by a factor of 2
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_4	RTC active layer frequency is prescaled by a factor of 4
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_8	RTC active layer frequency is prescaled by a factor of 8
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_16	RTC active layer frequency is prescaled by a factor of 16
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_32	RTC active layer frequency is prescaled by a factor of 32
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_64	RTC active layer frequency is prescaled by a factor of 64

Enum value	Description
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_128	RTC active layer frequency is prescaled by a factor of 128
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_256	RTC active layer frequency is prescaled by a factor of 256

15.7.4.8. Enum rtc_tamper_debounce_freq_divider

The available prescaler factor for the input debouncers.

Table 15-58. Members

Enum value	Description
RTC_TAMPER_DEBOUNCE_FREQ_DIV_2	RTC debounce frequency is prescaled by a factor of 2
RTC_TAMPER_DEBOUNCE_FREQ_DIV_4	RTC debounce frequency is prescaled by a factor of 4
RTC_TAMPER_DEBOUNCE_FREQ_DIV_8	RTC debounce frequency is prescaled by a factor of 8
RTC_TAMPER_DEBOUNCE_FREQ_DIV_16	RTC debounce frequency is prescaled by a factor of 16
RTC_TAMPER_DEBOUNCE_FREQ_DIV_32	RTC debounce frequency is prescaled by a factor of 32
RTC_TAMPER_DEBOUNCE_FREQ_DIV_64	RTC debounce frequency is prescaled by a factor of 64
RTC_TAMPER_DEBOUNCE_FREQ_DIV_128	RTC debounce frequency is prescaled by a factor of 128
RTC_TAMPER_DEBOUNCE_FREQ_DIV_256	RTC debounce frequency is prescaled by a factor of 256

15.7.4.9. Enum rtc_tamper_debounce_seq

The available sequential for tamper debounce.

Table 15-59. Members

Enum value	Description
RTC_TAMPER_DEBOUNCE_SYNC	Tamper input detect edge with synchronous stability debounce
RTC_TAMPER_DEBOUNCE_ASYNC	Tamper input detect edge with asynchronous stability debounce
RTC_TAMPER_DEBOUNCE_MAJORITY	Tamper input detect edge with majority debounce

15.7.4.10. Enum rtc_tamper_input_action

The available action taken by the tamper input.

Table 15-60. Members

Enum value	Description
RTC_TAMPER_INPUT_ACTION_OFF	RTC tamper input action is disabled
RTC_TAMPER_INPUT_ACTION_WAKE	RTC tamper input action is wake and set tamper flag
RTC_TAMPER_INPUT_ACTION_CAPTURE	RTC tamper input action is capture timestamp and set tamper flag
RTC_TAMPER_INPUT_ACTION_ACTL	RTC tamper input action is compare IN to OUT, when a mismatch occurs, capture timestamp and set tamper flag

15.7.4.11. Enum rtc_tamper_level_sel

The available edge condition for tamper INn level select.

Table 15-61. Members

Enum value	Description
RTC_TAMPER_LEVEL_FALLING	A falling edge condition will be detected on Tamper input
RTC_TAMPER_LEVEL_RISING	A rising edge condition will be detected on Tamper input

15.8. RTC Tamper Detect

The RTC provides several selectable polarity external inputs (INn) that can be used for tamper detection. When detect, tamper inputs support the four actions:

- Off
- Wake
- Capture
- Active layer protection

Note: The Active Layer Protection is a means of detecting broken traces on the PCB provided by RTC. In this mode an RTC output signal is routed over critical components on the board and fed back to one of the RTC inputs. The input and output signals are compared and a tamper condition is detected when they do not match.

Separate debouncers are embedded for each external input. The detection time depends on whether the debouncer operates synchronously or asynchronously, and whether majority detection is enabled or not. For details, refer to the section "Tamper Detection" of datasheet.

15.9. Extra Information for RTC COUNT Driver

15.9.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
RTC	Real Time Counter
PPM	Part Per Million
RC	Resistor/Capacitor

15.9.2. Dependencies

This driver has the following dependencies:

- None

15.9.3. Errata

There are no errata related to this driver.

15.9.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAM C21
Added support for SAM L21/L22
Added support for SAM R30
Added support for RTC tamper feature
Added driver instance parameter to all API function calls, except get_config_defaults
Updated initialization function to also enable the digital interface clock to the module if it is disabled
Initial Release

15.10. Examples for RTC (COUNT) Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM RTC Count (RTC COUNT) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for RTC (COUNT) - Basic
- Quick Start Guide for RTC (COUNT) - Callback
- Quick Start Guide for RTC Tamper with DMA

15.10.1. Quick Start Guide for RTC (COUNT) - Basic

In this use case, the RTC is set up in count mode. The example configures the RTC in 16-bit mode, with continuous updates to the COUNT register, together with a set compare register value. Every 2000ms a LED on the board is toggled.

15.10.1.1. Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                  true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME            SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT      true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ON_DEMAND               true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY          false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                  true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY          false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE
SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER               32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE           false
```

15.10.1.2. Setup

Initialization Code

Create an rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

Copy-paste the following setup code to your applications `main()`:

```
void configure_rtc_count(void)
{
    struct rtc_count_config config_rtc_count;

    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
#ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
    config_rtc_count.continuously_update = true;
#endif
    config_rtc_count.compare_values[0]   = 1000;
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_count_enable(&rtc_instance);
}
```

Add to Main

Add the following to your `main()`.

```
configure_rtc_count();
```

Workflow

1. Create an RTC configuration structure to hold the desired RTC driver settings.

   ```
   struct rtc_count_config config_rtc_count;
   ```

2. Fill the configuration structure with the default driver configuration.

   ```
   rtc_count_get_config_defaults(&config_rtc_count);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the RTC driver configuration to run in 16-bit counting mode, with continuous counter register updates.

   ```
   config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
   config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
   #ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
       config_rtc_count.continuously_update = true;
   #endif
       config_rtc_count.compare_values[0]   = 1000;
   ```

4. Initialize the RTC module.

   ```
   rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
   ```

5. Enable the RTC module, so that it may begin counting.

   ```
   rtc_count_enable(&rtc_instance);
   ```

15.10.1.3. Implementation

Code used to implement the initialized module.

Code

Add after initialization in main().

```
rtc_count_set_period(&rtc_instance, 2000);

while (true) {
    if (rtc_count_is_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0)) {
        /* Do something on RTC count match here */
        port_pin_toggle_output_level(LED_0_PIN);

        rtc_count_clear_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0);
    }
}
```

Workflow

1. Set RTC period to 2000ms (two seconds) so that it will overflow and reset back to zero every two seconds.

   ```
   rtc_count_set_period(&rtc_instance, 2000);
   ```

2. Enter an infinite loop to poll the RTC driver to check when a comparison match occurs.

   ```
   while (true) {
   ```

3. Check if the RTC driver has found a match on compare channel 0 against the current RTC count value.

```
if (rtc_count_is_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0)) {
```

4. Once a compare match occurs, perform the desired user action.

```
/* Do something on RTC count match here */
port_pin_toggle_output_level(LED_0_PIN);
```

5. Clear the compare match, so that future matches may occur.

```
rtc_count_clear_compare_match(&rtc_instance, RTC_COUNT_COMPARE_0);
```

15.10.2. Quick Start Guide for RTC (COUNT) - Callback

In this use case, the RTC is set up in count mode. The quick start configures the RTC in 16-bit mode and to continuously update COUNT register. The rest of the configuration is according to the default. A callback is implemented for when the RTC overflows.

15.10.2.1. Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                  true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME            SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT      true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ON_DEMAND               true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY          false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                  true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY          false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE
SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER               32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE           false
```

15.10.2.2. Setup

Code

Create an rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

The following must be added to the user application:

Function for setting up the module:

```
void configure_rtc_count(void)
{
```

```
    struct rtc_count_config config_rtc_count;
    rtc_count_get_config_defaults(&config_rtc_count);

    config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
    config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
#ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
    config_rtc_count.continuously_update = true;
#endif
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    rtc_count_enable(&rtc_instance);
}
```

Callback function:

```
void rtc_overflow_callback(void)
{
    /* Do something on RTC overflow here */
    port_pin_toggle_output_level(LED_0_PIN);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_rtc_callbacks(void)
{
    rtc_count_register_callback(
            &rtc_instance, rtc_overflow_callback,
RTC_COUNT_CALLBACK_OVERFLOW);
    rtc_count_enable_callback(&rtc_instance, RTC_COUNT_CALLBACK_OVERFLOW);
}
```

Add to user application main():

```
/* Initialize system. Must configure conf_clocks.h first. */
system_init();

/* Configure and enable RTC */
configure_rtc_count();

/* Configure and enable callback */
configure_rtc_callbacks();

/* Set period */
rtc_count_set_period(&rtc_instance, 2000);
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Configure and enable module.

   ```
   configure_rtc_count();
   ```

3. Create an RTC configuration structure to hold the desired RTC driver settings and fill it with the default driver configuration values.

   ```
   struct rtc_count_config config_rtc_count;
   rtc_count_get_config_defaults(&config_rtc_count);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the RTC driver configuration to run in 16-bit counting mode, with continuous counter register updates and a compare value of 1000ms.

```
config_rtc_count.prescaler           = RTC_COUNT_PRESCALER_DIV_1;
config_rtc_count.mode                = RTC_COUNT_MODE_16BIT;
#ifdef FEATURE_RTC_CONTINUOUSLY_UPDATED
    config_rtc_count.continuously_update = true;
#endif
```

5. Initialize the RTC module.

```
rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
```

6. Enable the RTC module, so that it may begin counting.

```
rtc_count_enable(&rtc_instance);
```

7. Configure callback functionality.

```
configure_rtc_callbacks();
```

    1. Register overflow callback.

```
rtc_count_register_callback(
        &rtc_instance, rtc_overflow_callback,
RTC_COUNT_CALLBACK_OVERFLOW);
```

    2. Enable overflow callback.

```
rtc_count_enable_callback(&rtc_instance,
RTC_COUNT_CALLBACK_OVERFLOW);
```

8. Set period.

```
rtc_count_set_period(&rtc_instance, 2000);
```

15.10.2.3. Implementation

Code

Add to user application main:

```
while (true) {
    /* Infinite while loop */
}
```

Workflow

1. Infinite while loop while waiting for callbacks.

```
while (true) {
    /* Infinite while loop */
}
```

15.10.2.4. Callback

Each time the RTC counter overflows, the callback function will be called.

Workflow

1. Perform the desired user action for each RTC overflow:

```
/* Do something on RTC overflow here */
port_pin_toggle_output_level(LED_0_PIN);
```

15.10.3. Quick Start Guide for RTC Tamper with DMA

In this use case, the RTC is set up in count mode. The quick start configures the RTC in 32-bit mode and . The rest of the configuration is according to the default. A callback is implemented for when the RTC capture tamper stamp.

15.10.3.1. Setup

Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Code

Add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

```
struct dma_resource example_resource;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;
```

The following must be added to the user application: Function for setting up the module:

```
void configure_rtc(void)
{
    struct rtc_count_config config_rtc_count;
    rtc_count_get_config_defaults(&config_rtc_count);
    config_rtc_count.prescaler = RTC_COUNT_PRESCALER_DIV_1;
    rtc_count_init(&rtc_instance, RTC, &config_rtc_count);

    struct rtc_tamper_config config_rtc_tamper;
    rtc_tamper_get_config_defaults(&config_rtc_tamper);
    config_rtc_tamper.dma_tamper_enable = true;
    config_rtc_tamper.in_cfg[0].level = RTC_TAMPER_LEVEL_RISING;
    config_rtc_tamper.in_cfg[0].action = RTC_TAMPER_INPUT_ACTION_CAPTURE;
    rtc_tamper_set_config(&rtc_instance, &config_rtc_tamper);

    rtc_count_enable(&rtc_instance);
}
```

Callback function:

```
void rtc_tamper_callback(void)
{
    /* Do something on RTC tamper capture here */
    LED_On(LED_0_PIN);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_rtc_callbacks(void)
{
    rtc_count_register_callback(
            &rtc_instance, rtc_tamper_callback, RTC_COUNT_CALLBACK_TAMPER);
    rtc_count_enable_callback(&rtc_instance, RTC_COUNT_CALLBACK_TAMPER);
}
```

Add to user application initialization (typically the start of `main()`):

```
/* Initialize system. Must configure conf_clocks.h first. */
system_init();

/* Configure and enable RTC */
configure_rtc();

/* Configure and enable callback */
configure_rtc_callbacks();

configure_dma_resource(&example_resource);

setup_transfer_descriptor(&example_descriptor);

dma_add_descriptor(&example_resource, &example_descriptor);

while (true) {
    /* Infinite while loop */
}
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Configure and enable module.

   ```
   configure_rtc();
   ```

   1. Create a RTC configuration structure to hold the desired RTC driver settings and fill it with the configuration values.

      ```
      struct rtc_count_config config_rtc_count;
      rtc_count_get_config_defaults(&config_rtc_count);
      config_rtc_count.prescaler = RTC_COUNT_PRESCALER_DIV_1;
      rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   2. Initialize the RTC module.

      ```
      struct rtc_count_config config_rtc_count;
      rtc_count_get_config_defaults(&config_rtc_count);
      config_rtc_count.prescaler = RTC_COUNT_PRESCALER_DIV_1;
      rtc_count_init(&rtc_instance, RTC, &config_rtc_count);
      ```

   3. Create a RTC tamper configuration structure and fill it with the configuration values.

      ```
      struct rtc_tamper_config config_rtc_tamper;
      rtc_tamper_get_config_defaults(&config_rtc_tamper);
      config_rtc_tamper.dma_tamper_enable = true;
      config_rtc_tamper.in_cfg[0].level = RTC_TAMPER_LEVEL_RISING;
      config_rtc_tamper.in_cfg[0].action =
      RTC_TAMPER_INPUT_ACTION_CAPTURE;
      rtc_tamper_set_config(&rtc_instance, &config_rtc_tamper);
      ```

   4. Enable the RTC module, so that it may begin counting.

      ```
      rtc_count_enable(&rtc_instance);
      ```

3. Configure callback functionality.

   ```
   configure_rtc_callbacks();
   ```

1. Register overflow callback.

```
rtc_count_register_callback(
        &rtc_instance, rtc_tamper_callback,
RTC_COUNT_CALLBACK_TAMPER);
```

2. Enable overflow callback.

```
rtc_count_enable_callback(&rtc_instance,
RTC_COUNT_CALLBACK_TAMPER);
```

4. Configure the DMA.
    1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

    2. Initialize the DMA resource configuration struct with the module's. default values.

```
dma_get_config_defaults(&config);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    3. Set extra configurations for the DMA resource. ADC_DMAC_ID_RESRDY trigger causes a beat transfer in this example.

```
config.peripheral_trigger = RTC_DMAC_ID_TIMESTAMP;
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

    4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

    5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

    6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    7. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_WORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = 1;
descriptor_config.source_address = (uint32_t)(&rtc_instance.hw-
>MODE0.TIMESTAMP.reg);
descriptor_config.destination_address = (uint32_t)
(buffer_rtc_tamper);
descriptor_config.next_descriptor_address = (uint32_t)descriptor;
```

    8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

9. Add DMA descriptor to DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

15.10.3.2. Implementation

Code

Add to user application main:

1. Infinite while loop while waiting for callbacks.

```
while (true) {
     /* Infinite while loop */
}
```

Callback

When the RTC tamper captured, the callback function will be called.

1. LED0 on for RTC tamper capture:

```
/* Do something on RTC tamper capture here */
LED_On(LED_0_PIN);
```

16. SAM RTC Calendar (RTC CAL) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Real Time Clock functionality in Calendar operating mode, for the configuration and retrieval of the current time and date as maintained by the RTC module. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- RTC (Real Time Clock)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

16.1. Prerequisites

There are no prerequisites for this module.

16.2. Module Overview

The RTC module in the SAM devices is a 32-bit counter, with a 10-bit programmable prescaler. Typically, the RTC clock is run continuously, including in the device's low-power sleep modes, to track the current time and date information. The RTC can be used as a source to wake up the system at a scheduled time or periodically using the alarm functions.

In this driver, the RTC is operated in Calendar mode. This allows for an easy integration of a real time clock and calendar into a user application to track the passing of time and/or perform scheduled tasks.

Whilst operating in Calendar mode, the RTC features:

- Time tracking in seconds, minutes, and hours
- 12 or 24 hour mode
- Date tracking in day, month, and year

- Automatic leap year correction

16.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_RTC_PERIODIC_INT	SAM L21/L22/C20/C21/R30
FEATURE_RTC_PRESCALER_OFF	SAM L21/L22/C20/C21/R30
FEATURE_RTC_CLOCK_SELECTION	SAM L21/L22/C20/C21/R30
FEATURE_RTC_GENERAL_PURPOSE_REG	SAM L21/L22/R30
FEATURE_RTC_CONTINUOUSLY_UPDATED	SAM D20, SAM D21, SAM R21, SAM D10, SAM D11, SAM DA1
FEATURE_RTC_TAMPER_DETECTION	SAM L22

Note: The specific features are only available in the driver when the selected device supports those features.

16.2.2. Alarms and Overflow

The RTC has up to four independent hardware alarms that can be configured by the user application. These alarms will be triggered on match with the current clock value, and can be set up to trigger an interrupt, event, or both. The RTC can also be configured to clear the clock value on alarm match, resetting the clock to the original start time.

If the RTC is operated in clock-only mode (i.e. with calendar disabled), the RTC counter value will instead be cleared on overflow once the maximum count value has been reached:

$$COUNT_{MAX} = 2^{32} - 1$$

When the RTC is operated with the calendar enabled and run using a nominal 1Hz input clock frequency, a register overflow will occur after 64 years.

16.2.3. Periodic Events

The RTC can generate events at periodic intervals, allowing for direct peripheral actions without CPU intervention. The periodic events can be generated on the upper eight bits of the RTC prescaler, and will be generated on the rising edge transition of the specified bit. The resulting periodic frequency can be calculated by the following formula:

$$f_{PERIODIC} = \frac{f_{ASY}}{2^{n+3}}$$

Where
f_{ASY}
refers to the *asynchronous* clock set up in the RTC module configuration. For the RTC to operate correctly in calendar mode, this frequency must be 1KHz, while the RTC's internal prescaler should be set to divide by 1024. The **n** parameter is the event source generator index of the RTC module. If the asynchronous clock is operated at the recommended 1KHz, the formula results in the values shown in Table 16-1.

Table 16-1. RTC Event Frequencies for Each Prescaler Bit Using a 1KHz Clock

n	Periodic event
7	1Hz
6	2Hz
5	4Hz
4	8Hz
3	16Hz
2	32Hz
1	64Hz
0	128Hz

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

16.2.4. Digital Frequency Correction

The RTC module contains Digital Frequency Correction logic to compensate for inaccurate source clock frequencies which would otherwise result in skewed time measurements. The correction scheme requires that at least two bits in the RTC module prescaler are reserved by the correction logic. As a result of this implementation, frequency correction is only available when the RTC is running from a 1Hz reference clock.

The correction procedure is implemented by subtracting or adding a single cycle from the RTC prescaler every 1024 RTC Generic Clock (GCLK) cycles. The adjustment is applied the specified number of time (maximum 127) over 976 of these periods. The corresponding correction in parts per million (PPM) will be given by:

$$Correction(PPM) = \frac{VALUE}{999424}10^6$$

The RTC clock will tick faster if provided with a positive correction value, and slower when given a negative correction value.

16.2.5. RTC Tamper Detect

See RTC Tamper Detect.

16.3. Special Considerations

16.3.1. Year Limit

The RTC module has a year range of 63 years from the starting year configured when the module is initialized. Dates outside the start to end year range described below will need software adjustment:

$$[YEAR_{START}, YEAR_{START} + 64]$$

16.3.2. Clock Setup

16.3.2.1. SAM D20/D21/R21/D10/D11/DA1 Clock Setup

The RTC is typically clocked by a specialized GCLK generator that has a smaller prescaler than the others. By default the RTC clock is on, selected to use the internal 32KHz Resistor/Capacitor (RC)-oscillator with a prescaler of 32, giving a resulting clock frequency of 1024Hz to the RTC. When the internal RTC prescaler is set to 1024, this yields an end-frequency of 1Hz for correct time keeping operations.

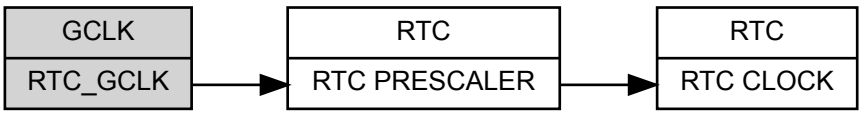
The implementer also has the option to set other end-frequencies. Table 16-2 lists the available RTC frequencies for each possible GCLK and RTC input prescaler options.

Table 16-2. RTC Output Frequencies from Allowable Input Clocks

End-frequency	GCLK prescaler	RTC prescaler
32KHz	1	1
1KHz	32	1
1Hz	32	1024

The overall RTC module clocking scheme is shown in Figure 16-1.

Figure 16-1. SAM D20/D21/R21/D10/D11/DA1 Clock Setup



Note: For the calendar to operate correctly, an asynchronous clock of 1Hz should be used.

16.3.2.2. SAM L21/C20/C21/R30 Clock Setup

The RTC clock can be selected from OSC32K, XOSC32K, or OSCULP32K. A 32KHz or 1KHz oscillator clock frequency is required. This clock must be configured and enabled in the 32KHz oscillator controller before using the RTC.

Table 16-3 lists the available RTC clock.

Table 16-3. RTC Clocks Source

RTC clock frequency	Clock source	Description
1.024kHz	ULP1K	1.024kHz from 32KHz internal ULP oscillator
32.768kHz	ULP32K	32.768kHz from 32KHz internal ULP oscillator
1.024kHz	OSC1K	1.024kHz from 32KHz internal oscillator
32.768kHz	OSC32K	32.768kHz from 3KkHz internal oscillator
1.024kHz	XOSC1K	1.024kHz from 32KHz internal oscillator
32.768kHz	XOSC32K	32.768kHz from 32KHz external crystal oscillator

Note: For the calendar to operate correctly, an asynchronous clock of 1Hz should be used.

16.4. Extra Information

For extra information, see Extra Information for RTC (CAL) Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

16.5. Examples

For a list of examples related to this driver, see Examples for RTC CAL Driver.

16.6. API Overview

16.6.1. Structure Definitions

16.6.1.1. Struct rtc_calendar_alarm_time

Alarm structure containing time of the alarm and a mask to determine when the alarm will trigger.

Table 16-4. Members

Type	Name	Description
enum rtc_calendar_alarm_mask	mask	Alarm mask to determine on what precision the alarm will match
struct rtc_calendar_time	time	Alarm time

16.6.1.2. Struct rtc_calendar_config

Configuration structure for the RTC instance. This structure should be initialized using the rtc_calendar_get_config_defaults() before any user configurations are set.

Table 16-5. Members

Type	Name	Description
struct rtc_calendar_alarm_time	alarm[]	Alarm values
bool	clear_on_match	If `true`, clears the clock on alarm match
bool	clock_24h	If `true`, time is represented in 24 hour mode
enum rtc_calendar_prescaler	prescaler	Input clock prescaler for the RTC module
uint16_t	year_init_value	Initial year for counter value 0

16.6.1.3. Struct rtc_calendar_events

Event flags for the rtc_calendar_enable_events() and rtc_calendar_disable_events().

Table 16-6. Members

Type	Name	Description
bool	generate_event_on_alarm[]	Generate an output event on an alarm channel match against the RTC count
bool	generate_event_on_overflow	Generate an output event on each overflow of the RTC count
bool	generate_event_on_periodic[]	Generate an output event periodically at a binary division of the RTC counter frequency
bool	generate_event_on_tamper	Generate an output event on every tamper input
bool	on_event_to_tamper	Tamper input event and capture the CLOCK value

16.6.1.4. Struct rtc_calendar_time

Time structure containing the time given by or set to the RTC calendar. The structure uses seven values to give second, minute, hour, PM/AM, day, month, and year. It should be initialized via the rtc_calendar_get_time_defaults() function before use.

Table 16-7. Members

Type	Name	Description
uint8_t	day	Day value, where day 1 is the first day of the month
uint8_t	hour	Hour value
uint8_t	minute	Minute value
uint8_t	month	Month value, where month 1 is January
bool	pm	PM/AM value, `true` for PM, or `false` for AM
uint8_t	second	Second value
uint16_t	year	Year value

16.6.1.5. Struct rtc_tamper_config

The configuration structure for the RTC tamper. This structure should be initialized using the rtc_tamper_get_config_defaults() before any user configurations are set.

Table 16-8. Members

Type	Name	Description
enum rtc_tamper_active_layer_freq_divider	actl_freq_div	Active layer frequency
bool	bkup_reset_on_tamper	Backup register reset on tamper enable
enum rtc_tamper_debounce_freq_divider	deb_freq_div	Debounce frequency
enum rtc_tamper_debounce_seq	deb_seq	Debounce sequential

Type	Name	Description
bool	dma_tamper_enable	DMA on tamper enable
bool	gp0_enable	General Purpose 0/1 Enable
bool	gp_reset_on_tamper	GP register reset on tamper enable
struct rtc_tamper_input_config	in_cfg[]	Tamper IN configuration

16.6.1.6. Struct rtc_tamper_input_config

The configuration structure for tamper INn.

Table 16-9. Members

Type	Name	Description
enum rtc_tamper_input_action	action	Tamper input action
bool	debounce_enable	Debounce enable
enum rtc_tamper_level_sel	level	Tamper level select

16.6.2. Macro Definitions

16.6.2.1. Macro FEATURE_RTC_PERIODIC_INT

```
#define FEATURE_RTC_PERIODIC_INT
```

Define port features set according to different device familyRTC periodic interval interrupt.

16.6.2.2. Macro FEATURE_RTC_PRESCALER_OFF

```
#define FEATURE_RTC_PRESCALER_OFF
```

RTC prescaler is off.

16.6.2.3. Macro FEATURE_RTC_CLOCK_SELECTION

```
#define FEATURE_RTC_CLOCK_SELECTION
```

RTC clock selection.

16.6.2.4. Macro FEATURE_RTC_GENERAL_PURPOSE_REG

```
#define FEATURE_RTC_GENERAL_PURPOSE_REG
```

General purpose registers.

16.6.2.5. Macro FEATURE_RTC_TAMPER_DETECTION

```
#define FEATURE_RTC_TAMPER_DETECTION
```

RTC tamper detection.

16.6.2.6. Macro RTC_TAMPER_DETECT_EVT

```
#define RTC_TAMPER_DETECT_EVT
```

RTC tamper input event detection bitmask.

16.6.2.7. Macro RTC_TAMPER_DETECT_ID0

```
#define RTC_TAMPER_DETECT_ID0
```

RTC tamper ID0 detection bitmask.

16.6.2.8. Macro RTC_TAMPER_DETECT_ID1

```
#define RTC_TAMPER_DETECT_ID1
```

RTC tamper ID1 detection bitmask.

16.6.2.9. Macro RTC_TAMPER_DETECT_ID2

```
#define RTC_TAMPER_DETECT_ID2
```

RTC tamper ID2 detection bitmask.

16.6.2.10. Macro RTC_TAMPER_DETECT_ID3

```
#define RTC_TAMPER_DETECT_ID3
```

RTC tamper ID3 detection bitmask.

16.6.2.11. Macro RTC_TAMPER_DETECT_ID4

```
#define RTC_TAMPER_DETECT_ID4
```

RTC tamper ID4 detection bitmask.

16.6.3. Function Definitions

16.6.3.1. Configuration and Initialization

Function rtc_calendar_get_time_defaults()

Initialize a `time` structure.

```
void rtc_calendar_get_time_defaults(
        struct rtc_calendar_time *const time)
```

This will initialize a given time structure to the time 00:00:00 (hh:mm:ss) and date 2000-01-01 (YYYY-MM-DD).

Table 16-10. Parameters

Data direction	Parameter name	Description
[out]	time	Time structure to initialize

Function rtc_calendar_get_config_defaults()

Gets the RTC default settings.

```
void rtc_calendar_get_config_defaults(
        struct rtc_calendar_config *const config)
```

Initializes the configuration structure to the known default values. This function should be called at the start of any RTC initiation.

The default configuration is as follows:

- Input clock divided by a factor of 1024
- Clear on alarm match off
- Continuously sync clock off
- 12 hour calendar
- Start year 2000 (Year 0 in the counter will be year 2000)
- Events off
- Alarms set to January 1. 2000, 00:00:00
- Alarm will match on second, minute, hour, day, month, and year
- Clock read synchronization is enabled for SAM L22

Table 16-11. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values

Function rtc_calendar_reset()

Resets the RTC module.

```
void rtc_calendar_reset(
        struct rtc_module *const module)
```

Resets the RTC module to hardware defaults.

Table 16-12. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_enable()

Enables the RTC module.

```
void rtc_calendar_enable(
        struct rtc_module *const module)
```

Enables the RTC module once it has been configured, ready for use. Most module configuration parameters cannot be altered while the module is enabled.

Table 16-13. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_disable()

Disables the RTC module.

```
void rtc_calendar_disable(
        struct rtc_module *const module)
```

Disables the RTC module.

Table 16-14. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_init()

Initializes the RTC module with given configurations.

```
void rtc_calendar_init(
        struct rtc_module *const module,
        Rtc *const hw,
        const struct rtc_calendar_config *const config)
```

Initializes the module, setting up all given configurations to provide the desired functionality of the RTC.

Table 16-15. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the configuration structure

Function rtc_calendar_swap_time_mode()

Swaps between 12h and 24h clock mode.

```
void rtc_calendar_swap_time_mode(
        struct rtc_module *const module)
```

Swaps the current RTC time mode:

- If currently in 12h mode, it will swap to 24h
- If currently in 24h mode, it will swap to 12h

Note: This will not change setting in user's configuration structure.

Table 16-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function rtc_calendar_frequency_correction()

Calibrate for too-slow or too-fast oscillator.

```
enum status_code rtc_calendar_frequency_correction(
        struct rtc_module *const module,
        const int8_t value)
```

When used, the RTC will compensate for an inaccurate oscillator. The RTC module will add or subtract cycles from the RTC prescaler to adjust the frequency in approximately 1 PPM steps. The provided correction value should be between -127 and 127, allowing for a maximum 127 PPM correction in either direction.

If no correction is needed, set value to zero.

Note: Can only be used when the RTC is operated at 1Hz.

Table 16-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	value	Between -127 and 127 used for the correction

Returns
Status of the calibration procedure.

Table 16-18. Return Values

Return value	Description
STATUS_OK	If calibration was done correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

16.6.3.2. Time and Alarm Management

Function rtc_calendar_time_to_register_value()

Convert time structure to register_value. Retrieves register_value convert by the time structure.

```
uint32_t rtc_calendar_time_to_register_value(
        struct rtc_module *const module,
        const struct rtc_calendar_time *const time)
```

Table 16-19. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	time	Pointer to the time structure

Returns
32-bit value.

Function rtc_calendar_register_value_to_time()

Convert register_value to time structure. Retrieves the time structure convert by register_value.

```
void rtc_calendar_register_value_to_time(
        struct rtc_module *const module,
        const uint32_t register_value,
        struct rtc_calendar_time *const time)
```

Table 16-20. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	register_value	The value stored in register
[out]	time	Pointer to the time structure

Function rtc_calendar_set_time()

Set the current calendar time to desired time.

```
void rtc_calendar_set_time(
        struct rtc_module *const module,
        const struct rtc_calendar_time *const time)
```

Sets the time provided to the calendar.

Table 16-21. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	time	The time to set in the calendar

Function rtc_calendar_get_time()

Get the current calendar value.

```
void rtc_calendar_get_time(
        struct rtc_module *const module,
        struct rtc_calendar_time *const time)
```

Retrieves the current time of the calendar.

Table 16-22. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	time	Pointer to value that will be filled with current time

Function rtc_calendar_set_alarm()

Set the alarm time for the specified alarm.

```
enum status_code rtc_calendar_set_alarm(
        struct rtc_module *const module,
        const struct rtc_calendar_alarm_time *const alarm,
        const enum rtc_calendar_alarm alarm_index)
```

Sets the time and mask specified to the requested alarm.

Table 16-23. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm	The alarm struct to set the alarm with
[in]	alarm_index	The index of the alarm to set

Returns
Status of setting alarm.

Table 16-24. Return Values

Return value	Description
STATUS_OK	If alarm was set correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

Function rtc_calendar_get_alarm()

Get the current alarm time of specified alarm.

```
enum status_code rtc_calendar_get_alarm(
        struct rtc_module *const module,
        struct rtc_calendar_alarm_time *const alarm,
        const enum rtc_calendar_alarm alarm_index)
```

Retrieves the current alarm time for the alarm specified alarm.

Table 16-25. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	alarm	Pointer to the struct that will be filled with alarm time and mask of the specified alarm
[in]	alarm_index	Index of alarm to get alarm time from

Returns
Status of getting alarm.

Table 16-26. Return Values

Return value	Description
STATUS_OK	If alarm was read correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

16.6.3.3. Status Flag Management

Function rtc_calendar_is_overflow()

Check if an RTC overflow has occurred.

```
bool rtc_calendar_is_overflow(
        struct rtc_module *const module)
```

Checks the overflow flag in the RTC. The flag is set when there is an overflow in the clock.

Table 16-27. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Returns
Overflow state of the RTC module.

Table 16-28. Return Values

Return value	Description
true	If the RTC count value has overflowed
false	If the RTC count value has not overflowed

Function rtc_calendar_clear_overflow()

Clears the RTC overflow flag.

```
void rtc_calendar_clear_overflow(
        struct rtc_module *const module)
```

Table 16-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Clears the RTC module counter overflow flag, so that new overflow conditions can be detected.

Function rtc_calendar_is_periodic_interval()

Check if an RTC periodic interval interrupt has occurred.

```
bool rtc_calendar_is_periodic_interval(
        struct rtc_module *const module,
        enum rtc_calendar_periodic_interval n)
```

Checks the periodic interval flag in the RTC.

Table 16-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	n	RTC periodic interval interrupt

Returns
Periodic interval interrupt state of the RTC module.

Table 16-31. Return Values

Return value	Description
true	RTC periodic interval interrupt occur
false	RTC periodic interval interrupt doesn't occur

Function rtc_calendar_clear_periodic_interval()

Clears the RTC periodic interval flag.

```
void rtc_calendar_clear_periodic_interval(
        struct rtc_module *const module,
        enum rtc_calendar_periodic_interval n)
```

Clears the RTC module counter periodic interval flag, so that new periodic interval conditions can be detected.

Table 16-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	RTC hardware module
[in]	n	RTC periodic interval interrupt

Function rtc_calendar_is_alarm_match()

Check the RTC alarm flag.

```
bool rtc_calendar_is_alarm_match(
        struct rtc_module *const module,
        const enum rtc_calendar_alarm alarm_index)
```

Check if the specified alarm flag is set. The flag is set when there is a compare match between the alarm value and the clock.

Table 16-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm_index	Index of the alarm to check

Returns
Match status of the specified alarm.

Table 16-34. Return Values

Return value	Description
true	If the specified alarm has matched the current time
false	If the specified alarm has not matched the current time

Function rtc_calendar_clear_alarm_match()

Clears the RTC alarm match flag.

```
enum status_code rtc_calendar_clear_alarm_match(
        struct rtc_module *const module,
        const enum rtc_calendar_alarm alarm_index)
```

Clear the requested alarm match flag, so that future alarm matches can be determined.

Table 16-35. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	alarm_index	The index of the alarm match to clear

Returns
Status of the alarm match clear operation.

Table 16-36. Return Values

Return value	Description
STATUS_OK	If flag was cleared correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

16.6.3.4. Event Management

Function rtc_calendar_enable_events()

Enables an RTC event output.

```
void rtc_calendar_enable_events(
        struct rtc_module *const module,
        struct rtc_calendar_events *const events)
```

Enables one or more output events from the RTC module. See rtc_calendar_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 16-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	events	Struct containing flags of events to enable

Function rtc_calendar_disable_events()

Disables an RTC event output.

```
void rtc_calendar_disable_events(
        struct rtc_module *const module,
        struct rtc_calendar_events *const events)
```

Disabled one or more output events from the RTC module. See rtc_calendar_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 16-38. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	events	Struct containing flags of events to disable

16.6.3.5. RTC General Purpose Registers

Function rtc_write_general_purpose_reg()

Write a value into general purpose register.

```
void rtc_write_general_purpose_reg(
        struct rtc_module *const module,
        const uint8_t index,
        uint32_t value)
```

Table 16-39. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	n	General purpose type
[in]	index	General purpose register index (0..3)

Function rtc_read_general_purpose_reg()

Read the value from general purpose register.

```
uint32_t rtc_read_general_purpose_reg(
        struct rtc_module *const module,
        const uint8_t index)
```

Table 16-40. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	index	General purpose register index (0..3)

Returns
Value of general purpose register.

16.6.3.6. Callbacks

Function rtc_calendar_register_callback()

Registers callback for the specified callback type.

```
enum status_code rtc_calendar_register_callback(
        struct rtc_module *const module,
        rtc_calendar_callback_t callback,
        enum rtc_calendar_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the rtc_calendar_enable_callback function must be used.

Table 16-41. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Returns
Status of registering callback.

Table 16-42. Return Values

Return value	Description
STATUS_OK	Registering was done successfully
STATUS_ERR_INVALID_ARG	If trying to register, a callback is not available

Function rtc_calendar_unregister_callback()

Unregisters callback for the specified callback type.

```
enum status_code rtc_calendar_unregister_callback(
        struct rtc_module *const module,
        enum rtc_calendar_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 16-43. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Specifies the callback type to unregister

Returns
Status of unregistering callback.

Table 16-44. Return Values

Return value	Description
STATUS_OK	Unregistering was done successfully
STATUS_ERR_INVALID_ARG	If trying to unregister, a callback is not available

Function rtc_calendar_enable_callback()

Enables callback.

```
void rtc_calendar_enable_callback(
        struct rtc_module *const module,
        enum rtc_calendar_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 16-45. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to enable

Function rtc_calendar_disable_callback()

Disables callback.

```
void rtc_calendar_disable_callback(
        struct rtc_module *const module,
        enum rtc_calendar_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 16-46. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[in]	callback_type	Callback type to disable

16.6.3.7. RTC Tamper Detection

Function rtc_tamper_get_config_defaults()

Gets the RTC tamper default configurations.

```
void rtc_tamper_get_config_defaults(
        struct rtc_tamper_config *const config)
```

Initializes the configuration structure to default values.

The default configuration is as follows:

- Disable backup register reset on tamper
- Disable GP register reset on tamper
- Active layer clock divided by a factor of 8
- Debounce clock divided by a factor of 8
- Detect edge on INn with synchronous stability debouncing
- Disable DMA on tamper
- Enable GP register
- Disable debouce, detect on falling edge and no action on INn

Table 16-47. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to be initialized to default values.

Function rtc_tamper_set_config()

```
enum status_code rtc_tamper_set_config(
        struct rtc_module *const module,
        struct rtc_tamper_config *const tamper_cfg)
```

Function rtc_tamper_get_detect_flag()

Retrieves the RTC tamper detection status.

```
uint32_t rtc_tamper_get_detect_flag(
        struct rtc_module *const module)
```

Retrieves the detection status of each input pin and the input event.

Table 16-48. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the RTC software instance struct

Returns
Bitmask of detection flags.

Table 16-49. Return Values

Return value	Description
RTC_TAMPER_DETECT_ID0	Tamper condition on IN0 has been detected
RTC_TAMPER_DETECT_ID1	Tamper condition on IN1 has been detected
RTC_TAMPER_DETECT_ID2	Tamper condition on IN2 has been detected
RTC_TAMPER_DETECT_ID3	Tamper condition on IN3 has been detected
RTC_TAMPER_DETECT_ID4	Tamper condition on IN4 has been detected
RTC_TAMPER_DETECT_EVT	Tamper input event has been detected

Function rtc_tamper_clear_detect_flag()

Clears RTC tamper detection flag.

```
void rtc_tamper_clear_detect_flag(
        struct rtc_module *const module,
        const uint32_t detect_flags)
```

Clears the given detection flag of the module.

Table 16-50. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the TC software instance struct
[in]	detect_flags	Bitmask of detection flags

16.6.3.8. Function rtc_tamper_get_stamp()

Get the tamper stamp value.

```
void rtc_tamper_get_stamp(
        struct rtc_module *const module,
        struct rtc_calendar_time *const time)
```

Table 16-51. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct
[out]	time	Pointer to value that filled with tamper stamp time

16.6.4. Enumeration Definitions

16.6.4.1. Enum rtc_calendar_alarm

Available alarm channels.

Note: Not all alarm channels are available on all devices.

Table 16-52. Members

Enum value	Description
RTC_CALENDAR_ALARM_0	Alarm channel 0
RTC_CALENDAR_ALARM_1	Alarm channel 1
RTC_CALENDAR_ALARM_2	Alarm channel 2
RTC_CALENDAR_ALARM_3	Alarm channel 3

16.6.4.2. Enum rtc_calendar_alarm_mask

Available mask options for alarms.

Table 16-53. Members

Enum value	Description
RTC_CALENDAR_ALARM_MASK_DISABLED	Alarm disabled
RTC_CALENDAR_ALARM_MASK_SEC	Alarm match on second
RTC_CALENDAR_ALARM_MASK_MIN	Alarm match on second and minute
RTC_CALENDAR_ALARM_MASK_HOUR	Alarm match on second, minute, and hour
RTC_CALENDAR_ALARM_MASK_DAY	Alarm match on second, minute, hour, and day
RTC_CALENDAR_ALARM_MASK_MONTH	Alarm match on second, minute, hour, day, and month
RTC_CALENDAR_ALARM_MASK_YEAR	Alarm match on second, minute, hour, day, month, and year

16.6.4.3. Enum rtc_calendar_callback

The available callback types for the RTC calendar module.

Table 16-54. Members

Enum value	Description
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_0	Callback for Periodic Interval 0 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_1	Callback for Periodic Interval 1 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_2	Callback for Periodic Interval 2 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_3	Callback for Periodic Interval 3 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_4	Callback for Periodic Interval 4 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_5	Callback for Periodic Interval 5 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_6	Callback for Periodic Interval 6 Interrupt
RTC_CALENDAR_CALLBACK_PERIODIC_INTERVAL_7	Callback for Periodic Interval 7 Interrupt
RTC_CALENDAR_CALLBACK_ALARM_0	Callback for alarm 0
RTC_CALENDAR_CALLBACK_ALARM_1	Callback for alarm 1
RTC_CALENDAR_CALLBACK_ALARM_2	Callback for alarm 2
RTC_CALENDAR_CALLBACK_ALARM_3	Callback for alarm 3
RTC_CALENDAR_CALLBACK_TAMPER	Callback for tamper
RTC_CALENDAR_CALLBACK_OVERFLOW	Callback for overflow

16.6.4.4. Enum rtc_calendar_periodic_interval

Table 16-55. Members

Enum value	Description
RTC_CALENDAR_PERIODIC_INTERVAL_0	Periodic interval 0
RTC_CALENDAR_PERIODIC_INTERVAL_1	Periodic interval 1
RTC_CALENDAR_PERIODIC_INTERVAL_2	Periodic interval 2
RTC_CALENDAR_PERIODIC_INTERVAL_3	Periodic interval 3
RTC_CALENDAR_PERIODIC_INTERVAL_4	Periodic interval 4
RTC_CALENDAR_PERIODIC_INTERVAL_5	Periodic interval 5
RTC_CALENDAR_PERIODIC_INTERVAL_6	Periodic interval 6
RTC_CALENDAR_PERIODIC_INTERVAL_7	Periodic interval 7

16.6.4.5. Enum rtc_calendar_prescaler

The available input clock prescaler values for the RTC calendar module.

Table 16-56. Members

Enum value	Description
RTC_CALENDAR_PRESCALER_OFF	RTC prescaler is off, and the input clock frequency is prescaled by a factor of 1
RTC_CALENDAR_PRESCALER_DIV_1	RTC input clock frequency is prescaled by a factor of 1
RTC_CALENDAR_PRESCALER_DIV_2	RTC input clock frequency is prescaled by a factor of 2
RTC_CALENDAR_PRESCALER_DIV_4	RTC input clock frequency is prescaled by a factor of 4
RTC_CALENDAR_PRESCALER_DIV_8	RTC input clock frequency is prescaled by a factor of 8
RTC_CALENDAR_PRESCALER_DIV_16	RTC input clock frequency is prescaled by a factor of 16
RTC_CALENDAR_PRESCALER_DIV_32	RTC input clock frequency is prescaled by a factor of 32
RTC_CALENDAR_PRESCALER_DIV_64	RTC input clock frequency is prescaled by a factor of 64
RTC_CALENDAR_PRESCALER_DIV_128	RTC input clock frequency is prescaled by a factor of 128
RTC_CALENDAR_PRESCALER_DIV_256	RTC input clock frequency is prescaled by a factor of 256
RTC_CALENDAR_PRESCALER_DIV_512	RTC input clock frequency is prescaled by a factor of 512
RTC_CALENDAR_PRESCALER_DIV_1024	RTC input clock frequency is prescaled by a factor of 1024

16.6.4.6. Enum rtc_clock_sel

Table 16-57. Members

Enum value	Description
RTC_CLOCK_SELECTION_ULP1K	1.024kHz from 32KHz internal ULP oscillator
RTC_CLOCK_SELECTION_ULP32K	32.768kHz from 32KHz internal ULP oscillator
RTC_CLOCK_SELECTION_OSC1K	1.024kHz from 32KHz internal oscillator
RTC_CLOCK_SELECTION_OSC32K	32.768kHz from 32KHz internal oscillator
RTC_CLOCK_SELECTION_XOSC1K	1.024kHz from 32KHz internal oscillator
RTC_CLOCK_SELECTION_XOSC32K	32.768kHz from 32.768kHz external crystal oscillator

16.6.4.7. Enum rtc_tamper_active_layer_freq_divider

The available prescaler factor for the RTC clock output used during active layer protection.

Table 16-58. Members

Enum value	Description
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_2	RTC active layer frequency is prescaled by a factor of 2
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_4	RTC active layer frequency is prescaled by a factor of 4
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_8	RTC active layer frequency is prescaled by a factor of 8
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_16	RTC active layer frequency is prescaled by a factor of 16
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_32	RTC active layer frequency is prescaled by a factor of 32
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_64	RTC active layer frequency is prescaled by a factor of 64
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_128	RTC active layer frequency is prescaled by a factor of 128
RTC_TAMPER_ACTIVE_LAYER_FREQ_DIV_256	RTC active layer frequency is prescaled by a factor of 256

16.6.4.8. Enum rtc_tamper_debounce_freq_divider

The available prescaler factor for the input debouncers.

Table 16-59. Members

Enum value	Description
RTC_TAMPER_DEBOUNCE_FREQ_DIV_2	RTC debounce frequency is prescaled by a factor of 2
RTC_TAMPER_DEBOUNCE_FREQ_DIV_4	RTC debounce frequency is prescaled by a factor of 4
RTC_TAMPER_DEBOUNCE_FREQ_DIV_8	RTC debounce frequency is prescaled by a factor of 8
RTC_TAMPER_DEBOUNCE_FREQ_DIV_16	RTC debounce frequency is prescaled by a factor of 16
RTC_TAMPER_DEBOUNCE_FREQ_DIV_32	RTC debounce frequency is prescaled by a factor of 32
RTC_TAMPER_DEBOUNCE_FREQ_DIV_64	RTC debounce frequency is prescaled by a factor of 64
RTC_TAMPER_DEBOUNCE_FREQ_DIV_128	RTC debounce frequency is prescaled by a factor of 128
RTC_TAMPER_DEBOUNCE_FREQ_DIV_256	RTC debounce frequency is prescaled by a factor of 256

16.6.4.9. Enum rtc_tamper_debounce_seq

The available sequential for tamper debounce.

Table 16-60. Members

Enum value	Description
RTC_TAMPER_DEBOUNCE_SYNC	Tamper input detect edge with synchronous stability debounce
RTC_TAMPER_DEBOUNCE_ASYNC	Tamper input detect edge with asynchronous stability debounce
RTC_TAMPER_DEBOUNCE_MAJORITY	Tamper input detect edge with majority debounce

16.6.4.10. Enum rtc_tamper_input_action

The available action taken by the tamper input.

Table 16-61. Members

Enum value	Description
RTC_TAMPER_INPUT_ACTION_OFF	RTC tamper input action is disabled
RTC_TAMPER_INPUT_ACTION_WAKE	RTC tamper input action is wake and set tamper flag
RTC_TAMPER_INPUT_ACTION_CAPTURE	RTC tamper input action is capture timestamp and set tamper flag
RTC_TAMPER_INPUT_ACTION_ACTL	RTC tamper input action is compare IN to OUT, when a mismatch occurs, capture timestamp and set tamper flag

16.6.4.11. Enum rtc_tamper_level_sel

The available edge condition for tamper INn level select.

Table 16-62. Members

Enum value	Description
RTC_TAMPER_LEVEL_FALLING	A falling edge condition will be detected on Tamper input
RTC_TAMPER_LEVEL_RISING	A rising edge condition will be detected on Tamper input

16.7. RTC Tamper Detect

The RTC provides several selectable polarity external inputs (INn) that can be used for tamper detection. When detect, tamper inputs support the four actions:

- Off
- Wake
- Capture
- Active layer protection

Note: The Active Layer Protection is a means of detecting broken traces on the PCB provided by RTC. In this mode an RTC output signal is routed over critical components on the board and fed back to one of the RTC inputs. The input and output signals are compared and a tamper condition is detected when they do not match.

Separate debouncers are embedded for each external input. The detection time depends on whether the debouncer operates synchronously or asynchronously, and whether majority detection is enabled or not. For details, refer to the section "Tamper Detection" of datasheet.

16.8. Extra Information for RTC (CAL) Driver

16.8.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
RTC	Real Time Counter
PPM	Part Per Million
RC	Resistor/Capacitor

16.8.2. Dependencies

This driver has the following dependencies:

- None

16.8.3. Errata

There are no errata related to this driver.

16.8.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for RTC tamper feature
Added driver instance parameter to all API function calls, except get_config_defaults
Updated initialization function to also enable the digital interface clock to the module if it is disabled
Initial release

16.9. Examples for RTC CAL Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM RTC Calendar (RTC CAL) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for RTC (CAL) - Basic
- Quick Start Guide for RTC (CAL) - Callback

16.9.1. Quick Start Guide for RTC (CAL) - Basic

In this use case, the RTC is set up in calendar mode. The time is set and also an alarm is set to show a general use of the RTC in calendar mode. Also the clock is swapped from 24h to 12h mode after initialization. The board LED will be toggled once the current time matches the set time.

16.9.1.1. Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                 true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME           SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT    true
#  define CONF_CLOCK_OSC32K_ON_DEMAND              true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY         false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                 true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY         false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE
SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER              32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE          false
```

16.9.1.2. Setup

Initialization Code

Create an rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

Copy-paste the following setup code to your application:

```
void configure_rtc_calendar(void)
{
    /* Initialize RTC in calendar mode. */
    struct rtc_calendar_config config_rtc_calendar;
    rtc_calendar_get_config_defaults(&config_rtc_calendar);

    struct rtc_calendar_time alarm;
    rtc_calendar_get_time_defaults(&alarm);
    alarm.year   = 2013;
    alarm.month  = 1;
    alarm.day    = 1;
    alarm.hour   = 0;
    alarm.minute = 0;
    alarm.second = 4;

    config_rtc_calendar.clock_24h     = true;
    config_rtc_calendar.alarm[0].time = alarm;
    config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;
```

```
    rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);

    rtc_calendar_enable(&rtc_instance);
}
```

Add to Main

Add the following to `main()`.

```
system_init();

struct rtc_calendar_time time;
time.year   = 2012;
time.month  = 12;
time.day    = 31;
time.hour   = 23;
time.minute = 59;
time.second = 59;

configure_rtc_calendar();

/* Set current time. */
rtc_calendar_set_time(&rtc_instance, &time);

rtc_calendar_swap_time_mode(&rtc_instance);
```

Workflow

1. Make configuration structure.

   ```
   struct rtc_calendar_config config_rtc_calendar;
   ```

2. Fill the configuration structure with the default driver configuration.

   ```
   rtc_calendar_get_config_defaults(&config_rtc_calendar);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Make time structure for alarm and set with default and desired values.

   ```
   struct rtc_calendar_time alarm;
   rtc_calendar_get_time_defaults(&alarm);
   alarm.year   = 2013;
   alarm.month  = 1;
   alarm.day    = 1;
   alarm.hour   = 0;
   alarm.minute = 0;
   alarm.second = 4;
   ```

4. Change configurations as desired.

   ```
   config_rtc_calendar.clock_24h     = true;
   config_rtc_calendar.alarm[0].time = alarm;
   config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;
   ```

5. Initialize module.

   ```
   rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);
   ```

6. Enable module.

   ```
   rtc_calendar_enable(&rtc_instance);
   ```

16.9.1.3. Implementation

Add the following to `main()`.

```
while (true) {
    if (rtc_calendar_is_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0)) {
        /* Do something on RTC alarm match here */
        port_pin_toggle_output_level(LED_0_PIN);

        rtc_calendar_clear_alarm_match(&rtc_instance,
RTC_CALENDAR_ALARM_0);
    }
}
```

Workflow

1. Start an infinite loop, to continuously poll for a RTC alarm match.

   ```
   while (true) {
   ```

2. Check to see if a RTC alarm match has occurred.

   ```
   if (rtc_calendar_is_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0)) {
   ```

3. Once an alarm match occurs, perform the desired user action.

   ```
   /* Do something on RTC alarm match here */
   port_pin_toggle_output_level(LED_0_PIN);
   ```

4. Clear the alarm match, so that future alarms may occur.

   ```
   rtc_calendar_clear_alarm_match(&rtc_instance, RTC_CALENDAR_ALARM_0);
   ```

16.9.2. Quick Start Guide for RTC (CAL) - Callback

In this use case, the RTC is set up in calendar mode. The time is set and an alarm is enabled, as well as a callback for when the alarm time is hit. Each time the callback fires, the alarm time is reset to five seconds in the future and the board LED toggled.

16.9.2.1. Prerequisites

The Generic Clock Generator for the RTC should be configured and enabled; if you are using the System Clock driver, this may be done via `conf_clocks.h`.

Clocks and Oscillators

The `conf_clock.h` file needs to be changed with the following values to configure the clocks and oscillators for the module.

The following oscillator settings are needed:

```
/* SYSTEM_CLOCK_SOURCE_OSC32K configuration - Internal 32KHz oscillator */
#  define CONF_CLOCK_OSC32K_ENABLE                  true
#  define CONF_CLOCK_OSC32K_STARTUP_TIME            SYSTEM_OSC32K_STARTUP_130
#  define CONF_CLOCK_OSC32K_ENABLE_1KHZ_OUTPUT      true
#  define CONF_CLOCK_OSC32K_ENABLE_32KHZ_OUTPUT     true
#  define CONF_CLOCK_OSC32K_ON_DEMAND               true
#  define CONF_CLOCK_OSC32K_RUN_IN_STANDBY          false
```

The following generic clock settings are needed:

```
/* Configure GCLK generator 2 (RTC) */
#  define CONF_CLOCK_GCLK_2_ENABLE                  true
#  define CONF_CLOCK_GCLK_2_RUN_IN_STANDBY          false
#  define CONF_CLOCK_GCLK_2_CLOCK_SOURCE
```

```
SYSTEM_CLOCK_SOURCE_OSC32K
#  define CONF_CLOCK_GCLK_2_PRESCALER             32
#  define CONF_CLOCK_GCLK_2_OUTPUT_ENABLE         false
```

16.9.2.2. Setup

Code

Create an rtc_module struct and add to the main application source file, outside of any functions:

```
struct rtc_module rtc_instance;
```

The following must be added to the user application:

Function for setting up the module:

```
void configure_rtc_calendar(void)
{
    /* Initialize RTC in calendar mode. */
    struct rtc_calendar_config config_rtc_calendar;
    rtc_calendar_get_config_defaults(&config_rtc_calendar);

    alarm.time.year      = 2013;
    alarm.time.month     = 1;
    alarm.time.day       = 1;
    alarm.time.hour      = 0;
    alarm.time.minute    = 0;
    alarm.time.second    = 4;

    config_rtc_calendar.clock_24h = true;
    config_rtc_calendar.alarm[0].time = alarm.time;
    config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;

    rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);

    rtc_calendar_enable(&rtc_instance);
}
```

Callback function:

```
void rtc_match_callback(void)
{
    /* Do something on RTC alarm match here */
    port_pin_toggle_output_level(LED_0_PIN);

    /* Set new alarm in 5 seconds */
    alarm.mask = RTC_CALENDAR_ALARM_MASK_SEC;

    alarm.time.second += 5;
    alarm.time.second = alarm.time.second % 60;

    rtc_calendar_set_alarm(&rtc_instance, &alarm, RTC_CALENDAR_ALARM_0);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_rtc_callbacks(void)
{
    rtc_calendar_register_callback(
            &rtc_instance, rtc_match_callback,
RTC_CALENDAR_CALLBACK_ALARM_0);
    rtc_calendar_enable_callback(&rtc_instance,
RTC_CALENDAR_CALLBACK_ALARM_0);
}
```

Add to user application `main()`:

```
system_init();

struct rtc_calendar_time time;
rtc_calendar_get_time_defaults(&time);
time.year   = 2012;
time.month  = 12;
time.day    = 31;
time.hour   = 23;
time.minute = 59;
time.second = 59;

/* Configure and enable RTC */
configure_rtc_calendar();

/* Configure and enable callback */
configure_rtc_callbacks();

/* Set current time. */
rtc_calendar_set_time(&rtc_instance, &time);
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Create and initialize a time structure.

   ```
   struct rtc_calendar_time time;
   rtc_calendar_get_time_defaults(&time);
   time.year   = 2012;
   time.month  = 12;
   time.day    = 31;
   time.hour   = 23;
   time.minute = 59;
   time.second = 59;
   ```

3. Configure and enable module.

   ```
   configure_rtc_calendar();
   ```

   1. Create an RTC configuration structure to hold the desired RTC driver settings and fill it with the default driver configuration values.

      ```
      struct rtc_calendar_config config_rtc_calendar;
      rtc_calendar_get_config_defaults(&config_rtc_calendar);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   2. Create and initialize an alarm.

      ```
      alarm.time.year      = 2013;
      alarm.time.month     = 1;
      alarm.time.day       = 1;
      alarm.time.hour      = 0;
      alarm.time.minute    = 0;
      alarm.time.second    = 4;
      ```

3. Change settings in the configuration and set alarm.

```
config_rtc_calendar.clock_24h = true;
config_rtc_calendar.alarm[0].time = alarm.time;
config_rtc_calendar.alarm[0].mask = RTC_CALENDAR_ALARM_MASK_YEAR;
```

4. Initialize the module with the set configurations.

```
rtc_calendar_init(&rtc_instance, RTC, &config_rtc_calendar);
```

5. Enable the module.

```
rtc_calendar_enable(&rtc_instance);
```

4. Configure callback functionality.

```
configure_rtc_callbacks();
```

1. Register overflow callback.

```
rtc_calendar_register_callback(
        &rtc_instance, rtc_match_callback,
RTC_CALENDAR_CALLBACK_ALARM_0);
```

2. Enable overflow callback.

```
rtc_calendar_enable_callback(&rtc_instance,
RTC_CALENDAR_CALLBACK_ALARM_0);
```

5. Set time of the RTC calendar.

```
rtc_calendar_set_time(&rtc_instance, &time);
```

16.9.2.3. Implementation

Code

Add to user application main:

```
while (true) {
     /* Infinite loop */
}
```

Workflow

1. Infinite while loop while waiting for callbacks.

```
while (true) {
```

16.9.2.4. Callback

Each time the RTC time matches the configured alarm, the callback function will be called.

Workflow

1. Create alarm struct and initialize the time with current time.

```
struct rtc_calendar_alarm_time alarm;
```

2. Set alarm to trigger on seconds only.

```
alarm.mask = RTC_CALENDAR_ALARM_MASK_SEC;
```

3. Add one second to the current time and set new alarm.

```
alarm.time.second += 5;
alarm.time.second = alarm.time.second % 60;
```

```
rtc_calendar_set_alarm(&rtc_instance, &alarm, RTC_CALENDAR_ALARM_0);
```

17. SAM Sigma-Delta Analog-to-Digital Converter (SDADC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's SDADC functionality.

The following peripheral is used by this module:

- SDADC (Sigma-Delta Analog-to-Digital Converter)

The following devices can use this module:

- Atmel | SMART SAM C21

The outline of this documentation is as follows:

17.1. Prerequisites

There are no prerequisites for this module.

17.2. Module Overview

The Sigma-Delta Analog-to-Digital Converter (SDADC) converts analog signals to digital values. The sigma-delta architecture of the SDADC implies a filtering and a decimation of the bitstream at the output of the SDADC. The input selection is up to three input analog channels.

The SDADC provides up to 16-bit resolution at about 1000 samples per second (1KSPS) and sized 24 bits signed result to handle filtering and gain correction without overflow. The SDADC measurements can be started by either application software or an incoming event from another peripheral in the device.

The conversion is performed on a full range between 0V and the reference voltage. Both internal and external reference voltages can be selected. The reference range must be set to match the voltage of the reference used. Analog inputs between these voltages convert to values based on a linear conversion.

17.2.1. Sample Clock

A generic clock (GCLK_SDADC) is required to generate the CLK_SDADC to the SDADC module. The SDADC features a prescaler, which enables conversion at lower clock rates than the input Generic Clock to the SDADC module.

The SDADC data sampling frequency (CLK_SDADC_FS) in the SDADC module is the CLK_SDADC/4, the reduction comes from the phase generator between the prescaler and the SDADC.

OSR is the Over Sampling Ratio, which can be modified to change the output data rate. The conversion time depends on the selected OSR and the sampling frequency of the SDADC. The conversion time can be described with:

$$t_{SAMPLE} = \frac{22 + 3 \times OSR}{CLK\_SDADC\_FS}$$

1. Initialization of the SDADC (22 sigma-delta samples).
2. Filling of the decimation filter (3*OSR sigma-delta samples).

17.2.2. Gain and Offset Correction

A specific offset, gain, and shift can be applied to each source of the SDADC by performing the following operation:

$$Data = \left(Data_0 + OFFSET\right) \times \frac{GAIN}{2^{SHIFT}}$$

17.2.3. Window Monitor

The SDADC module window monitor function can be used to automatically compare the conversion result against a predefined pair of upper and lower threshold values.

17.2.4. Events

Event generation and event actions are configurable in the SDADC.

The SDADC has two actions that can be triggered upon event reception:

- Start conversion
- Conversion flush

The SDADC can generate two kinds of events:

- Window monitor
- Result ready

If the event actions are enabled in the configuration, any incoming event will trigger the action.

If the window monitor event is enabled, an event will be generated when the configured window condition is detected.

If the result ready event is enabled, an event will be generated when a conversion is completed.

17.3. Special Considerations

There are no special considerations for this module.

17.4. Extra Information

For extra information see Extra Information for SDADC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

17.5. Examples

For a list of examples related to this driver, see Examples for SDADC Driver.

17.6. API Overview

17.6.1. Variable and Type Definitions

17.6.1.1. Type sdadc_callback_t

```
typedef void(* sdadc_callback_t )(const struct sdadc_module *const module)
```

Type of the callback functions.

17.6.2. Structure Definitions

17.6.2.1. Struct sdadc_config

Configuration structure for an SDADC instance. This structure should be initialized by the sdadc_get_config_defaults() function before being modified by the user application.

Table 17-1. Members

Type	Name	Description
uint8_t	clock_prescaler	Clock prescaler
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
struct sdadc_correction_config	correction	Gain and offset correction configuration structure
enum sdadc_event_action	event_action	Event action to take on incoming event
bool	freerunning	Enables free running mode if true
enum sdadc_mux_input	mux_input	MUX input
bool	on_command	Enables SDADC depend on other peripheral if true
enum sdadc_over_sampling_ratio	osr	Over sampling ratio
struct sdadc_reference	reference	Voltage reference
bool	run_in_standby	Enables SDADC in standby sleep mode if true
bool	seq_enable[]	Enables positive input in the sequence if true
uint8_t	skip_count	Skip Count
struct sdadc_window_config	window	Window monitor configuration structure

17.6.2.2. Struct sdadc_correction_config

Offset, gain, and shift correction configuration structure. Part of the sdadc_config struct will be initialized by sdadc_get_config_defaults.

Table 17-2. Members

Type	Name	Description
uint16_t	gain_correction	Gain correction
int32_t	offset_correction	Offset correction
uint8_t	shift_correction	Shift correction

17.6.2.3. Struct sdadc_events

Event flags for the SDADC module. This is used to enable and disable events via sdadc_enable_events() and sdadc_disable_events().

Table 17-3. Members

Type	Name	Description
bool	generate_event_on_conversion_done	Enable event generation on conversion done
bool	generate_event_on_window_monitor	Enable event generation on window monitor

17.6.2.4. Struct sdadc_module

SDADC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

17.6.2.5. Struct sdadc_reference

Reference configuration structure.

Table 17-4. Members

Type	Name	Description
bool	on_ref_buffer	Reference buffer turning switch
enum sdadc_reference_select	ref_range	Reference voltage range
enum sdadc_reference_select	ref_sel	Reference voltage selection

17.6.2.6. Struct sdadc_window_config

Window monitor configuration structure.

Table 17-5. Members

Type	Name	Description
int32_t	window_lower_value	Lower window value
enum sdadc_window_mode	window_mode	Selected window mode
int32_t	window_upper_value	Upper window value

17.6.3. Macro Definitions

17.6.3.1. Module Status Flags

SDADC status flags, returned by sdadc_get_status() and cleared by sdadc_clear_status().

Macro SDADC_STATUS_RESULT_READY

```
#define SDADC_STATUS_RESULT_READY
```

SDADC result ready.

Macro SDADC_STATUS_OVERRUN

```
#define SDADC_STATUS_OVERRUN
```

SDADC result overwritten before read.

Macro SDADC_STATUS_WINDOW

```
#define SDADC_STATUS_WINDOW
```

Window monitor match.

17.6.4. Function Definitions

17.6.4.1. Driver Initialization and Configuration

Function sdadc_init()

Initializes the SDADC.

```
enum status_code sdadc_init(
        struct sdadc_module *const module_inst,
        Sdadc * hw,
        struct sdadc_config * config)
```

Initializes the SDADC device struct and the hardware module based on the given configuration struct values.

Table 17-6. Parameters

Data direction	Parameter name	Description
[out]	module_inst	Pointer to the SDADC software instance struct
[in]	hw	Pointer to the SDADC module instance
[in]	config	Pointer to the configuration struct

Returns

Status of the initialization procedure.

Table 17-7. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_ERR_INVALID_ARG	Invalid argument(s) were provided

Return value	Description
STATUS_BUSY	The module is busy with a reset operation
STATUS_ERR_DENIED	The module is enabled

Function sdadc_get_config_defaults()

Initializes an SDADC configuration structure to defaults.

```
void sdadc_get_config_defaults(
        struct sdadc_config *const config)
```

Initializes a given SDADC configuration struct to a set of known default values. This function should be called on any new instance of the configuration struct before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- Positive reference 1
- Div 2 clock prescaler
- Over Sampling Ratio is 64
- Skip 0 samples
- MUX input on SDADC AIN1
- All events (input and generation) disabled
- Free running disabled
- Run in standby disabled
- On command disabled
- Disable all positive input in sequence
- Window monitor disabled
- No gain/offset/shift correction

Table 17-8. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration struct to initialize to default values

17.6.4.2. Status Management

Function sdadc_get_status()

Retrieves the current module status.

```
uint32_t sdadc_get_status(
        struct sdadc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 17-9. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Returns
Bitmask of `SDADC_STATUS_*` flags.

Table 17-10. Return Values

Return value	Description
SDADC_STATUS_RESULT_READY	SDADC result is ready to be read
SDADC_STATUS_WINDOW	SDADC has detected a value inside the set window range
SDADC_STATUS_OVERRUN	SDADC result has overrun

Function sdadc_clear_status()

Clears a module status flag.

```
void sdadc_clear_status(
        struct sdadc_module *const module_inst,
        const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 17-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	status_flags	Bitmask of `SDADC_STATUS_*` flags to clear

Function sdadc_get_sequence_status()

Get a module sequence flag.

```
bool sdadc_get_sequence_status(
        struct sdadc_module *const module_inst,
        uint8_t * seq_state)
```

Get the given status flag of the module.

Table 17-12. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[out]	seq_state	Identifies the last conversion done in the sequence

Returns
Status of the SDADC sequence conversion.

Table 17-13. Return Values

Return value	Description
true	When the sequence start
false	When the last conversion in a sequence is done

17.6.4.3. Enable, Disable, and Reset SDADC Module, Start Conversion and Read Result

Function sdadc_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool sdadc_is_syncing(
        struct sdadc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 17-14. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 17-15. Return Values

Return value	Description
true	If the module synchronization is ongoing
false	If the module has completed synchronization

Function sdadc_enable()

Enables the SDADC module.

```
enum status_code sdadc_enable(
        struct sdadc_module *const module_inst)
```

Enables an SDADC module that has previously been configured. If any internal reference is selected it will be enabled.

Table 17-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Function sdadc_disable()

Disables the SDADC module.

```
enum status_code sdadc_disable(
        struct sdadc_module *const module_inst)
```

Disables an SDADC module that was previously enabled.

Table 17-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Function sdadc_reset()

Resets the SDADC module.

```
enum status_code sdadc_reset(
        struct sdadc_module *const module_inst)
```

Resets an SDADC module, clearing all module state, and registers to their default values.

Table 17-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Function sdadc_enable_events()

Enables an SDADC event input or output.

```
void sdadc_enable_events(
        struct sdadc_module *const module_inst,
        struct sdadc_events *const events)
```

Enables one or more input or output events to or from the SDADC module. See sdadc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 17-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the SDADC peripheral
[in]	events	Struct containing flags of events to enable

Function sdadc_disable_events()

Disables an SDADC event input or output.

```
void sdadc_disable_events(
        struct sdadc_module *const module_inst,
        struct sdadc_events *const events)
```

Disables one or more input or output events to or from the SDADC module. See sdadc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 17-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Software instance for the SDADC peripheral
[in]	events	Struct containing flags of events to disable

Function sdadc_start_conversion()

Starts an SDADC conversion.

```
void sdadc_start_conversion(
        struct sdadc_module *const module_inst)
```

Starts a new SDADC conversion.

Table 17-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Function sdadc_read()

Reads the SDADC result.

```
enum status_code sdadc_read(
        struct sdadc_module *const module_inst,
        int32_t * result)
```

Reads the result from an SDADC conversion that was previously started.

Table 17-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[out]	result	Pointer to store the result value in

Returns
Status of the SDADC read request.

Table 17-23. Return Values

Return value	Description
STATUS_OK	The result was retrieved successfully
STATUS_BUSY	A conversion result was not ready
STATUS_ERR_OVERFLOW	The result register has been overwritten by the SDADC module before the result was read by the software

17.6.4.4. Runtime Changes of SDADC Module

Function sdadc_flush()

Flushes the SDADC pipeline.

```
void sdadc_flush(
        struct sdadc_module *const module_inst)
```

Flushes the pipeline and restart the SDADC clock on the next peripheral clock edge. All conversions in progress will be lost. When flush is complete, the module will resume where it left off.

Table 17-24. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct

Function sdadc_set_window_mode()

Sets the SDADC window mode.

```
void sdadc_set_window_mode(
        struct sdadc_module *const module_inst,
        const enum sdadc_window_mode window_mode,
        const int16_t window_lower_value,
        const int16_t window_upper_value)
```

Sets the SDADC window mode to a given mode and value range.

Table 17-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	window_mode	Window monitor mode to set
[in]	window_lower_value	Lower window monitor threshold value
[in]	window_upper_value	Upper window monitor threshold value

Function sdadc_set_mux_input()

Sets MUX SDADC input pin.

```
void sdadc_set_mux_input(
        struct sdadc_module *const module_inst,
        const enum sdadc_mux_input mux_input)
```

Sets the MUX SDADC input pin selection.

Table 17-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	mux_input	MUX input pin

17.6.4.5. Enable and Disable Interrupts

Function sdadc_enable_interrupt()

Enable interrupt.

```
void sdadc_enable_interrupt(
        struct sdadc_module *const module_inst,
        enum sdadc_interrupt_flag interrupt)
```

Enable the given interrupt request from the SDADC module.

Table 17-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	interrupt	Interrupt to enable

Function sdadc_disable_interrupt()

Disable interrupt.

```
void sdadc_disable_interrupt(
        struct sdadc_module *const module_inst,
        enum sdadc_interrupt_flag interrupt)
```

Disable the given interrupt request from the SDADC module.

Table 17-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	interrupt	Interrupt to disable

17.6.4.6. Callback Management

Function sdadc_register_callback()

Registers a callback.

```
void sdadc_register_callback(
        struct sdadc_module *const module,
        sdadc_callback_t callback_func,
        enum sdadc_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note: The callback must be enabled by for the interrupt handler to call it when the condition for the callback is met.

Table 17-29. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SDADC software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function sdadc_unregister_callback()

Unregisters a callback.

```
void sdadc_unregister_callback(
        struct sdadc_module * module,
        enum sdadc_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 17-30. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SDADC software instance struct
[in]	callback_type	Callback type given by an enum

Function sdadc_enable_callback()

Enables callback.

```
void sdadc_enable_callback(
        struct sdadc_module *const module,
        enum sdadc_callback callback_type)
```

Enables the callback function registered by sdadc_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 17-31. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SDADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns
Status of the operation.

Table 17-32. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

Function sdadc_disable_callback()

Disables callback.

```
void sdadc_disable_callback(
        struct sdadc_module *const module,
        enum sdadc_callback callback_type)
```

Disables the callback function registered by the sdadc_register_callback.

Table 17-33. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SDADC software instance struct
[in]	callback_type	Callback type given by an enum

Returns
Status of the operation.

Table 17-34. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID	If operation was not completed, due to invalid callback_type

17.6.4.7. Job Management

Function sdadc_read_buffer_job()

Read multiple samples from SDADC.

```
enum status_code sdadc_read_buffer_job(
        struct sdadc_module *const module_inst,
        int32_t * buffer,
        uint16_t samples)
```

Read `samples` from the SDADC into the `buffer`. If there is no hardware trigger defined (event action) the driver will retrigger the SDADC conversion whenever a conversion is complete until `samples` has been acquired. To avoid jitter in the sampling frequency using an event trigger is advised.

Table 17-35. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	samples	Number of samples to acquire
[out]	buffer	Buffer to store the SDADC samples

Returns
Status of the job start.

Table 17-36. Return Values

Return value	Description
STATUS_OK	The conversion job was started successfully and is in progress
STATUS_BUSY	The SDADC is already busy with another job

Function sdadc_get_job_status()

Gets the status of a job.

```
enum status_code sdadc_get_job_status(
        struct sdadc_module * module_inst,
        enum sdadc_job_type type)
```

Gets the status of an ongoing or the last job.

Table 17-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	type	Type of job to abort

Returns
Status of the job.

Function sdadc_abort_job()

Aborts an ongoing job.

```
void sdadc_abort_job(
        struct sdadc_module * module_inst,
        enum sdadc_job_type type)
```

Aborts an ongoing job with given type.

Table 17-38. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the SDADC software instance struct
[in]	type	Type of job to abort

17.6.5. Enumeration Definitions

17.6.5.1. Enum sdadc_callback

Callback types for SDADC callback driver.

Table 17-39. Members

Enum value	Description
SDADC_CALLBACK_READ_BUFFER	Callback for buffer received
SDADC_CALLBACK_WINDOW	Callback when window is hit
SDADC_CALLBACK_ERROR	Callback for error

17.6.5.2. Enum sdadc_event_action

Enum for the possible actions to take on an incoming event.

Table 17-40. Members

Enum value	Description
SDADC_EVENT_ACTION_DISABLED	Event action disabled
SDADC_EVENT_ACTION_FLUSH_START_CONV	Flush SDADC and start conversion
SDADC_EVENT_ACTION_START_CONV	Start conversion

17.6.5.3. Enum sdadc_interrupt_flag

Enum for the possible SDADC interrupt flags.

Table 17-41. Members

Enum value	Description
SDADC_INTERRUPT_RESULT_READY	SDADC result ready
SDADC_INTERRUPT_OVERRUN	SDADC result overwritten before read
SDADC_INTERRUPT_WINDOW	Window monitor match

17.6.5.4. Enum sdadc_job_type

Enum for the possible types of SDADC asynchronous jobs that may be issued to the driver.

Table 17-42. Members

Enum value	Description
SDADC_JOB_READ_BUFFER	Asynchronous SDADC read into a user provided buffer

17.6.5.5. Enum sdadc_mux_input

Enum for the possible MUX input selections for the SDADC.

Table 17-43. Members

Enum value	Description
SDADC_MUX_INPUT_AIN0	Select SDADC AINN0 and AINP0 pins
SDADC_MUX_INPUT_AIN1	Select SDADC AINN1 and AINP1 pins
SDADC_MUX_INPUT_AIN2	Select SDADC AINN2 and AINP2 pins

17.6.5.6. Enum sdadc_over_sampling_ratio

Enum for the over sampling ratio, which change the output data rate.

Table 17-44. Members

Enum value	Description
SDADC_OVER_SAMPLING_RATIO64	SDADC over Sampling Ratio is 64
SDADC_OVER_SAMPLING_RATIO128	SDADC over Sampling Ratio is 128
SDADC_OVER_SAMPLING_RATIO256	SDADC over Sampling Ratio is 256
SDADC_OVER_SAMPLING_RATIO512	SDADC over Sampling Ratio is 512
SDADC_OVER_SAMPLING_RATIO1024	SDADC over Sampling Ratio is 1024

17.6.5.7. Enum sdadc_reference_range

Enum for the matched voltage range of the SDADC reference used.

Table 17-45. Members

Enum value	Description
SDADC_REFRANGE_0	Vref < 1.4V
SDADC_REFRANGE_1	1.4V < Vref < 2.4V
SDADC_REFRANGE_2	2.4V < Vref < 3.6V
SDADC_REFRANGE_3	Vref > 3.6V

17.6.5.8. Enum sdadc_reference_select

Enum for the possible reference voltages for the SDADC.

Table 17-46. Members

Enum value	Description
SDADC_REFERENCE_INTREF	Internal Bandgap Reference
SDADC_REFERENCE_AREFB	External reference B
SDADC_REFERENCE_DACOUT	DACOUT
SDADC_REFERENCE_INTVCC	VDDANA

17.6.5.9. Enum sdadc_window_mode

Enum for the possible window monitor modes for the SDADC.

Table 17-47. Members

Enum value	Description
SDADC_WINDOW_MODE_DISABLE	No window mode
SDADC_WINDOW_MODE_ABOVE	RESULT > WINLT
SDADC_WINDOW_MODE_BELOW	RESULT < WINUT
SDADC_WINDOW_MODE_INSIDE	WINLT < RESULT < WINUT
SDADC_WINDOW_MODE_OUTSIDE	!(WINLT < RESULT < WINUT)

17.7. Extra Information for SDADC Driver

17.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
SDADC	Sigma-Delta Analog-to-Digital Converter
OSR	Over Sampling Ratio

17.7.2. Dependencies

This driver has no dependencies.

17.7.3. Errata

There are no errata related to this driver.

17.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

17.8. Examples for SDADC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Sigma-Delta Analog-to-Digital Converter (SDADC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SDADC - Basic
- Quick Start Guide for SDADC - Callback

17.8.1. Quick Start Guide for SDADC - Basic

In this use case, the SDADC will be configured with the following settings:

- GCLK generator 0 (GCLK main) clock source
- Internal bandgap reference 1V
- Div 2 clock prescaler
- Over Sampling Ratio is 64
- Skip 2 samples
- MUX input on SDADC AIN1
- All events (input and generation) disabled
- Free running disabled
- Run in standby disabled
- On command disabled
- Disable all positive input in sequence
- Window monitor disabled
- No gain/offset/shift correction

17.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct sdadc_module sdadc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_sdadc(void)
{
    struct sdadc_config config_sdadc;
    sdadc_get_config_defaults(&config_sdadc);

    sdadc_init(&sdadc_instance, SDADC, &config_sdadc);

    sdadc_enable(&sdadc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_sdadc();
```

Workflow

1. Create a module software instance structure for the SDADC module to store the SDADC driver state while it is in use.

   ```
   struct sdadc_module sdadc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the SDADC module.
   - Create a SDADC module configuration struct, which can be filled out to adjust the configuration of a physical SDADC peripheral.

     ```
     struct sdadc_config config_sdadc;
     ```
   - Initialize the SDADC configuration struct with the module's default values.

     ```
     sdadc_get_config_defaults(&config_sdadc);
     ```

     Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   - Set SDADC configurations.

     ```
     sdadc_init(&sdadc_instance, SDADC, &config_sdadc);
     ```
   - Enable the SDADC module so that conversions can be made.

     ```
     sdadc_enable(&sdadc_instance);
     ```

17.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
sdadc_start_conversion(&sdadc_instance);

int32_t result;

do {
    /* Wait for conversion to be done and read out result */
} while (sdadc_read(&sdadc_instance, &result) == STATUS_BUSY);
```

```
while (1) {
     /* Infinite loop */
}
```

Workflow

1. Start conversion.
```
sdadc_start_conversion(&sdadc_instance);
```
2. Wait until conversion is done and read result.
```
int32_t result;

do {
     /* Wait for conversion to be done and read out result */
} while (sdadc_read(&sdadc_instance, &result) == STATUS_BUSY);
```
3. Enter an infinite loop once the conversion is complete.
```
while (1) {
     /* Infinite loop */
}
```

17.8.2. Quick Start Guide for SDADC - Callback

In this use case, the SDADC will convert 128 samples using interrupt driven conversion. When all samples have been sampled, a callback will be called that signals the main application that conversion is compete.

The SDADC will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Internal bandgap reference 1V
- Div 2 clock prescaler
- Over Sampling Ratio is 1024
- Skip 2 samples
- MUX input on SDADC AIN2
- All events (input and generation) disabled
- Free running disabled
- Run in standby disabled
- On command disabled
- Disable all positive input in sequence
- Window monitor disabled
- No gain/offset/shift correction

17.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct sdadc_module sdadc_instance;
```

```
#define SDADC_SAMPLES 128
int32_t sdadc_result_buffer[SDADC_SAMPLES];
```

Callback function:

```
volatile bool sdadc_read_done = false;

void sdadc_complete_callback(
        const struct sdadc_module *const module)
{
    sdadc_read_done = true;
}
```

Copy-paste the following setup code to your user application:

```
void configure_sdadc(void)
{
    struct sdadc_config config_sdadc;
    sdadc_get_config_defaults(&config_sdadc);

    config_sdadc.clock_prescaler = 2;
    config_sdadc.reference.ref_sel = SDADC_REFERENCE_INTREF;
    config_sdadc.osr             = SDADC_OVER_SAMPLING_RATIO1024;
    config_sdadc.mux_input       = SDADC_MUX_INPUT_AIN2;

    sdadc_init(&sdadc_instance, SDADC, &config_sdadc);

    sdadc_enable(&sdadc_instance);
}

void configure_sdadc_callbacks(void)
{
    sdadc_register_callback(&sdadc_instance,
            sdadc_complete_callback, SDADC_CALLBACK_READ_BUFFER);
    sdadc_enable_callback(&sdadc_instance, SDADC_CALLBACK_READ_BUFFER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_sdadc();
configure_sdadc_callbacks();
```

Workflow

1. Create a module software instance structure for the SDADC module to store the SDADC driver state while it is in use.

   ```
   struct sdadc_module sdadc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a buffer for the SDADC samples to be stored in by the driver asynchronously.

   ```
   #define SDADC_SAMPLES 128
   int32_t sdadc_result_buffer[SDADC_SAMPLES];
   ```

3. Create a callback function that will be called each time the SDADC completes an asynchronous read job.

```
volatile bool sdadc_read_done = false;

void sdadc_complete_callback(
        const struct sdadc_module *const module)
{
    sdadc_read_done = true;
}
```

4. Configure the SDADC module.
   - Create a SDADC module configuration struct, which can be filled out to adjust the configuration of a physical SDADC peripheral.

     ```
     struct sdadc_config config_sdadc;
     ```

   - Initialize the SDADC configuration struct with the module's default values.

     ```
     sdadc_get_config_defaults(&config_sdadc);
     ```

     Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   - Change the SDADC module configuration to suit the application.

     ```
     config_sdadc.clock_prescaler = 2;
     config_sdadc.reference.ref_sel = SDADC_REFERENCE_INTREF;
     config_sdadc.osr              = SDADC_OVER_SAMPLING_RATIO1024;
     config_sdadc.mux_input        = SDADC_MUX_INPUT_AIN2;
     ```

   - Set SDADC configurations.

     ```
     sdadc_init(&sdadc_instance, SDADC, &config_sdadc);
     ```

   - Enable the SDADC module so that conversions can be made.

     ```
     sdadc_enable(&sdadc_instance);
     ```

5. Register and enable the SDADC read buffer complete callback handler.
   - Register the user-provided read buffer complete callback function with the driver, so that it will be run when an asynchronous buffer read job completes.

     ```
     sdadc_register_callback(&sdadc_instance,
             sdadc_complete_callback, SDADC_CALLBACK_READ_BUFFER);
     ```

   - Enable the read buffer complete callback so that it will generate callbacks.

     ```
     sdadc_enable_callback(&sdadc_instance,
     SDADC_CALLBACK_READ_BUFFER);
     ```

17.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

sdadc_read_buffer_job(&sdadc_instance, sdadc_result_buffer, SDADC_SAMPLES);

while (sdadc_read_done == false) {
    /* Wait for asynchronous SDADC read to complete */
}

while (1) {
```

```
    /* Infinite loop */
}
```

Workflow

- Enable global interrupts, so that callbacks can be generated by the driver.

```
system_interrupt_enable_global();
```

- Start an asynchronous SDADC conversion, to store SDADC samples into the global buffer and generate a callback when complete.

```
sdadc_read_buffer_job(&sdadc_instance, sdadc_result_buffer,
SDADC_SAMPLES);
```

- Wait until the asynchronous conversion is complete.

```
while (sdadc_read_done == false) {
    /* Wait for asynchronous SDADC read to complete */
}
```

- Enter an infinite loop once the conversion is complete.

```
while (1) {
    /* Infinite loop */
}
```

18. SAM Serial USART (SERCOM USART) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the SERCOM module in its USART mode to transfer or receive USART data frames. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- SERCOM (Serial Communication Interface)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

- Prerequisites
- Module Overview
- Special Considerations
- Extra Information
- Examples
- API Overview

18.1. Prerequisites

To use the USART you need to have a GCLK generator enabled and running that can be used as the SERCOM clock source. This can either be configured in conf_clocks.h or by using the system clock driver.

18.2. Module Overview

This driver will use one (or more) SERCOM interface(s) in the system and configure it to run as a USART interface in either synchronous or asynchronous mode.

18.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_USART_SYNC_SCHEME_V2	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_OVER_SAMPLE	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_HARDWARE_FLOW_CONTROL	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_IRDA	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_LIN_SLAVE	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_COLLISION_DECTION	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_START_FRAME_DECTION	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_IMMEDIATE_BUFFER_OVERFLOW_NOTIFICATION	SAM D21/R21/D09/D10/D11/L21/ L22/DA1/C20/C21
FEATURE_USART_RS485	SAM C20/C21
FEATURE_USART_LIN_MASTER	SAM L22/C20/C21

Note: The specific features are only available in the driver when the selected device supports those features.

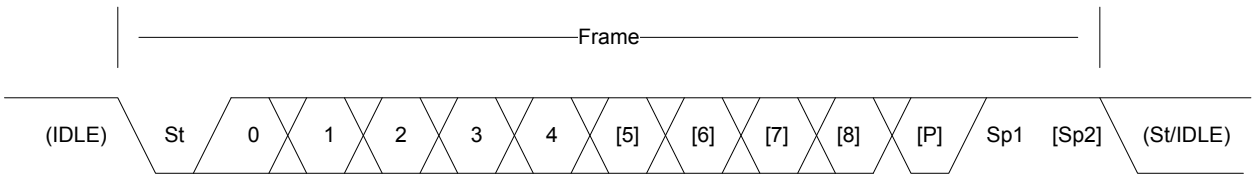
18.2.2. Frame Format

Communication is based on frames, where the frame format can be customized to accommodate a wide range of standards. A frame consists of a start bit, a number of data bits, an optional parity bit for error detection as well as a configurable length stop bit(s) - see Figure 18-1. Table 18-1 shows the available parameters you can change in a frame.

Table 18-1. USART Frame Parameters

Parameter	Options
Start bit	1
Data bits	5, 6, 7, 8, 9
Parity bit	None, Even, Odd
Stop bits	1, 2

Figure 18-1. USART Frame Overview



18.2.3. Synchronous Mode

In synchronous mode a dedicated clock line is provided; either by the USART itself if in master mode, or by an external master if in slave mode. Maximum transmission speed is the same as the GCLK clocking the USART peripheral when in slave mode, and the GCLK divided by two if in master mode. In synchronous mode the interface needs three lines to communicate:

- TX (Transmit pin)
- RX (Receive pin)
- XCK (Clock pin)

18.2.3.1. Data Sampling

In synchronous mode the data is sampled on either the rising or falling edge of the clock signal. This is configured by setting the clock polarity in the configuration struct.

18.2.4. Asynchronous Mode

In asynchronous mode no dedicated clock line is used, and the communication is based on matching the clock speed on the transmitter and receiver. The clock is generated from the internal SERCOM baudrate generator, and the frames are synchronized by using the frame start bits. Maximum transmission speed is limited to the SERCOM GCLK divided by 16. In asynchronous mode the interface only needs two lines to communicate:

- TX (Transmit pin)
- RX (Receive pin)

18.2.4.1. Transmitter/receiver Clock Matching

For successful transmit and receive using the asynchronous mode the receiver and transmitter clocks needs to be closely matched. When receiving a frame that does not match the selected baudrate closely enough the receiver will be unable to synchronize the frame(s), and garbage transmissions will result.

18.2.5. Parity

Parity can be enabled to detect if a transmission was in error. This is done by counting the number of "1" bits in the frame. When using even parity the parity bit will be set if the total number of "1"s in the frame are an even number. If using odd parity the parity bit will be set if the total number of "1"s are odd.

When receiving a character the receiver will count the number of "1"s in the frame and give an error if the received frame and parity bit disagree.

18.2.6. GPIO Configuration

The SERCOM module has four internal pads; the RX pin can be placed freely on any one of the four pads, and the TX and XCK pins have two predefined positions that can be selected as a pair. The pads can then be routed to an external GPIO pin using the normal pin multiplexing scheme on the SAM.

18.3. Special Considerations

Never execute large portions of code in the callbacks. These are run from the interrupt routine, and thus having long callbacks will keep the processor in the interrupt handler for an equally long time. A common way to handle this is to use global flags signaling the main application that an interrupt event has happened, and only do the minimal needed processing in the callback.

18.4. Extra Information

For extra information, see Extra Information for SERCOM USART Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

18.5. Examples

For a list of examples related to this driver, see Examples for SERCOM USART Driver.

18.6. API Overview

18.6.1. Variable and Type Definitions

18.6.1.1. Type usart_callback_t

```
typedef void(* usart_callback_t )(struct usart_module *const module)
```

Type of the callback functions.

18.6.2. Structure Definitions

18.6.2.1. Struct iso7816_config_t

ISO7816 configuration structure.

Table 18-2. Members

Type	Name	Description
bool	enable_inverse	Enable inverse transmission and reception
bool	enabled	
enum iso7816_guard_time	guard_time	Guard time, which lasts two bit times
enum iso7816_inhibit_nack	inhibit_nack	Inhibit Non Acknowledge: • 0: the NACK is generated; • 1: the NACK is not generated.
uint32_t	max_iterations	
enum iso7816_protocol_type	protocol_t	ISO7816 protocol type
enum iso7816_successive_recv_nack	successive_recv_nack	Disable successive NACKs. • 0: NACK is sent on the ISO line as soon as a parity error occurs in the received character. Successive parity errors are counted up to the value in the max_iterations field. These parity errors generate a NACK on the ISO line. As soon as this value is reached, no additional NACK is sent on the ISO line. The ITERATION flag is asserted.

18.6.2.2. Struct usart_config

Configuration options for USART.

Table 18-3. Members

Type	Name	Description
uint32_t	baudrate	USART baudrate
enum usart_character_size	character_size	USART character size
bool	clock_polarity_inverted	USART Clock Polarity. If true, data changes on falling XCK edge and is sampled at rising edge. If false, data changes on rising XCK edge and is sampled at falling edge.
bool	collision_detection_enable	Enable collision dection
enum usart_dataorder	data_order	USART bit order (MSB or LSB first)
bool	encoding_format_enable	Enable IrDA encoding format

Type	Name	Description
uint32_t	ext_clock_freq	External clock frequency in synchronous mode. This must be set if `use_external_clock` is true.
enum gclk_generator	generator_source	GCLK generator source
bool	immediate_buffer_overflow_notification	Controls when the buffer overflow status bit is asserted when a buffer overflow occurs
struct iso7816_config_t	iso7816_config	Enable ISO7816 for smart card interfacing
enum lin_master_break_length	lin_break_length	LIN Master Break Length
enum lin_master_header_delay	lin_header_delay	LIN master header delay
enum lin_node_type	lin_node	LIN node type
bool	lin_slave_enable	Enable LIN Slave Support
enum usart_signal_mux_settings	mux_setting	USART pin out
enum usart_parity	parity	USART parity
uint32_t	pinmux_pad0	PAD0 pinmux. If current USARTx has several alternative multiplexing I/O pins for PAD0, then only one peripheral multiplexing I/O can be enabled for current USARTx PAD0 function. Make sure that no other alternative multiplexing I/O is associated with the same USARTx PAD0.
uint32_t	pinmux_pad1	PAD1 pinmux. If current USARTx has several alternative multiplexing I/O pins for PAD1, then only one peripheral multiplexing I/O can be enabled for current USARTx PAD1 function. Make sure that no other alternative multiplexing I/O is associated with the same USARTx PAD1.

Type	Name	Description
uint32_t	pinmux_pad2	PAD2 pinmux. If current USARTx has several alternative multiplexing I/O pins for PAD2, then only one peripheral multiplexing I/O can be enabled for current USARTx PAD2 function. Make sure that no other alternative multiplexing I/O is associated with the same USARTx PAD2.
uint32_t	pinmux_pad3	PAD3 pinmux. If current USARTx has several alternative multiplexing I/O pins for PAD3, then only one peripheral multiplexing I/O can be enabled for current USARTx PAD3 function. Make sure that no other alternative multiplexing I/O is associated with the same USARTx PAD3.
uint8_t	receive_pulse_length	The minimum pulse length required for a pulse to be accepted by the IrDA receiver
bool	receiver_enable	Enable receiver
enum rs485_guard_time	rs485_guard_time	RS485 guard time
bool	run_in_standby	If true the USART will be kept running in Standby sleep mode
enum usart_sample_adjustment	sample_adjustment	USART sample adjustment
enum usart_sample_rate	sample_rate	USART sample rate
bool	start_frame_detection_enable	Enable start of frame dection
enum usart_stopbits	stopbits	Number of stop bits
enum usart_transfer_mode	transfer_mode	USART in asynchronous or synchronous mode

Type	Name	Description
bool	transmitter_enable	Enable transmitter
bool	use_external_clock	States whether to use the external clock applied to the XCK pin. In synchronous mode the shift register will act directly on the XCK clock. In asynchronous mode the XCK will be the input to the USART hardware module.

18.6.2.3. Struct usart_module

SERCOM USART driver software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

18.6.3. Macro Definitions

18.6.3.1. Driver Feature Definition

Define SERCOM USART features set according to different device family.

Macro FEATURE_USART_SYNC_SCHEME_V2

```
#define FEATURE_USART_SYNC_SCHEME_V2
```

USART sync scheme version 2.

Macro FEATURE_USART_OVER_SAMPLE

```
#define FEATURE_USART_OVER_SAMPLE
```

USART oversampling.

Macro FEATURE_USART_HARDWARE_FLOW_CONTROL

```
#define FEATURE_USART_HARDWARE_FLOW_CONTROL
```

USART hardware control flow.

Macro FEATURE_USART_IRDA

```
#define FEATURE_USART_IRDA
```

IrDA mode.

Macro FEATURE_USART_LIN_SLAVE

```
#define FEATURE_USART_LIN_SLAVE
```

LIN slave mode.

Macro FEATURE_USART_COLLISION_DECTION

```
#define FEATURE_USART_COLLISION_DECTION
```

USART collision detection.

Macro FEATURE_USART_START_FRAME_DECTION

```
#define FEATURE_USART_START_FRAME_DECTION
```

USART start frame detection.

Macro FEATURE_USART_IMMEDIATE_BUFFER_OVERFLOW_NOTIFICATION

```
#define FEATURE_USART_IMMEDIATE_BUFFER_OVERFLOW_NOTIFICATION
```

USART start buffer overflow notification.

Macro FEATURE_USART_ISO7816

```
#define FEATURE_USART_ISO7816
```

ISO7816 for smart card interfacing.

Macro FEATURE_USART_LIN_MASTER

```
#define FEATURE_USART_LIN_MASTER
```

LIN master mode.

Macro FEATURE_USART_RS485

```
#define FEATURE_USART_RS485
```

RS485 mode.

18.6.3.2. Macro PINMUX_DEFAULT

```
#define PINMUX_DEFAULT
```

Default pinmux

18.6.3.3. Macro PINMUX_UNUSED

```
#define PINMUX_UNUSED
```

Unused pinmux

18.6.3.4. Macro USART_TIMEOUT

```
#define USART_TIMEOUT
```

USART timeout value

18.6.4. Function Definitions

18.6.4.1. Lock/Unlock

Function usart_lock()

Attempt to get lock on driver instance.

```
enum status_code usart_lock(
        struct usart_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 18-4. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 18-5. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

Function usart_unlock()

Unlock driver instance.

```
void usart_unlock(
        struct usart_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 18-6. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

18.6.4.2. Writing and Reading

Function usart_write_wait()

Transmit a character via the USART.

```
enum status_code usart_write_wait(
        struct usart_module *const module,
        const uint16_t tx_data)
```

This blocking function will transmit a single character via the USART.

Table 18-7. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Data to transfer

Returns
Status of the operation.

Table 18-8. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_BUSY	If the operation was not completed, due to the USART module being busy
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_wait()

Receive a character via the USART.

```
enum status_code usart_read_wait(
        struct usart_module *const module,
        uint16_t *const rx_data)
```

This blocking function will receive a character via the USART.

Table 18-9. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Pointer to received data

Returns

Status of the operation.

Table 18-10. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_BUSY	If the operation was not completed, due to the USART module being busy
STATUS_ERR_BAD_FORMAT	If the operation was not completed, due to configuration mismatch between USART and the sender
STATUS_ERR_BAD_OVERFLOW	If the operation was not completed, due to the baudrate being too low or the system frequency being too high
STATUS_ERR_BAD_DATA	If the operation was not completed, due to data being corrupted
STATUS_ERR_DENIED	If the receiver is not enabled

Function usart_write_buffer_wait()

Transmit a buffer of characters via the USART.

```
enum status_code usart_write_buffer_wait(
        struct usart_module *const module,
        const uint8_t * tx_data,
        uint16_t length)
```

This blocking function will transmit a block of `length` characters via the USART.

Note: Using this function in combination with the interrupt (`_job`) functions is not recommended as it has no functionality to check if there is an ongoing interrupt driven operation running or not.

Table 18-11. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Pointer to data to transmit
[in]	length	Number of characters to transmit

Note: If using 9-bit data, the array that *tx_data point to should be defined as uint16_t array and should be casted to uint8_t* pointer. Because it is an address pointer, the highest byte is not discarded. For example:

```
#define TX_LEN 3
uint16_t tx_buf[TX_LEN] = {0x0111, 0x0022, 0x0133};
usart_write_buffer_wait(&module, (uint8_t*)tx_buf, TX_LEN);
```

Returns
Status of the operation.

Table 18-12. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_TIMEOUT	If operation was not completed, due to USART module timing out
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_buffer_wait()

Receive a buffer of `length` characters via the USART.

```
enum status_code usart_read_buffer_wait(
        struct usart_module *const module,
        uint8_t * rx_data,
        uint16_t length)
```

This blocking function will receive a block of `length` characters via the USART.

Note: Using this function in combination with the interrupt (`*_job`) functions is not recommended as it has no functionality to check if there is an ongoing interrupt driven operation running or not.

Table 18-13. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	rx_data	Pointer to receive buffer
[in]	length	Number of characters to receive

Note: If using 9-bit data, the array that *rx_data point to should be defined as uint16_t array and should be casted to uint8_t* pointer. Because it is an address pointer, the highest byte is not discarded. For example:

```
#define RX_LEN 3
uint16_t rx_buf[RX_LEN] = {0x0,};
usart_read_buffer_wait(&module, (uint8_t*)rx_buf, RX_LEN);
```

Returns

Status of the operation.

Table 18-14. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_ERR_INVALID_ARG	If operation was not completed, due to an invalid argument being supplied
STATUS_ERR_TIMEOUT	If operation was not completed, due to USART module timing out
STATUS_ERR_BAD_FORMAT	If the operation was not completed, due to a configuration mismatch between USART and the sender
STATUS_ERR_BAD_OVERFLOW	If the operation was not completed, due to the baudrate being too low or the system frequency being too high
STATUS_ERR_BAD_DATA	If the operation was not completed, due to data being corrupted
STATUS_ERR_DENIED	If the receiver is not enabled

18.6.4.3. Enabling/Disabling Receiver and Transmitter

Function usart_enable_transceiver()

Enable Transceiver.

```
void usart_enable_transceiver(
        struct usart_module *const module,
        enum usart_transceiver_type transceiver_type)
```

Enable the given transceiver. Either RX or TX.

Table 18-15. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transceiver type

Function usart_disable_transceiver()

Disable Transceiver.

```
void usart_disable_transceiver(
        struct usart_module *const module,
        enum usart_transceiver_type transceiver_type)
```

Disable the given transceiver (RX or TX).

Table 18-16. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transceiver type

18.6.4.4. LIN Master Command and Status

Function lin_master_send_cmd()

Sending LIN command.

```
void lin_master_send_cmd(
        struct usart_module *const module,
        enum lin_master_cmd cmd)
```

Sending LIN command.

Table 18-17. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	cmd	Cammand type

Function lin_master_transmission_status()

Get LIN transmission status.

```
bool lin_master_transmission_status(
        struct usart_module *const module)
```

Get LIN transmission status.

Table 18-18. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

Returns
Status of LIN master transmission.

Table 18-19. Return Values

Return value	Description
true	Data transmission completed
false	Transmission is ongoing

18.6.4.5. Callback Management

Function usart_register_callback()

Registers a callback.

```
void usart_register_callback(
        struct usart_module *const module,
        usart_callback_t callback_func,
        enum usart_callback callback_type)
```

Registers a callback function, which is implemented by the user.

Note: The callback must be enabled by usart_enable_callback in order for the interrupt handler to call it when the conditions for the callback type are met.

Table 18-20. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function usart_unregister_callback()

Unregisters a callback.

```
void usart_unregister_callback(
        struct usart_module * module,
        enum usart_callback callback_type)
```

Unregisters a callback function, which is implemented by the user.

Table 18-21. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

Function usart_enable_callback()

Enables callback.

```
void usart_enable_callback(
        struct usart_module *const module,
        enum usart_callback callback_type)
```

Enables the callback function registered by the usart_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 18-22. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

Function usart_disable_callback()

Disable callback.

```
void usart_disable_callback(
        struct usart_module *const module,
        enum usart_callback callback_type)
```

Disables the callback function registered by the usart_register_callback, and the callback will not be called from the interrupt routine.

Table 18-23. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_type	Callback type given by an enum

18.6.4.6. Writing and Reading

Function usart_write_job()

Asynchronous write a single char.

```
enum status_code usart_write_job(
        struct usart_module *const module,
        const uint16_t * tx_data)
```

Sets up the driver to write the data given. If registered and enabled, a callback function will be called when the transmit is completed.

Table 18-24. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Data to transfer

Returns
Status of the operation.

Table 18-25. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_job()

Asynchronous read a single char.

```
enum status_code usart_read_job(
        struct usart_module *const module,
        uint16_t *const rx_data)
```

Sets up the driver to read data from the USART module to the data pointer given. If registered and enabled, a callback will be called when the receiving is completed.

Table 18-26. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	rx_data	Pointer to where received data should be put

Returns
Status of the operation.

Table 18-27. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_BUSY	If operation was not completed

Function usart_write_buffer_job()

Asynchronous buffer write.

```
enum status_code usart_write_buffer_job(
        struct usart_module *const module,
        uint8_t * tx_data,
        uint16_t length)
```

Sets up the driver to write a given buffer over the USART. If registered and enabled, a callback function will be called.

Table 18-28. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	tx_data	Pointer do data buffer to transmit
[in]	length	Length of the data to transmit

Note: If using 9-bit data, the array that *tx_data point to should be defined as uint16_t array and should be casted to uint8_t* pointer. Because it is an address pointer, the highest byte is not discarded. For example:

```
#define TX_LEN 3
uint16_t tx_buf[TX_LEN] = {0x0111, 0x0022, 0x0133};
usart_write_buffer_job(&module, (uint8_t*)tx_buf, TX_LEN);
```

Returns
Status of the operation.

Table 18-29. Return Values

Return value	Description
STATUS_OK	If operation was completed successfully.
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_read_buffer_job()

Asynchronous buffer read.

```
enum status_code usart_read_buffer_job(
        struct usart_module *const module,
        uint8_t * rx_data,
        uint16_t length)
```

Sets up the driver to read from the USART to a given buffer. If registered and enabled, a callback function will be called.

Table 18-30. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Note: If using 9-bit data, the array that *rx_data point to should be defined as uint16_t array and should be casted to uint8_t* pointer. Because it is an address pointer, the highest byte is not discarded. For example:

```
#define RX_LEN 3
uint16_t rx_buf[RX_LEN] = {0x0,};
usart_read_buffer_job(&module, (uint8_t*)rx_buf, RX_LEN);
```

Returns

Status of the operation.

Table 18-31. Return Values

Return value	Description
STATUS_OK	If operation was completed
STATUS_BUSY	If operation was not completed, due to the USART module being busy
STATUS_ERR_INVALID_ARG	If operation was not completed, due to invalid arguments
STATUS_ERR_DENIED	If the transmitter is not enabled

Function usart_abort_job()

Cancels ongoing read/write operation.

```
void usart_abort_job(
        struct usart_module *const module,
        enum usart_transceiver_type transceiver_type)
```

Cancels the ongoing read/write operation modifying parameters in the USART software struct.

Table 18-32. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transfer type to cancel

Function usart_get_job_status()

Get status from the ongoing or last asynchronous transfer operation.

```
enum status_code usart_get_job_status(
        struct usart_module *const module,
        enum usart_transceiver_type transceiver_type)
```

Returns the error from a given ongoing or last asynchronous transfer operation. Either from a read or write transfer.

Table 18-33. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	transceiver_type	Transfer type to check

Returns
Status of the given job.

Table 18-34. Return Values

Return value	Description
STATUS_OK	No error occurred during the last transfer
STATUS_BUSY	A transfer is ongoing
STATUS_ERR_BAD_DATA	The last operation was aborted due to a parity error. The transfer could be affected by external noise
STATUS_ERR_BAD_FORMAT	The last operation was aborted due to a frame error
STATUS_ERR_OVERFLOW	The last operation was aborted due to a buffer overflow
STATUS_ERR_INVALID_ARG	An invalid transceiver enum given

18.6.4.7. Function usart_disable()

Disable module.

```
void usart_disable(
        const struct usart_module *const module)
```

Disables the USART module.

Table 18-35. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

18.6.4.8. Function usart_enable()

Enable the module.

```
void usart_enable(
        const struct usart_module *const module)
```

Enables the USART module.

Table 18-36. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct

18.6.4.9. Function usart_get_config_defaults()

Initializes the device to predefined defaults.

```
void usart_get_config_defaults(
        struct usart_config *const config)
```

Initialize the USART device to predefined defaults:

- 8-bit asynchronous USART

- No parity
- One stop bit
- 9600 baud
- Transmitter enabled
- Receiver enabled
- GCLK generator 0 as clock source
- Default pin configuration

The configuration struct will be updated with the default configuration.

Table 18-37. Parameters

Data direction	Parameter name	Description
[in, out]	config	Pointer to configuration struct

18.6.4.10. Function usart_init()

Initializes the device.

```
enum status_code usart_init(
        struct usart_module *const module,
        Sercom *const hw,
        const struct usart_config *const config)
```

Initializes the USART device based on the setting specified in the configuration struct.

Table 18-38. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to USART device
[in]	hw	Pointer to USART hardware instance
[in]	config	Pointer to configuration struct

Returns
Status of the initialization.

Table 18-39. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_BUSY	The USART module is busy resetting
STATUS_ERR_DENIED	The USART has not been disabled in advance of initialization
STATUS_ERR_INVALID_ARG	The configuration struct contains invalid configuration
STATUS_ERR_ALREADY_INITIALIZED	The SERCOM instance has already been initialized with different clock configuration
STATUS_ERR_BAUD_UNAVAILABLE	The BAUD rate given by the configuration struct cannot be reached with the current clock configuration

18.6.4.11. Function usart_is_syncing()

Check if peripheral is busy syncing registers across clock domains.

```
bool usart_is_syncing(
        const struct usart_module *const module)
```

Return peripheral synchronization status. If doing a non-blocking implementation this function can be used to check the sync state and hold of any new actions until sync is complete. If this function is not run; the functions will block until the sync has completed.

Table 18-40. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to peripheral module

Returns

Peripheral sync status.

Table 18-41. Return Values

Return value	Description
true	Peripheral is busy syncing
false	Peripheral is not busy syncing and can be read/written without stalling the bus

18.6.4.12. Function usart_reset()

Resets the USART module.

```
void usart_reset(
        const struct usart_module *const module)
```

Disables and resets the USART module.

Table 18-42. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the USART software instance struct

18.6.5. Enumeration Definitions

18.6.5.1. Enum iso7816_guard_time

The value of ISO7816 guard time.

Table 18-43. Members

Enum value	Description
ISO7816_GUARD_TIME_2_BIT	The guard time is 2-bit times
ISO7816_GUARD_TIME_3_BIT	The guard time is 3-bit times
ISO7816_GUARD_TIME_4_BIT	The guard time is 4-bit times

Enum value	Description
ISO7816_GUARD_TIME_5_BIT	The guard time is 5-bit times
ISO7816_GUARD_TIME_6_BIT	The guard time is 6-bit times
ISO7816_GUARD_TIME_7_BIT	The guard time is 7-bit times

18.6.5.2. Enum iso7816_inhibit_nack

The value of ISO7816 receive NACK inhibit.

Table 18-44. Members

Enum value	Description
ISO7816_INHIBIT_NACK_DISABLE	The NACK is generated
ISO7816_INHIBIT_NACK_ENABLE	The NACK is not generated

18.6.5.3. Enum iso7816_protocol_type

ISO7816 protocol type.

Table 18-45. Members

Enum value	Description
ISO7816_PROTOCOL_T_0	ISO7816 protocol type 0
ISO7816_PROTOCOL_T_1	ISO7816 protocol type 1

18.6.5.4. Enum iso7816_successive_recv_nack

The value of ISO7816 disable successive receive NACK.

Table 18-46. Members

Enum value	Description
ISO7816_SUCCESSIVE_RECV_NACK_DISABLE	The successive receive NACK is enable.
ISO7816_SUCCESSIVE_RECV_NACK_ENABLE	The successive receive NACK is disable.

18.6.5.5. Enum lin_master_break_length

Length of the break field transmitted when in LIN master mode

Table 18-47. Members

Enum value	Description
LIN_MASTER_BREAK_LENGTH_13_BIT	Break field transmission is 13 bit times
LIN_MASTER_BREAK_LENGTH_17_BIT	Break field transmission is 17 bit times
LIN_MASTER_BREAK_LENGTH_21_BIT	Break field transmission is 21 bit times
LIN_MASTER_BREAK_LENGTH_26_BIT	Break field transmission is 26 bit times

18.6.5.6. Enum lin_master_cmd

LIN master command enum.

Table 18-48. Members

Enum value	Description
LIN_MASTER_SOFTWARE_CONTROL_TRANSMIT_CMD	LIN master software control transmission command
LIN_MASTER_AUTO_TRANSMIT_CMD	LIN master automatically transmission command

18.6.5.7. Enum lin_master_header_delay

LIN master header delay between break and sync transmission, and between the sync and identifier (ID) fields. This field is only valid when using automatically transmission command

Table 18-49. Members

Enum value	Description
LIN_MASTER_HEADER_DELAY_0	Delay between break and sync transmission is 1 bit time. Delay between sync and ID transmission is 1 bit time.
LIN_MASTER_HEADER_DELAY_1	Delay between break and sync transmission is 4 bit time. Delay between sync and ID transmission is 4 bit time.
LIN_MASTER_HEADER_DELAY_2	Delay between break and sync transmission is 8 bit time. Delay between sync and ID transmission is 4 bit time.
LIN_MASTER_HEADER_DELAY_3	Delay between break and sync transmission is 14 bit time. Delay between sync and ID transmission is 4 bit time.

18.6.5.8. Enum lin_node_type

LIN node type.

Table 18-50. Members

Enum value	Description
LIN_MASTER_NODE	LIN master mode
LIN_SLAVE_NODE	LIN slave mode
LIN_INVALID_MODE	Neither LIN master nor LIN slave mode

18.6.5.9. Enum rs485_guard_time

The value of RS485 guard time.

Table 18-51. Members

Enum value	Description
RS485_GUARD_TIME_0_BIT	The guard time is 0-bit time
RS485_GUARD_TIME_1_BIT	The guard time is 1-bit time
RS485_GUARD_TIME_2_BIT	The guard time is 2-bit times
RS485_GUARD_TIME_3_BIT	The guard time is 3-bit times
RS485_GUARD_TIME_4_BIT	The guard time is 4-bit times
RS485_GUARD_TIME_5_BIT	The guard time is 5-bit times
RS485_GUARD_TIME_6_BIT	The guard time is 6-bit times
RS485_GUARD_TIME_7_BIT	The guard time is 7-bit times

18.6.5.10. Enum usart_callback

Callbacks for the Asynchronous USART driver.

Table 18-52. Members

Enum value	Description
USART_CALLBACK_BUFFER_TRANSMITTED	Callback for buffer transmitted
USART_CALLBACK_BUFFER_RECEIVED	Callback for buffer received
USART_CALLBACK_ERROR	Callback for error
USART_CALLBACK_BREAK_RECEIVED	Callback for break character is received
USART_CALLBACK_CTS_INPUT_CHANGE	Callback for a change is detected on the CTS pin
USART_CALLBACK_START_RECEIVED	Callback for a start condition is detected on the RxD line

18.6.5.11. Enum usart_character_size

Number of bits for the character sent in a frame.

Table 18-53. Members

Enum value	Description
USART_CHARACTER_SIZE_5BIT	The char being sent in a frame is five bits long
USART_CHARACTER_SIZE_6BIT	The char being sent in a frame is six bits long
USART_CHARACTER_SIZE_7BIT	The char being sent in a frame is seven bits long
USART_CHARACTER_SIZE_8BIT	The char being sent in a frame is eight bits long
USART_CHARACTER_SIZE_9BIT	The char being sent in a frame is nine bits long

18.6.5.12. Enum usart_dataorder

The data order decides which MSB or LSB is shifted out first when data is transferred.

Table 18-54. Members

Enum value	Description
USART_DATAORDER_MSB	The MSB will be shifted out first during transmission, and shifted in first during reception
USART_DATAORDER_LSB	The LSB will be shifted out first during transmission, and shifted in first during reception

18.6.5.13. Enum usart_parity

Select parity USART parity mode.

Table 18-55. Members

Enum value	Description
USART_PARITY_ODD	For odd parity checking, the parity bit will be set if number of ones being transferred is even
USART_PARITY_EVEN	For even parity checking, the parity bit will be set if number of ones being received is odd
USART_PARITY_NONE	No parity checking will be executed, and there will be no parity bit in the received frame

18.6.5.14. Enum usart_sample_adjustment

The value of sample number used for majority voting.

Table 18-56. Members

Enum value	Description
USART_SAMPLE_ADJUSTMENT_7_8_9	The first, middle and last sample number used for majority voting is 7-8-9
USART_SAMPLE_ADJUSTMENT_9_10_11	The first, middle and last sample number used for majority voting is 9-10-11
USART_SAMPLE_ADJUSTMENT_11_12_13	The first, middle and last sample number used for majority voting is 11-12-13
USART_SAMPLE_ADJUSTMENT_13_14_15	The first, middle and last sample number used for majority voting is 13-14-15

18.6.5.15. Enum usart_sample_rate

The value of sample rate and baudrate generation mode.

Table 18-57. Members

Enum value	Description
USART_SAMPLE_RATE_16X_ARITHMETIC	16x over-sampling using arithmetic baudrate generation
USART_SAMPLE_RATE_16X_FRACTIONAL	16x over-sampling using fractional baudrate generation
USART_SAMPLE_RATE_8X_ARITHMETIC	8x over-sampling using arithmetic baudrate generation
USART_SAMPLE_RATE_8X_FRACTIONAL	8x over-sampling using fractional baudrate generation
USART_SAMPLE_RATE_3X_ARITHMETIC	3x over-sampling using arithmetic baudrate generation

18.6.5.16. Enum usart_signal_mux_settings

Set the functionality of the SERCOM pins.

See SERCOM USART MUX Settings for a description of the various MUX setting options.

Table 18-58. Members

Enum value	Description
USART_RX_0_TX_0_XCK_1	MUX setting RX_0_TX_0_XCK_1
USART_RX_0_TX_2_XCK_3	MUX setting RX_0_TX_2_XCK_3
USART_RX_0_TX_0_RTS_2_CTS_3	MUX setting USART_RX_0_TX_0_RTS_2_CTS_3
USART_RX_1_TX_0_XCK_1	MUX setting RX_1_TX_0_XCK_1
USART_RX_1_TX_2_XCK_3	MUX setting RX_1_TX_2_XCK_3
USART_RX_1_TX_0_RTS_2_CTS_3	MUX setting USART_RX_1_TX_0_RTS_2_CTS_3
USART_RX_2_TX_0_XCK_1	MUX setting RX_2_TX_0_XCK_1
USART_RX_2_TX_2_XCK_3	MUX setting RX_2_TX_2_XCK_3
USART_RX_2_TX_0_RTS_2_CTS_3	MUX setting USART_RX_2_TX_0_RTS_2_CTS_3
USART_RX_3_TX_0_XCK_1	MUX setting RX_3_TX_0_XCK_1
USART_RX_3_TX_2_XCK_3	MUX setting RX_3_TX_2_XCK_3
USART_RX_3_TX_0_RTS_2_CTS_3	MUX setting USART_RX_3_TX_0_RTS_2_CTS_3
USART_RX_0_TX_0_XCK_1_TE_2	MUX setting USART_RX_0_TX_0_XCK_1_TE_2
USART_RX_1_TX_0_XCK_1_TE_2	MUX setting USART_RX_1_TX_0_XCK_1_TE_2
USART_RX_2_TX_0_XCK_1_TE_2	MUX setting USART_RX_2_TX_0_XCK_1_TE_2
USART_RX_3_TX_0_XCK_1_TE_2	MUX setting USART_RX_3_TX_0_XCK_1_TE_2

18.6.5.17. Enum usart_stopbits

Number of stop bits for a frame.

Table 18-59. Members

Enum value	Description
USART_STOPBITS_1	Each transferred frame contains one stop bit
USART_STOPBITS_2	Each transferred frame contains two stop bits

18.6.5.18. Enum usart_transceiver_type

Select Receiver or Transmitter.

Table 18-60. Members

Enum value	Description
USART_TRANSCEIVER_RX	The parameter is for the Receiver
USART_TRANSCEIVER_TX	The parameter is for the Transmitter

18.6.5.19. Enum usart_transfer_mode

Select USART transfer mode.

Table 18-61. Members

Enum value	Description
USART_TRANSFER_SYNCHRONOUSLY	Transfer of data is done synchronously
USART_TRANSFER_ASYNCHRONOUSLY	Transfer of data is done asynchronously

18.7. Extra Information for SERCOM USART Driver

18.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
SERCOM	Serial Communication Interface
USART	Universal Synchronous and Asynchronous Serial Receiver and Transmitter
LSB	Least Significant Bit
MSB	Most Significant Bit
DMA	Direct Memory Access

18.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver
- System clock configuration

18.7.3. Errata

There are no errata related to this driver.

18.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added new feature as below: • ISO7816
Added new features as below: • LIN master • RS485
Added new features as below: • Oversample • Buffer overflow notification • Irda • Lin slave • Start frame detection • Hardware flow control • Collision detection • DMA support
• Added new `transmitter_enable` and `receiver_enable` Boolean values to `struct` usart_config • Altered `usart_write_*` and usart_read_* functions to abort with an error code if the relevant transceiver is not enabled • Fixed `usart_write_buffer_wait()` and `usart_read_buffer_wait()` not aborting correctly when a timeout condition occurs
Initial Release

18.8. Examples for SERCOM USART Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Serial USART (SERCOM USART) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SERCOM USART - Basic
- Quick Start Guide for SERCOM USART - Callback
- Quick Start Guide for Using DMA with SERCOM USART
- Quick Start Guide for SERCOM USART LIN

18.8.1. Quick Start Guide for SERCOM USART - Basic

This quick start will echo back characters typed into the terminal. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and one Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

18.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;

    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();
```

Workflow

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   struct usart_module usart_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the USART module.
   1. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

      ```
      struct usart_config config_usart;
      ```

2. Initialize the USART configuration struct with the module's default values.

```
usart_get_config_defaults(&config_usart);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the USART settings to configure the physical pinout, baudrate, and other relevant parameters.

```
config_usart.baudrate    = 9600;
config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

4. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
while (usart_init(&usart_instance,
        EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
}
```

5. Enable the USART module.

```
usart_enable(&usart_instance);
```

18.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));

uint16_t temp;

while (true) {
    if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
        while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
        }
    }
}
```

Workflow

1. Send a string to the USART to show the demo is running, blocking until all characters have been sent.

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));
```

2. Enter an infinite loop to continuously echo received values on the USART.

```
while (true) {
    if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
        while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
        }
    }
}
```

3. Perform a blocking read of the USART, storing the received character into the previously declared temporary variable.

```
if (usart_read_wait(&usart_instance, &temp) == STATUS_OK) {
```

4. Echo the received variable back to the USART via a blocking write.

```
while (usart_write_wait(&usart_instance, temp) != STATUS_OK) {
}
```

18.8.2. Quick Start Guide for SERCOM USART - Callback

This quick start will echo back characters typed into the terminal, using asynchronous TX and RX callbacks from the USART peripheral. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and one Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

18.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

```
#define MAX_RX_BUFFER_LENGTH   5

volatile uint8_t rx_buffer[MAX_RX_BUFFER_LENGTH];
```

Copy-paste the following callback function code to your user application:

```
void usart_read_callback(struct usart_module *const usart_module)
{
    usart_write_buffer_job(&usart_instance,
            (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
}

void usart_write_callback(struct usart_module *const usart_module)
{
    port_pin_toggle_output_level(LED_0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

```
    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}

void configure_usart_callbacks(void)
{
    usart_register_callback(&usart_instance,
            usart_write_callback, USART_CALLBACK_BUFFER_TRANSMITTED);
    usart_register_callback(&usart_instance,
            usart_read_callback, USART_CALLBACK_BUFFER_RECEIVED);

    usart_enable_callback(&usart_instance,
USART_CALLBACK_BUFFER_TRANSMITTED);
    usart_enable_callback(&usart_instance, USART_CALLBACK_BUFFER_RECEIVED);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();
configure_usart_callbacks();
```

Workflow

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   struct usart_module usart_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the USART module.
   1. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

      ```
      struct usart_config config_usart;
      ```

   2. Initialize the USART configuration struct with the module's default values.

      ```
      usart_get_config_defaults(&config_usart);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   3. Alter the USART settings to configure the physical pinout, baudrate, and other relevant parameters.

      ```
      config_usart.baudrate    = 9600;
      config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
      config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
      config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
      config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
      config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
      ```

   4. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

      ```
      while (usart_init(&usart_instance,
              EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
      }
      ```

5. Enable the USART module.

```
usart_enable(&usart_instance);
```

3. Configure the USART callbacks.
   1. Register the TX and RX callback functions with the driver.

```
usart_register_callback(&usart_instance,
        usart_write_callback, USART_CALLBACK_BUFFER_TRANSMITTED);
usart_register_callback(&usart_instance,
        usart_read_callback, USART_CALLBACK_BUFFER_RECEIVED);
```

   2. Enable the TX and RX callbacks so that they will be called by the driver when appropriate.

```
usart_enable_callback(&usart_instance,
USART_CALLBACK_BUFFER_TRANSMITTED);
usart_enable_callback(&usart_instance,
USART_CALLBACK_BUFFER_RECEIVED);
```

18.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));

while (true) {
    usart_read_buffer_job(&usart_instance,
            (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
}
```

Workflow

1. Enable global interrupts, so that the callbacks can be fired.

```
system_interrupt_enable_global();
```

2. Send a string to the USART to show the demo is running, blocking until all characters have been sent.

```
uint8_t string[] = "Hello World!\r\n";
usart_write_buffer_wait(&usart_instance, string, sizeof(string));
```

3. Enter an infinite loop to continuously echo received values on the USART.

```
while (true) {
```

4. Perform an asynchronous read of the USART, which will fire the registered callback when characters are received.

```
usart_read_buffer_job(&usart_instance,
        (uint8_t *)rx_buffer, MAX_RX_BUFFER_LENGTH);
```

18.8.3. Quick Start Guide for Using DMA with SERCOM USART

The supported board list:

- SAM D21 Xplained Pro
- SAM R21 Xplained Pro
- SAM D11 Xplained Pro

- SAM DA1 Xplained Pro
- SAM L21 Xplained Pro
- SAM L22 Xplained Pro
- SAM C21 Xplained Pro

This quick start will receive eight bytes of data from the PC terminal and transmit back the string to the terminal through DMA. In this use case the USART will be configured with the following settings:

- Asynchronous mode
- 9600 Baudrate
- 8-bits, No Parity and one Stop Bit
- TX and RX enabled and connected to the Xplained Pro Embedded Debugger virtual COM port

18.8.3.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct usart_module usart_instance;
```

```
struct dma_resource usart_dma_resource_rx;
struct dma_resource usart_dma_resource_tx;
```

```
#define BUFFER_LEN    8
static uint16_t string[BUFFER_LEN];
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor_rx SECTION_DMAC_DESCRIPTOR;
DmacDescriptor example_descriptor_tx SECTION_DMAC_DESCRIPTOR;
```

Copy-paste the following setup code to your user application:

```
static void transfer_done_rx(struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_tx);
}

static void transfer_done_tx(struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_rx);
}

static void configure_dma_resource_rx(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = EDBG_CDC_SERCOM_DMAC_ID_RX;
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor_rx(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;
```

```
    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = BUFFER_LEN;
    descriptor_config.destination_address =
            (uint32_t)string + sizeof(string);
    descriptor_config.source_address =
            (uint32_t)(&usart_instance.hw->USART.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}

static void configure_dma_resource_tx(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = EDBG_CDC_SERCOM_DMAC_ID_TX;
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(resource, &config);
}

static void setup_transfer_descriptor_tx(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.block_transfer_count = BUFFER_LEN;
    descriptor_config.source_address = (uint32_t)string + sizeof(string);
    descriptor_config.destination_address =
        (uint32_t)(&usart_instance.hw->USART.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}

static void configure_usart(void)
{
    struct usart_config config_usart;
    usart_get_config_defaults(&config_usart);

    config_usart.baudrate    = 9600;
    config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
    config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;

    while (usart_init(&usart_instance,
            EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
    }

    usart_enable(&usart_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_usart();

configure_dma_resource_rx(&usart_dma_resource_rx);
```

```
configure_dma_resource_tx(&usart_dma_resource_tx);

setup_transfer_descriptor_rx(&example_descriptor_rx);
setup_transfer_descriptor_tx(&example_descriptor_tx);

dma_add_descriptor(&usart_dma_resource_rx, &example_descriptor_rx);
dma_add_descriptor(&usart_dma_resource_tx, &example_descriptor_tx);

dma_register_callback(&usart_dma_resource_rx, transfer_done_rx,
        DMA_CALLBACK_TRANSFER_DONE);
dma_register_callback(&usart_dma_resource_tx, transfer_done_tx,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&usart_dma_resource_rx,
        DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&usart_dma_resource_tx,
        DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

Create variables

1. Create a module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   struct usart_module usart_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create module software instance structures for DMA resources to store the DMA resource state while it is in use.

   ```
   struct dma_resource usart_dma_resource_rx;
   struct dma_resource usart_dma_resource_tx;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
3. Create a buffer to store the data to be transferred /received.

   ```
   #define BUFFER_LEN    8
   static uint16_t string[BUFFER_LEN];
   ```
4. Create DMA transfer descriptors for RX/TX.

   ```
   COMPILER_ALIGNED(16)
   DmacDescriptor example_descriptor_rx SECTION_DMAC_DESCRIPTOR;
   DmacDescriptor example_descriptor_tx SECTION_DMAC_DESCRIPTOR;
   ```

Configure the USART

1. Create a USART module configuration struct, which can be filled out to adjust the configuration of a physical USART peripheral.

   ```
   struct usart_config config_usart;
   ```
2. Initialize the USART configuration struct with the module's default values.

   ```
   usart_get_config_defaults(&config_usart);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the USART settings to configure the physical pinout, baudrate, and other relevant parameters.

```
config_usart.baudrate    = 9600;
config_usart.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
config_usart.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
config_usart.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
config_usart.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
config_usart.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
```

4. Configure the USART module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
while (usart_init(&usart_instance,
        EDBG_CDC_MODULE, &config_usart) != STATUS_OK) {
}
```

5. Enable the USART module.

```
usart_enable(&usart_instance);
```

Configure DMA

1. Create a callback function of receiver done.

```
static void transfer_done_rx(struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_tx);
}
```

2. Create a callback function of transmission done.

```
static void transfer_done_tx(struct dma_resource* const resource )
{
    dma_start_transfer_job(&usart_dma_resource_rx);
}
```

3. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

4. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

5. Set extra configurations for the DMA resource. It is using peripheral trigger. SERCOM TX empty trigger causes a beat transfer in this example.

```
config.peripheral_trigger = EDBG_CDC_SERCOM_DMAC_ID_RX;
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

6. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

7. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

8. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

9. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = BUFFER_LEN;
descriptor_config.destination_address =
        (uint32_t)string + sizeof(string);
descriptor_config.source_address =
        (uint32_t)(&usart_instance.hw->USART.DATA.reg);
```

10. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

11. Create a DMA resource configuration structure for TX, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

12. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

13. Set extra configurations for the DMA resource. It is using peripheral trigger. SERCOM RX Ready trigger causes a beat transfer in this example.

```
config.peripheral_trigger = EDBG_CDC_SERCOM_DMAC_ID_TX;
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

14. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

15. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

16. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

17. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.block_transfer_count = BUFFER_LEN;
descriptor_config.source_address = (uint32_t)string + sizeof(string);
descriptor_config.destination_address =
    (uint32_t)(&usart_instance.hw->USART.DATA.reg);
```

18. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

18.8.3.2. Use Case

Code

Copy-paste the following code to your user application:

```
dma_start_transfer_job(&usart_dma_resource_rx);

while (true) {
}
```

Workflow

1. Wait for receiving data.

   ```
   dma_start_transfer_job(&usart_dma_resource_rx);
   ```

2. Enter endless loop.

   ```
   while (true) {
   }
   ```

18.8.4. Quick Start Guide for SERCOM USART LIN

The supported board list:

- SAMC21 Xplained Pro

This quick start will set up LIN frame format transmission according to your configuration `CONF_LIN_NODE_TYPE`. For LIN master, it will send LIN command after startup. For LIN salve, once received a format from LIN master with ID `LIN_ID_FIELD_VALUE`, it will reply four data bytes plus a checksum.

18.8.4.1. Setup

Prerequisites

When verify data transmission between LIN master and slave, two boards are needed: one is for LIN master and the other is for LIN slave. connect LIN master LIN PIN with LIN slave LIN PIN.

Code

Add to the main application source file, outside of any functions:

```
static struct usart_module cdc_instance,lin_instance;

#define LIN_ID_FIELD_VALUE 0x64

#define LIN_DATA_LEN 5
static uint8_t rx_buffer[LIN_DATA_LEN]={0};
const static uint8_t tx_buffer[LIN_DATA_LEN]={0x4a,0x55,0x93,0xe5,0xe6};
```

Copy-paste the following setup code to your user application:

```
static void configure_usart_cdc(void)
{

    struct usart_config config_cdc;
    usart_get_config_defaults(&config_cdc);
    config_cdc.baudrate    = 115200;
    config_cdc.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
    config_cdc.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
    config_cdc.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
    config_cdc.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
```

```
    config_cdc.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
    stdio_serial_init(&cdc_instance, EDBG_CDC_MODULE, &config_cdc);
    usart_enable(&cdc_instance);
}

static void lin_read_callback(struct usart_module *const usart_module)
{

    uint8_t i = 0;

    if (CONF_LIN_NODE_TYPE == LIN_MASTER_NODE) {
        for(i = 0; i < LIN_DATA_LEN; i++){
            if(rx_buffer[i] != tx_buffer[i]) {
                printf("Data error\r\n");
                break;
            }
        }
        if(i == LIN_DATA_LEN){
            printf("Slave response: OK\r\n");
        }
    } else if (CONF_LIN_NODE_TYPE == LIN_SLAVE_NODE) {
        if(rx_buffer[0] == LIN_ID_FIELD_VALUE) {
            usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_TX);
            printf("Receive ID field from mater: OK \r\n");
            usart_write_buffer_job(&lin_instance,
                (uint8_t *)tx_buffer, LIN_DATA_LEN);
        }
    }
}
static void lin_read_error_callback(struct usart_module *const usart_module)
{
      printf("Data Read error\r\n");
}

static void configure_usart_lin(void)
{

    struct port_config pin_conf;
    port_get_config_defaults(&pin_conf);
    pin_conf.direction  = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LIN_EN_PIN, &pin_conf);

    /* Enable LIN module*/
    port_pin_set_output_level(LIN_EN_PIN, 1);

    struct usart_config config_lin;
    usart_get_config_defaults(&config_lin);

    /* LIN frame format*/
    config_lin.lin_node = CONF_LIN_NODE_TYPE;
    config_lin.transfer_mode = USART_TRANSFER_ASYNCHRONOUSLY;
    config_lin.sample_rate = USART_SAMPLE_RATE_16X_FRACTIONAL;

    config_lin.baudrate = 115200;
    config_lin.mux_setting = LIN_USART_SERCOM_MUX_SETTING;
    config_lin.pinmux_pad0 = LIN_USART_SERCOM_PINMUX_PAD0;
    config_lin.pinmux_pad1 = LIN_USART_SERCOM_PINMUX_PAD1;
    config_lin.pinmux_pad2 = LIN_USART_SERCOM_PINMUX_PAD2;
    config_lin.pinmux_pad3 = LIN_USART_SERCOM_PINMUX_PAD3;

    /* Disable receiver and transmitter */
    config_lin.receiver_enable  = false;
    config_lin.transmitter_enable = false;
```

```
    if (CONF_LIN_NODE_TYPE == LIN_SLAVE_NODE) {
        config_lin.lin_slave_enable = true;
    }

    while (usart_init(&lin_instance,
        LIN_USART_MODULE, &config_lin) != STATUS_OK) {
    }

    usart_enable(&lin_instance);

    usart_register_callback(&lin_instance,
        lin_read_callback, USART_CALLBACK_BUFFER_RECEIVED);
    usart_enable_callback(&lin_instance, USART_CALLBACK_BUFFER_RECEIVED);
      usart_register_callback(&lin_instance,
        lin_read_error_callback, USART_CALLBACK_ERROR);
    usart_enable_callback(&lin_instance, USART_CALLBACK_ERROR);
    system_interrupt_enable_global();
}
```

Add to user application initialization (typically the start of `main()`):

```
system_init();
configure_usart_cdc();
```

Workflow

1. Create USART CDC and LIN module software instance structure for the USART module to store the USART driver state while it is in use.

   ```
   static struct usart_module cdc_instance,lin_instance;
   ```

2. Define LIN ID field for header format.

   ```
   #define LIN_ID_FIELD_VALUE 0x64
   ```

   Note: The ID `LIN_ID_FIELD_VALUE` is eight bits as [P1,P0,ID5...ID0], when it's 0x64, the data field length is four bytes plus a checksum byte.

3. Define LIN RX/TX buffer.

   ```
   #define LIN_DATA_LEN 5
   static uint8_t rx_buffer[LIN_DATA_LEN]={0};
   const static uint8_t tx_buffer[LIN_DATA_LEN]={0x4a,0x55,0x93,0xe5,0xe6};
   ```

   Note: For `tx_buffer` and `rx_buffer`, the last byte is for checksum.

4. Configure the USART CDC for output message.

   ```
   static void configure_usart_cdc(void)
   {

       struct usart_config config_cdc;
       usart_get_config_defaults(&config_cdc);
       config_cdc.baudrate    = 115200;
       config_cdc.mux_setting = EDBG_CDC_SERCOM_MUX_SETTING;
       config_cdc.pinmux_pad0 = EDBG_CDC_SERCOM_PINMUX_PAD0;
       config_cdc.pinmux_pad1 = EDBG_CDC_SERCOM_PINMUX_PAD1;
       config_cdc.pinmux_pad2 = EDBG_CDC_SERCOM_PINMUX_PAD2;
       config_cdc.pinmux_pad3 = EDBG_CDC_SERCOM_PINMUX_PAD3;
       stdio_serial_init(&cdc_instance, EDBG_CDC_MODULE, &config_cdc);
       usart_enable(&cdc_instance);
   }
   ```

5. Configure the USART LIN module.

```
static void lin_read_callback(struct usart_module *const usart_module)
{

    uint8_t i = 0;

    if (CONF_LIN_NODE_TYPE == LIN_MASTER_NODE) {
        for(i = 0; i < LIN_DATA_LEN; i++){
            if(rx_buffer[i] != tx_buffer[i]) {
                printf("Data error\r\n");
                break;
            }
        }
        if(i == LIN_DATA_LEN){
            printf("Slave response: OK\r\n");
        }
    } else if (CONF_LIN_NODE_TYPE == LIN_SLAVE_NODE) {
        if(rx_buffer[0] == LIN_ID_FIELD_VALUE) {

usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_TX);
            printf("Receive ID field from mater: OK \r\n");
            usart_write_buffer_job(&lin_instance,
                (uint8_t *)tx_buffer, LIN_DATA_LEN);
        }
    }
}
static void lin_read_error_callback(struct usart_module *const
usart_module)
{
      printf("Data Read error\r\n");
}

static void configure_usart_lin(void)
{

    struct port_config pin_conf;
    port_get_config_defaults(&pin_conf);
    pin_conf.direction  = PORT_PIN_DIR_OUTPUT;
    port_pin_set_config(LIN_EN_PIN, &pin_conf);

    /* Enable LIN module*/
    port_pin_set_output_level(LIN_EN_PIN, 1);

    struct usart_config config_lin;
    usart_get_config_defaults(&config_lin);

    /* LIN frame format*/
    config_lin.lin_node = CONF_LIN_NODE_TYPE;
    config_lin.transfer_mode = USART_TRANSFER_ASYNCHRONOUSLY;
    config_lin.sample_rate = USART_SAMPLE_RATE_16X_FRACTIONAL;

    config_lin.baudrate = 115200;
    config_lin.mux_setting = LIN_USART_SERCOM_MUX_SETTING;
    config_lin.pinmux_pad0 = LIN_USART_SERCOM_PINMUX_PAD0;
    config_lin.pinmux_pad1 = LIN_USART_SERCOM_PINMUX_PAD1;
    config_lin.pinmux_pad2 = LIN_USART_SERCOM_PINMUX_PAD2;
    config_lin.pinmux_pad3 = LIN_USART_SERCOM_PINMUX_PAD3;

    /* Disable receiver and transmitter */
    config_lin.receiver_enable  = false;
    config_lin.transmitter_enable = false;
```

```
    if (CONF_LIN_NODE_TYPE == LIN_SLAVE_NODE) {
        config_lin.lin_slave_enable = true;
    }

    while (usart_init(&lin_instance,
        LIN_USART_MODULE, &config_lin) != STATUS_OK) {
    }

    usart_enable(&lin_instance);

    usart_register_callback(&lin_instance,
        lin_read_callback, USART_CALLBACK_BUFFER_RECEIVED);
    usart_enable_callback(&lin_instance,
USART_CALLBACK_BUFFER_RECEIVED);
      usart_register_callback(&lin_instance,
        lin_read_error_callback, USART_CALLBACK_ERROR);
    usart_enable_callback(&lin_instance, USART_CALLBACK_ERROR);
    system_interrupt_enable_global();
}
```

Note: The LIN frame format can be configured as master or slave, refer to `CONF_LIN_NODE_TYPE`.

18.8.4.2. Use Case

Code

Copy-paste the following code to your user application:

```
configure_usart_lin();

if (CONF_LIN_NODE_TYPE == LIN_MASTER_NODE) {
    printf("LIN Works in Master Mode\r\n");
    if (lin_master_transmission_status(&lin_instance)) {
        usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_TX);
        lin_master_send_cmd(&lin_instance,LIN_MASTER_AUTO_TRANSMIT_CMD);
        usart_write_wait(&lin_instance,LIN_ID_FIELD_VALUE);
        usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_RX);
        while(1) {
            usart_read_buffer_job(&lin_instance,
            (uint8_t *)rx_buffer, 5);
        }
    }
} else {
    printf("LIN Works in Slave Mode\r\n");
    usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_RX);
    while(1) {
        usart_read_buffer_job(&lin_instance,
        (uint8_t *)rx_buffer, 1);
    }
}
```

Workflow

1. Set up USART LIN module.

   ```
   configure_usart_lin();
   ```

2. For LIN master, sending LIN command. For LIN slaver, start reading data .

   ```
   if (CONF_LIN_NODE_TYPE == LIN_MASTER_NODE) {
       printf("LIN Works in Master Mode\r\n");
       if (lin_master_transmission_status(&lin_instance)) {
   ```

```
        usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_TX);

lin_master_send_cmd(&lin_instance,LIN_MASTER_AUTO_TRANSMIT_CMD);
        usart_write_wait(&lin_instance,LIN_ID_FIELD_VALUE);
        usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_RX);
        while(1) {
            usart_read_buffer_job(&lin_instance,
            (uint8_t *)rx_buffer, 5);
        }
    }
} else {
    printf("LIN Works in Slave Mode\r\n");
    usart_enable_transceiver(&lin_instance,USART_TRANSCEIVER_RX);
    while(1) {
        usart_read_buffer_job(&lin_instance,
        (uint8_t *)rx_buffer, 1);
    }
}
```

18.9. SERCOM USART MUX Settings

The following lists the possible internal SERCOM module pad function assignments, for the four SERCOM pads when in USART mode. Note that this is in addition to the physical GPIO pin MUX of the device, and can be used in conjunction to optimize the serial data pin-out.

When TX and RX are connected to the same pin, the USART will operate in half-duplex mode if both one transmitter and several receivers are enabled.

Note: When RX and XCK are connected to the same pin, the receiver must not be enabled if the USART is configured to use an external clock.

MUX/Pad	PAD 0	PAD 1	PAD 2	PAD 3
RX_0_TX_0_XCK_1	TX / RX	XCK	-	-
RX_0_TX_2_XCK_3	RX	-	TX	XCK
RX_1_TX_0_XCK_1	TX	RX / XCK	-	-
RX_1_TX_2_XCK_3	-	RX	TX	XCK
RX_2_TX_0_XCK_1	TX	XCK	RX	-
RX_2_TX_2_XCK_3	-	-	TX / RX	XCK
RX_3_TX_0_XCK_1	TX	XCK	-	RX
RX_3_TX_2_XCK_3	-	-	TX	RX / XCK

19. SAM I²C Master Mode (SERCOM I2C) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's SERCOM I²C module, for the transfer of data via an I²C bus. The following driver API modes are covered by this manual:

- Master Mode Polled APIs
- Master Mode Callback APIs

The following peripheral is used by this module:

- SERCOM (Serial Communication Interface)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

19.1. Prerequisites

There are no prerequisites.

19.2. Module Overview

The outline of this section is as follows:

19.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_10_BIT_ADDRESS	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_SCL_STRETCH_MODE	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_SCL_EXTEND_TIMEOUT	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21

Note: The specific features are only available in the driver when the selected device supports those features.

Note: When using the I2C high-speed mode for off-board communication, there are various high frequency interference, which can lead to distortion of the signals and communication failure. When using Xplained Pro boards in order to test I2C high-speed communication, the following recommendation should be followed:

- Use the SDA-line on PA08 and SCL-line on PA09 for both boards. This will provide stronger pull-ups on both SDA and SCL.
- The SCL should not be higher than 1.5MHz.

19.2.2. Functional Description

The I^2C provides a simple two-wire bidirectional bus consisting of a wired-AND type serial clock line (SCL) and a wired-AND type serial data line (SDA).

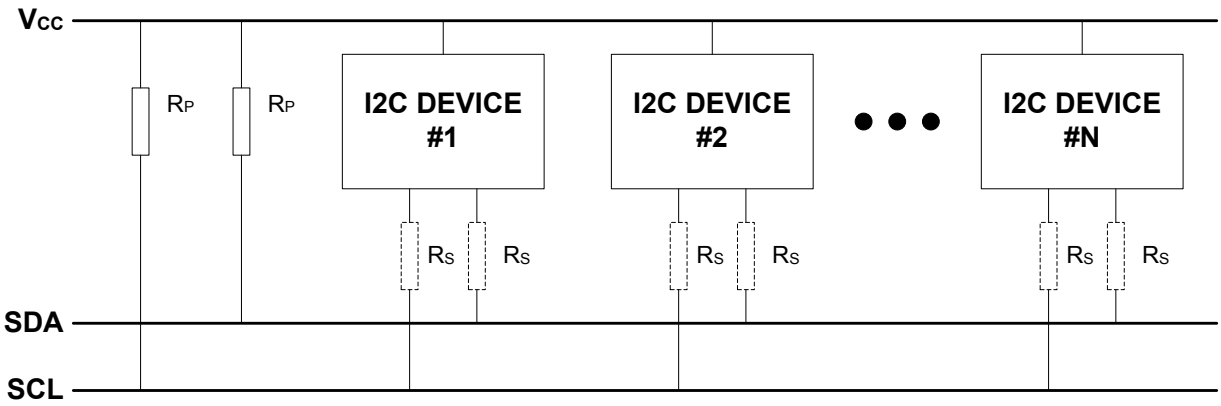
The I^2C bus provides a simple, but efficient method of interconnecting multiple master and slave devices. An arbitration mechanism is provided for resolving bus ownership between masters, as only one master device may own the bus at any given time. The arbitration mechanism relies on the wired-AND connections to avoid bus drivers short-circuiting.

A unique address is assigned to all slave devices connected to the bus. A device can contain both master and slave logic, and can emulate multiple slave devices by responding to more than one address.

19.2.3. Bus Topology

The I^2C bus topology is illustrated in Figure 19-1. The pull-up resistors (Rs) will provide a high level on the bus lines when none of the I^2C devices are driving the bus. These are optional, and can be replaced with a constant current source.

Figure 19-1. I²C Bus Topology



Note: R_S is optional

19.2.4. Transactions

The I²C standard defines three fundamental transaction formats:

- Master Write
  - The master transmits data packets to the slave after addressing it
- Master Read
  - The slave transmits data packets to the master after being addressed
- Combined Read/Write
  - A combined transaction consists of several write and read transactions

A data transfer starts with the master issuing a **Start** condition on the bus, followed by the address of the slave together with a bit to indicate whether the master wants to read from or write to the slave. The addressed slave must respond to this by sending an **ACK** back to the master.

After this, data packets are sent from the master or slave, according to the read/write bit. Each packet must be acknowledged (ACK) or not acknowledged (NACK) by the receiver.

If a slave responds with a NACK, the master must assume that the slave cannot receive any more data and cancel the write operation.

The master completes a transaction by issuing a **Stop** condition.

A master can issue multiple **Start** conditions during a transaction; this is then called a **Repeated Start** condition.

19.2.4.1. Address Packets

The slave address consists of seven bits. The 8th bit in the transfer determines the data direction (read or write). An address packet always succeeds a **Start** or **Repeated Start** condition. The 8th bit is handled in the driver, and the user will only have to provide the 7-bit address.

19.2.4.2. Data Packets

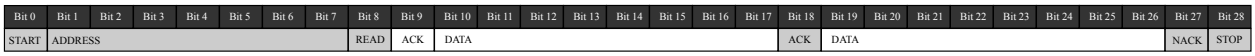
Data packets are nine bits long, consisting of one 8-bit data byte, and an acknowledgement bit. Data packets follow either an address packet or another data packet on the bus.

19.2.4.3. Transaction Examples

The gray bits in the following examples are sent from master to slave, and the white bits are sent from slave to master. Example of a read transaction is shown in Figure 19-2. Here, the master first issues a

Start condition and gets ownership of the bus. An address packet with the direction flag set to read is then sent and acknowledged by the slave. Then the slave sends one data packet which is acknowledged by the master. The slave sends another packet, which is not acknowledged by the master and indicates that the master will terminate the transaction. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 19-2. I²C Packet Read



Example of a write transaction is shown in Figure 19-3. Here, the master first issues a **Start** condition and gets ownership of the bus. An address packet with the dir flag set to write is then sent and acknowledged by the slave. Then the master sends two data packets, each acknowledged by the slave. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 19-3. I²C Packet Write

19.2.4.4. Packet Timeout

When a master sends an I²C packet, there is no way of being sure that a slave will acknowledge the packet. To avoid stalling the device forever while waiting for an acknowledge, a user selectable timeout is provided in the i2c_master_config struct which lets the driver exit a read or write operation after the specified time. The function will then return the STATUS_ERR_TIMEOUT flag.

This is also the case for the slave when using the functions postfixed `_wait`.

The time before the timeout occurs, will be the same as for unknown bus state timeout.

19.2.4.5. Repeated Start

To issue a **Repeated Start**, the functions postfixed `_no_stop` must be used. These functions will not send a **Stop** condition when the transfer is done, thus the next transfer will start with a **Repeated Start**. To end the transaction, the functions without the `_no_stop` postfix must be used for the last read/write.

19.2.5. Multi Master

In a multi master environment, arbitration of the bus is important, as only one master can own the bus at any point.

19.2.5.1. Arbitration

Clock stretching The serial clock line is always driven by a master device. However, all devices connected to the bus are allowed stretch the low period of the clock to slow down the overall clock frequency or to insert wait states while processing data. Both master and slave can randomly stretch the clock, which will force the other device into a wait-state until the clock line goes high again.

Arbitration on the data line If two masters start transmitting at the same time, they will both transmit until one master detects that the other master is pulling the data line low. When this is detected, the master not pulling the line low, will stop the transmission and wait until the bus is idle. As it is the master trying to contact the slave with the lowest address that will get the bus ownership, this will create an arbitration scheme always prioritizing the slaves with the lowest address in case of a bus collision.

19.2.5.2. Clock Synchronization

In situations where more than one master is trying to control the bus clock line at the same time, a clock synchronization algorithm based on the same principles used for clock stretching is necessary.

19.2.6. Bus States

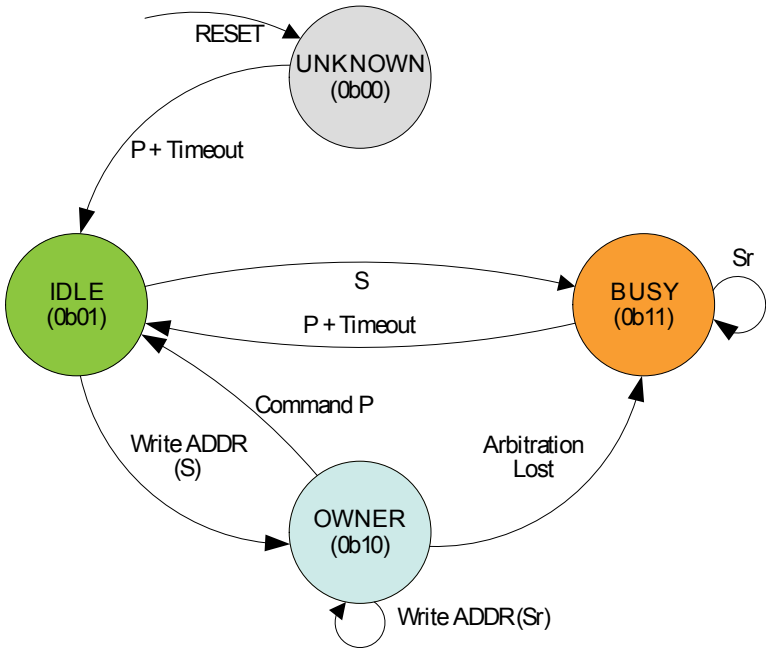
As the I²C bus is limited to one transaction at the time, a master that wants to perform a bus transaction must wait until the bus is free. Because of this, it is necessary for all masters in a multi-master system to know the current status of the bus to be able to avoid conflicts and to ensure data integrity.

- **IDLE** No activity on the bus (between a **Stop** and a new **Start** condition)
- **OWNER** If the master initiates a transaction successfully
- **BUSY** If another master is driving the bus
- **UNKNOWN** If the master has recently been enabled or connected to the bus. Is forced to **IDLE** after given timeout when the master module is enabled

The bus state diagram can be seen in Figure 19-4.

- S: Start condition
- P: Stop condition
- Sr: Repeated start condition

Figure 19-4. I²C Bus State Diagram



19.2.7. Bus Timing

Inactive bus timeout for the master and SDA hold time is configurable in the drivers.

19.2.7.1. Unknown Bus State Timeout

When a master is enabled or connected to the bus, the bus state will be unknown until either a given timeout or a stop command has occurred. The timeout is configurable in the i2c_master_config struct. The timeout time will depend on toolchain and optimization level used, as the timeout is a loop incrementing a value until it reaches the specified timeout value.

19.2.7.2. SDA Hold Timeout

When using the I²C in slave mode, it will be important to set a SDA hold time which assures that the master will be able to pick up the bit sent from the slave. The SDA hold time makes sure that this is the case by holding the data line low for a given period after the negative edge on the clock.

The SDA hold time is also available for the master driver, but is not a necessity.

19.2.8. Operation in Sleep Modes

The I²C module can operate in all sleep modes by setting the run_in_standby Boolean in the i2c_master_config or i2c_slave_config struct. The operation in slave and master mode is shown in Table 19-1.

Table 19-1. I²C Standby Operations

Run in standby	Slave	Master
false	Disabled, all reception is dropped	Generic Clock (GCLK) disabled when master is idle
true	Wake on address match when enabled	GCLK enabled while in sleep modes

19.3. Special Considerations

19.3.1. Interrupt-driven Operation

While an interrupt-driven operation is in progress, subsequent calls to a write or read operation will return the STATUS_BUSY flag, indicating that only one operation is allowed at any given time.

To check if another transmission can be initiated, the user can either call another transfer operation, or use the i2c_master_get_job_status/i2c_slave_get_job_status functions depending on mode.

If the user would like to get callback from operations while using the interrupt-driven driver, the callback must be registered and then enabled using the "register_callback" and "enable_callback" functions.

19.4. Extra Information

For extra information, see Extra Information for SERCOM I2C Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

19.5. Examples

For a list of examples related to this driver, see Examples for SERCOM I2C Driver.

19.6. API Overview

19.6.1. Structure Definitions

19.6.1.1. Struct i2c_master_config

This is the configuration structure for the I²C Master device. It is used as an argument for i2c_master_init to provide the desired configurations for the module. The structure should be initialized using the i2c_master_get_config_defaults.

Table 19-2. Members

Type	Name	Description
uint32_t	baud_rate	Baud rate (in KHz) for I²C operations in standard-mode, Fast-mode, and Fast-mode Plus Transfers, i2c_master_baud_rate
uint32_t	baud_rate_high_speed	Baud rate (in KHz) for I²C operations in High-speed mode, i2c_master_baud_rate
uint16_t	buffer_timeout	Timeout for packet write to wait for slave
enum gclk_generator	generator_source	GCLK generator to use as clock source
enum i2c_master_inactive_timeout	inactive_timeout	Inactive bus time out
bool	master_scl_low_extend_timeout	Set to enable maser SCL low extend time-out
uint32_t	pinmux_pad0	PAD0 (SDA) pinmux
uint32_t	pinmux_pad1	PAD1 (SCL) pinmux
bool	run_in_standby	Set to keep module active in sleep modes
bool	scl_low_timeout	Set to enable SCL low time-out
bool	scl_stretch_only_after_ack_bit	Set to enable SCL stretch only after ACK bit (required for high speed)
uint16_t	sda_scl_rise_time_ns	Get more accurate BAUD, considering rise time(required for standard-mode and Fast-mode)
bool	slave_scl_low_extend_timeout	Set to enable slave SCL low extend time-out

Type	Name	Description
enum i2c_master_start_hold_time	start_hold_time	Bus hold time after start signal on data line
enum i2c_master_transfer_speed	transfer_speed	Transfer speed mode
uint16_t	unknown_bus_state_timeout	Unknown bus state timeout

19.6.1.2. Struct i2c_master_module

SERCOM I²C Master driver software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

19.6.1.3. Struct i2c_master_packet

Structure to be used when transferring I²C master packets.

Table 19-3. Members

Type	Name	Description
uint16_t	address	Address to slave device
uint8_t *	data	Data array containing all data to be transferred
uint16_t	data_length	Length of data array
bool	high_speed	Use high speed transfer. Set to false if the feature is not supported by the device
uint8_t	hs_master_code	High speed mode master code (0000 1XXX), valid when high_speed is true
bool	ten_bit_address	Use 10-bit addressing. Set to false if the feature is not supported by the device

19.6.2. Macro Definitions

19.6.2.1. Driver Feature Definition

Define SERCOM I²C driver features set according to different device family.

Macro FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED

```
#define FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED
```

Fast mode plus and high speed support.

Macro FEATURE_I2C_10_BIT_ADDRESS

```
#define FEATURE_I2C_10_BIT_ADDRESS
```

10-bit address support

Macro FEATURE_I2C_SCL_STRETCH_MODE

```
#define FEATURE_I2C_SCL_STRETCH_MODE
```

SCL stretch mode support

Macro FEATURE_I2C_SCL_EXTEND_TIMEOUT

```
#define FEATURE_I2C_SCL_EXTEND_TIMEOUT
```

SCL extend timeout support

Macro FEATURE_I2C_DMA_SUPPORT

```
#define FEATURE_I2C_DMA_SUPPORT
```

19.6.3. Function Definitions

19.6.3.1. Lock/Unlock

Function i2c_master_lock()

Attempt to get lock on driver instance.

```
enum status_code i2c_master_lock(
        struct i2c_master_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 19-4. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 19-5. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

Function i2c_master_unlock()

Unlock driver instance.

```
void i2c_master_unlock(
        struct i2c_master_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 19-6. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 19-7. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

19.6.3.2. Configuration and Initialization

Function i2c_master_is_syncing()

Returns the synchronization status of the module.

```
bool i2c_master_is_syncing(
        const struct i2c_master_module *const module)
```

Returns the synchronization status of the module.

Table 19-8. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns
Status of the synchronization.

Table 19-9. Return Values

Return value	Description
true	Module is busy synchronizing
false	Module is not synchronizing

Function i2c_master_get_config_defaults()

Gets the I^2C master default configurations.

```
void i2c_master_get_config_defaults(
        struct i2c_master_config *const config)
```

Use to initialize the configuration structure to known default values.

The default configuration is as follows:

- Baudrate 100KHz
- GCLK generator 0
- Do not run in standby
- Start bit hold time 300ns - 600ns
- Buffer timeout = 65535
- Unknown bus status timeout = 65535
- Do not run in standby
- PINMUX_DEFAULT for SERCOM pads

Those default configuration only available if the device supports it:

- High speed baudrate 3.4MHz

- Standard-mode and Fast-mode transfer speed
- SCL stretch disabled
- Slave SCL low extend time-out disabled
- Master SCL low extend time-out disabled

Table 19-10. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration structure to be initiated

Function i2c_master_init()

Initializes the requested I²C hardware module.

```
enum status_code i2c_master_init(
        struct i2c_master_module *const module,
        Sercom *const hw,
        const struct i2c_master_config *const config)
```

Initializes the SERCOM I²C master device requested and sets the provided software module struct. Run this function before any further use of the driver.

Table 19-11. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module struct
[in]	hw	Pointer to the hardware instance
[in]	config	Pointer to the configuration struct

Returns
Status of initialization.

Table 19-12. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting
STATUS_ERR_ALREADY_INITIALIZED	If setting other GCLK generator than previously set
STATUS_ERR_BAUDRATE_UNAVAILABLE	If given baudrate is not compatible with set GCLK frequency

Function i2c_master_enable()

Enables the I²C module.

```
void i2c_master_enable(
        const struct i2c_master_module *const module)
```

Enables the requested I²C module and set the bus state to IDLE after the specified timeout period if no stop bit is detected.

Table 19-13. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_master_disable()

Disable the I²C module.

```
void i2c_master_disable(
        const struct i2c_master_module *const module)
```

Disables the requested I²C module.

Table 19-14. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_master_reset()

Resets the hardware module.

```
void i2c_master_reset(
        struct i2c_master_module *const module)
```

Reset the module to hardware defaults.

Table 19-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

19.6.3.3. Read and Write

Function i2c_master_read_packet_wait()

Reads data packet from slave.

```
enum status_code i2c_master_read_packet_wait(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I²C bus and sends a stop condition when finished.

Note: This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 19-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of reading packet.

Table 19-17. Return Values

Return value	Description
STATUS_OK	The packet was read successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_read_packet_wait_no_stop()

Reads data packet from slave without sending a stop condition when done.

```
enum status_code i2c_master_read_packet_wait_no_stop(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I²C bus without sending a stop condition when done, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition must be performed.

Note: This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 19-18. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of reading packet.

Table 19-19. Return Values

Return value	Description
STATUS_OK	The packet was read successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period

Return value	Description
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_write_packet_wait()

Writes data packet to slave.

```
enum status_code i2c_master_write_packet_wait(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I²C bus and sends a stop condition when finished.

Note: This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 19-20. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns

Status of write packet.

Table 19-21. Return Values

Return value	Description
STATUS_OK	If packet was write successfully
STATUS_BUSY	If master module is busy with a job
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave does not want more data and was not able to read last data sent

Function i2c_master_write_packet_wait_no_stop()

Writes data packet to slave without sending a stop condition when done.

```
enum status_code i2c_master_write_packet_wait_no_stop(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I²C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition or sending a stop with the i2c_master_send_stop function must be performed.

Note: This will stall the device from any other operation. For interrupt-driven operation, see i2c_master_read_packet_job.

Table 19-22. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of write packet.

Table 19-23. Return Values

Return value	Description
STATUS_OK	If packet was write successfully
STATUS_BUSY	If master module is busy
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave do not want more data

Function i2c_master_send_stop()

Sends stop condition on bus.

```
void i2c_master_send_stop(
        struct i2c_master_module *const module)
```

Sends a stop condition on bus.

Note: This function can only be used after the i2c_master_write_packet_wait_no_stop function. If a stop condition is to be sent after a read, the i2c_master_read_packet_wait function must be used.

Table 19-24. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function i2c_master_send_nack()

Sends nack signal on bus.

```
void i2c_master_send_nack(
        struct i2c_master_module *const module)
```

Sends a nack signal on bus.

Note: This function can only be used after the i2c_master_write_packet_wait_no_nack function, or i2c_master_read_byte function.

Table 19-25. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function i2c_master_read_byte()

Reads one byte data from slave.

```
enum status_code i2c_master_read_byte(
        struct i2c_master_module *const module,
        uint8_t * byte)
```

Table 19-26. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[out]	byte	Read one byte data to slave

Returns
Status of reading byte.

Table 19-27. Return Values

Return value	Description
STATUS_OK	One byte was read successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_write_byte()

Write one byte data to slave.

```
enum status_code i2c_master_write_byte(
        struct i2c_master_module *const module,
        uint8_t byte)
```

Table 19-28. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in]	byte	Send one byte data to slave

Returns
Status of writing byte.

Table 19-29. Return Values

Return value	Description
STATUS_OK	One byte was write successfully
STATUS_ERR_TIMEOUT	If no response was given within specified timeout period
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address

Function i2c_master_read_packet_wait_no_nack()

```
enum status_code i2c_master_read_packet_wait_no_nack(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

19.6.3.4. SERCOM I²C Master with DMA Interfaces

Function i2c_master_dma_set_transfer()

Set I²C for DMA transfer with slave address and transfer size.

```
void i2c_master_dma_set_transfer(
        struct i2c_master_module *const module,
        uint16_t addr,
        uint8_t length,
        enum i2c_transfer_direction direction)
```

This function will set the slave address, transfer size and enable the auto transfer mode for DMA.

Table 19-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock
[in]	addr	I²C slave address
[in]	length	I²C transfer length with DMA
[in]	direction	I²C transfer direction

19.6.3.5. Callbacks

Function i2c_master_register_callback()

Registers callback for the specified callback type.

```
void i2c_master_register_callback(
        struct i2c_master_module *const module,
        i2c_master_callback_t callback,
        enum i2c_master_callback callback_type)
```

Associates the given callback function with the specified callback type.

To enable the callback, the i2c_master_enable_callback function must be used.

Table 19-31. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Function i2c_master_unregister_callback()

Unregisters callback for the specified callback type.

```
void i2c_master_unregister_callback(
        struct i2c_master_module *const module,
        enum i2c_master_callback callback_type)
```

When called, the currently registered callback for the given callback type will be removed.

Table 19-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Specifies the callback type to unregister

Function i2c_master_enable_callback()

Enables callback.

```
void i2c_master_enable_callback(
        struct i2c_master_module *const module,
        enum i2c_master_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 19-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to enable

Function i2c_master_disable_callback()

Disables callback.

```
void i2c_master_disable_callback(
        struct i2c_master_module *const module,
        enum i2c_master_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 19-34. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to disable

19.6.3.6. Read and Write, Interrupt-driven

Function i2c_master_read_bytes()

```
enum status_code i2c_master_read_bytes(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Function i2c_master_read_packet_job()

Initiates a read packet operation.

```
enum status_code i2c_master_read_packet_job(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I^{2}C bus. This is the non-blocking equivalent of i2c_master_read_packet_wait.

Table 19-35. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^{2}C packet to transfer

Returns

Status of starting reading I^{2}C packet.

Table 19-36. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_master_read_packet_job_no_stop()

Initiates a read packet operation without sending a STOP condition when done.

```
enum status_code i2c_master_read_packet_job_no_stop(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I²C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition must be performed.

This is the non-blocking equivalent of i2c_master_read_packet_wait_no_stop.

Table 19-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns

Status of starting reading I²C packet.

Table 19-38. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another operation

Function i2c_master_read_packet_job_no_nack()

Initiates a read packet operation without sending a NACK signal and a STOP condition when done.

```
enum status_code i2c_master_read_packet_job_no_nack(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Reads a data packet from the specified slave address on the I²C bus without sending a nack and a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition must be performed.

This is the non-blocking equivalent of i2c_master_read_packet_wait_no_stop.

Table 19-39. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns

Status of starting reading I²C packet.

Table 19-40. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another operation

Function i2c_master_write_bytes()

```
enum status_code i2c_master_write_bytes(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Function i2c_master_write_packet_job()

Initiates a write packet operation.

```
enum status_code i2c_master_write_packet_job(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I²C bus. This is the non-blocking equivalent of i2c_master_write_packet_wait.

Table 19-41. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of starting writing I²C packet job.

Table 19-42. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_master_write_packet_job_no_stop()

Initiates a write packet operation without sending a STOP condition when done.

```
enum status_code i2c_master_write_packet_job_no_stop(
        struct i2c_master_module *const module,
        struct i2c_master_packet *const packet)
```

Writes a data packet to the specified slave address on the I²C bus without sending a stop condition, thus retaining ownership of the bus when done. To end the transaction, a read or write with stop condition or sending a stop with the i2c_master_send_stop function must be performed.

This is the non-blocking equivalent of i2c_master_write_packet_wait_no_stop.

Table 19-43. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of starting writing I²C packet job.

Table 19-44. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another

Function i2c_master_cancel_job()

Cancel any currently ongoing operation.

```
void i2c_master_cancel_job(
        struct i2c_master_module *const module)
```

Terminates the running transfer operation.

Table 19-45. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_master_get_job_status()

Get status from ongoing job.

```
enum status_code i2c_master_get_job_status(
        struct i2c_master_module *const module)
```

Will return the status of a transfer operation.

Table 19-46. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns
Last status code from transfer operation.

Table 19-47. Return Values

Return value	Description
STATUS_OK	No error has occurred
STATUS_BUSY	If transfer is in progress

Return value	Description
STATUS_BUSY	If master module is busy
STATUS_ERR_DENIED	If error on bus
STATUS_ERR_PACKET_COLLISION	If arbitration is lost
STATUS_ERR_BAD_ADDRESS	If slave is busy, or no slave acknowledged the address
STATUS_ERR_TIMEOUT	If timeout occurred
STATUS_ERR_OVERFLOW	If slave did not acknowledge last sent data, indicating that slave does not want more data and was not able to read

19.6.4. Enumeration Definitions

19.6.4.1. Enum i2c_master_baud_rate

Values for I^{2}C speeds supported by the module. The driver will also support setting any other value, in which case set the value in the i2c_master_config at desired value divided by 1000.

Example: If 10KHz operation is required, give baud_rate in the configuration structure the value 10.

Table 19-48. Members

Enum value	Description
I2C_MASTER_BAUD_RATE_100KHZ	Baud rate at 100KHz (Standard-mode)
I2C_MASTER_BAUD_RATE_400KHZ	Baud rate at 400KHz (Fast-mode)
I2C_MASTER_BAUD_RATE_1000KHZ	Baud rate at 1MHz (Fast-mode Plus)
I2C_MASTER_BAUD_RATE_3400KHZ	Baud rate at 3.4MHz (High-speed mode)

19.6.4.2. Enum i2c_master_callback

The available callback types for the I^{2}C master module.

Table 19-49. Members

Enum value	Description
I2C_MASTER_CALLBACK_WRITE_COMPLETE	Callback for packet write complete
I2C_MASTER_CALLBACK_READ_COMPLETE	Callback for packet read complete
I2C_MASTER_CALLBACK_ERROR	Callback for error

19.6.4.3. Enum i2c_master_inactive_timeout

If the inactive bus time-out is enabled and the bus is inactive for longer than the time-out setting, the bus state logic will be set to idle.

Table 19-50. Members

Enum value	Description
I2C_MASTER_INACTIVE_TIMEOUT_DISABLED	Inactive bus time-out disabled
I2C_MASTER_INACTIVE_TIMEOUT_55US	Inactive bus time-out 5-6 SCL cycle time-out
I2C_MASTER_INACTIVE_TIMEOUT_105US	Inactive bus time-out 10-11 SCL cycle time-out
I2C_MASTER_INACTIVE_TIMEOUT_205US	Inactive bus time-out 20-21 SCL cycle time-out

19.6.4.4. Enum i2c_master_interrupt_flag

Flags used when reading or setting interrupt flags.

Table 19-51. Members

Enum value	Description
I2C_MASTER_INTERRUPT_WRITE	Interrupt flag used for write
I2C_MASTER_INTERRUPT_READ	Interrupt flag used for read

19.6.4.5. Enum i2c_master_start_hold_time

Values for the possible I^2C master mode SDA internal hold times after start bit has been sent.

Table 19-52. Members

Enum value	Description
I2C_MASTER_START_HOLD_TIME_DISABLED	Internal SDA hold time disabled
I2C_MASTER_START_HOLD_TIME_50NS_100NS	Internal SDA hold time 50ns - 100ns
I2C_MASTER_START_HOLD_TIME_300NS_600NS	Internal SDA hold time 300ns - 600ns
I2C_MASTER_START_HOLD_TIME_400NS_800NS	Internal SDA hold time 400ns - 800ns

19.6.4.6. Enum i2c_master_transfer_speed

Enum for the transfer speed.

Table 19-53. Members

Enum value	Description
I2C_MASTER_SPEED_STANDARD_AND_FAST	Standard-mode (Sm) up to 100KHz and Fast-mode (Fm) up to 400KHz
I2C_MASTER_SPEED_FAST_MODE_PLUS	Fast-mode Plus (Fm+) up to 1MHz
I2C_MASTER_SPEED_HIGH_SPEED	High-speed mode (Hs-mode) up to 3.4MHz

19.6.4.7. Enum i2c_transfer_direction

For master: transfer direction or setting direction bit in address. For slave: direction of request from master.

Table 19-54. Members

Enum value	Description
I2C_TRANSFER_WRITE	Master write operation is in progress
I2C_TRANSFER_READ	Master read operation is in progress

19.7. Extra Information for SERCOM I²C Driver

19.7.1. Acronyms

Table 19-55 is a table listing the acronyms used in this module, along with their intended meanings.

Table 19-55. Acronyms

Acronym	Description
SDA	Serial Data Line
SCL	Serial Clock Line
SERCOM	Serial Communication Interface
DMA	Direct Memory Access

19.7.2. Dependencies

The I²C driver has the following dependencies:

- System Pin Multiplexer Driver

19.7.3. Errata

There are no errata related to this driver.

19.7.4. Module History

Table 19-56 is an overview of the module history, detailing enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version listed in Table 19-56.

Table 19-56. Module History

Changelog
• Added 10-bit addressing and high speed support in SAM D21 • Separate structure i2c_packet into i2c_master_packet and i2c_slave packet
• Added support for SCL stretch and extended timeout hardware features in SAM D21 • Added fast mode plus support in SAM D21
Fixed incorrect logical mask for determining if a bus error has occurred in I²C Slave mode
Initial Release

19.8. Examples for SERCOM I2C Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM I2C Master Mode (SERCOM I2C) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the I2C Master module - Basic Use Case
  - Quick Start Guide for the I2C Master module - Callback Use Case
- Quick Start Guide for the I2C Master module - DMA Use Case

19.8.1. Quick Start Guide for SERCOM I2C Master - Basic

In this use case, the I2C will used and set up as follows:

- Master mode
- 100KHz operation speed
- Not operational in standby
- 10000 packet timeout value
- 65535 unknown bus state timeout value

19.8.1.1. Prerequisites

The device must be connected to an I2C slave.

19.8.1.2. Setup

Code

The following must be added to the user application:

- A sample buffer to send, a sample buffer to read:

```
#define DATA_LENGTH 10
static uint8_t write_buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};

static uint8_t read_buffer[DATA_LENGTH];
```

- Slave address to access:

```
#define SLAVE_ADDRESS 0x12
```

- Number of times to try to send packet if it fails:

```
#define TIMEOUT 1000
```

- Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

- Function for setting up the module:

```
void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;
```

```
#if SAMR30
    config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
    config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
#endif
    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

- Add to user application `main()`:

```
/* Configure device and enable. */
configure_i2c_master();

/* Timeout counter. */
uint16_t timeout = 0;

/* Init i2c packet. */
struct i2c_master_packet packet = {
    .address      = SLAVE_ADDRESS,
    .data_length = DATA_LENGTH,
    .data         = write_buffer,
    .ten_bit_address = false,
    .high_speed      = false,
    .hs_master_code  = 0x0,
};
```

Workflow

1. Configure and enable module.

```
void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;
#if SAMR30
    config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
    config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
#endif
    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

   1. Create and initialize configuration structure.

```
struct i2c_master_config config_i2c_master;
i2c_master_get_config_defaults(&config_i2c_master);
```

   2. Change settings in the configuration.

```
config_i2c_master.buffer_timeout = 10000;
#if SAMR30
    config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
#endif
```

3. Initialize the module with the set configurations.

```
i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master);
```

4. Enable the module.

```
i2c_master_enable(&i2c_master_instance);
```

2. Create a variable to see when we should stop trying to send packet.

```
uint16_t timeout = 0;
```

3. Create a packet to send.

```
struct i2c_master_packet packet = {
    .address     = SLAVE_ADDRESS,
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
    .ten_bit_address = false,
    .high_speed      = false,
    .hs_master_code  = 0x0,
};
```

19.8.1.3. Implementation

Code

Add to user application `main()`:

```
/* Write buffer to slave until success. */
while (i2c_master_write_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}

/* Read from slave until success. */
packet.data = read_buffer;
while (i2c_master_read_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}
```

Workflow

1. Write packet to slave.

```
while (i2c_master_write_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}
```

The module will try to send the packet TIMEOUT number of times or until it is successfully sent.

2. Read packet from slave.

```
packet.data = read_buffer;
while (i2c_master_read_packet_wait(&i2c_master_instance, &packet) !=
        STATUS_OK) {
    /* Increment timeout counter and check if timed out. */
    if (timeout++ == TIMEOUT) {
        break;
    }
}
```

The module will try to read the packet TIMEOUT number of times or until it is successfully read.

19.8.2. Quick Start Guide for SERCOM I²C Master - Callback

In this use case, the I²C will used and set up as follows:

- Master mode
- 100KHz operation speed
- Not operational in standby
- 65535 unknown bus state timeout value

19.8.2.1. Prerequisites

The device must be connected to an I²C slave.

19.8.2.2. Setup

Code

The following must be added to the user application:

A sample buffer to write from, a reversed buffer to write from and length of buffers.

```
#define DATA_LENGTH 8

static uint8_t wr_buffer[DATA_LENGTH] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07
};

static uint8_t wr_buffer_reversed[DATA_LENGTH] = {
    0x07, 0x06, 0x05, 0x04, 0x03, 0x02, 0x01, 0x00
};

static uint8_t rd_buffer[DATA_LENGTH];
```

Address of slave:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

Globally accessible packet:

```
struct i2c_master_packet wr_packet;
struct i2c_master_packet rd_packet;
```

Function for setting up module:

```
void configure_i2c(void)
{
    /* Initialize config structure and software module */
```

```
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer */
    config_i2c_master.buffer_timeout = 65535;
#if SAMR30
    config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
    config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
#endif

    /* Initialize and enable device with config */
    while(i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master)      \
            != STATUS_OK);

    i2c_master_enable(&i2c_master_instance);
}
```

Callback function for write complete:

```
void i2c_write_complete_callback(
        struct i2c_master_module *const module)
{
    /* Initiate new packet read */
    i2c_master_read_packet_job(&i2c_master_instance,&rd_packet);
}
```

Function for setting up the callback functionality of the driver:

```
void configure_i2c_callbacks(void)
{
    /* Register callback function. */
    i2c_master_register_callback(&i2c_master_instance,
i2c_write_complete_callback,
            I2C_MASTER_CALLBACK_WRITE_COMPLETE);
    i2c_master_enable_callback(&i2c_master_instance,
            I2C_MASTER_CALLBACK_WRITE_COMPLETE);
}
```

Add to user application `main()`:

```
/* Configure device and enable. */
configure_i2c();
/* Configure callbacks and enable. */
configure_i2c_callbacks();
```

Workflow

1. Configure and enable module.

   ```
   configure_i2c();
   ```

   1. Create and initialize configuration structure.

      ```
      struct i2c_master_config config_i2c_master;
      i2c_master_get_config_defaults(&config_i2c_master);
      ```

   2. Change settings in the configuration.

      ```
      config_i2c_master.buffer_timeout = 65535;
      #if SAMR30
          config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
      config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
      #endif
      ```

3. Initialize the module with the set configurations.

```
while(i2c_master_init(&i2c_master_instance,
CONF_I2C_MASTER_MODULE, &config_i2c_master)      \
        != STATUS_OK);
```

4. Enable the module.

```
i2c_master_enable(&i2c_master_instance);
```

2. Configure callback functionality.

```
configure_i2c_callbacks();
```

1. Register write complete callback.

```
i2c_master_register_callback(&i2c_master_instance,
i2c_write_complete_callback,
        I2C_MASTER_CALLBACK_WRITE_COMPLETE);
```

2. Enable write complete callback.

```
i2c_master_enable_callback(&i2c_master_instance,
        I2C_MASTER_CALLBACK_WRITE_COMPLETE);
```

3. Create a packet to send to slave.

```
wr_packet.address     = SLAVE_ADDRESS;
wr_packet.data_length = DATA_LENGTH;
wr_packet.data        = wr_buffer;
```

19.8.2.3. Implementation

Code

Add to user application `main()`:

```
while (true) {
    /* Infinite loop */
    if (!port_pin_get_input_level(BUTTON_0_PIN)) {
        while (!port_pin_get_input_level(BUTTON_0_PIN)) {
            /* Waiting for button steady */
        }
        /* Send every other packet with reversed data */
        if (wr_packet.data[0] == 0x00) {
            wr_packet.data = &wr_buffer_reversed[0];
        } else {
            wr_packet.data = &wr_buffer[0];
        }
        i2c_master_write_packet_job(&i2c_master_instance, &wr_packet);
    }
}
```

Workflow

1. Write packet to slave.

```
wr_packet.address     = SLAVE_ADDRESS;
wr_packet.data_length = DATA_LENGTH;
wr_packet.data        = wr_buffer;
```

2. Infinite while loop, while waiting for interaction with slave.

```
while (true) {
    /* Infinite loop */
    if (!port_pin_get_input_level(BUTTON_0_PIN)) {
```

```
        while (!port_pin_get_input_level(BUTTON_0_PIN)) {
            /* Waiting for button steady */
        }
        /* Send every other packet with reversed data */
        if (wr_packet.data[0] == 0x00) {
            wr_packet.data = &wr_buffer_reversed[0];
        } else {
            wr_packet.data = &wr_buffer[0];
        }
        i2c_master_write_packet_job(&i2c_master_instance, &wr_packet);
    }
}
```

19.8.2.4. Callback

Each time a packet is sent, the callback function will be called.

Workflow

- Write complete callback:
  1. Send every other packet in reversed order.

```
if (wr_packet.data[0] == 0x00) {
    wr_packet.data = &wr_buffer_reversed[0];
} else {
    wr_packet.data = &wr_buffer[0];
}
```

  2. Write new packet to slave.

```
wr_packet.address     = SLAVE_ADDRESS;
wr_packet.data_length = DATA_LENGTH;
wr_packet.data        = wr_buffer;
```

19.8.3. Quick Start Guide for Using DMA with SERCOM I²C Master

The supported board list:

- SAMD21 Xplained Pro
- SAMR21 Xplained Pro
- SAML21 Xplained Pro
- SAML22 Xplained Pro
- SAMDA1 Xplained Pro
- SAMC21 Xplained Pro

In this use case, the I²C will used and set up as follows:

- Master mode
- 100KHz operation speed
- Not operational in standby
- 10000 packet timeout value
- 65535 unknown bus state timeout value

19.8.3.1. Prerequisites

The device must be connected to an I²C slave.

19.8.3.2. Setup

Code

The following must be added to the user application:

- A sample buffer to send, number of entries to send and address of slave:

```
#define DATA_LENGTH 10
static uint8_t buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};

#define SLAVE_ADDRESS 0x12
```

Number of times to try to send packet if it fails:

```
#define TIMEOUT 1000
```

- Globally accessible module structure:

```
struct i2c_master_module i2c_master_instance;
```

- Function for setting up the module:

```
static void configure_i2c_master(void)
{
    /* Initialize config structure and software module. */
    struct i2c_master_config config_i2c_master;
    i2c_master_get_config_defaults(&config_i2c_master);

    /* Change buffer timeout to something longer. */
    config_i2c_master.buffer_timeout = 10000;
#if SAMR30
config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
config_i2c_master.pinmux_pad1    = CONF_MASTER_SCK_PINMUX;
#endif

    /* Initialize and enable device with config. */
    i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master);

    i2c_master_enable(&i2c_master_instance);
}
```

- Globally accessible DMA module structure:

```
struct dma_resource example_resource;
```

- Globally transfer done flag:

```
static volatile bool transfer_is_done = false;
```

- Globally accessible DMA transfer descriptor:

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;
```

- Function for transfer done callback:

```
static void transfer_done(struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}
```

- Function for setting up the DMA resource:

```
static void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;
```

```
    dma_get_config_defaults(&config);

    config.peripheral_trigger = CONF_I2C_DMA_TRIGGER;
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(resource, &config);
}
```

- Function for setting up the DMA transfer descriptor:

```
static void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.block_transfer_count = DATA_LENGTH;
    descriptor_config.source_address = (uint32_t)buffer + DATA_LENGTH;
    descriptor_config.destination_address =
            (uint32_t)(&i2c_master_instance.hw->I2CM.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

- Add to user application `main()`:

```
configure_i2c_master();

configure_dma_resource(&example_resource);
setup_dma_descriptor(&example_descriptor);
dma_add_descriptor(&example_resource, &example_descriptor);
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&example_resource, DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

1. Configure and enable module:

```
configure_i2c_master();
```

   1. Create and initialize configuration structure.

```
struct i2c_master_config config_i2c_master;
i2c_master_get_config_defaults(&config_i2c_master);
```

   2. Change settings in the configuration.

```
config_i2c_master.buffer_timeout = 10000;
#if SAMR30
config_i2c_master.pinmux_pad0    = CONF_MASTER_SDA_PINMUX;
config_i2c_master.pinmux_pad1 = CONF_MASTER_SCK_PINMUX;
#endif
```

   3. Initialize the module with the set configurations.

```
i2c_master_init(&i2c_master_instance, CONF_I2C_MASTER_MODULE,
&config_i2c_master);
```

   4. Enable the module.

```
i2c_master_enable(&i2c_master_instance);
```

2. Configure DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set extra configurations for the DMA resource. It is using peripheral trigger. SERCOM TX trigger causes a transaction transfer in this example.

```
config.peripheral_trigger = CONF_I2C_DMA_TRIGGER;
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
descriptor_config.dst_increment_enable = false;
descriptor_config.block_transfer_count = DATA_LENGTH;
descriptor_config.source_address = (uint32_t)buffer + DATA_LENGTH;
descriptor_config.destination_address =
        (uint32_t)(&i2c_master_instance.hw->I2CM.DATA.reg);
```

8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

19.8.3.3. Implementation

Code

Add to user application `main()`:

```
dma_start_transfer_job(&example_resource);

i2c_master_dma_set_transfer(&i2c_master_instance, SLAVE_ADDRESS,
        DATA_LENGTH, I2C_TRANSFER_WRITE);

while (!transfer_is_done) {
    /* Wait for transfer done */
}

while (true) {
}
```

Workflow

1. Start the DMA transfer job.

```
dma_start_transfer_job(&example_resource);
```

2. Set the auto address length and enable flag.

```
i2c_master_dma_set_transfer(&i2c_master_instance, SLAVE_ADDRESS,
        DATA_LENGTH, I2C_TRANSFER_WRITE);
```

3. Waiting for transfer complete.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

4. Enter an infinite loop once transfer complete.

```
while (true) {
}
```

20. SAM I²C Slave Mode (SERCOM I2C) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's SERCOM I²C module, for the transfer of data via an I²C bus. The following driver API modes are covered by this manual:

- Slave Mode Polled APIs
- Slave Mode Callback APIs

The following peripheral is used by this module:

- SERCOM (Serial Communication Interface)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

20.1. Prerequisites

There are no prerequisites.

20.2. Module Overview

The outline of this section is as follows:

20.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_10_BIT_ADDRESS	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_SCL_STRETCH_MODE	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21
FEATURE_I2C_SCL_EXTEND_TIMEOUT	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21

Note: The specific features are only available in the driver when the selected device supports those features.

Note: When using the I2C high-speed mode for off-board communication, there are various high frequency interference, which can lead to distortion of the signals and communication failure. When using Xplained Pro boards in order to test I2C high-speed communication, the following recommendation should be followed:

- Use the SDA-line on PA08 and SCL-line on PA09 for both boards. This will provide stronger pull-ups on both SDA and SCL.
- The SCL should not be higher than 1.5MHz.

20.2.2. Functional Description

The I^2C provides a simple two-wire bidirectional bus consisting of a wired-AND type serial clock line (SCL) and a wired-AND type serial data line (SDA).

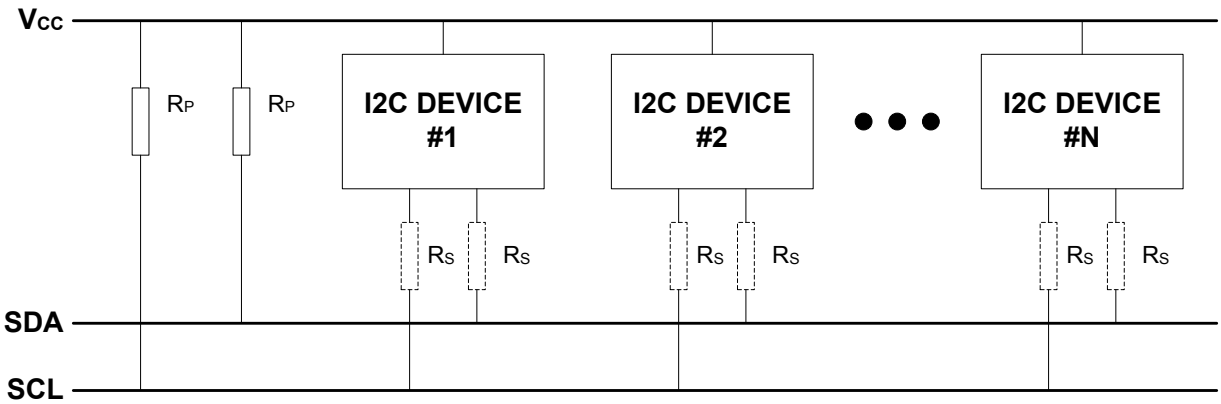
The I^2C bus provides a simple, but efficient method of interconnecting multiple master and slave devices. An arbitration mechanism is provided for resolving bus ownership between masters, as only one master device may own the bus at any given time. The arbitration mechanism relies on the wired-AND connections to avoid bus drivers short-circuiting.

A unique address is assigned to all slave devices connected to the bus. A device can contain both master and slave logic, and can emulate multiple slave devices by responding to more than one address.

20.2.3. Bus Topology

The I^2C bus topology is illustrated in Figure 20-1. The pull-up resistors (Rs) will provide a high level on the bus lines when none of the I^2C devices are driving the bus. These are optional, and can be replaced with a constant current source.

Figure 20-1. I²C Bus Topology



Note: R_S is optional

20.2.4. Transactions

The I²C standard defines three fundamental transaction formats:

- Master Write
  - The master transmits data packets to the slave after addressing it
- Master Read
  - The slave transmits data packets to the master after being addressed
- Combined Read/Write
  - A combined transaction consists of several write and read transactions

A data transfer starts with the master issuing a **Start** condition on the bus, followed by the address of the slave together with a bit to indicate whether the master wants to read from or write to the slave. The addressed slave must respond to this by sending an **ACK** back to the master.

After this, data packets are sent from the master or slave, according to the read/write bit. Each packet must be acknowledged (ACK) or not acknowledged (NACK) by the receiver.

If a slave responds with a NACK, the master must assume that the slave cannot receive any more data and cancel the write operation.

The master completes a transaction by issuing a **Stop** condition.

A master can issue multiple **Start** conditions during a transaction; this is then called a **Repeated Start** condition.

20.2.4.1. Address Packets

The slave address consists of seven bits. The 8th bit in the transfer determines the data direction (read or write). An address packet always succeeds a **Start** or **Repeated Start** condition. The 8th bit is handled in the driver, and the user will only have to provide the 7-bit address.

20.2.4.2. Data Packets

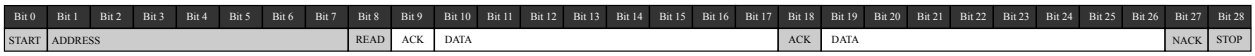
Data packets are nine bits long, consisting of one 8-bit data byte, and an acknowledgement bit. Data packets follow either an address packet or another data packet on the bus.

20.2.4.3. Transaction Examples

The gray bits in the following examples are sent from master to slave, and the white bits are sent from slave to master. Example of a read transaction is shown in Figure 20-2. Here, the master first issues a

Start condition and gets ownership of the bus. An address packet with the direction flag set to read is then sent and acknowledged by the slave. Then the slave sends one data packet which is acknowledged by the master. The slave sends another packet, which is not acknowledged by the master and indicates that the master will terminate the transaction. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 20-2. I²C Packet Read



Example of a write transaction is shown in Figure 20-3. Here, the master first issues a **Start** condition and gets ownership of the bus. An address packet with the dir flag set to write is then sent and acknowledged by the slave. Then the master sends two data packets, each acknowledged by the slave. In the end, the transaction is terminated by the master issuing a **Stop** condition.

Figure 20-3. I²C Packet Write

20.2.4.4. Packet Timeout

When a master sends an I²C packet, there is no way of being sure that a slave will acknowledge the packet. To avoid stalling the device forever while waiting for an acknowledge, a user selectable timeout is provided in the i2c_master_config struct which lets the driver exit a read or write operation after the specified time. The function will then return the STATUS_ERR_TIMEOUT flag.

This is also the case for the slave when using the functions postfixed `_wait`.

The time before the timeout occurs, will be the same as for unknown bus state timeout.

20.2.4.5. Repeated Start

To issue a **Repeated Start**, the functions postfixed `_no_stop` must be used. These functions will not send a **Stop** condition when the transfer is done, thus the next transfer will start with a **Repeated Start**. To end the transaction, the functions without the `_no_stop` postfix must be used for the last read/write.

20.2.5. Multi Master

In a multi master environment, arbitration of the bus is important, as only one master can own the bus at any point.

20.2.5.1. Arbitration

Clock stretching The serial clock line is always driven by a master device. However, all devices connected to the bus are allowed stretch the low period of the clock to slow down the overall clock frequency or to insert wait states while processing data. Both master and slave can randomly stretch the clock, which will force the other device into a wait-state until the clock line goes high again.

Arbitration on the data line If two masters start transmitting at the same time, they will both transmit until one master detects that the other master is pulling the data line low. When this is detected, the master not pulling the line low, will stop the transmission and wait until the bus is idle. As it is the master trying to contact the slave with the lowest address that will get the bus ownership, this will create an arbitration scheme always prioritizing the slaves with the lowest address in case of a bus collision.

20.2.5.2. Clock Synchronization

In situations where more than one master is trying to control the bus clock line at the same time, a clock synchronization algorithm based on the same principles used for clock stretching is necessary.

20.2.6. Bus States

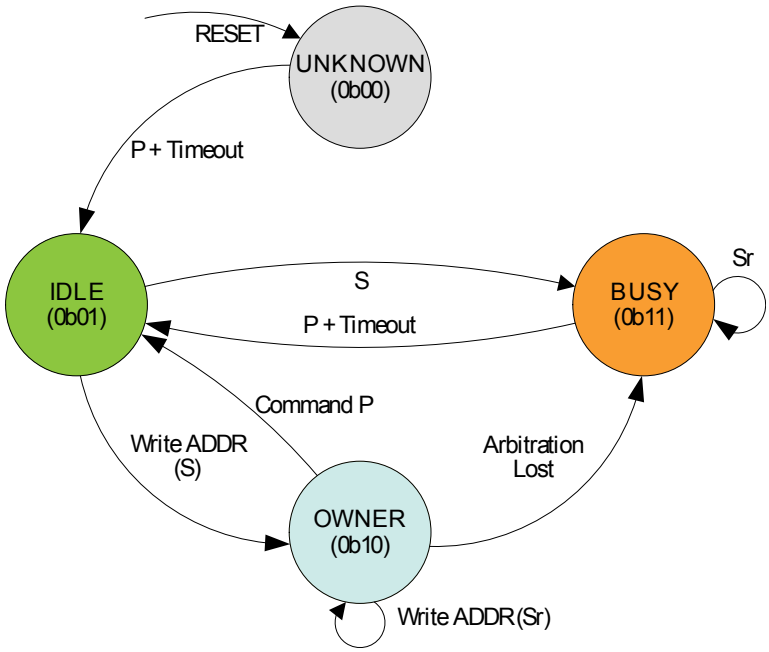
As the I²C bus is limited to one transaction at the time, a master that wants to perform a bus transaction must wait until the bus is free. Because of this, it is necessary for all masters in a multi-master system to know the current status of the bus to be able to avoid conflicts and to ensure data integrity.

- **IDLE** No activity on the bus (between a **Stop** and a new **Start** condition)
- **OWNER** If the master initiates a transaction successfully
- **BUSY** If another master is driving the bus
- **UNKNOWN** If the master has recently been enabled or connected to the bus. Is forced to **IDLE** after given timeout when the master module is enabled

The bus state diagram can be seen in Figure 20-4.

- S: Start condition
- P: Stop condition
- Sr: Repeated start condition

Figure 20-4. I²C Bus State Diagram



20.2.7. Bus Timing

Inactive bus timeout for the master and SDA hold time is configurable in the drivers.

20.2.7.1. Unknown Bus State Timeout

When a master is enabled or connected to the bus, the bus state will be unknown until either a given timeout or a stop command has occurred. The timeout is configurable in the i2c_master_config struct. The timeout time will depend on toolchain and optimization level used, as the timeout is a loop incrementing a value until it reaches the specified timeout value.

20.2.7.2. SDA Hold Timeout

When using the I²C in slave mode, it will be important to set a SDA hold time which assures that the master will be able to pick up the bit sent from the slave. The SDA hold time makes sure that this is the case by holding the data line low for a given period after the negative edge on the clock.

The SDA hold time is also available for the master driver, but is not a necessity.

20.2.8. Operation in Sleep Modes

The I²C module can operate in all sleep modes by setting the run_in_standby Boolean in the i2c_master_config or i2c_slave_config struct. The operation in slave and master mode is shown in Table 20-1.

Table 20-1. I²C Standby Operations

Run in standby	Slave	Master
false	Disabled, all reception is dropped	Generic Clock (GCLK) disabled when master is idle
true	Wake on address match when enabled	GCLK enabled while in sleep modes

20.3. Special Considerations

20.3.1. Interrupt-driven Operation

While an interrupt-driven operation is in progress, subsequent calls to a write or read operation will return the STATUS_BUSY flag, indicating that only one operation is allowed at any given time.

To check if another transmission can be initiated, the user can either call another transfer operation, or use the i2c_master_get_job_status/i2c_slave_get_job_status functions depending on mode.

If the user would like to get callback from operations while using the interrupt-driven driver, the callback must be registered and then enabled using the "register_callback" and "enable_callback" functions.

20.4. Extra Information

For extra information, see Extra Information for SERCOM I2C Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

20.5. Examples

For a list of examples related to this driver, see Examples for SERCOM I2C Driver.

20.6. API Overview

20.6.1. Structure Definitions

20.6.1.1. Struct i2c_slave_config

This is the configuration structure for the I²C slave device. It is used as an argument for i2c_slave_init to provide the desired configurations for the module. The structure should be initialized using the i2c_slave_get_config_defaults.

Table 20-2. Members

Type	Name	Description
uint16_t	address	Address or upper limit of address range
uint16_t	address_mask	Address mask, second address, or lower limit of address range
enum i2c_slave_address_mode	address_mode	Addressing mode
uint16_t	buffer_timeout	Timeout to wait for master in polled functions
bool	enable_general_call_address	Enable general call address recognition (general call address is defined as 0000000 with direction bit 0).
bool	enable_nack_on_address	Enable NACK on address match (this can be changed after initialization via the i2c_slave_enable_nack_on_address and i2c_slave_disable_nack_on_address functions).
bool	enable_scl_low_timeout	Set to enable the SCL low timeout
enum gclk_generator	generator_source	GCLK generator to use as clock source
uint32_t	pinmux_pad0	PAD0 (SDA) pinmux
uint32_t	pinmux_pad1	PAD1 (SCL) pinmux
bool	run_in_standby	Set to keep module active in sleep modes
bool	scl_low_timeout	Set to enable SCL low time-out
bool	scl_stretch_only_after_ack_bit	Set to enable SCL stretch only after ACK bit (required for high speed)
enum i2c_slave_sda_hold_time	sda_hold_time	SDA hold time with respect to the negative edge of SCL
bool	slave_scl_low_extend_timeout	Set to enable slave SCL low extend time-out

Type	Name	Description
bool	ten_bit_address	Enable 10-bit addressing
enum i2c_slave_transfer_speed	transfer_speed	Transfer speed mode

20.6.1.2. Struct i2c_slave_module

SERCOM I²C slave driver software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

20.6.1.3. Struct i2c_slave_packet

Structure to be used when transferring I²C slave packets.

Table 20-3. Members

Type	Name	Description
uint8_t *	data	Data array containing all data to be transferred
uint16_t	data_length	Length of data array

20.6.2. Macro Definitions

20.6.2.1. Driver Feature Definition

Define SERCOM I²C driver features set according to different device family.

Macro FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED

```
#define FEATURE_I2C_FAST_MODE_PLUS_AND_HIGH_SPEED
```

Fast mode plus and high speed support.

Macro FEATURE_I2C_10_BIT_ADDRESS

```
#define FEATURE_I2C_10_BIT_ADDRESS
```

10-bit address support

Macro FEATURE_I2C_SCL_STRETCH_MODE

```
#define FEATURE_I2C_SCL_STRETCH_MODE
```

SCL stretch mode support

Macro FEATURE_I2C_SCL_EXTEND_TIMEOUT

```
#define FEATURE_I2C_SCL_EXTEND_TIMEOUT
```

SCL extend timeout support

Macro FEATURE_I2C_DMA_SUPPORT

```
#define FEATURE_I2C_DMA_SUPPORT
```

20.6.2.2. I²C Slave Status Flags

I²C slave status flags, returned by i2c_slave_get_status() and cleared by i2c_slave_clear_status().

Macro I2C_SLAVE_STATUS_ADDRESS_MATCH

```
#define I2C_SLAVE_STATUS_ADDRESS_MATCH
```

Address Match.
Note: Should only be cleared internally by driver.

Macro I2C_SLAVE_STATUS_DATA_READY

```
#define I2C_SLAVE_STATUS_DATA_READY
```

Data Ready.

Macro I2C_SLAVE_STATUS_STOP_RECEIVED

```
#define I2C_SLAVE_STATUS_STOP_RECEIVED
```

Stop Received.

Macro I2C_SLAVE_STATUS_CLOCK_HOLD

```
#define I2C_SLAVE_STATUS_CLOCK_HOLD
```

Clock Hold.
Note: Cannot be cleared, only valid when I2C_SLAVE_STATUS_ADDRESS_MATCH is set.

Macro I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT

```
#define I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT
```

SCL Low Timeout.

Macro I2C_SLAVE_STATUS_REPEATED_START

```
#define I2C_SLAVE_STATUS_REPEATED_START
```

Repeated Start.
Note: Cannot be cleared, only valid when I2C_SLAVE_STATUS_ADDRESS_MATCH is set.

Macro I2C_SLAVE_STATUS_RECEIVED_NACK

```
#define I2C_SLAVE_STATUS_RECEIVED_NACK
```

Received not acknowledge.
Note: Cannot be cleared.

Macro I2C_SLAVE_STATUS_COLLISION

```
#define I2C_SLAVE_STATUS_COLLISION
```

Transmit Collision.

Macro I2C_SLAVE_STATUS_BUS_ERROR

```
#define I2C_SLAVE_STATUS_BUS_ERROR
```

Bus error.

20.6.3. Function Definitions

20.6.3.1. Lock/Unlock

Function i2c_slave_lock()

Attempt to get lock on driver instance.

```
enum status_code i2c_slave_lock(
        struct i2c_slave_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 20-4. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 20-5. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

Function i2c_slave_unlock()

Unlock driver instance.

```
void i2c_slave_unlock(
        struct i2c_slave_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 20-6. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 20-7. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

20.6.3.2. Configuration and Initialization

Function i2c_slave_is_syncing()

Returns the synchronization status of the module.

```
bool i2c_slave_is_syncing(
        const struct i2c_slave_module *const module)
```

Returns the synchronization status of the module.

Table 20-8. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module structure

Returns
Status of the synchronization.

Table 20-9. Return Values

Return value	Description
true	Module is busy synchronizing
false	Module is not synchronizing

Function i2c_slave_get_config_defaults()

Gets the I^{2}C slave default configurations.

```
void i2c_slave_get_config_defaults(
        struct i2c_slave_config *const config)
```

This will initialize the configuration structure to known default values.

The default configuration is as follows:

- Disable SCL low timeout
- 300ns - 600ns SDA hold time
- Buffer timeout = 65535
- Address with mask
- Address = 0
- Address mask = 0 (one single address)
- General call address disabled
- Address nack disabled if the interrupt driver is used
- GCLK generator 0
- Do not run in standby
- PINMUX_DEFAULT for SERCOM pads

Those default configuration only available if the device supports it:

- Not using 10-bit addressing
- Standard-mode and Fast-mode transfer speed
- SCL stretch disabled
- Slave SCL low extend time-out disabled

Table 20-10. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration structure to be initialized

Function i2c_slave_init()

Initializes the requested I²C hardware module.

```
enum status_code i2c_slave_init(
        struct i2c_slave_module *const module,
        Sercom *const hw,
        const struct i2c_slave_config *const config)
```

Initializes the SERCOM I²C slave device requested and sets the provided software module struct. Run this function before any further use of the driver.

Table 20-11. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to software module struct
[in]	hw	Pointer to the hardware instance
[in]	config	Pointer to the configuration struct

Returns
Status of initialization.

Table 20-12. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting
STATUS_ERR_ALREADY_INITIALIZED	If setting other GCLK generator than previously set

Function i2c_slave_enable()

Enables the I²C module.

```
void i2c_slave_enable(
        const struct i2c_slave_module *const module)
```

This will enable the requested I²C module.

Table 20-13. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_slave_disable()

Disables the I²C module.

```
void i2c_slave_disable(
        const struct i2c_slave_module *const module)
```

This will disable the I²C module specified in the provided software module structure.

Table 20-14. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct

Function i2c_slave_reset()

Resets the hardware module.

```
void i2c_slave_reset(
        struct i2c_slave_module *const module)
```

This will reset the module to hardware defaults.

Table 20-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

20.6.3.3. Read and Write

Function i2c_slave_write_packet_wait()

Writes a packet to the master.

```
enum status_code i2c_slave_write_packet_wait(
        struct i2c_slave_module *const module,
        struct i2c_slave_packet *const packet)
```

Writes a packet to the master. This will wait for the master to issue a request.

Table 20-16. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure
[in]	packet	Packet to write to master

Returns

Status of packet write.

Table 20-17. Return Values

Return value	Description
STATUS_OK	Packet was written successfully
STATUS_ERR_DENIED	Start condition not received, another interrupt flag is set

Return value	Description
STATUS_ERR_IO	There was an error in the previous transfer
STATUS_ERR_BAD_FORMAT	Master wants to write data
STATUS_ERR_INVALID_ARG	Invalid argument(s) was provided
STATUS_ERR_BUSY	The I^{2}C module is busy with a job
STATUS_ERR_ERR_OVERFLOW	Master NACKed before entire packet was transferred
STATUS_ERR_TIMEOUT	No response was given within the timeout period

Function i2c_slave_read_packet_wait()

Reads a packet from the master.

```
enum status_code i2c_slave_read_packet_wait(
        struct i2c_slave_module *const module,
        struct i2c_slave_packet *const packet)
```

Reads a packet from the master. This will wait for the master to issue a request.

Table 20-18. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure
[out]	packet	Packet to read from master

Returns

Status of packet read.

Table 20-19. Return Values

Return value	Description
STATUS_OK	Packet was read successfully
STATUS_ABORTED	Master sent stop condition or repeated start before specified length of bytes was received
STATUS_ERR_IO	There was an error in the previous transfer
STATUS_ERR_DENIED	Start condition not received, another interrupt flag is set
STATUS_ERR_INVALID_ARG	Invalid argument(s) was provided
STATUS_ERR_BUSY	The I^{2}C module is busy with a job
STATUS_ERR_BAD_FORMAT	Master wants to read data
STATUS_ERR_ERR_OVERFLOW	Last byte received overflows buffer

Function i2c_slave_get_direction_wait()

Waits for a start condition on the bus.

```
enum i2c_slave_direction i2c_slave_get_direction_wait(
        struct i2c_slave_module *const module)
```

Note: This function is only available for 7-bit slave addressing.

Waits for the master to issue a start condition on the bus.

Note: This function does not check for errors in the last transfer, this will be discovered when reading or writing.

Table 20-20. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to software module structure

Returns
Direction of the current transfer, when in slave mode.

Table 20-21. Return Values

Return value	Description
I2C_SLAVE_DIRECTION_NONE	No request from master within timeout period
I2C_SLAVE_DIRECTION_READ	Write request from master
I2C_SLAVE_DIRECTION_WRITE	Read request from master

20.6.3.4. Status Management

Function i2c_slave_get_status()

Retrieves the current module status.

```
uint32_t i2c_slave_get_status(
        struct i2c_slave_module *const module)
```

Checks the status of the module and returns it as a bitmask of status flags.

Table 20-22. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the I^2C slave software device struct

Returns
Bitmask of status flags.

Table 20-23. Return Values

Return value	Description
I2C_SLAVE_STATUS_ADDRESS_MATCH	A valid address has been received
I2C_SLAVE_STATUS_DATA_READY	A I^2C slave byte transmission is successfully completed

Return value	Description
I2C_SLAVE_STATUS_STOP_RECEIVED	A stop condition is detected for a transaction being processed
I2C_SLAVE_STATUS_CLOCK_HOLD	The slave is holding the SCL line low
I2C_SLAVE_STATUS_SCL_LOW_TIMEOUT	An SCL low time-out has occurred
I2C_SLAVE_STATUS_REPEATED_START	Indicates a repeated start, only valid if I2C_SLAVE_STATUS_ADDRESS_MATCH is set
I2C_SLAVE_STATUS_RECEIVED_NACK	The last data packet sent was not acknowledged
I2C_SLAVE_STATUS_COLLISION	The I²C slave was not able to transmit a high data or NACK bit
I2C_SLAVE_STATUS_BUS_ERROR	An illegal bus condition has occurred on the bus

Function i2c_slave_clear_status()

Clears a module status flag.

```
void i2c_slave_clear_status(
        struct i2c_slave_module *const module,
        uint32_t status_flags)
```

Clears the given status flag of the module.

Note: Not all status flags can be cleared.

Table 20-24. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the I²C software device struct
[in]	status_flags	Bit mask of status flags to clear

20.6.3.5. SERCOM I²C slave with DMA Interfaces

Function i2c_slave_dma_read_interrupt_status()

Read SERCOM I²C interrupt status.

```
uint8_t i2c_slave_dma_read_interrupt_status(
        struct i2c_slave_module *const module)
```

Read I²C interrupt status for DMA transfer.

Table 20-25. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Function i2c_slave_dma_write_interrupt_status()

Write SERCOM I²C interrupt status.

```
void i2c_slave_dma_write_interrupt_status(
        struct i2c_slave_module *const module,
        uint8_t flag)
```

Write I²C interrupt status for DMA transfer.

Table 20-26. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock
[in]	flag	Interrupt flag status

20.6.3.6. Address Match Functionality

Function i2c_slave_enable_nack_on_address()

Enables sending of NACK on address match.

```
void i2c_slave_enable_nack_on_address(
        struct i2c_slave_module *const module)
```

Enables sending of NACK on address match, thus discarding any incoming transaction.

Table 20-27. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_slave_disable_nack_on_address()

Disables sending NACK on address match.

```
void i2c_slave_disable_nack_on_address(
        struct i2c_slave_module *const module)
```

Disables sending of NACK on address match, thus acknowledging incoming transactions.

Table 20-28. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

20.6.3.7. Callbacks

Function i2c_slave_register_callback()

Registers callback for the specified callback type.

```
void i2c_slave_register_callback(
        struct i2c_slave_module *const module,
        i2c_slave_callback_t callback,
        enum i2c_slave_callback callback_type)
```

Associates the given callback function with the specified callback type. To enable the callback, the i2c_slave_enable_callback function must be used.

Table 20-29. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback	Pointer to the function desired for the specified callback
[in]	callback_type	Callback type to register

Function i2c_slave_unregister_callback()

Unregisters callback for the specified callback type.

```
void i2c_slave_unregister_callback(
        struct i2c_slave_module *const module,
        enum i2c_slave_callback callback_type)
```

Removes the currently registered callback for the given callback type.

Table 20-30. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to unregister

Function i2c_slave_enable_callback()

Enables callback.

```
void i2c_slave_enable_callback(
        struct i2c_slave_module *const module,
        enum i2c_slave_callback callback_type)
```

Enables the callback specified by the callback_type.

Table 20-31. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to enable

Function i2c_slave_disable_callback()

Disables callback.

```
void i2c_slave_disable_callback(
        struct i2c_slave_module *const module,
        enum i2c_slave_callback callback_type)
```

Disables the callback specified by the callback_type.

Table 20-32. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software module struct
[in]	callback_type	Callback type to disable

20.6.3.8. Read and Write, Interrupt-Driven

Function i2c_slave_read_packet_job()

Initiates a reads packet operation.

```
enum status_code i2c_slave_read_packet_job(
        struct i2c_slave_module *const module,
        struct i2c_slave_packet *const packet)
```

Reads a data packet from the master. A write request must be initiated by the master before the packet can be read.

The I2C_SLAVE_CALLBACK_WRITE_REQUEST callback can be used to call this function.

Table 20-33. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I^2C packet to transfer

Returns
Status of starting asynchronously reading I^2C packet.

Table 20-34. Return Values

Return value	Description
STATUS_OK	If reading was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_slave_write_packet_job()

Initiates a write packet operation.

```
enum status_code i2c_slave_write_packet_job(
        struct i2c_slave_module *const module,
        struct i2c_slave_packet *const packet)
```

Writes a data packet to the master. A read request must be initiated by the master before the packet can be written.

The I2C_SLAVE_CALLBACK_READ_REQUEST callback can be used to call this function.

Table 20-35. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module struct
[in, out]	packet	Pointer to I²C packet to transfer

Returns
Status of starting writing I²C packet.

Table 20-36. Return Values

Return value	Description
STATUS_OK	If writing was started successfully
STATUS_BUSY	If module is currently busy with another transfer

Function i2c_slave_cancel_job()

Cancels any currently ongoing operation.

```
void i2c_slave_cancel_job(
        struct i2c_slave_module *const module)
```

Terminates the running transfer operation.

Table 20-37. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Function i2c_slave_get_job_status()

Gets status of ongoing job.

```
enum status_code i2c_slave_get_job_status(
        struct i2c_slave_module *const module)
```

Will return the status of the ongoing job, or the error that occurred in the last transfer operation. The status will be cleared when starting a new job.

Table 20-38. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to software module structure

Returns
Status of job.

Table 20-39. Return Values

Return value	Description
STATUS_OK	No error has occurred
STATUS_BUSY	Transfer is in progress
STATUS_ERR_IO	A collision, timeout or bus error happened in the last transfer
STATUS_ERR_TIMEOUT	A timeout occurred
STATUS_ERR_OVERFLOW	Data from master overflows receive buffer

20.6.4. Enumeration Definitions

20.6.4.1. Enum i2c_slave_address_mode

Enum for the possible address modes.

Table 20-40. Members

Enum value	Description
I2C_SLAVE_ADDRESS_MODE_MASK	Address match on address_mask used as a mask to address
I2C_SLAVE_ADDRESS_MODE_TWO_ADDRESSES	Address math on both address and address_mask
I2C_SLAVE_ADDRESS_MODE_RANGE	Address match on range of addresses between and including address and address_mask

20.6.4.2. Enum i2c_slave_callback

The available callback types for the I^2C slave.

Table 20-41. Members

Enum value	Description
I2C_SLAVE_CALLBACK_WRITE_COMPLETE	Callback for packet write complete
I2C_SLAVE_CALLBACK_READ_COMPLETE	Callback for packet read complete
I2C_SLAVE_CALLBACK_READ_REQUEST	Callback for read request from master - can be used to issue a write
I2C_SLAVE_CALLBACK_WRITE_REQUEST	Callback for write request from master - can be used to issue a read
I2C_SLAVE_CALLBACK_ERROR	Callback for error
I2C_SLAVE_CALLBACK_ERROR_LAST_TRANSFER	Callback for error in last transfer. Discovered on a new address interrupt.

20.6.4.3. Enum i2c_slave_direction

Enum for the direction of a request.

Table 20-42. Members

Enum value	Description
I2C_SLAVE_DIRECTION_READ	Read
I2C_SLAVE_DIRECTION_WRITE	Write
I2C_SLAVE_DIRECTION_NONE	No direction

20.6.4.4. Enum i2c_slave_sda_hold_time

Enum for the possible SDA hold times with respect to the negative edge of SCL.

Table 20-43. Members

Enum value	Description
I2C_SLAVE_SDA_HOLD_TIME_DISABLED	SDA hold time disabled
I2C_SLAVE_SDA_HOLD_TIME_50NS_100NS	SDA hold time 50ns - 100ns
I2C_SLAVE_SDA_HOLD_TIME_300NS_600NS	SDA hold time 300ns - 600ns
I2C_SLAVE_SDA_HOLD_TIME_400NS_800NS	SDA hold time 400ns - 800ns

20.6.4.5. Enum i2c_slave_transfer_speed

Enum for the transfer speed.

Table 20-44. Members

Enum value	Description
I2C_SLAVE_SPEED_STANDARD_AND_FAST	Standard-mode (Sm) up to 100KHz and Fast-mode (Fm) up to 400KHz
I2C_SLAVE_SPEED_FAST_MODE_PLUS	Fast-mode Plus (Fm+) up to 1MHz
I2C_SLAVE_SPEED_HIGH_SPEED	High-speed mode (Hs-mode) up to 3.4MHz

20.6.4.6. Enum i2c_transfer_direction

For master: transfer direction or setting direction bit in address. For slave: direction of request from master.

Table 20-45. Members

Enum value	Description
I2C_TRANSFER_WRITE	Master write operation is in progress
I2C_TRANSFER_READ	Master read operation is in progress

20.7. Extra Information for SERCOM I2C Driver

20.7.1. Acronyms

Table 20-46 is a table listing the acronyms used in this module, along with their intended meanings.

Table 20-46. Acronyms

Acronym	Description
SDA	Serial Data Line
SCL	Serial Clock Line
SERCOM	Serial Communication Interface
DMA	Direct Memory Access

20.7.2. Dependencies

The I2C driver has the following dependencies:

- System Pin Multiplexer Driver

20.7.3. Errata

There are no errata related to this driver.

20.7.4. Module History

Table 20-47 is an overview of the module history, detailing enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version listed in Table 20-47.

Table 20-47. Module History

Changelog
• Added 10-bit addressing and high speed support in SAM D21 • Separate structure i2c_packet into i2c_master_packet and i2c_slave packet
• Added support for SCL stretch and extended timeout hardware features in SAM D21 • Added fast mode plus support in SAM D21
Fixed incorrect logical mask for determining if a bus error has occurred in I2C Slave mode
Initial Release

20.8. Examples for SERCOM I2C Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM I2C Slave Mode (SERCOM I2C) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the I2C Slave module - Basic Use Case

- Quick Start Guide for the I2C Slave module - Callback Use Case
- Quick Start Guide for the I2C Slave module - DMA Use Case

20.8.1. Quick Start Guide for SERCOM I²C Slave - Basic

In this use case, the I²C will used and set up as follows:

- Slave mode
- 100KHz operation speed
- Not operational in standby
- 10000 packet timeout value

20.8.1.1. Prerequisites

The device must be connected to an I²C master.

20.8.1.2. Setup

Code

The following must be added to the user application:

A sample buffer to write from, a sample buffer to read to and length of buffers:

```
#define DATA_LENGTH 10

uint8_t write_buffer[DATA_LENGTH] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09
};
uint8_t read_buffer[DATA_LENGTH];
```

Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

Function for setting up the module:

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);

    /* Change address and address_mode */
    config_i2c_slave.address         = SLAVE_ADDRESS;
    config_i2c_slave.address_mode    = I2C_SLAVE_ADDRESS_MODE_MASK;
#if SAMR30
    config_i2c_slave.pinmux_pad0     = CONF_SLAVE_SDA_PINMUX;
    config_i2c_slave.pinmux_pad1     = CONF_SLAVE_SCK_PINMUX;
#endif
    config_i2c_slave.buffer_timeout = 1000;

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

Add to user application `main()`:

```
configure_i2c_slave();

enum i2c_slave_direction dir;
struct i2c_slave_packet packet = {
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
};
```

Workflow

1. Configure and enable module.

```
configure_i2c_slave();
```

   1. Create and initialize configuration structure.

```
struct i2c_slave_config config_i2c_slave;
i2c_slave_get_config_defaults(&config_i2c_slave);
```

   2. Change address and address mode settings in the configuration.

```
config_i2c_slave.address        = SLAVE_ADDRESS;
config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
#if SAMR30
    config_i2c_slave.pinmux_pad0    = CONF_SLAVE_SDA_PINMUX;
config_i2c_slave.pinmux_pad1    = CONF_SLAVE_SCK_PINMUX;
#endif
    config_i2c_slave.buffer_timeout = 1000;
```

   3. Initialize the module with the set configurations.

```
i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);
```

   4. Enable the module.

```
i2c_slave_enable(&i2c_slave_instance);
```

2. Create variable to hold transfer direction.

```
enum i2c_slave_direction dir;
```

3. Create packet variable to transfer.

```
struct i2c_slave_packet packet = {
    .data_length = DATA_LENGTH,
    .data        = write_buffer,
};
```

20.8.1.3. Implementation

Code

Add to user application `main()`:

```
while (true) {
    /* Wait for direction from master */
    dir = i2c_slave_get_direction_wait(&i2c_slave_instance);

    /* Transfer packet in direction requested by master */
    if (dir == I2C_SLAVE_DIRECTION_READ) {
        packet.data = read_buffer;
        i2c_slave_read_packet_wait(&i2c_slave_instance, &packet);
    } else if (dir == I2C_SLAVE_DIRECTION_WRITE) {
```

```
        packet.data = write_buffer;
        i2c_slave_write_packet_wait(&i2c_slave_instance, &packet);
    }
}
```

Workflow

1. Wait for start condition from master and get transfer direction.

```
dir = i2c_slave_get_direction_wait(&i2c_slave_instance);
```

2. Depending on transfer direction, set up buffer to read to or write from, and write or read from master.

```
if (dir == I2C_SLAVE_DIRECTION_READ) {
    packet.data = read_buffer;
    i2c_slave_read_packet_wait(&i2c_slave_instance, &packet);
} else if (dir == I2C_SLAVE_DIRECTION_WRITE) {
    packet.data = write_buffer;
    i2c_slave_write_packet_wait(&i2c_slave_instance, &packet);
}
```

20.8.2. Quick Start Guide for SERCOM I²C Slave - Callback

In this use case, the I²C will used and set up as follows:

- Slave mode
- 100KHz operation speed
- Not operational in standby
- 10000 packet timeout value

20.8.2.1. Prerequisites

The device must be connected to an I²C master.

20.8.2.2. Setup

Code

The following must be added to the user application:

A sample buffer to write from, a sample buffer to read to and length of buffers:

```
#define DATA_LENGTH 10
static uint8_t write_buffer[DATA_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
};
static uint8_t read_buffer [DATA_LENGTH];
```

Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

Globally accessible packet:

```
static struct i2c_slave_packet packet;
```

Function for setting up the module:

```
void configure_i2c_slave(void)
{
    /* Initialize config structure and module instance */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);
    /* Change address and address_mode */
    config_i2c_slave.address      = SLAVE_ADDRESS;
    config_i2c_slave.address_mode = I2C_SLAVE_ADDRESS_MODE_MASK;
#if SAMR30
    config_i2c_slave.pinmux_pad0    = CONF_SLAVE_SDA_PINMUX;
    config_i2c_slave.pinmux_pad1    = CONF_SLAVE_SCK_PINMUX;
#endif
    /* Initialize and enable device with config */
    i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

Callback function for read request from a master:

```
void i2c_read_request_callback(
        struct i2c_slave_module *const module)
{
    /* Init i2c packet */
    packet.data_length = DATA_LENGTH;
    packet.data        = write_buffer;

    /* Write buffer to master */
    i2c_slave_write_packet_job(module, &packet);
}
```

Callback function for write request from a master:

```
void i2c_write_request_callback(
        struct i2c_slave_module *const module)
{
    /* Init i2c packet */
    packet.data_length = DATA_LENGTH;
    packet.data        = read_buffer;

    /* Read buffer from master */
    if (i2c_slave_read_packet_job(module, &packet) != STATUS_OK) {
    }
}
```

Function for setting up the callback functionality of the driver:

```
void configure_i2c_slave_callbacks(void)
{
    /* Register and enable callback functions */
    i2c_slave_register_callback(&i2c_slave_instance,
i2c_read_request_callback,
            I2C_SLAVE_CALLBACK_READ_REQUEST);
    i2c_slave_enable_callback(&i2c_slave_instance,
            I2C_SLAVE_CALLBACK_READ_REQUEST);

    i2c_slave_register_callback(&i2c_slave_instance,
i2c_write_request_callback,
            I2C_SLAVE_CALLBACK_WRITE_REQUEST);
    i2c_slave_enable_callback(&i2c_slave_instance,
```

```
            I2C_SLAVE_CALLBACK_WRITE_REQUEST);
}
```

Add to user application `main()`:

```
/* Configure device and enable */
configure_i2c_slave();
configure_i2c_slave_callbacks();
```

Workflow

1. Configure and enable module.

```
configure_i2c_slave();
```

   1. Create and initialize configuration structure.

```
struct i2c_slave_config config_i2c_slave;
i2c_slave_get_config_defaults(&config_i2c_slave);
```

   2. Change address and address mode settings in the configuration.

```
config_i2c_slave.address      = SLAVE_ADDRESS;
config_i2c_slave.address_mode = I2C_SLAVE_ADDRESS_MODE_MASK;
#if SAMR30
    config_i2c_slave.pinmux_pad0    = CONF_SLAVE_SDA_PINMUX;
config_i2c_slave.pinmux_pad1    = CONF_SLAVE_SCK_PINMUX;
#endif
```

   3. Initialize the module with the set configurations.

```
i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);
```

   4. Enable the module.

```
i2c_slave_enable(&i2c_slave_instance);
```

2. Register and enable callback functions.

```
configure_i2c_slave_callbacks();
```

   1. Register and enable callbacks for read and write requests from master.

```
i2c_slave_register_callback(&i2c_slave_instance,
i2c_read_request_callback,
        I2C_SLAVE_CALLBACK_READ_REQUEST);
i2c_slave_enable_callback(&i2c_slave_instance,
        I2C_SLAVE_CALLBACK_READ_REQUEST);

i2c_slave_register_callback(&i2c_slave_instance,
i2c_write_request_callback,
        I2C_SLAVE_CALLBACK_WRITE_REQUEST);
i2c_slave_enable_callback(&i2c_slave_instance,
        I2C_SLAVE_CALLBACK_WRITE_REQUEST);
```

20.8.2.3. Implementation

Code

Add to user application `main()`:

```
while (true) {
    /* Infinite loop while waiting for I2C master interaction */
}
```

Workflow

1. Infinite while loop, while waiting for interaction from master.

```
while (true) {
     /* Infinite loop while waiting for I2C master interaction */
}
```

20.8.2.4. Callback

When an address packet is received, one of the callback functions will be called, depending on the DIR bit in the received packet.

Workflow

- Read request callback:
  1. Length of buffer and buffer to be sent to master is initialized.

```
packet.data_length = DATA_LENGTH;
packet.data        = write_buffer;
```

  2. Write packet to master.

```
i2c_slave_write_packet_job(module, &packet);
```

- Write request callback:
  1. Length of buffer and buffer to be read from master is initialized.

```
packet.data_length = DATA_LENGTH;
packet.data        = read_buffer;
```

  2. Read packet from master.

```
if (i2c_slave_read_packet_job(module, &packet) != STATUS_OK) {
}
```

20.8.3. Quick Start Guide for Using DMA with SERCOM I²C Slave

The supported board list:

- SAMD21 Xplained Pro
- SAMR21 Xplained Pro
- SAML21 Xplained Pro
- SAML22 Xplained Pro
- SAMDA1 Xplained Pro
- SAMC21 Xplained Pro

In this use case, the I²C will used and set up as follows:

- Slave mode
- 100KHz operation speed
- Not operational in standby
- 65535 unknown bus state timeout value

20.8.3.1. Prerequisites

The device must be connected to an I²C slave.

20.8.3.2. Setup

Code

The following must be added to the user application:

- Address to respond to:

```
#define SLAVE_ADDRESS 0x12
```

- A sample buffer to send, number of entries to send and address of slave:

```
#define DATA_LENGTH 10
uint8_t read_buffer[DATA_LENGTH];
```

- Globally accessible module structure:

```
struct i2c_slave_module i2c_slave_instance;
```

- Function for setting up the module:

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);

    /* Change address and address_mode */
    config_i2c_slave.address         = SLAVE_ADDRESS;
    config_i2c_slave.address_mode    = I2C_SLAVE_ADDRESS_MODE_MASK;
    config_i2c_slave.buffer_timeout = 1000;
#if SAMR30
    config_i2c_slave.pinmux_pad0     = CONF_SLAVE_SDA_PINMUX;
    config_i2c_slave.pinmux_pad1     = CONF_SLAVE_SCK_PINMUX;
#endif

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

- Globally accessible DMA module structure:

```
struct dma_resource i2c_dma_resource;
```

- Globally accessible DMA transfer descriptor:

```
COMPILER_ALIGNED(16)
DmacDescriptor i2c_dma_descriptor SECTION_DMAC_DESCRIPTOR;
```

- Function for setting up the DMA resource:

```
void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.peripheral_trigger = CONF_I2C_DMA_TRIGGER;
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(resource, &config);
}
```

- Function for setting up the DMA transfer descriptor:

```
void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);
```

```
    descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    descriptor_config.src_increment_enable = false;
    descriptor_config.block_transfer_count = DATA_LENGTH;
    descriptor_config.destination_address = (uint32_t)read_buffer +
DATA_LENGTH;
    descriptor_config.source_address =
            (uint32_t)(&i2c_slave_instance.hw->I2CS.DATA.reg);

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

- Add to user application `main()`:

```
configure_i2c_slave();

configure_dma_resource(&i2c_dma_resource);
setup_dma_descriptor(&i2c_dma_descriptor);
dma_add_descriptor(&i2c_dma_resource, &i2c_dma_descriptor);
```

Workflow

1. Configure and enable module:

```
void configure_i2c_slave(void)
{
    /* Create and initialize config_i2c_slave structure */
    struct i2c_slave_config config_i2c_slave;
    i2c_slave_get_config_defaults(&config_i2c_slave);

    /* Change address and address_mode */
    config_i2c_slave.address        = SLAVE_ADDRESS;
    config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
    config_i2c_slave.buffer_timeout = 1000;
#if SAMR30
    config_i2c_slave.pinmux_pad0    = CONF_SLAVE_SDA_PINMUX;
    config_i2c_slave.pinmux_pad1    = CONF_SLAVE_SCK_PINMUX;
#endif

    /* Initialize and enable device with config_i2c_slave */
    i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);

    i2c_slave_enable(&i2c_slave_instance);
}
```

   1. Create and initialize configuration structure.

```
struct i2c_slave_config config_i2c_slave;
i2c_slave_get_config_defaults(&config_i2c_slave);
```

   2. Change settings in the configuration.

```
config_i2c_slave.address        = SLAVE_ADDRESS;
config_i2c_slave.address_mode   = I2C_SLAVE_ADDRESS_MODE_MASK;
config_i2c_slave.buffer_timeout = 1000;
#if SAMR30
    config_i2c_slave.pinmux_pad0    = CONF_SLAVE_SDA_PINMUX;
config_i2c_slave.pinmux_pad1    = CONF_SLAVE_SCK_PINMUX;
#endif
```

   3. Initialize the module with the set configurations.

```
i2c_slave_init(&i2c_slave_instance, CONF_I2C_SLAVE_MODULE,
&config_i2c_slave);
```

4. Enable the module.

```
i2c_slave_enable(&i2c_slave_instance);
```

2. Configure DMA
    1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

    2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    3. Set extra configurations for the DMA resource. It is using peripheral trigger. SERCOM RX trigger causes a beat transfer in this example.

```
config.peripheral_trigger = CONF_I2C_DMA_TRIGGER;
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

    4. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

    5. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

    6. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

    Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    7. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
descriptor_config.src_increment_enable = false;
descriptor_config.block_transfer_count = DATA_LENGTH;
descriptor_config.destination_address = (uint32_t)read_buffer +
DATA_LENGTH;
descriptor_config.source_address =
        (uint32_t)(&i2c_slave_instance.hw->I2CS.DATA.reg);
```

    8. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

20.8.3.3. Implementation

Code

Add to user application `main()`:

```
dma_start_transfer_job(&i2c_dma_resource);

while (true) {
    if (i2c_slave_dma_read_interrupt_status(&i2c_slave_instance) &
                SERCOM_I2CS_INTFLAG_AMATCH) {
        i2c_slave_dma_write_interrupt_status(&i2c_slave_instance,
```

```
                    SERCOM_I2CS_INTFLAG_AMATCH);
    }
}
```

Workflow

1. Start to wait a packet from master.

```
dma_start_transfer_job(&i2c_dma_resource);
```

2. Once data ready, clear the address match status.

```
while (true) {
    if (i2c_slave_dma_read_interrupt_status(&i2c_slave_instance) &
                SERCOM_I2CS_INTFLAG_AMATCH) {
        i2c_slave_dma_write_interrupt_status(&i2c_slave_instance,
                SERCOM_I2CS_INTFLAG_AMATCH);
    }
}
```

21. SAM Serial Peripheral Interface (SERCOM SPI) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the SERCOM module in its SPI mode to transfer SPI data frames. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- SERCOM (Serial Communication Interface)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

21.1. Prerequisites

There are no prerequisites.

21.2. Module Overview

The Serial Peripheral Interface (SPI) is a high-speed synchronous data transfer interface using three or four pins. It allows fast communication between a master device and one or more peripheral devices.

A device connected to the bus must act as a master or a slave. The master initiates and controls all data transactions. The SPI master initiates a communication cycle by pulling low the Slave Select (SS) pin of the desired slave. The Slave Select pin is active low. Master and slave prepare data to be sent in their respective shift registers, and the master generates the required clock pulses on the SCK line to interchange data. Data is always shifted from master to slave on the Master Out - Slave In (MOSI) line, and from slave to master on the Master In - Slave Out (MISO) line. After each data transfer, the master can synchronize to the slave by pulling the SS line high.

21.2.1. Driver Feature Macro Definition

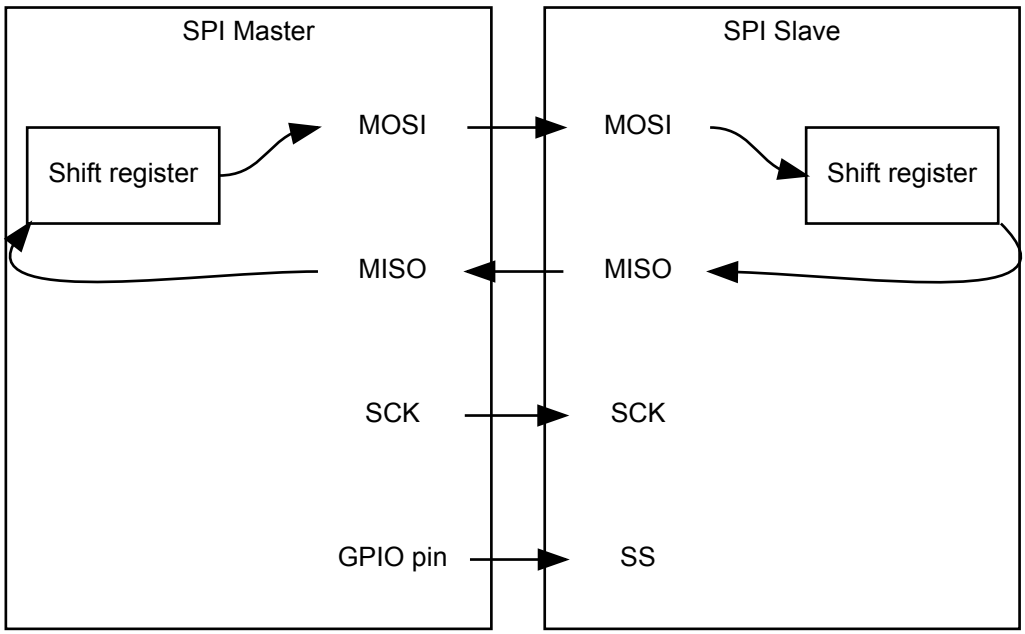
Driver feature macro	Supported devices
FEATURE_SPI_SLAVE_SELECT_LOW_DETECT	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21/R30
FEATURE_SPI_HARDWARE_SLAVE_SELECT	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21/R30
FEATURE_SPI_ERROR_INTERRUPT	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21/R30
FEATURE_SPI_SYNC_SCHEME_VERSION_2	SAM D21/R21/D10/D11/L21/L22/DA1/C20/C21/R30

Note: The specific features are only available in the driver when the selected device supports those features.

21.2.2. SPI Bus Connection

In Figure 21-1, the connection between one master and one slave is shown.

Figure 21-1. SPI Bus Connection



The different lines are as follows:

- **MISO** Master Input Slave Output. The line where the data is shifted out from the slave and into the master.
- **MOSI** Master Output Slave Input. The line where the data is shifted out from the master and into the slave.
- **SCK** Serial Clock. Generated by the master device.
- **SS** Slave Select. To initiate a transaction, the master must pull this line low.

If the bus consists of several SPI slaves, they can be connected in parallel and the SPI master can use general I/O pins to control separate SS lines to each slave on the bus.

It is also possible to connect all slaves in series. In this configuration, a common SS is provided to `N` slaves, enabling them simultaneously. The MISO from the `N-1` slaves is connected to the MOSI on the next slave. The `Nth` slave connects its MISO back to the master. For a complete transaction, the master must shift `N+1` characters.

21.2.3. SPI Character Size

The SPI character size is configurable to eight or nine bits.

21.2.4. Master Mode

When configured as a master, the SS pin will be configured as an output.

21.2.4.1. Data Transfer

Writing a character will start the SPI clock generator, and the character is transferred to the shift register when the shift register is empty. Once this is done, a new character can be written. As each character is shifted out from the master, a character is shifted in from the slave. If the receiver is enabled, the data is moved to the receive buffer at the completion of the frame and can be read.

21.2.5. Slave Mode

When configured as a slave, the SPI interface will remain inactive with MISO tri-stated as long as the SS pin is driven high.

21.2.5.1. Data Transfer

The data register can be updated at any time. As the SPI slave shift register is clocked by SCK, a minimum of three SCK cycles are needed from the time new data is written, until the character is ready to be shifted out. If the shift register has not been loaded with data, the current contents will be transmitted.

If constant transmission of data is needed in SPI slave mode, the system clock should be faster than SCK. If the receiver is enabled, the received character can be read from the receive buffer. When SS line is driven high, the slave will not receive any additional data.

21.2.5.2. Address Recognition

When the SPI slave is configured with address recognition, the first character in a transaction is checked for an address match. If there is a match, the MISO output is enabled and the transaction is processed. If the address does not match, the complete transaction is ignored.

If the device is asleep, it can be woken up by an address match in order to process the transaction.

Note: In master mode, an address packet is written by the spi_select_slave function if the address_enabled configuration is set in the spi_slave_inst_config struct.

21.2.6. Data Modes

There are four combinations of SCK phase and polarity with respect to serial data. Table 21-1 shows the clock polarity (CPOL) and clock phase (CPHA) in the different modes. *Leading edge* is the first clock edge in a clock cycle and *trailing edge* is the last clock edge in a clock cycle.

Table 21-1. SPI Data Modes

Mode	CPOL	CPHA	Leading Edge	Trailing Edge
0	0	0	Rising, Sample	Falling, Setup
1	0	1	Rising, Setup	Falling, Sample
2	1	0	Falling, Sample	Rising, Setup
3	1	1	Falling, Setup	Rising, Sample

21.2.7. SERCOM Pads

The SERCOM pads are automatically configured as seen in Table 21-2. If the receiver is disabled, the data input (MISO for master, MOSI for slave) can be used for other purposes.

In master mode, the SS pin(s) must be configured using the spi_slave_inst struct.

Table 21-2. SERCOM SPI Pad Usages

Pin	Master SPI	Slave SPI
MOSI	Output	Input
MISO	Input	Output
SCK	Output	Input
SS	User defined output enable	Input

21.2.8. Operation in Sleep Modes

The SPI module can operate in all sleep modes by setting the run_in_standby option in the spi_config struct. The operation in slave and master mode is shown in the table below.

run_in_standby	Slave	Master
false	Disabled, all reception is dropped	GCLK is disabled when master is idle, wake on transmit complete
true	Wake on reception	GCLK is enabled while in sleep modes, wake on all interrupts

21.2.9. Clock Generation

In SPI master mode, the clock (SCK) is generated internally using the SERCOM baudrate generator. In SPI slave mode, the clock is provided by an external master on the SCK pin. This clock is used to directly clock the SPI shift register.

21.3. Special Considerations

21.3.1. pinmux Settings

The pin MUX settings must be configured properly, as not all settings can be used in different modes of operation.

21.4. Extra Information

For extra information, see Extra Information for SERCOM SPI Driver. This includes:

- Acronyms
- Dependencies
- Workarounds Implemented by Driver
- Module History

21.5. Examples

For a list of examples related to this driver, see Examples for SERCOM SPI Driver.

21.6. API Overview

21.6.1. Variable and Type Definitions

21.6.1.1. Type spi_callback_t

```
typedef void(* spi_callback_t )(struct spi_module *const module)
```

Type of the callback functions

21.6.2. Structure Definitions

21.6.2.1. Struct spi_config

Configuration structure for an SPI instance. This structure should be initialized by the spi_get_config_defaults function before being modified by the user application.

Table 21-3. Members

Type	Name	Description
enum spi_character_size	character_size	SPI character size
enum spi_data_order	data_order	Data order
enum gclk_generator	generator_source	GCLK generator to use as clock source
bool	master_slave_select_enable	Enable Master Slave Select
enum spi_mode	mode	SPI mode
union spi_config.mode_specific	mode_specific	Union for slave or master specific configuration
enum spi_signal_mux_setting	mux_setting	MUX setting
uint32_t	pinmux_pad0	PAD0 pinmux

Type	Name	Description
uint32_t	pinmux_pad1	PAD1 pinmux
uint32_t	pinmux_pad2	PAD2 pinmux
uint32_t	pinmux_pad3	PAD3 pinmux
bool	receiver_enable	Enable receiver
bool	run_in_standby	Enabled in sleep modes
bool	select_slave_low_detect_enable	Enable Slave Select Low Detect
enum spi_transfer_mode	transfer_mode	Transfer mode

21.6.2.2. Union spi_config.mode_specific

Union for slave or master specific configuration

Table 21-4. Members

Type	Name	Description
struct spi_master_config	master	Master specific configuration
struct spi_slave_config	slave	Slave specific configuration

21.6.2.3. Struct spi_master_config

SPI Master configuration structure.

Table 21-5. Members

Type	Name	Description
uint32_t	baudrate	Baud rate

21.6.2.4. Struct spi_module

SERCOM SPI driver software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

21.6.2.5. Struct spi_slave_config

SPI slave configuration structure.

Table 21-6. Members

Type	Name	Description
uint8_t	address	Address
uint8_t	address_mask	Address mask
enum spi_addr_mode	address_mode	Address mode

Type	Name	Description
enum spi_frame_format	frame_format	Frame format
bool	preload_enable	Preload data to the shift register while SS is high

21.6.2.6. Struct spi_slave_inst

SPI peripheral slave software instance structure, used to configure the correct SPI transfer mode settings for an attached slave. See spi_select_slave.

Table 21-7. Members

Type	Name	Description
uint8_t	address	Address of slave device
bool	address_enabled	Address recognition enabled in slave device
uint8_t	ss_pin	Pin to use as slave select

21.6.2.7. Struct spi_slave_inst_config

SPI Peripheral slave configuration structure.

Table 21-8. Members

Type	Name	Description
uint8_t	address	Address of slave
bool	address_enabled	Enable address
uint8_t	ss_pin	Pin to use as slave select

21.6.3. Macro Definitions

21.6.3.1. Driver Feature Definition

Define SERCOM SPI features set according to different device family.

Macro FEATURE_SPI_SLAVE_SELECT_LOW_DETECT

```
#define FEATURE_SPI_SLAVE_SELECT_LOW_DETECT
```

SPI slave select low detection.

Macro FEATURE_SPI_HARDWARE_SLAVE_SELECT

```
#define FEATURE_SPI_HARDWARE_SLAVE_SELECT
```

Slave select can be controlled by hardware.

Macro FEATURE_SPI_ERROR_INTERRUPT

```
#define FEATURE_SPI_ERROR_INTERRUPT
```

SPI with error detect feature.

Macro FEATURE_SPI_SYNC_SCHEME_VERSION_2

```
#define FEATURE_SPI_SYNC_SCHEME_VERSION_2
```

SPI sync scheme version 2.

21.6.3.2. Macro PINMUX_DEFAULT

```
#define PINMUX_DEFAULT
```

Default pinmux.

21.6.3.3. Macro PINMUX_UNUSED

```
#define PINMUX_UNUSED
```

Unused pinmux.

21.6.3.4. Macro SPI_TIMEOUT

```
#define SPI_TIMEOUT
```

SPI timeout value.

21.6.4. Function Definitions

21.6.4.1. Driver Initialization and Configuration

Function spi_get_config_defaults()

Initializes an SPI configuration structure to default values.

```
void spi_get_config_defaults(
        struct spi_config *const config)
```

This function will initialize a given SPI configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Master mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- MUX Setting D
- Character size eight bits
- Not enabled in sleep mode
- Receiver enabled
- Baudrate 100000
- Default pinmux settings for all pads
- GCLK generator 0

Table 21-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function spi_slave_inst_get_config_defaults()

Initializes an SPI peripheral slave device configuration structure to default values.

```
void spi_slave_inst_get_config_defaults(
        struct spi_slave_inst_config *const config)
```

This function will initialize a given SPI slave device configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Slave Select on GPIO pin 10
- Addressing not enabled

Table 21-10. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function spi_attach_slave()

Attaches an SPI peripheral slave.

```
void spi_attach_slave(
        struct spi_slave_inst *const slave,
        const struct spi_slave_inst_config *const config)
```

This function will initialize the software SPI peripheral slave, based on the values of the config struct. The slave can then be selected and optionally addressed by the spi_select_slave function.

Table 21-11. Parameters

Data direction	Parameter name	Description
[out]	slave	Pointer to the software slave instance struct
[in]	config	Pointer to the config struct

Function spi_init()

Initializes the SERCOM SPI module.

```
enum status_code spi_init(
        struct spi_module *const module,
        Sercom *const hw,
        const struct spi_config *const config)
```

This function will initialize the SERCOM SPI module, based on the values of the config struct.

Table 21-12. Parameters

Data direction	Parameter name	Description
[out]	module	Pointer to the software instance struct
[in]	hw	Pointer to hardware instance
[in]	config	Pointer to the config struct

Returns
Status of the initialization.

Table 21-13. Return Values

Return value	Description
STATUS_OK	Module initiated correctly
STATUS_ERR_DENIED	If module is enabled
STATUS_BUSY	If module is busy resetting
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided

21.6.4.2. Enable/Disable

Function spi_enable()

Enables the SERCOM SPI module.

```
void spi_enable(
        struct spi_module *const module)
```

This function will enable the SERCOM SPI module.

Table 21-14. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function spi_disable()

Disables the SERCOM SPI module.

```
void spi_disable(
        struct spi_module *const module)
```

This function will disable the SERCOM SPI module.

Table 21-15. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

Function spi_reset()

Resets the SPI module.

```
void spi_reset(
        struct spi_module *const module)
```

This function will reset the SPI module to its power on default values and disable it.

Table 21-16. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the software instance struct

21.6.4.3. Lock/Unlock

Function spi_lock()

Attempt to get lock on driver instance.

```
enum status_code spi_lock(
        struct spi_module *const module)
```

This function checks the instance's lock, which indicates whether or not it is currently in use, and sets the lock if it was not already set.

The purpose of this is to enable exclusive access to driver instances, so that, e.g., transactions by different services will not interfere with each other.

Table 21-17. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 21-18. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

Function spi_unlock()

Unlock driver instance.

```
void spi_unlock(
        struct spi_module *const module)
```

This function clears the instance lock, indicating that it is available for use.

Table 21-19. Parameters

Data direction	Parameter name	Description
[in, out]	module	Pointer to the driver instance to lock

Table 21-20. Return Values

Return value	Description
STATUS_OK	If the module was locked
STATUS_BUSY	If the module was already locked

21.6.4.4. Ready to Write/Read

Function spi_is_write_complete()

Checks if the SPI in master mode has shifted out last data, or if the master has ended the transfer in slave mode.

```
bool spi_is_write_complete(
        struct spi_module *const module)
```

This function will check if the SPI master module has shifted out last data, or if the slave select pin has been drawn high by the master for the SPI slave module.

Table 21-21. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns
Indication of whether any writes are ongoing.

Table 21-22. Return Values

Return value	Description
true	If the SPI master module has shifted out data, or slave select has been drawn high for SPI slave
false	If the SPI master module has not shifted out data

Function spi_is_ready_to_write()

Checks if the SPI module is ready to write data.

```
bool spi_is_ready_to_write(
        struct spi_module *const module)
```

This function will check if the SPI module is ready to write data.

Table 21-23. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns
Indication of whether the module is ready to read data or not.

Table 21-24. Return Values

Return value	Description
true	If the SPI module is ready to write data
false	If the SPI module is not ready to write data

Function spi_is_ready_to_read()

Checks if the SPI module is ready to read data.

```
bool spi_is_ready_to_read(
        struct spi_module *const module)
```

This function will check if the SPI module is ready to read data.

Table 21-25. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct

Returns
Indication of whether the module is ready to read data or not.

Table 21-26. Return Values

Return value	Description
true	If the SPI module is ready to read data
false	If the SPI module is not ready to read data

21.6.4.5. Read/Write

Function spi_write()

Transfers a single SPI character.

```
enum status_code spi_write(
        struct spi_module * module,
        uint16_t tx_data)
```

This function will send a single SPI character via SPI and ignore any data shifted in by the connected device. To both send and receive data, use the spi_transceive_wait function or use the spi_read function after writing a character. The spi_is_ready_to_write function should be called before calling this function.

Note that this function does not handle the SS (Slave Select) pin(s) in master mode; this must be handled from the user application.

Note: In slave mode, the data will not be transferred before a master initiates a transaction.

Table 21-27. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Data to transmit

Returns
Status of the procedure.

Table 21-28. Return Values

Return value	Description
STATUS_OK	If the data was written
STATUS_BUSY	If the last write was not completed

Function spi_write_buffer_wait()

Sends a buffer of `length` SPI characters.

```
enum status_code spi_write_buffer_wait(
        struct spi_module *const module,
        const uint8_t * tx_data,
        uint16_t length)
```

This function will send a buffer of SPI characters via the SPI and discard any data that is received. To both send and receive a buffer of data, use the spi_transceive_buffer_wait function.

Note that this function does not handle the _SS (slave select) pin(s) in master mode; this must be handled by the user application.

Table 21-29. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Pointer to the buffer to transmit
[in]	length	Number of SPI characters to transfer

Returns
Status of the write operation.

Table 21-30. Return Values

Return value	Description
STATUS_OK	If the write was completed
STATUS_ABORTED	If transaction was ended by master before entire buffer was transferred
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode

Function spi_read()

Reads last received SPI character.

```
enum status_code spi_read(
        struct spi_module *const module,
        uint16_t * rx_data)
```

This function will return the last SPI character shifted into the receive register by the spi_write function.

Note: The spi_is_ready_to_read function should be called before calling this function.

Note: Receiver must be enabled in the configuration.

Table 21-31. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Pointer to store the received data

Returns
Status of the read operation.

Table 21-32. Return Values

Return value	Description
STATUS_OK	If data was read
STATUS_ERR_IO	If no data is available
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_read_buffer_wait()

Reads buffer of `length` SPI characters.

```
enum status_code spi_read_buffer_wait(
        struct spi_module *const module,
        uint8_t * rx_data,
        uint16_t length,
        uint16_t dummy)
```

This function will read a buffer of data from an SPI peripheral by sending dummy SPI character if in master mode, or by waiting for data in slave mode.

Note: If address matching is enabled for the slave, the first character received and placed in the buffer will be the address.

Table 21-33. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[out]	rx_data	Data buffer for received data
[in]	length	Length of data to receive
[in]	dummy	8- or 9-bit dummy byte to shift out in master mode

Returns
Status of the read operation.

Table 21-34. Return Values

Return value	Description
STATUS_OK	If the read was completed
STATUS_ABORTED	If transaction was ended by master before the entire buffer was transferred
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode

Return value	Description
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_transceive_wait()

Sends and reads a single SPI character.

```
enum status_code spi_transceive_wait(
        struct spi_module *const module,
        uint16_t tx_data,
        uint16_t * rx_data)
```

This function will transfer a single SPI character via SPI and return the SPI character that is shifted into the shift register.

In master mode the SPI character will be sent immediately and the received SPI character will be read as soon as the shifting of the data is complete.

In slave mode this function will place the data to be sent into the transmit buffer. It will then block until an SPI master has shifted a complete SPI character, and the received data is available.

Note: The data to be sent might not be sent before the next transfer, as loading of the shift register is dependent on SCK.

Note: If address matching is enabled for the slave, the first character received and placed in the buffer will be the address.

Table 21-35. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	SPI character to transmit
[out]	rx_data	Pointer to store the received SPI character

Returns
Status of the operation.

Table 21-36. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the incoming data is overflown

Function spi_transceive_buffer_wait()

Sends and receives a buffer of `length` SPI characters.

```
enum status_code spi_transceive_buffer_wait(
        struct spi_module *const module,
        uint8_t * tx_data,
        uint8_t * rx_data,
        uint16_t length)
```

This function will send and receive a buffer of data via the SPI.

In master mode the SPI characters will be sent immediately and the received SPI character will be read as soon as the shifting of the SPI character is complete.

In slave mode this function will place the data to be sent into the transmit buffer. It will then block until an SPI master has shifted the complete buffer and the received data is available.

Table 21-37. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	tx_data	Pointer to the buffer to transmit
[out]	rx_data	Pointer to the buffer where received data will be stored
[in]	length	Number of SPI characters to transfer

Returns
Status of the operation.

Table 21-38. Return Values

Return value	Description
STATUS_OK	If the operation was completed
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_ERR_TIMEOUT	If the operation was not completed within the timeout in slave mode
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_OVERFLOW	If the data is overflown

Function spi_select_slave()

Selects slave device.

```
enum status_code spi_select_slave(
        struct spi_module *const module,
        struct spi_slave_inst *const slave,
        bool select)
```

This function will drive the slave select pin of the selected device low or high depending on the select Boolean. If slave address recognition is enabled, the address will be sent to the slave when selecting it.

Table 21-39. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software module struct
[in]	slave	Pointer to the attached slave
[in]	select	Boolean stating if the slave should be selected or deselected

Returns
Status of the operation.

Table 21-40. Return Values

Return value	Description
STATUS_OK	If the slave device was selected
STATUS_ERR_UNSUPPORTED_DEV	If the SPI module is operating in slave mode
STATUS_BUSY	If the SPI module is not ready to write the slave address

21.6.4.6. Callback Management

Function spi_register_callback()

Registers a SPI callback function.

```
void spi_register_callback(
        struct spi_module *const module,
        spi_callback_t callback_func,
        enum spi_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note: The callback must be enabled by spi_enable_callback, in order for the interrupt handler to call it when the conditions for the callback type are met.

Table 21-41. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to USART software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function spi_unregister_callback()

Unregisters a SPI callback function.

```
void spi_unregister_callback(
        struct spi_module * module,
        enum spi_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 21-42. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

Function spi_enable_callback()

Enables an SPI callback of a given type.

```
void spi_enable_callback(
        struct spi_module *const module,
        enum spi_callback callback_type)
```

Enables the callback function registered by the spi_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 21-43. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

Function spi_disable_callback()

Disables callback.

```
void spi_disable_callback(
        struct spi_module *const module,
        enum spi_callback callback_type)
```

Disables the callback function registered by the spi_register_callback, and the callback will not be called from the interrupt routine.

Table 21-44. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	callback_type	Callback type given by an enum

21.6.4.7. Writing and Reading

Function spi_write_buffer_job()

Asynchronous buffer write.

```
enum status_code spi_write_buffer_job(
        struct spi_module *const module,
        uint8_t * tx_data,
        uint16_t length)
```

Sets up the driver to write to the SPI from a given buffer. If registered and enabled, a callback function will be called when the write is finished.

Table 21-45. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[out]	tx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Returns
Status of the write request operation.

Table 21-46. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a write operation
STATUS_ERR_INVALID_ARG	If requested write length was zero

Function spi_read_buffer_job()

Asynchronous buffer read.

```
enum status_code spi_read_buffer_job(
        struct spi_module *const module,
        uint8_t * rx_data,
        uint16_t length,
        uint16_t dummy)
```

Sets up the driver to read from the SPI to a given buffer. If registered and enabled, a callback function will be called when the read is finished.

Note: If address matching is enabled for the slave, the first character received and placed in the RX buffer will be the address.

Table 21-47. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length
[in]	dummy	Dummy character to send when reading in master mode

Returns
Status of the operation.

Table 21-48. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a read operation
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_INVALID_ARG	If requested read length was zero

Function spi_transceive_buffer_job()

Asynchronous buffer write and read.

```
enum status_code spi_transceive_buffer_job(
        struct spi_module *const module,
        uint8_t * tx_data,
        uint8_t * rx_data,
        uint16_t length)
```

Sets up the driver to write and read to and from given buffers. If registered and enabled, a callback function will be called when the transfer is finished.

Note: If address matching is enabled for the slave, the first character received and placed in the RX buffer will be the address.

Table 21-49. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct
[in]	tx_data	Pointer to data buffer to send
[out]	rx_data	Pointer to data buffer to receive
[in]	length	Data buffer length

Returns

Status of the operation.

Table 21-50. Return Values

Return value	Description
STATUS_OK	If the operation completed successfully
STATUS_ERR_BUSY	If the SPI was already busy with a read operation
STATUS_ERR_DENIED	If the receiver is not enabled
STATUS_ERR_INVALID_ARG	If requested read length was zero

Function spi_abort_job()

Aborts an ongoing job.

```
void spi_abort_job(
        struct spi_module *const module)
```

This function will abort the specified job type.

Table 21-51. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Function spi_get_job_status()

Retrieves the current status of a job.

```
enum status_code spi_get_job_status(
        const struct spi_module *const module)
```

Retrieves the current status of a job that was previously issued.

Table 21-52. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Returns
Current job status.

Function spi_get_job_status_wait()

Retrieves the status of job once it ends.

```
enum status_code spi_get_job_status_wait(
        const struct spi_module *const module)
```

Waits for current job status to become non-busy, then returns its value.

Table 21-53. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to SPI software instance struct

Returns
Current non-busy job status.

21.6.4.8. Function spi_is_syncing()

Determines if the SPI module is currently synchronizing to the bus.

```
bool spi_is_syncing(
        struct spi_module *const module)
```

This function will check if the underlying hardware peripheral module is currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on the module until it is ready.

Table 21-54. Parameters

Data direction	Parameter name	Description
[in]	module	SPI hardware module

Returns
Synchronization status of the underlying hardware module.

Table 21-55. Return Values

Return value	Description
true	Module synchronization is ongoing
false	Module synchronization is not ongoing

21.6.4.9. Function spi_set_baudrate()

Set the baudrate of the SPI module.

```
enum status_code spi_set_baudrate(
        struct spi_module *const module,
        uint32_t baudrate)
```

This function will set the baudrate of the SPI module.

Table 21-56. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to the software instance struct
[in]	baudrate	The baudrate wanted

Returns
The status of the configuration.

Table 21-57. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	If invalid argument(s) were provided
STATUS_OK	If the configuration was written

21.6.5. Enumeration Definitions

21.6.5.1. Enum spi_addr_mode

For slave mode when using the SPI frame with address format.

Table 21-58. Members

Enum value	Description
SPI_ADDR_MODE_MASK	`address_mask` in the spi_config struct is used as a mask to the register
SPI_ADDR_MODE_UNIQUE	The slave responds to the two unique addresses in `address` and `address_mask` in the spi_config struct
SPI_ADDR_MODE_RANGE	The slave responds to the range of addresses between and including `address` and `address_mask` in the spi_config struct

21.6.5.2. Enum spi_callback

Callbacks for SPI callback driver.

Note: For slave mode, these callbacks will be called when a transaction is ended by the master pulling Slave Select high.

Table 21-59. Members

Enum value	Description
SPI_CALLBACK_BUFFER_TRANSMITTED	Callback for buffer transmitted
SPI_CALLBACK_BUFFER_RECEIVED	Callback for buffer received
SPI_CALLBACK_BUFFER_TRANSCEIVED	Callback for buffers transceived
SPI_CALLBACK_ERROR	Callback for error
SPI_CALLBACK_SLAVE_TRANSMISSION_COMPLETE	Callback for transmission ended by master before the entire buffer was read or written from slave
SPI_CALLBACK_SLAVE_SELECT_LOW	Callback for slave select low
SPI_CALLBACK_COMBINED_ERROR	Callback for combined error happen

21.6.5.3. Enum spi_character_size

SPI character size.

Table 21-60. Members

Enum value	Description
SPI_CHARACTER_SIZE_8BIT	8-bit character
SPI_CHARACTER_SIZE_9BIT	9-bit character

21.6.5.4. Enum spi_data_order

SPI data order.

Table 21-61. Members

Enum value	Description
SPI_DATA_ORDER_LSB	The LSB of the data is transmitted first
SPI_DATA_ORDER_MSB	The MSB of the data is transmitted first

21.6.5.5. Enum spi_frame_format

Frame format for slave mode.

Table 21-62. Members

Enum value	Description
SPI_FRAME_FORMAT_SPI_FRAME	SPI frame
SPI_FRAME_FORMAT_SPI_FRAME_ADDR	SPI frame with address

21.6.5.6. Enum spi_interrupt_flag

Interrupt flags for the SPI module.

Table 21-63. Members

Enum value	Description
SPI_INTERRUPT_FLAG_DATA_REGISTER_EMPTY	This flag is set when the contents of the data register has been moved to the shift register and the data register is ready for new data
SPI_INTERRUPT_FLAG_TX_COMPLETE	This flag is set when the contents of the shift register has been shifted out
SPI_INTERRUPT_FLAG_RX_COMPLETE	This flag is set when data has been shifted into the data register
SPI_INTERRUPT_FLAG_SLAVE_SELECT_LOW	This flag is set when slave select low
SPI_INTERRUPT_FLAG_COMBINED_ERROR	This flag is set when combined error happen

21.6.5.7. Enum spi_mode

SPI mode selection.

Table 21-64. Members

Enum value	Description
SPI_MODE_MASTER	Master mode
SPI_MODE_SLAVE	Slave mode

21.6.5.8. Enum spi_signal_mux_setting

Set the functionality of the SERCOM pins. As not all combinations can be used in different modes of operation, proper combinations must be chosen according to the rest of the configuration.

Note: In master operation: DI is MISO, DO is MOSI. In slave operation: DI is MOSI, DO is MISO.

See MUX Settings for a description of the various MUX setting options.

Table 21-65. Members

Enum value	Description
SPI_SIGNAL_MUX_SETTING_A	SPI MUX combination A. DOPO: 0x0, DIPO: 0x0
SPI_SIGNAL_MUX_SETTING_B	SPI MUX combination B. DOPO: 0x0, DIPO: 0x1
SPI_SIGNAL_MUX_SETTING_C	SPI MUX combination C. DOPO: 0x0, DIPO: 0x2
SPI_SIGNAL_MUX_SETTING_D	SPI MUX combination D. DOPO: 0x0, DIPO: 0x3
SPI_SIGNAL_MUX_SETTING_E	SPI MUX combination E. DOPO: 0x1, DIPO: 0x0
SPI_SIGNAL_MUX_SETTING_F	SPI MUX combination F. DOPO: 0x1, DIPO: 0x1
SPI_SIGNAL_MUX_SETTING_G	SPI MUX combination G. DOPO: 0x1, DIPO: 0x2
SPI_SIGNAL_MUX_SETTING_H	SPI MUX combination H. DOPO: 0x1, DIPO: 0x3
SPI_SIGNAL_MUX_SETTING_I	SPI MUX combination I. DOPO: 0x2, DIPO: 0x0
SPI_SIGNAL_MUX_SETTING_J	SPI MUX combination J. DOPO: 0x2, DIPO: 0x1
SPI_SIGNAL_MUX_SETTING_K	SPI MUX combination K. DOPO: 0x2, DIPO: 0x2
SPI_SIGNAL_MUX_SETTING_L	SPI MUX combination L. DOPO: 0x2, DIPO: 0x3
SPI_SIGNAL_MUX_SETTING_M	SPI MUX combination M. DOPO: 0x3, DIPO: 0x0
SPI_SIGNAL_MUX_SETTING_N	SPI MUX combination N. DOPO: 0x3, DIPO: 0x1
SPI_SIGNAL_MUX_SETTING_O	SPI MUX combination O. DOPO: 0x3, DIPO: 0x2
SPI_SIGNAL_MUX_SETTING_P	SPI MUX combination P. DOPO: 0x3, DIPO: 0x3

21.6.5.9. Enum spi_transfer_mode

SPI transfer mode.

Table 21-66. Members

Enum value	Description
SPI_TRANSFER_MODE_0	Mode 0. Leading edge: rising, sample. Trailing edge: falling, setup
SPI_TRANSFER_MODE_1	Mode 1. Leading edge: rising, setup. Trailing edge: falling, sample
SPI_TRANSFER_MODE_2	Mode 2. Leading edge: falling, sample. Trailing edge: rising, setup
SPI_TRANSFER_MODE_3	Mode 3. Leading edge: falling, setup. Trailing edge: rising, sample

21.7. Extra Information for SERCOM SPI Driver

21.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
SERCOM	Serial Communication Interface
SPI	Serial Peripheral Interface
SCK	Serial Clock
MOSI	Master Output Slave Input
MISO	Master Input Slave Output
SS	Slave Select
DIO	Data Input Output
DO	Data Output
DI	Data Input
DMA	Direct Memory Access

21.7.2. Dependencies

The SPI driver has the following dependencies:

- System Pin Multiplexer Driver

21.7.3. Workarounds Implemented by Driver

No workarounds in driver.

21.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added new features as below: • Slave select low detect • Hardware slave select • DMA support
Edited slave part of write and transceive buffer functions to ensure that second character is sent at the right time

Changelog
Renamed the anonymous union in `struct` spi_config to `mode_specific`
Initial Release

21.8. Examples for SERCOM SPI Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Serial Peripheral Interface (SERCOM SPI) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SERCOM SPI Master - Polled
- Quick Start Guide for SERCOM SPI Slave - Polled
- Quick Start Guide for SERCOM SPI Master - Callback
- Quick Start Guide for SERCOM SPI Slave - Callback
- Quick Start Guide for Using DMA with SERCOM SPI

21.8.1. Quick Start Guide for SERCOM SPI Master - Polled

In this use case, the SPI on extension header 1 of the Xplained Pro board will be configured with the following settings:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Master Mode Settings)
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

21.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application:

A sample buffer to send via SPI.

```
static uint8_t buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
        0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer.

```
#define BUF_LENGTH 20
```

GPIO pin to use as Slave Select.

```
#define SLAVE_SELECT_PIN CONF_MASTER_SS_PIN
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_master_instance;
```

A globally available peripheral slave software device instance struct.

```
struct spi_slave_inst slave;
```

A function for configuring the SPI.

```
void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;

    config_spi_master.pinmux_pad0 = CONF_MASTER_PINMUX_PAD0;
    config_spi_master.pinmux_pad1 = CONF_MASTER_PINMUX_PAD1;
    config_spi_master.pinmux_pad2 = CONF_MASTER_PINMUX_PAD2;
    config_spi_master.pinmux_pad3 = CONF_MASTER_PINMUX_PAD3;

    spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
&config_spi_master);

    spi_enable(&spi_master_instance);

}
```

Add to user application `main()`.

```
system_init();
configure_spi_master();
```

21.8.1.2. Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Set-up the SPI.

   ```
   configure_spi_master();
   ```

   1. Create configuration struct.

      ```
      struct spi_config config_spi_master;
      ```

   2. Create peripheral slave configuration struct.

      ```
      struct spi_slave_inst_config slave_dev_config;
      ```

   3. Create peripheral slave software device instance struct.

      ```
      struct spi_slave_inst slave;
      ```

4. Get default peripheral slave configuration.
```
spi_slave_inst_get_config_defaults(&slave_dev_config);
```
5. Set Slave Select pin.
```
slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
```
6. Initialize peripheral slave software instance with configuration.
```
spi_attach_slave(&slave, &slave_dev_config);
```
7. Get default configuration to edit.
```
spi_get_config_defaults(&config_spi_master);
```
8. Set MUX setting E.
```
config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;
```
9. Set pinmux for pad 0 (data in (MISO)).
10. Set pinmux for pad 1 as unused, so the pin can be used for other purposes.
11. Set pinmux for pad 2 (data out (MOSI)).
12. Set pinmux for pad 3 (SCK).
13. Initialize SPI module with configuration.
```
spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
&config_spi_master);
```
14. Enable SPI module.
```
spi_enable(&spi_master_instance);
```

21.8.1.3. Use Case

Code

Add the following to your user application `main()`.

```
while (true) {
     /* Infinite loop */
     if(!port_pin_get_input_level(BUTTON_0_PIN)) {
          spi_select_slave(&spi_master_instance, &slave, true);
          spi_write_buffer_wait(&spi_master_instance, buffer, BUF_LENGTH);
          spi_select_slave(&spi_master_instance, &slave, false);
          port_pin_set_output_level(LED_0_PIN, LED0_ACTIVE);
     }
}
```

Workflow

1. Select slave.
```
spi_select_slave(&spi_master_instance, &slave, true);
```
2. Write buffer to SPI slave.
```
spi_write_buffer_wait(&spi_master_instance, buffer, BUF_LENGTH);
```

3. Deselect slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

4. Light up.

```
port_pin_set_output_level(LED_0_PIN, LED0_ACTIVE);
```

5. Infinite loop.

```
while (true) {
    /* Infinite loop */
    if(!port_pin_get_input_level(BUTTON_0_PIN)) {
        spi_select_slave(&spi_master_instance, &slave, true);
        spi_write_buffer_wait(&spi_master_instance, buffer,
BUF_LENGTH);
        spi_select_slave(&spi_master_instance, &slave, false);
        port_pin_set_output_level(LED_0_PIN, LED0_ACTIVE);
    }
}
```

21.8.2. Quick Start Guide for SERCOM SPI Slave - Polled

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Slave Mode Settings)
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

21.8.2.1. Setup

Prerequisites

The device must be connected to an SPI master which must read from the device.

Code

The following must be added to the user application source file, outside any functions:

A sample buffer to send via SPI.

```
static uint8_t buffer_expect[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
static uint8_t buffer_rx[BUF_LENGTH] = {0x00};
```

Number of entries in the sample buffer.

```
#define BUF_LENGTH 20
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_slave_instance;
```

A function for configuring the SPI.

```
void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format =
SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;

    config_spi_slave.pinmux_pad0 = CONF_SLAVE_PINMUX_PAD0;
    config_spi_slave.pinmux_pad1 = CONF_SLAVE_PINMUX_PAD1;
    config_spi_slave.pinmux_pad2 = CONF_SLAVE_PINMUX_PAD2;
    config_spi_slave.pinmux_pad3 = CONF_SLAVE_PINMUX_PAD3;

    spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);

    spi_enable(&spi_slave_instance);

}
```

Add to user application `main()`.

```
uint8_t result = 0;

/* Initialize system */
system_init();

configure_spi_slave();
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Set-up the SPI.

   ```
   configure_spi_slave();
   ```

   1. Create configuration struct.

      ```
      struct spi_config config_spi_slave;
      ```

   2. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_slave);
      ```

   3. Set the SPI in slave mode.

      ```
      config_spi_slave.mode = SPI_MODE_SLAVE;
      ```

   4. Enable preloading of shift register.

      ```
      config_spi_slave.mode_specific.slave.preload_enable = true;
      ```

   5. Set frame format to SPI frame.

      ```
      config_spi_slave.mode_specific.slave.frame_format =
      SPI_FRAME_FORMAT_SPI_FRAME;
      ```

6. Set MUX setting E.

```
config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;
```

7. Set pinmux for pad 0 (data in MOSI).

8. Set pinmux for pad 1 (slave select).

9. Set pinmux for pad 2 (data out MISO).

10. Set pinmux for pad 3 (SCK).

11. Initialize SPI module with configuration.

```
spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);
```

12. Enable SPI module.

```
spi_enable(&spi_slave_instance);
```

21.8.2.2. Use Case

Code

Add the following to your user application `main()`.

```
while(spi_read_buffer_wait(&spi_slave_instance, buffer_rx, BUF_LENGTH,
    0x00) != STATUS_OK) {
    /* Wait for transfer from the master */
}
for (uint8_t i = 0; i < BUF_LENGTH; i++) {
    if(buffer_rx[i] != buffer_expect[i]) {
        result++;
    }
}
while (true) {
    /* Infinite loop */
    if (result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 30000;
        while(delay--) {
        }
    } else {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 600000;
        while(delay--) {
        }
    }
}
```

Workflow

1. Read data from SPI master.

```
while(spi_read_buffer_wait(&spi_slave_instance, buffer_rx, BUF_LENGTH,
    0x00) != STATUS_OK) {
    /* Wait for transfer from the master */
}
```

2. Compare the received data with the transmitted data from SPI master.

```
for (uint8_t i = 0; i < BUF_LENGTH; i++) {
    if(buffer_rx[i] != buffer_expect[i]) {
        result++;
    }
}
```

3. Infinite loop. If the data is matched, LED0 will flash slowly. Otherwise, LED will flash quickly.

```
while (true) {
    /* Infinite loop */
    if (result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 30000;
        while(delay--) {
        }
    } else {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 600000;
        while(delay--) {
        }
    }
}
```

21.8.3. Quick Start Guide for SERCOM SPI Master - Callback

In this use case, the SPI on extension header 1 of the Xplained Pro board will be configured with the following settings:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Master Mode Settings)
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

21.8.3.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

The following must be added to the user application.

A sample buffer to send via SPI.

```
static uint8_t wr_buffer[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
static uint8_t rd_buffer[BUF_LENGTH];
```

Number of entries in the sample buffer.

```
#define BUF_LENGTH 20
```

GPIO pin to use as Slave Select.

```
#define SLAVE_SELECT_PIN CONF_MASTER_SS_PIN
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_master_instance;
```

A globally available peripheral slave software device instance struct.

```
struct spi_slave_inst slave;
```

A function for configuring the SPI.

```
void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;

    config_spi_master.pinmux_pad0 = CONF_MASTER_PINMUX_PAD0;
    config_spi_master.pinmux_pad1 = CONF_MASTER_PINMUX_PAD1;
    config_spi_master.pinmux_pad2 = CONF_MASTER_PINMUX_PAD2;
    config_spi_master.pinmux_pad3 = CONF_MASTER_PINMUX_PAD3;

    spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
&config_spi_master);

    spi_enable(&spi_master_instance);

}
```

A function for configuring the callback functionality of the SPI.

```
void configure_spi_master_callbacks(void)
{
    spi_register_callback(&spi_master_instance, callback_spi_master,
            SPI_CALLBACK_BUFFER_TRANSCEIVED);
    spi_enable_callback(&spi_master_instance,
SPI_CALLBACK_BUFFER_TRANSCEIVED);
}
```

A global variable that can flag to the application that the buffer has been transferred.

```
volatile bool transrev_complete_spi_master = false;
```

Callback function.

```
static void callback_spi_master( struct spi_module *const module)
{
    transrev_complete_spi_master = true;
}
```

Add to user application `main()`.

```
/* Initialize system */
system_init();
```

```
configure_spi_master();
configure_spi_master_callbacks();
```

21.8.3.2. Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Set-up the SPI.

   ```
   configure_spi_master();
   ```

   1. Create configuration struct.

      ```
      struct spi_config config_spi_master;
      ```

   2. Create peripheral slave configuration struct.

      ```
      struct spi_slave_inst_config slave_dev_config;
      ```

   3. Get default peripheral slave configuration.

      ```
      spi_slave_inst_get_config_defaults(&slave_dev_config);
      ```

   4. Set Slave Select pin.

      ```
      slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
      ```

   5. Initialize peripheral slave software instance with configuration.

      ```
      spi_attach_slave(&slave, &slave_dev_config);
      ```

   6. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_master);
      ```

   7. Set MUX setting E.

      ```
      config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;
      ```

   8. Set pinmux for pad 0 (data in MISO).

      ```
      ```

   9. Set pinmux for pad 1 as unused, so the pin can be used for other purposes.

      ```
      ```

   10. Set pinmux for pad 2 (data out MOSI).

       ```
       ```

   11. Set pinmux for pad 3 (SCK).

       ```
       ```

   12. Initialize SPI module with configuration.

       ```
       spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
       &config_spi_master);
       ```

   13. Enable SPI module.

       ```
       spi_enable(&spi_master_instance);
       ```

3. Setup the callback functionality.

   ```
   configure_spi_master_callbacks();
   ```

1. Register callback function for buffer transmitted.

```
spi_register_callback(&spi_master_instance, callback_spi_master,
        SPI_CALLBACK_BUFFER_TRANSCEIVED);
```

2. Enable callback for buffer transmitted.

```
spi_enable_callback(&spi_master_instance,
SPI_CALLBACK_BUFFER_TRANSCEIVED);
```

21.8.3.3. Use Case

Code

Add the following to your user application `main()`.

```
while (true) {
    /* Infinite loop */
    if (!port_pin_get_input_level(BUTTON_0_PIN)) {
        spi_select_slave(&spi_master_instance, &slave, true);
        spi_transceive_buffer_job(&spi_master_instance,
wr_buffer,rd_buffer,BUF_LENGTH);
        while (!transrev_complete_spi_master) {
        }
        transrev_complete_spi_master = false;
        spi_select_slave(&spi_master_instance, &slave, false);
    }
}
```

Workflow

1. Select slave.

```
spi_select_slave(&spi_master_instance, &slave, true);
```

2. Write buffer to SPI slave.

```
spi_transceive_buffer_job(&spi_master_instance,
wr_buffer,rd_buffer,BUF_LENGTH);
```

3. Wait for the transfer to be complete.

```
while (!transrev_complete_spi_master) {
}
transrev_complete_spi_master = false;
```

4. Deselect slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

5. Infinite loop.

```
while (true) {
    /* Infinite loop */
    if (!port_pin_get_input_level(BUTTON_0_PIN)) {
        spi_select_slave(&spi_master_instance, &slave, true);
        spi_transceive_buffer_job(&spi_master_instance,
wr_buffer,rd_buffer,BUF_LENGTH);
        while (!transrev_complete_spi_master) {
        }
        transrev_complete_spi_master = false;
        spi_select_slave(&spi_master_instance, &slave, false);
    }
}
```

21.8.3.4. Callback

When the buffer is successfully transmitted to the slave, the callback function will be called.

Workflow

1. Let the application know that the buffer is transmitted by setting the global variable to true.

```
transrev_complete_spi_master = true;
```

21.8.4. Quick Start Guide for SERCOM SPI Slave - Callback

In this use case, the SPI on extension header 1 of the Xplained Pro board will configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E (see Slave Mode Settings)
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

21.8.4.1. Setup

Prerequisites

The device must be connected to a SPI master, which must read from the device.

Code

The following must be added to the user application source file, outside any functions.

A sample buffer to send via SPI.

```
static uint8_t buffer_rx[BUF_LENGTH] = {0x00,};
static uint8_t buffer_expect[BUF_LENGTH] = {
        0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
         0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13
};
```

Number of entries in the sample buffer.

```
#define BUF_LENGTH 20
```

A globally available software device instance struct to store the SPI driver state while it is in use.

```
struct spi_module spi_slave_instance;
```

A function for configuring the SPI.

```
void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format =
SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;
```

```
    config_spi_slave.pinmux_pad0 = CONF_SLAVE_PINMUX_PAD0;
    config_spi_slave.pinmux_pad1 = CONF_SLAVE_PINMUX_PAD1;
    config_spi_slave.pinmux_pad2 = CONF_SLAVE_PINMUX_PAD2;
    config_spi_slave.pinmux_pad3 = CONF_SLAVE_PINMUX_PAD3;

    spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);

    spi_enable(&spi_slave_instance);

}
```

A function for configuring the callback functionality of the SPI.

```
void configure_spi_slave_callbacks(void)
{
    spi_register_callback(&spi_slave_instance, spi_slave_callback,
            SPI_CALLBACK_BUFFER_RECEIVED);
    spi_enable_callback(&spi_slave_instance, SPI_CALLBACK_BUFFER_RECEIVED);
}
```

A global variable that can flag to the application that the buffer has been transferred.

```
volatile bool transfer_complete_spi_slave = false;
```

Callback function.

```
static void spi_slave_callback(struct spi_module *const module)
{
    transfer_complete_spi_slave = true;
}
```

Add to user application `main()`.

```
uint8_t result = 0;

/* Initialize system */
system_init();

configure_spi_slave();
configure_spi_slave_callbacks();
```

Workflow

1. Initialize system.

   ```
   system_init();
   ```

2. Set-up the SPI.

   ```
   configure_spi_slave();
   ```

   1. Create configuration struct.

      ```
      struct spi_config config_spi_slave;
      ```

   2. Get default configuration to edit.

      ```
      spi_get_config_defaults(&config_spi_slave);
      ```

   3. Set the SPI in slave mode.

      ```
      config_spi_slave.mode = SPI_MODE_SLAVE;
      ```

4. Enable preloading of shift register.

```
config_spi_slave.mode_specific.slave.preload_enable = true;
```

5. Set frame format to SPI frame.

```
config_spi_slave.mode_specific.slave.frame_format =
SPI_FRAME_FORMAT_SPI_FRAME;
```

6. Set MUX setting E.

```
config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;
```

7. Set pinmux for pad 0 (data in MOSI).

8. Set pinmux for pad 1 (slave select).

9. Set pinmux for pad 2 (data out MISO).

10. Set pinmux for pad 3 (SCK).

11. Initialize SPI module with configuration.

```
spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);
```

12. Enable SPI module.

```
spi_enable(&spi_slave_instance);
```

3. Setup of the callback functionality.

```
configure_spi_slave_callbacks();
```

1. Register callback function for buffer transmitted.

```
spi_register_callback(&spi_slave_instance, spi_slave_callback,
        SPI_CALLBACK_BUFFER_RECEIVED);
```

2. Enable callback for buffer transmitted.

```
spi_enable_callback(&spi_slave_instance,
SPI_CALLBACK_BUFFER_RECEIVED);
```

21.8.4.2. Use Case

Code

Add the following to your user application `main()`.

```
spi_read_buffer_job(&spi_slave_instance, buffer_rx, BUF_LENGTH, 0x00);
while(!transfer_complete_spi_slave) {
    /* Wait for transfer from master */
}
for (uint8_t i = 0; i < BUF_LENGTH; i++) {
    if(buffer_rx[i] != buffer_expect[i]) {
        result++;
    }
}

while (true) {
    /* Infinite loop */
    if (result) {
        port_pin_toggle_output_level(LED_0_PIN);
```

```
            /* Add a short delay to see LED toggle */
            volatile uint32_t delay = 30000;
            while(delay--) {
            }
        } else {
            port_pin_toggle_output_level(LED_0_PIN);
            /* Add a short delay to see LED toggle */
            volatile uint32_t delay = 600000;
            while(delay--) {
            }
        }
}
```

Workflow

1. Initiate a read buffer job.

```
spi_read_buffer_job(&spi_slave_instance, buffer_rx, BUF_LENGTH, 0x00);
```

2. Wait for the transfer to be complete.

```
while(!transfer_complete_spi_slave) {
    /* Wait for transfer from master */
}
```

3. Compare the received data with the transmitted data from SPI master.

```
for (uint8_t i = 0; i < BUF_LENGTH; i++) {
    if(buffer_rx[i] != buffer_expect[i]) {
        result++;
    }
}
```

4. Infinite loop. If the data is matched, LED0 will flash slowly. Otherwise, LED will flash quickly.

```
while (true) {
    /* Infinite loop */
    if (result) {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 30000;
        while(delay--) {
        }
    } else {
        port_pin_toggle_output_level(LED_0_PIN);
        /* Add a short delay to see LED toggle */
        volatile uint32_t delay = 600000;
        while(delay--) {
        }
    }
}
```

21.8.4.3. Callback

When the buffer is successfully transmitted from the master, the callback function will be called.

Workflow

1. Let the application know that the buffer is transmitted by setting the global variable to true.

```
transfer_complete_spi_slave = true;
```

21.8.5. Quick Start Guide for Using DMA with SERCOM SPI

The supported board list:

- SAM D21 Xplained Pro
- SAM R21 Xplained Pro
- SAM L21 Xplained Pro
- SAM L22 Xplained Pro
- SAM DA1 Xplained Pro
- SAM C21 Xplained Pro
- SAM R30 Xplained Pro

This quick start will transmit a buffer data from master to slave through DMA. In this use case the SPI master will be configured with the following settings on SAM Xplained Pro:

- Master Mode enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E
- 8-bit character size
- Not enabled in sleep mode
- Baudrate 100000
- GLCK generator 0

The SPI slave will be configured with the following settings:

- Slave mode enabled
- Preloading of shift register enabled
- MSB of the data is transmitted first
- Transfer mode 0
- SPI MUX Setting E
- 8-bit character size
- Not enabled in sleep mode
- GLCK generator 0

Note that the pinouts on other boards may different, see next sector for details.

21.8.5.1. Setup

Prerequisites

The following connections has to be made using wires:

- SAM D21/DA1 Xplained Pro.
  - **SS_0:** EXT1 PIN15 (PA05) <> EXT2 PIN15 (PA17)
  - **DO/DI**: EXT1 PIN16 (PA06) <> EXT2 PIN17 (PA16)
  - **DI/DO**: EXT1 PIN17 (PA04) <> EXT2 PIN16 (PA18)
  - **SCK:** EXT1 PIN18 (PA07) <> EXT2 PIN18 (PA19)
- SAM R21 Xplained Pro.
  - **SS_0:** EXT1 PIN15 (PB03) <> EXT1 PIN10 (PA23)
  - **DO/DI**: EXT1 PIN16 (PB22) <> EXT1 PIN9 (PA22)
  - **DI/DO**: EXT1 PIN17 (PB02) <> EXT1 PIN7 (PA18)
  - **SCK:** EXT1 PIN18 (PB23) <> EXT1 PIN8 (PA19)
- SAM L21 Xplained Pro.
  - **SS_0:** EXT1 PIN15 (PA05) <> EXT1 PIN12 (PA09)

        - **DO/DI**: EXT1 PIN16 (PA06) <> EXT1 PIN11 (PA08)
        - **DI/DO**: EXT1 PIN17 (PA04) <> EXT2 PIN03 (PA10)
        - **SCK:** EXT1 PIN18 (PA07) <> EXT2 PIN04 (PA11)
    - SAM L22 Xplained Pro.
        - **SS_0:** EXT1 PIN15 (PB21) <> EXT2 PIN15 (PA17)
        - **DO/DI**: EXT1 PIN16 (PB00) <> EXT2 PIN17 (PA16)
        - **DI/DO**: EXT1 PIN17 (PB02) <> EXT2 PIN16 (PA18)
        - **SCK:** EXT1 PIN18 (PB01) <> EXT2 PIN18 (PA19)
    - SAM C21 Xplained Pro.
        - **SS_0:** EXT1 PIN15 (PA17) <> EXT2 PIN15 (PB03)
        - **DO/DI**: EXT1 PIN16 (PA18) <> EXT2 PIN17 (PB02)
        - **DI/DO**: EXT1 PIN17 (PA16) <> EXT2 PIN16 (PB00)
        - **SCK:** EXT1 PIN18 (PA19) <> EXT2 PIN18 (PB01)

Code

Add to the main application source file, before user definitions and functions according to your board:

For SAM D21 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  EXT2_SPI_MODULE
#define CONF_MASTER_SS_PIN      EXT2_PIN_SPI_SS_0
#define CONF_MASTER_MUX_SETTING EXT2_SPI_SERCOM_MUX_SETTING
#define CONF_MASTER_PINMUX_PAD0 EXT2_SPI_SERCOM_PINMUX_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 EXT2_SPI_SERCOM_PINMUX_PAD2
#define CONF_MASTER_PINMUX_PAD3 EXT2_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   SERCOM1_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   SERCOM0_DMAC_ID_RX
```

For SAM R21 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  SERCOM3
#define CONF_MASTER_SS_PIN      EXT1_PIN_10
#define CONF_MASTER_MUX_SETTING SPI_SIGNAL_MUX_SETTING_E
#define CONF_MASTER_PINMUX_PAD0 PINMUX_PA22C_SERCOM3_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 PINMUX_PA18D_SERCOM3_PAD2
#define CONF_MASTER_PINMUX_PAD3 PINMUX_PA19D_SERCOM3_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
```

```
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   SERCOM3_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   SERCOM5_DMAC_ID_RX
```

For SAM L21 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  SERCOM2
#define CONF_MASTER_SS_PIN      EXT1_PIN_12
#define CONF_MASTER_MUX_SETTING SPI_SIGNAL_MUX_SETTING_E
#define CONF_MASTER_PINMUX_PAD0 PINMUX_PA08D_SERCOM2_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 PINMUX_PA10D_SERCOM2_PAD2
#define CONF_MASTER_PINMUX_PAD3 PINMUX_PA11D_SERCOM2_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   SERCOM2_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   SERCOM0_DMAC_ID_RX
```

For SAM L22 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  EXT2_SPI_MODULE
#define CONF_MASTER_SS_PIN      EXT2_PIN_SPI_SS_0
#define CONF_MASTER_MUX_SETTING EXT2_SPI_SERCOM_MUX_SETTING
#define CONF_MASTER_PINMUX_PAD0 EXT2_SPI_SERCOM_PINMUX_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 EXT2_SPI_SERCOM_PINMUX_PAD2
#define CONF_MASTER_PINMUX_PAD3 EXT2_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   EXT2_SPI_SERCOM_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   EXT1_SPI_SERCOM_DMAC_ID_RX
```

For SAM DA1 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  EXT2_SPI_MODULE
#define CONF_MASTER_SS_PIN      EXT2_PIN_SPI_SS_0
#define CONF_MASTER_MUX_SETTING EXT2_SPI_SERCOM_MUX_SETTING
#define CONF_MASTER_PINMUX_PAD0 EXT2_SPI_SERCOM_PINMUX_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 EXT2_SPI_SERCOM_PINMUX_PAD2
#define CONF_MASTER_PINMUX_PAD3 EXT2_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
```

```
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   SERCOM1_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   SERCOM0_DMAC_ID_RX
```

For SAM C21 Xplained Pro:

```
#define CONF_MASTER_SPI_MODULE  EXT2_SPI_MODULE
#define CONF_MASTER_SS_PIN      EXT2_PIN_SPI_SS_0
#define CONF_MASTER_MUX_SETTING EXT2_SPI_SERCOM_MUX_SETTING
#define CONF_MASTER_PINMUX_PAD0 EXT2_SPI_SERCOM_PINMUX_PAD0
#define CONF_MASTER_PINMUX_PAD1 PINMUX_UNUSED
#define CONF_MASTER_PINMUX_PAD2 EXT2_SPI_SERCOM_PINMUX_PAD2
#define CONF_MASTER_PINMUX_PAD3 EXT2_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_SLAVE_SPI_MODULE  EXT1_SPI_MODULE
#define CONF_SLAVE_MUX_SETTING EXT1_SPI_SERCOM_MUX_SETTING
#define CONF_SLAVE_PINMUX_PAD0 EXT1_SPI_SERCOM_PINMUX_PAD0
#define CONF_SLAVE_PINMUX_PAD1 EXT1_SPI_SERCOM_PINMUX_PAD1
#define CONF_SLAVE_PINMUX_PAD2 EXT1_SPI_SERCOM_PINMUX_PAD2
#define CONF_SLAVE_PINMUX_PAD3 EXT1_SPI_SERCOM_PINMUX_PAD3
```

```
#define CONF_PERIPHERAL_TRIGGER_TX   SERCOM5_DMAC_ID_TX
#define CONF_PERIPHERAL_TRIGGER_RX   SERCOM1_DMAC_ID_RX
```

Add to the main application source file, outside of any functions:

```
#define BUF_LENGTH 20
```

```
#define TEST_SPI_BAUDRATE             1000000UL
```

```
#define SLAVE_SELECT_PIN CONF_MASTER_SS_PIN
```

```
static const uint8_t buffer_tx[BUF_LENGTH] = {
        0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0A,
        0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13, 0x14,
};
static uint8_t buffer_rx[BUF_LENGTH];
```

```
struct spi_module spi_master_instance;
struct spi_module spi_slave_instance;
```

```
static volatile bool transfer_tx_is_done = false;
static volatile bool transfer_rx_is_done = false;
```

```
struct spi_slave_inst slave;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor_tx SECTION_DMAC_DESCRIPTOR;
DmacDescriptor example_descriptor_rx SECTION_DMAC_DESCRIPTOR;
```

Copy-paste the following setup code to your user application:

```
static void transfer_tx_done(struct dma_resource* const resource )
{
    transfer_tx_is_done = true;
```

```
}

static void transfer_rx_done(struct dma_resource* const resource )
{
    transfer_rx_is_done = true;
}

static void configure_dma_resource_tx(struct dma_resource *tx_resource)
{
    struct dma_resource_config tx_config;

    dma_get_config_defaults(&tx_config);

    tx_config.peripheral_trigger = CONF_PERIPHERAL_TRIGGER_TX;
    tx_config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(tx_resource, &tx_config);
}

static void configure_dma_resource_rx(struct dma_resource *rx_resource)
{
    struct dma_resource_config rx_config;

    dma_get_config_defaults(&rx_config);

    rx_config.peripheral_trigger = CONF_PERIPHERAL_TRIGGER_RX;
    rx_config.trigger_action = DMA_TRIGGER_ACTION_BEAT;

    dma_allocate(rx_resource, &rx_config);
}

static void setup_transfer_descriptor_tx(DmacDescriptor *tx_descriptor)
{
    struct dma_descriptor_config tx_descriptor_config;

    dma_descriptor_get_config_defaults(&tx_descriptor_config);

    tx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    tx_descriptor_config.dst_increment_enable = false;
    tx_descriptor_config.block_transfer_count = sizeof(buffer_tx)/
sizeof(uint8_t);
    tx_descriptor_config.source_address = (uint32_t)buffer_tx +
sizeof(buffer_tx);
    tx_descriptor_config.destination_address =
        (uint32_t)(&spi_master_instance.hw->SPI.DATA.reg);

    dma_descriptor_create(tx_descriptor, &tx_descriptor_config);
}

static void setup_transfer_descriptor_rx(DmacDescriptor *rx_descriptor)
{
    struct dma_descriptor_config rx_descriptor_config;

    dma_descriptor_get_config_defaults(&rx_descriptor_config);

    rx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
    rx_descriptor_config.src_increment_enable = false;
    rx_descriptor_config.block_transfer_count = sizeof(buffer_rx)/
sizeof(uint8_t);
    rx_descriptor_config.source_address =
        (uint32_t)(&spi_slave_instance.hw->SPI.DATA.reg);
    rx_descriptor_config.destination_address =
        (uint32_t)buffer_rx + sizeof(buffer_rx);

    dma_descriptor_create(rx_descriptor, &rx_descriptor_config);
}
```

```
static void configure_spi_master(void)
{
    struct spi_config config_spi_master;
    struct spi_slave_inst_config slave_dev_config;
    /* Configure and initialize software device instance of peripheral slave */
    spi_slave_inst_get_config_defaults(&slave_dev_config);
    slave_dev_config.ss_pin = SLAVE_SELECT_PIN;
    spi_attach_slave(&slave, &slave_dev_config);
    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_master);
    config_spi_master.mode_specific.master.baudrate = TEST_SPI_BAUDRATE;
    config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;

    config_spi_master.pinmux_pad0 = CONF_MASTER_PINMUX_PAD0;
    config_spi_master.pinmux_pad1 = CONF_MASTER_PINMUX_PAD1;
    config_spi_master.pinmux_pad2 = CONF_MASTER_PINMUX_PAD2;
    config_spi_master.pinmux_pad3 = CONF_MASTER_PINMUX_PAD3;

    spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
&config_spi_master);

    spi_enable(&spi_master_instance);

}

static void configure_spi_slave(void)
{
    struct spi_config config_spi_slave;

    /* Configure, initialize and enable SERCOM SPI module */
    spi_get_config_defaults(&config_spi_slave);
    config_spi_slave.mode = SPI_MODE_SLAVE;
    config_spi_slave.mode_specific.slave.preload_enable = true;
    config_spi_slave.mode_specific.slave.frame_format =
SPI_FRAME_FORMAT_SPI_FRAME;
    config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;

    config_spi_slave.pinmux_pad0 = CONF_SLAVE_PINMUX_PAD0;
    config_spi_slave.pinmux_pad1 = CONF_SLAVE_PINMUX_PAD1;
    config_spi_slave.pinmux_pad2 = CONF_SLAVE_PINMUX_PAD2;
    config_spi_slave.pinmux_pad3 = CONF_SLAVE_PINMUX_PAD3;

    spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);

    spi_enable(&spi_slave_instance);

}
```

Add to user application initialization (typically the start of `main()`):

```
configure_spi_master();
configure_spi_slave();

configure_dma_resource_tx(&example_resource_tx);
configure_dma_resource_rx(&example_resource_rx);

setup_transfer_descriptor_tx(&example_descriptor_tx);
setup_transfer_descriptor_rx(&example_descriptor_rx);

dma_add_descriptor(&example_resource_tx, &example_descriptor_tx);
dma_add_descriptor(&example_resource_rx, &example_descriptor_rx);
```

```
dma_register_callback(&example_resource_tx, transfer_tx_done,
        DMA_CALLBACK_TRANSFER_DONE);
dma_register_callback(&example_resource_rx, transfer_rx_done,
        DMA_CALLBACK_TRANSFER_DONE);

dma_enable_callback(&example_resource_tx, DMA_CALLBACK_TRANSFER_DONE);
dma_enable_callback(&example_resource_rx, DMA_CALLBACK_TRANSFER_DONE);
```

Workflow

1. Create a module software instance structure for the SPI module to store the SPI driver state while it is in use.

   ```
   struct spi_module spi_master_instance;
   struct spi_module spi_slave_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a module software instance structure for DMA resource to store the DMA resource state while it is in use.

   ```
   struct dma_resource example_resource_tx;
   struct dma_resource example_resource_rx;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

3. Create transfer done flag to indication DMA transfer done.

   ```
   static volatile bool transfer_tx_is_done = false;
   static volatile bool transfer_rx_is_done = false;
   ```

4. Define the buffer length for TX/RX.

   ```
   #define BUF_LENGTH 20
   ```

5. Create buffer to store the data to be transferred.

   ```
   static const uint8_t buffer_tx[BUF_LENGTH] = {
           0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0A,
           0x0B, 0x0C, 0x0D, 0x0E, 0x0F, 0x10, 0x11, 0x12, 0x13, 0x14,
   };
   static uint8_t buffer_rx[BUF_LENGTH];
   ```

6. Create the SPI module configuration struct, which can be filled out to adjust the configuration of a physical SPI peripheral.

   ```
   struct spi_config config_spi_master;
   ```

   ```
   struct spi_config config_spi_slave;
   ```

7. Initialize the SPI configuration struct with the module's default values.

   ```
   spi_get_config_defaults(&config_spi_master);
   ```

   ```
   spi_get_config_defaults(&config_spi_slave);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

8. Alter the SPI settings to configure the physical pinout, baudrate, and other relevant parameters.

```
config_spi_master.mux_setting = CONF_MASTER_MUX_SETTING;
```

```
config_spi_slave.mux_setting = CONF_SLAVE_MUX_SETTING;
```

9. Configure the SPI module with the desired settings, retrying while the driver is busy until the configuration is stressfully set.

```
spi_init(&spi_master_instance, CONF_MASTER_SPI_MODULE,
&config_spi_master);
```

```
spi_init(&spi_slave_instance, CONF_SLAVE_SPI_MODULE,
&config_spi_slave);
```

10. Enable the SPI module.

```
spi_enable(&spi_master_instance);
```

```
spi_enable(&spi_slave_instance);
```

11. Create the DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config tx_config;
```

```
struct dma_resource_config rx_config;
```

12. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&tx_config);
```

```
dma_get_config_defaults(&rx_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

13. Set extra configurations for the DMA resource. It is using peripheral trigger. SERCOM TX empty and RX complete trigger causes a beat transfer in this example.

```
tx_config.peripheral_trigger = CONF_PERIPHERAL_TRIGGER_TX;
tx_config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

```
rx_config.peripheral_trigger = CONF_PERIPHERAL_TRIGGER_RX;
rx_config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
```

14. Allocate a DMA resource with the configurations.

```
dma_allocate(tx_resource, &tx_config);
```

```
dma_allocate(rx_resource, &rx_config);
```

15. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config tx_descriptor_config;
```

```
struct dma_descriptor_config rx_descriptor_config;
```

16. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&tx_descriptor_config);
```

```
dma_descriptor_get_config_defaults(&rx_descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

17. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
tx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
tx_descriptor_config.dst_increment_enable = false;
tx_descriptor_config.block_transfer_count = sizeof(buffer_tx)/
sizeof(uint8_t);
tx_descriptor_config.source_address = (uint32_t)buffer_tx +
sizeof(buffer_tx);
tx_descriptor_config.destination_address =
    (uint32_t)(&spi_master_instance.hw->SPI.DATA.reg);
```

```
rx_descriptor_config.beat_size = DMA_BEAT_SIZE_BYTE;
rx_descriptor_config.src_increment_enable = false;
rx_descriptor_config.block_transfer_count = sizeof(buffer_rx)/
sizeof(uint8_t);
rx_descriptor_config.source_address =
    (uint32_t)(&spi_slave_instance.hw->SPI.DATA.reg);
rx_descriptor_config.destination_address =
    (uint32_t)buffer_rx + sizeof(buffer_rx);
```

18. Create the DMA transfer descriptor.

```
dma_descriptor_create(tx_descriptor, &tx_descriptor_config);
```

```
dma_descriptor_create(rx_descriptor, &rx_descriptor_config);
```

21.8.5.2. Use Case

Code

Copy-paste the following code to your user application:

```
spi_select_slave(&spi_master_instance, &slave, true);

dma_start_transfer_job(&example_resource_rx);
dma_start_transfer_job(&example_resource_tx);

while (!transfer_rx_is_done) {
    /* Wait for transfer done */
}

spi_select_slave(&spi_master_instance, &slave, false);

while (true) {
}
```

Workflow

1. Select the slave.

```
spi_select_slave(&spi_master_instance, &slave, true);
```

2. Start the transfer job.

```
dma_start_transfer_job(&example_resource_rx);
dma_start_transfer_job(&example_resource_tx);
```

3. Wait for transfer done.

```
while (!transfer_rx_is_done) {
    /* Wait for transfer done */
}
```

4. Deselect the slave.

```
spi_select_slave(&spi_master_instance, &slave, false);
```

5. Enter endless loop.

```
while (true) {
}
```

21.9. MUX Settings

The following lists the possible internal SERCOM module pad function assignments for the four SERCOM pads in both SPI Master and SPI Slave modes. They are combinations of DOPO and DIPO in CTRLA. Note that this is in addition to the physical GPIO pin MUX of the device, and can be used in conjunction to optimize the serial data pin-out.

21.9.1. Master Mode Settings

The following table describes the SERCOM pin functionalities for the various MUX settings, whilst in SPI Master mode.

Note: If MISO is unlisted, the SPI receiver must not be enabled for the given MUX setting.

Combination	DOPO / DIPO	SERCOM PAD[0]	SERCOM PAD[1]	SERCOM PAD[2]	SERCOM PAD[3]
A	0x0 / 0x0	MOSI	SCK	-	-
B	0x0 / 0x1	MOSI	SCK	-	-
C	0x0 / 0x2	MOSI	SCK	MISO	-
D	0x0 / 0x3	MOSI	SCK	-	MISO
E	0x1 / 0x0	MISO	-	MOSI	SCK
F	0x1 / 0x1	-	MISO	MOSI	SCK
G	0x1 / 0x2	-	-	MOSI	SCK
H	0x1 / 0x3	-	-	MOSI	SCK
I	0x2 / 0x0	MISO	SCK	-	MOSI
J	0x2 / 0x1	-	SCK	-	MOSI
K	0x2 / 0x2	-	SCK	MISO	MOSI

Combination	DOPO / DIPO	SERCOM PAD[0]	SERCOM PAD[1]	SERCOM PAD[2]	SERCOM PAD[3]
L	0x2 / 0x3	-	SCK	-	MOSI
M	0x3 / 0x0	MOSI	-	-	SCK
N	0x3 / 0x1	MOSI	MISO	-	SCK
O	0x3 / 0x2	MOSI	-	MISO	SCK
P	0x3 / 0x3	MOSI	-	-	SCK

21.9.2. Slave Mode Settings

The following table describes the SERCOM pin functionalities for the various MUX settings, whilst in SPI Slave mode.

Note: If MISO is unlisted, the SPI receiver must not be enabled for the given MUX setting.

Combination	DOPO / DIPO	SERCOM PAD[0]	SERCOM PAD[1]	SERCOM PAD[2]	SERCOM PAD[3]
A	0x0 / 0x0	MISO	SCK	/SS	-
B	0x0 / 0x1	MISO	SCK	/SS	-
C	0x0 / 0x2	MISO	SCK	/SS	-
D	0x0 / 0x3	MISO	SCK	/SS	MOSI
E	0x1 / 0x0	MOSI	/SS	MISO	SCK
F	0x1 / 0x1	-	/SS	MISO	SCK
G	0x1 / 0x2	-	/SS	MISO	SCK
H	0x1 / 0x3	-	/SS	MISO	SCK
I	0x2 / 0x0	MOSI	SCK	/SS	MISO
J	0x2 / 0x1	-	SCK	/SS	MISO
K	0x2 / 0x2	-	SCK	/SS	MISO
L	0x2 / 0x3	-	SCK	/SS	MISO
M	0x3 / 0x0	MISO	/SS	-	SCK
N	0x3 / 0x1	MISO	/SS	-	SCK
O	0x3 / 0x2	MISO	/SS	MOSI	SCK
P	0x3 / 0x3	MISO	/SS	-	SCK

22. SAM System (SYSTEM) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's system relation functionality, necessary for the basic device operation. This is not limited to a single peripheral, but extends across multiple hardware peripherals.

The following peripherals are used by this module:

- PM (Power Manager)
- RSTC (Reset Controller)
- SUPC (Supply Controller)

The following devices can use this module:

- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

22.1. Prerequisites

There are no prerequisites for this module.

22.2. Module Overview

The System driver provides a collection of interfaces between the user application logic, and the core device functionality (such as clocks, reset cause determination, etc.) that is required for all applications. It contains a number of sub-modules that control one specific aspect of the device:

- System Core (this module)
- System Clock Control (sub-module)
- System Interrupt Control (sub-module)
- System Pin Multiplexer Control (sub-module)

22.2.1. Voltage Regulator

The SAM device controls the voltage regulators for the core (VDDCORE). It sets the voltage regulators according to the sleep modes.

There are a selectable reference voltage and voltage dependent on the temperature which can be used by analog modules like the ADC.

22.2.2. Voltage References

The various analog modules within the SAM devices (such as AC, ADC, and DAC) require a voltage reference to be configured to act as a reference point for comparisons and conversions.

The SAM devices contain multiple references, including an internal temperature sensor and a fixed band-gap voltage source. When enabled, the associated voltage reference can be selected within the desired peripheral where applicable.

22.2.3. System Reset Cause

In some applications there may be a need to execute a different program flow based on how the device was reset. For example, if the cause of reset was the Watchdog timer (WDT), this might indicate an error in the application, and a form of error handling or error logging might be needed.

For this reason, an API is provided to retrieve the cause of the last system reset, so that appropriate action can be taken.

22.2.4. Sleep Modes

The SAM devices have several sleep modes. The sleep mode controls which clock systems on the device will remain enabled or disabled when the device enters a low power sleep mode. Table 22-1 lists the clock settings of the different sleep modes.

Table 22-1. SAM Device Sleep Modes

Sleep mode	CPU clock	AHB clock	APB clocks	Clock sources	System clock	32KHz	Reg mode	RAM mode
Idle 0	Stop	Run	Run	Run	Run	Run	Normal	Normal
Idle 1	Stop	Stop	Run	Run	Run	Run	Normal	Normal
Idle 2	Stop	Stop	Stop	Run	Run	Run	Normal	Normal
Standby	Stop	Stop	Stop	Stop	Stop	Stop	Low Power	Source/ Drain biasing

Before entering device sleep, one of the available sleep modes must be set. The device will automatically wake up in response to an interrupt being generated or upon any other sleep mode exit condition.

Some peripheral clocks will remain enabled during sleep, depending on their configuration. If desired, the modules can remain clocked during sleep to allow them continue to operate while other parts of the system are powered down to save power.

22.3. Special Considerations

Most of the functions in this driver have device specific restrictions and caveats; refer to your device datasheet.

22.4. Extra Information

For extra information, see Extra Information for SYSTEM Driver. This includes:

- Acronyms
- Dependencies
- Errata

- Module History

22.5. Examples

For SYSTEM module related examples, refer to the sub-modules listed in the Module Overview.

22.6. API Overview

22.6.1. Structure Definitions

22.6.1.1. Struct system_standby_config

Configuration structure for standby mode.

Table 22-2. Members

Type	Name	Description
bool	hmcramchs_back_bias	Back bias for HMCRAMCHS (false: no, true: standby)
enum system_vreg_switch_mode	vreg_switch_mode	Regulator switch mode in standby

22.6.1.2. Struct system_voltage_references_config

Configuration structure for VREF.

Table 22-3. Members

Type	Name	Description
bool	on_demand	On demand control
bool	run_in_standby	Run in standby
enum system_voltage_references_sel	sel	Voltage references selection

22.6.1.3. Struct system_voltage_regulator_config

Configuration structure for VREG.

Table 22-4. Members

Type	Name	Description
bool	run_in_standby	Run in standby in standby sleep mode

22.6.2. Function Definitions

22.6.2.1. Voltage Regulator

Function system_voltage_regulator_get_config_defaults()

Retrieve the default configuration for voltage regulator.

```
void system_voltage_regulator_get_config_defaults(
        struct system_voltage_regulator_config *const config)
```

Fills a configuration structure with the default configuration:

- The voltage regulator is in low power mode in Standby sleep mode

Table 22-5. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_voltage_regulator_set_config()

Configure voltage regulator.

```
void system_voltage_regulator_set_config(
        struct system_voltage_regulator_config *const config)
```

Configures voltage regulator with the given configuration.

Table 22-6. Parameters

Data direction	Parameter name	Description
[in]	config	Voltage regulator configuration structure containing the new config

Function system_voltage_regulator_enable()

Enable the selected voltage regulator.

```
void system_voltage_regulator_enable( void )
```

Enables the selected voltage regulator source.

Function system_voltage_regulator_disable()

Disable the selected voltage regulator.

```
void system_voltage_regulator_disable( void )
```

Disables the selected voltage regulator.

22.6.2.2. Voltage References

Function system_voltage_reference_get_config_defaults()

Retrieve the default configuration for voltage reference.

```
void system_voltage_reference_get_config_defaults(
        struct system_voltage_references_config *const config)
```

Fill a configuration structure with the default configuration:

- 1.024V voltage reference typical value
- On demand control:disabled
- The voltage reference and the temperature sensor are halted during standby sleep mode

Table 22-7. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_voltage_reference_set_config()

Configure voltage reference.

```
void system_voltage_reference_set_config(
        struct system_voltage_references_config *const config)
```

Configures voltage reference with the given configuration.

Table 22-8. Parameters

Data direction	Parameter name	Description
[in]	config	Voltage reference configuration structure containing the new config

Function system_voltage_reference_enable()

Enable the selected voltage reference.

```
void system_voltage_reference_enable(
        const enum system_voltage_reference vref)
```

Enables the selected voltage reference source, making the voltage reference available on a pin as well as an input source to the analog peripherals.

Table 22-9. Parameters

Data direction	Parameter name	Description
[in]	vref	Voltage reference to enable

Function system_voltage_reference_disable()

Disable the selected voltage reference.

```
void system_voltage_reference_disable(
        const enum system_voltage_reference vref)
```

Disables the selected voltage reference source.

Table 22-10. Parameters

Data direction	Parameter name	Description
[in]	vref	Voltage reference to disable

22.6.2.3. Device Sleep Control

Function system_set_sleepmode()

Set the sleep mode of the device.

```
void system_set_sleepmode(
        const enum system_sleepmode sleep_mode)
```

Sets the sleep mode of the device; the configured sleep mode will be entered upon the next call of the system_sleep() function.

For an overview of which systems are disabled in sleep for the different sleep modes, see Sleep Modes.

Table 22-11. Parameters

Data direction	Parameter name	Description
[in]	sleep_mode	Sleep mode to configure for the next sleep operation

Function system_sleep()

Put the system to sleep waiting for interrupt.

```
void system_sleep( void )
```

Executes a device DSB (Data Synchronization Barrier) instruction to ensure all ongoing memory accesses have completed, then a WFI (Wait For Interrupt) instruction to place the device into the sleep mode specified by system_set_sleepmode until woken by an interrupt.

22.6.2.4. Standby Configuration

Function system_standby_get_config_defaults()

Retrieve the default configuration for standby.

```
void system_standby_get_config_defaults(
        struct system_standby_config *const config)
```

Fills a configuration structure with the default configuration for standby:

- Automatic VREG switching is used
- Retention back biasing mode for HMCRAMCHS

Table 22-12. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_standby_set_config()

Configure standby mode.

```
void system_standby_set_config(
        struct system_standby_config *const config)
```

Configures standby with the given configuration.

Table 22-13. Parameters

Data direction	Parameter name	Description
[in]	config	Standby configuration structure containing the new config

22.6.2.5. Reset Control

Function system_reset()

Reset the MCU.

```
void system_reset( void )
```

Resets the MCU and all associated peripherals and registers, except RTC, OSC32KCTRL, RSTC, GCLK(if WRTLOCK is set) and I/O retention state of PM.

Function system_get_reset_cause()

Get the reset cause.

```
enum system_reset_cause system_get_reset_cause( void )
```

Retrieves the cause of the last system reset.

Returns
An enum value indicating the cause of the last system reset.

22.6.2.6. System Debugger

Function system_is_debugger_present()

Check if debugger is present.

```
bool system_is_debugger_present( void )
```

Check if debugger is connected to the onboard debug system (DAP).

Returns
A bool identifying if a debugger is present.

Table 22-14. Return Values

Return value	Description
true	Debugger is connected to the system
false	Debugger is not connected to the system

22.6.2.7. System Identification

Function system_get_device_id()

Retrieve the device identification signature.

```
uint32_t system_get_device_id( void )
```

Retrieves the signature of the current device.

Returns
Device ID signature as a 32-bit integer.

22.6.2.8. System Initialization

Function system_init()

Initialize system.

```
void system_init( void )
```

This function will call the various initialization functions within the system namespace. If a given optional system module is not available, the associated call will effectively be a NOP (No Operation).

Currently the following initialization functions are supported:

- System clock initialization (via the SYSTEM CLOCK sub-module)
- Board hardware initialization (via the Board module)

- Event system driver initialization (via the EVSYS module)
- External Interrupt driver initialization (via the EXTINT module)

22.6.3. Enumeration Definitions

22.6.3.1. Enum system_reset_cause

List of possible reset causes of the system.

Table 22-15. Members

Enum value	Description
SYSTEM_RESET_CAUSE_SOFTWARE	The system was last reset by a software reset
SYSTEM_RESET_CAUSE_WDT	The system was last reset by the watchdog timer
SYSTEM_RESET_CAUSE_EXTERNAL_RESET	The system was last reset because the external reset line was pulled low
SYSTEM_RESET_CAUSE_BODVDD	The system was last reset by VDD brown out detector
SYSTEM_RESET_CAUSE_BODCORE	The system was last reset by VDDCORE brown out detector
SYSTEM_RESET_CAUSE_POR	The system was last reset by the POR (Power on reset)

22.6.3.2. Enum system_sleepmode

List of available sleep modes in the device. A table of clocks available in different sleep modes can be found in Sleep Modes.

Table 22-16. Members

Enum value	Description
SYSTEM_SLEEPMODE_IDLE_0	IDLE 0 sleep mode
SYSTEM_SLEEPMODE_IDLE_1	IDLE 1 sleep mode
SYSTEM_SLEEPMODE_IDLE_2	IDLE 2 sleep mode
SYSTEM_SLEEPMODE_STANDBY	Standby sleep mode

22.6.3.3. Enum system_voltage_reference

List of available voltage references (VREF) that may be used within the device.

Table 22-17. Members

Enum value	Description
SYSTEM_VOLTAGE_REFERENCE_TEMPSENSE	Temperature sensor voltage reference
SYSTEM_VOLTAGE_REFERENCE_OUTPUT	Voltage reference output for ADC/DAC

22.6.3.4. Enum system_voltage_references_sel

Voltage references selection for ADC/DAC.

Table 22-18. Members

Enum value	Description
SYSTEM_VOLTAGE_REFERENCE_1V024	1.024V voltage reference typical value
SYSTEM_VOLTAGE_REFERENCE_2V048	2.048V voltage reference typical value
SYSTEM_VOLTAGE_REFERENCE_4V096	4.096V voltage reference typical value

22.6.3.5. Enum system_vreg_switch_mode

Table 22-19. Members

Enum value	Description
SYSTEM_VREG_SWITCH_AUTO	Automatic mode
SYSTEM_VREG_SWITCH_PERFORMANCE	Performance oriented
SYSTEM_VREG_SWITCH_LP	Low Power consumption oriented

22.7. Extra Information for SYSTEM Driver

22.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Definition
PM	Power Manager
SUPC	Supply Controller
RSTC	Reset Controller

22.7.2. Dependencies

This driver has the following dependencies:

- None

22.7.3. Errata

There are no errata related to this driver.

22.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

23. SAM System Clock Management (SYSTEM CLOCK) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's clocking related functions. This includes the various clock sources, bus clocks, and generic clocks within the device, with functions to manage the enabling, disabling, source selection, and prescaling of clocks to various internal peripherals.

The following peripherals are used by this module:

- GCLK (Generic Clock Management)
- PM (Power Management)
- OSCCTRL (Oscillators Controller)
- OSC32KCTRL (32K Oscillators Controller)
- MCLK (Main Clock)

The following devices can use this module:

- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

23.1. Prerequisites

There are no prerequisites for this module.

23.2. Module Overview

The SAM devices contain a sophisticated clocking system, which is designed to give the maximum flexibility to the user application. This system allows a system designer to tune the performance and power consumption of the device in a dynamic manner, to achieve the best trade-off between the two for a particular application.

This driver provides a set of functions for the configuration and management of the various clock related functionality within the device.

23.2.1. Clock Sources

The SAM devices have a number of master clock source modules, each of which being capable of producing a stabilized output frequency, which can then be fed into the various peripherals and modules within the device.

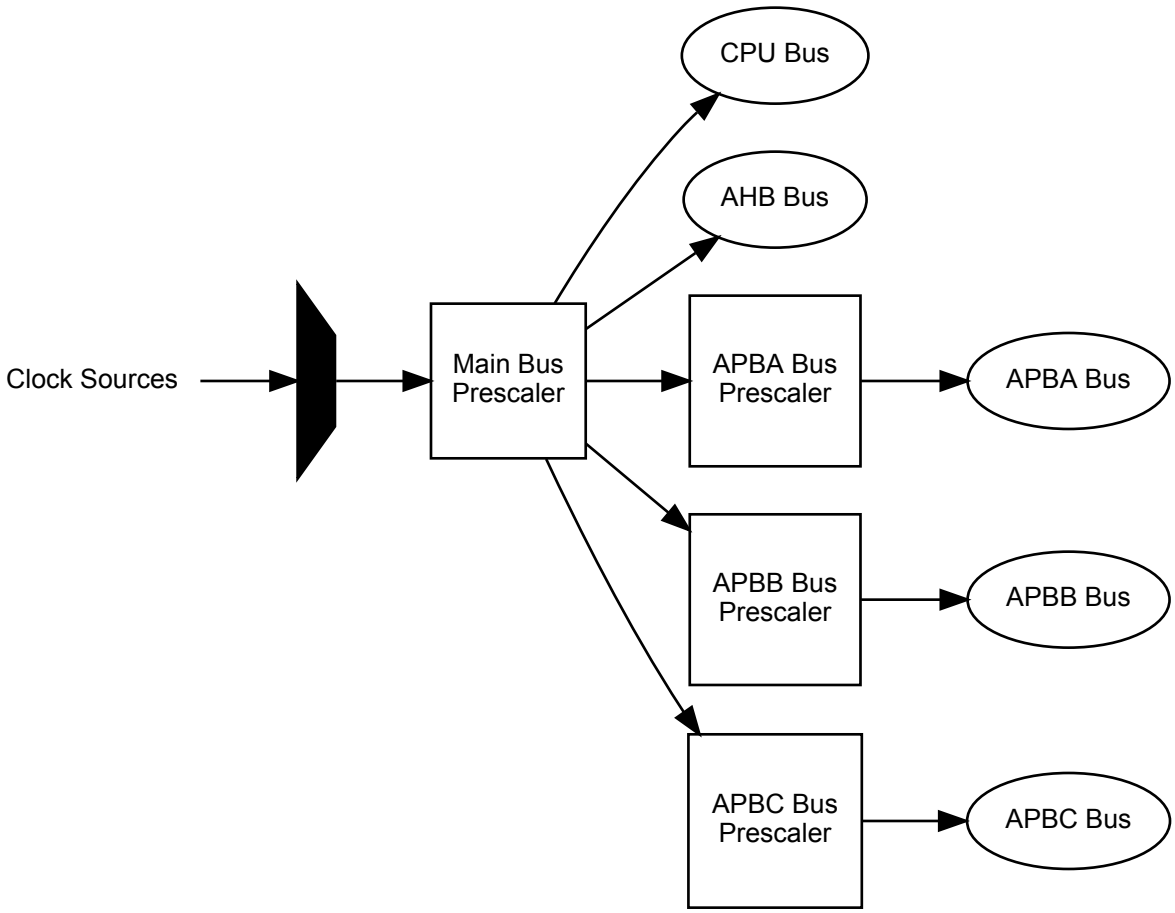
Possible clock source modules include internal R/C oscillators as well as external crystal oscillators and/or clock inputs.

23.2.2. CPU / Bus Clocks

The CPU and AHB/APBx buses are clocked by the same physical clock source (referred in this module as the Main Clock), however the APBx buses may have additional prescaler division ratios set to give each peripheral bus a different clock speed.

The general main clock tree for the CPU and associated buses is shown in the figure below.

Figure 23-1. CPU / Bus Clocks



23.2.3. Clock Masking

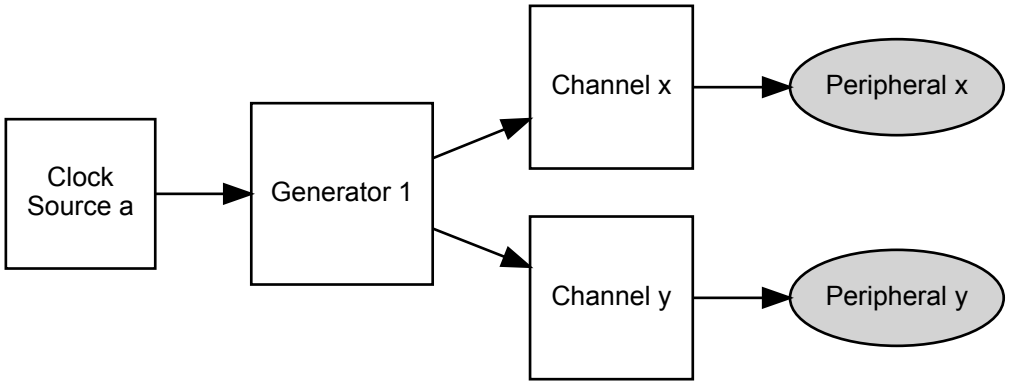
To save power, the input clock to one or more peripherals on the AHB and APBx buses can be masked away - when masked, no clock is passed into the module. Disabling of clocks of unused modules will prevent all access to the masked module, and will reduce the overall device power consumption.

23.2.4. Generic Clocks

Within the SAM devices there are a number of Generic Clocks; these are used to provide clocks to the various peripheral clock domains in the device in a standardized manner. One or more master source clocks can be selected as the input clock to a Generic Clock Generator, which can prescale down the input frequency to a slower rate for use in a peripheral.

Additionally, a number of individually selectable Generic Clock Channels are provided, which multiplex and gate the various generator outputs for one or more peripherals within the device. This setup allows for a single common generator to feed one or more channels, which can then be enabled or disabled individually as required.

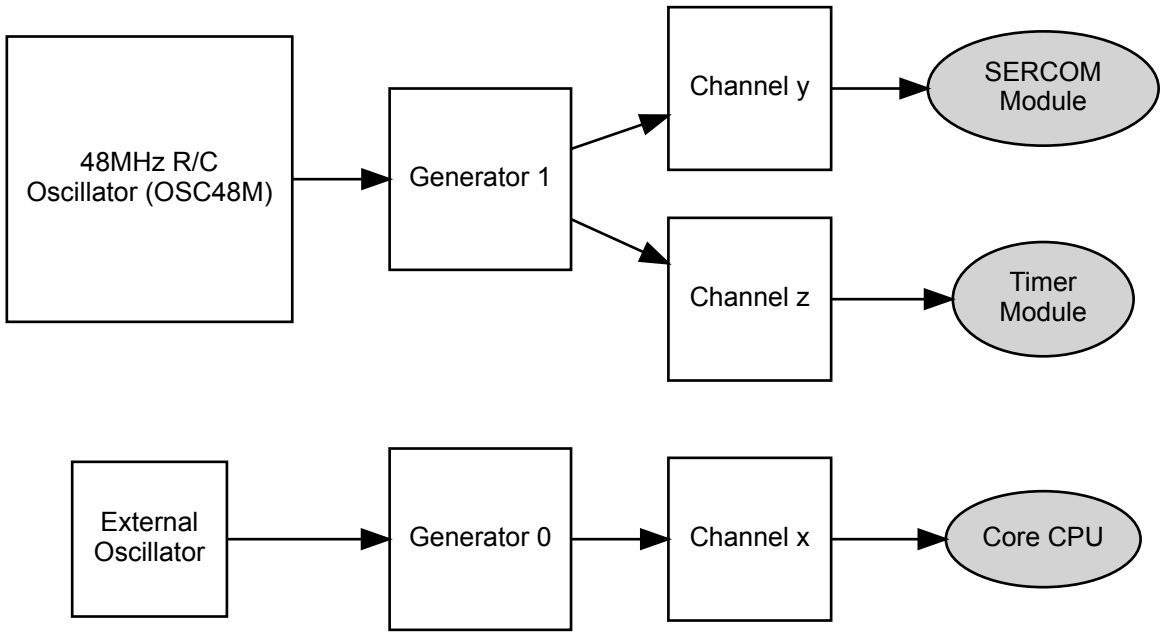
Figure 23-2. Generic Clocks



23.2.4.1. Clock Chain Example

An example setup of a complete clock chain within the device is shown in the figure below.

Figure 23-3. Clock Chain Example



23.2.4.2. Generic Clock Generators

Each Generic Clock generator within the device can source its input clock from one of the provided Source Clocks, and prescale the output for one or more Generic Clock Channels in a one-to-many relationship. The generators thus allow for several clocks to be generated of different frequencies, power usages, and accuracies, which can be turned on and off individually to disable the clocks to multiple peripherals as a group.

23.2.4.3. Generic Clock Channels

To connect a Generic Clock Generator to a peripheral within the device, a Generic Clock Channel is used. Each peripheral or peripheral group has an associated Generic Clock Channel, which serves as the clock input for the peripheral(s). To supply a clock to the peripheral module(s), the associated channel must be connected to a running Generic Clock Generator and the channel enabled.

23.3. Special Considerations

There are no special considerations for this module.

23.4. Extra Information

For extra information, see Extra Information for SYSTEM CLOCK Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

23.5. Examples

For a list of examples related to this driver, see Examples for System Clock Driver.

23.6. API Overview

23.6.1. Structure Definitions

23.6.1.1. Struct system_clock_source_dpll_config

DPLL oscillator configuration structure.

Table 23-1. Members

Type	Name	Description
enum system_clock_source_dpll_filter	filter	Filter type of the DPLL module
bool	lock_bypass	Bypass lock signal
enum system_clock_source_dpll_lock_time	lock_time	Lock time-out value of the DPLL module
bool	low_power_enable	Enable low power mode
bool	on_demand	Run On Demand. If this is set the DPLL won't run until requested by a peripheral
uint32_t	output_frequency	Output frequency of the clock
enum system_clock_source_dpll_prescaler	prescaler	DPLL prescaler
enum system_clock_source_dpll_reference_clock	reference_clock	Reference clock source of the DPLL module
uint16_t	reference_divider	Devider of reference clock

Type	Name	Description
uint32_t	reference_frequency	Reference frequency of the clock
bool	run_in_standby	Keep the DPLL enabled in standby sleep mode
bool	wake_up_fast	Wake up fast. If this is set DPLL output clock is enabled after the startup time

23.6.1.2. Struct system_clock_source_osc32k_config

Internal 32KHz oscillator configuration structure.

Table 23-2. Members

Type	Name	Description
bool	enable_1khz_output	Enable 1KHz output
bool	enable_32khz_output	Enable 32KHz output
bool	on_demand	Run On Demand. If this is set the OSC32K won't run until requested by a peripheral
bool	run_in_standby	Keep the OSC32K enabled in standby sleep mode
enum system_osc32k_startup	startup_time	Startup time
bool	write_once	Lock configuration after it has been written, a device reset will release the lock

23.6.1.3. Struct system_clock_source_osc48m_config

Internal 48MHz (nominal) oscillator configuration structure.

Table 23-3. Members

Type	Name	Description
enum system_osc48m_div	div	Internal 48MHz RC oscillator divider
bool	on_demand	Run On Demand. If this is set the OSC48M won't run until requested by a peripheral
bool	run_in_standby	Keep the OSC48M enabled in standby sleep mode
enum system_osc48m_startup	startup_time	Crystal oscillator startup time

23.6.1.4. Struct system_clock_source_osculp32k_config

Internal 32KHz Ultra Low Power oscillator configuration structure.

Table 23-4. Members

Type	Name	Description
bool	write_once	Lock configuration after it has been written, a device reset will release the lock

23.6.1.5. Struct system_clock_source_xosc32k_config

External 32KHz oscillator clock configuration structure.

Table 23-5. Members

Type	Name	Description
enum system_clock_xosc32k_failure_detector_prescaler	clock_failure_detector_prescaler	Clock failure detector prescaler from OSCULP32K
bool	enable_1khz_output	Enable 1KHz output
bool	enable_32khz_output	Enable 32KHz output
bool	enable_clock_failure_detector	Enable clock failure detector
bool	enable_clock_failure_detector_event_outut	Enable clock failure detector event output
bool	enable_clock_switch_back	Enable clock switch back
enum system_clock_external	external_clock	External clock type
uint32_t	frequency	External clock/crystal frequency
bool	on_demand	Run On Demand. If this is set the XOSC32K won't run until requested by a peripheral

Type	Name	Description
bool	run_in_standby	Keep the XOSC32K enabled in standby sleep mode
enum system_xosc32k_startup	startup_time	Crystal oscillator startup time
bool	write_once	Lock configuration after it has been written. A device reset will release the lock

23.6.1.6. Struct system_clock_source_xosc_config

External oscillator clock configuration structure.

Table 23-6. Members

Type	Name	Description
bool	auto_gain_control	Enable automatic amplitude gain control
enum system_clock_xosc_failure_detector_prescaler	clock_failure_detector_prescaler	Clock failure detector prescaler from OSC48M for clock the CFD prescaler
bool	enable_clock_failure_detector	Enable clock failure detector
bool	enable_clock_failure_detector_event_outut	Enable clock failure detector event output

Type	Name	Description
bool	enable_clock_switch_back	Enable clock switch back
enum system_clock_external	external_clock	External clock type
uint32_t	frequency	External clock/crystal frequency
bool	on_demand	Run On Demand. If this is set the XOSC won't run until requested by a peripheral
bool	run_in_standby	Keep the XOSC enabled in standby sleep mode
enum system_xosc_startup	startup_time	Crystal oscillator startup time

23.6.1.7. Struct system_gclk_chan_config

Configuration structure for a Generic Clock channel. This structure should be initialized by the system_gclk_chan_get_config_defaults() function before being modified by the user application.

Table 23-7. Members

Type	Name	Description
enum gclk_generator	source_generator	Generic Clock Generator source channel

23.6.1.8. Struct system_gclk_gen_config

Configuration structure for a Generic Clock Generator channel. This structure should be initialized by the system_gclk_gen_get_config_defaults() function before being modified by the user application.

Table 23-8. Members

Type	Name	Description
uint32_t	division_factor	Integer division factor of the clock output compared to the input
bool	high_when_disabled	If `true`, the generator output level is high when disabled
bool	output_enable	If `true`, enables GCLK generator clock output to a GPIO pin
bool	run_in_standby	If `true`, the clock is kept enabled during device standby mode
uint8_t	source_clock	Source clock input channel index, see the system_clock_source

23.6.2. Function Definitions

23.6.2.1. External Oscillator Management

Function system_clock_source_xosc_get_config_defaults()

Retrieve the default configuration for XOSC.

```
void system_clock_source_xosc_get_config_defaults(
        struct system_clock_source_xosc_config *const config)
```

Fills a configuration structure with the default configuration for an external oscillator module:

- External Crystal
- Startup time of 16384 external clock cycles
- Automatic crystal gain control mode enabled
- Frequency of 12MHz
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)
- Clock failure detector prescaler is 1
- Clock failure detector event outut is disabled
- Clock failure detector is disabled
- Clock switch back is disabled

Table 23-9. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_xosc_set_config()

Configure the external oscillator clock source.

```
void system_clock_source_xosc_set_config(
        struct system_clock_source_xosc_config *const config)
```

Configures the external oscillator clock source with the given configuration settings.

Table 23-10. Parameters

Data direction	Parameter name	Description
[in]	config	External oscillator configuration structure containing the new config

Function system_clock_xosc_clock_failure_detected()

Checks if XOSC clock failure detected.

```
bool system_clock_xosc_clock_failure_detected( void )
```

Checks if XOSC clock detected.

Returns
XOSC clock failure detected state.

Table 23-11. Return Values

Return value	Description
true	XOSC clock failure detected
false	XOSC clock failure is not detected

Function system_clock_xosc_is_switched()

Checks if XOSC is switched and provides the safe clock.

```
bool system_clock_xosc_is_switched( void )
```

Checks if XOSC is switched and provides the safe clock.

Returns
XOSC clock switch state.

Table 23-12. Return Values

Return value	Description
true	XOSC clock is switched and provides the safe clock
false	XOSC clock is not switched and provides the external clock or crystal oscillator clock

23.6.2.2. External 32KHz Oscillator Management

Function system_clock_source_xosc32k_get_config_defaults()

Retrieve the default configuration for XOSC32K.

```
void system_clock_source_xosc32k_get_config_defaults(
        struct system_clock_source_xosc32k_config *const config)
```

Fills a configuration structure with the default configuration for an external 32KHz oscillator module:

- External Crystal
- Startup time of 16384 external clock cycles
- Automatic crystal gain control mode disabled
- Frequency of 32.768KHz
- 1KHz clock output disabled
- 32KHz clock output enabled
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)

- Don't lock registers after configuration has been written
- Clock failure detector prescaler is 1
- Clock failure detector event outut is disabled
- Clock failure detector is disabled
- Clock switch back is disabled

Table 23-13. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_xosc32k_set_config()

Configure the XOSC32K external 32KHz oscillator clock source.

```
void system_clock_source_xosc32k_set_config(
        struct system_clock_source_xosc32k_config *const config)
```

Configures the external 32KHz oscillator clock source with the given configuration settings.

Table 23-14. Parameters

Data direction	Parameter name	Description
[in]	config	XOSC32K configuration structure containing the new config

Function system_clock_xosc32k_clock_failure_detected()

Checks if XOSC32K clock failure detected.

```
bool system_clock_xosc32k_clock_failure_detected( void )
```

Checks if XOSC32K clock detected.

Returns
XOSC32K clock failure detected state.

Table 23-15. Return Values

Return value	Description
true	XOSC32K clock failure detected
false	XOSC32K clock failure is not detected

Function system_clock_xosc32k_is_switched()

Checks if XOSC32K is switched and provides the safe clock.

```
bool system_clock_xosc32k_is_switched( void )
```

Checks if XOSC32K is switched and provides the safe clock.

Returns
XOSC32K clock switch state.

Table 23-16. Return Values

Return value	Description
true	XOSC32K clock is switched and provides the safe clock
false	XOSC32K clock is not switched and provides the external clock or crystal oscillator clock

23.6.2.3. Internal 32KHz Oscillator Management

Function system_clock_source_osc32k_get_config_defaults()

Retrieve the default configuration for OSC32K.

```
void system_clock_source_osc32k_get_config_defaults(
        struct system_clock_source_osc32k_config *const config)
```

Fills a configuration structure with the default configuration for an internal 32KHz oscillator module:

- 1KHz clock output enabled
- 32KHz clock output enabled
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)
- Set startup time to 130 cycles
- Don't lock registers after configuration has been written

Table 23-17. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_osc32k_set_config()

Configure the internal OSC32K oscillator clock source.

```
void system_clock_source_osc32k_set_config(
        struct system_clock_source_osc32k_config *const config)
```

Configures the 32KHz (nominal) internal RC oscillator with the given configuration settings.

Table 23-18. Parameters

Data direction	Parameter name	Description
[in]	config	OSC32K configuration structure containing the new config

23.6.2.4. Internal Ultra Low Power 32KHz Oscillator management

Function system_clock_source_osculp32k_get_config_defaults()

Retrieve the default configuration for OSCULP32K.

```
void system_clock_source_osculp32k_get_config_defaults(
        struct system_clock_source_osculp32k_config *const config)
```

Fills a configuration structure with the default configuration for an internal Ultra Low Power 32KHz oscillator module:

- 1KHz clock output enabled

- 32KHz clock output enabled

Table 23-19. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_osculp32k_set_config()

Configure the internal OSCULP32K oscillator clock source.

```
void system_clock_source_osculp32k_set_config(
        struct system_clock_source_osculp32k_config *const config)
```

Configures the Ultra Low Power 32KHz internal RC oscillator with the given configuration settings.

Table 23-20. Parameters

Data direction	Parameter name	Description
[in]	config	OSCULP32K configuration structure containing the new config

23.6.2.5. Internal 48MHz Oscillator Management

Function system_clock_source_osc48m_get_config_defaults()

Retrieve the default configuration for OSC48M.

```
void system_clock_source_osc48m_get_config_defaults(
        struct system_clock_source_osc48m_config *const config)
```

Fills a configuration structure with the default configuration for an internal 48MHz (nominal) oscillator module:

- Clock divider by 12 and output frequency 4MHz
- Don't run in STANDBY sleep mode
- Run only when requested by peripheral (on demand)
- Startup time of eight clock cycles

Table 23-21. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_osc48m_set_config()

Configure the internal OSC48M oscillator clock source.

```
void system_clock_source_osc48m_set_config(
        struct system_clock_source_osc48m_config *const config)
```

Configures the 48MHz (nominal) internal RC oscillator with the given configuration settings.

Note: Frequency selection can be done only when OSC48M is disabled.

Table 23-22. Parameters

Data direction	Parameter name	Description
[in]	config	OSC48M configuration structure containing the new config

23.6.2.6. Clock Source Management

Function system_clock_source_write_calibration()

```
enum status_code system_clock_source_write_calibration(
        const enum system_clock_source system_clock_source,
        const uint16_t calibration_value,
        const uint8_t freq_range)
```

Function system_clock_source_enable()

```
enum status_code system_clock_source_enable(
        const enum system_clock_source system_clock_source)
```

Function system_clock_source_disable()

Disables a clock source.

```
enum status_code system_clock_source_disable(
        const enum system_clock_source clk_source)
```

Disables a clock source that was previously enabled.

Table 23-23. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to disable

Table 23-24. Return Values

Return value	Description
STATUS_OK	Clock source was disabled successfully
STATUS_ERR_INVALID_ARG	An invalid or unavailable clock source was given

Function system_clock_source_is_ready()

Checks if a clock source is ready.

```
bool system_clock_source_is_ready(
        const enum system_clock_source clk_source)
```

Checks if a given clock source is ready to be used.

Table 23-25. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to check if ready

Returns

Ready state of the given clock source.

Table 23-26. Return Values

Return value	Description
true	Clock source is enabled and ready
false	Clock source is disabled or not yet ready

Function system_clock_source_get_hz()

Retrieve the frequency of a clock source.

```
uint32_t system_clock_source_get_hz(
        const enum system_clock_source clk_source)
```

Determines the current operating frequency of a given clock source.

Table 23-27. Parameters

Data direction	Parameter name	Description
[in]	clock_source	Clock source to get the frequency of

Returns
Frequency of the given clock source, in Hz.

23.6.2.7. Main Clock Management

Function system_cpu_clock_set_divider()

Set main CPU clock divider.

```
void system_cpu_clock_set_divider(
        const enum system_main_clock_div divider)
```

Sets the clock divider used on the main clock to provide the CPU clock.

Table 23-28. Parameters

Data direction	Parameter name	Description
[in]	divider	CPU clock divider to set

Function system_cpu_clock_get_hz()

Retrieves the current frequency of the CPU core.

```
uint32_t system_cpu_clock_get_hz( void )
```

Retrieves the operating frequency of the CPU core, obtained from the main generic clock and the set CPU bus divider.

Returns
Current CPU frequency in Hz.

23.6.2.8. Bus Clock Masking

Function system_ahb_clock_set_mask()

Set bits in the clock mask for the AHB bus.

```
void system_ahb_clock_set_mask(
        const uint32_t ahb_mask)
```

This function will set bits in the clock mask for the AHB bus. Any bits set to 1 will enable that clock, zero bits in the mask will be ignored

Table 23-29. Parameters

Data direction	Parameter name	Description
[in]	ahb_mask	AHB clock mask to enable

Function system_ahb_clock_clear_mask()

Clear bits in the clock mask for the AHB bus.

```
void system_ahb_clock_clear_mask(
        const uint32_t ahb_mask)
```

This function will clear bits in the clock mask for the AHB bus. Any bits set to 1 will disable that clock, zero bits in the mask will be ignored.

Table 23-30. Parameters

Data direction	Parameter name	Description
[in]	ahb_mask	AHB clock mask to disable

Function system_apb_clock_set_mask()

Set bits in the clock mask for an APBx bus.

```
enum status_code system_apb_clock_set_mask(
        const enum system_clock_apb_bus bus,
        const uint32_t mask)
```

This function will set bits in the clock mask for an APBx bus. Any bits set to 1 will enable the corresponding module clock, zero bits in the mask will be ignored.

Table 23-31. Parameters

Data direction	Parameter name	Description
[in]	mask	APBx clock mask, a `SYSTEM_CLOCK_APB_APBx` constant from the device header files
[in]	bus	Bus to set clock mask bits for, a mask of `PM_APBxMASK_*` constants from the device header files

Returns

Status indicating the result of the clock mask change operation.

Table 23-32. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid bus given
STATUS_OK	The clock mask was set successfully

Function system_apb_clock_clear_mask()

Clear bits in the clock mask for an APBx bus.

```
enum status_code system_apb_clock_clear_mask(
        const enum system_clock_apb_bus bus,
        const uint32_t mask)
```

This function will clear bits in the clock mask for an APBx bus. Any bits set to 1 will disable the corresponding module clock, zero bits in the mask will be ignored.

Table 23-33. Parameters

Data direction	Parameter name	Description
[in]	mask	APBx clock mask, a `SYSTEM_CLOCK_APB_APBx` constant from the device header files
[in]	bus	Bus to clear clock mask bits

Returns
Status indicating the result of the clock mask change operation.

Table 23-34. Return Values

Return value	Description
STATUS_ERR_INVALID_ARG	Invalid bus ID was given
STATUS_OK	The clock mask was changed successfully

23.6.2.9. Internal DPLL Management

Function system_clock_source_dpll_get_config_defaults()

Retrieve the default configuration for DPLL.

```
void system_clock_source_dpll_get_config_defaults(
        struct system_clock_source_dpll_config *const config)
```

Fills a configuration structure with the default configuration for a DPLL oscillator module:

- Run only when requested by peripheral (on demand)
- Don't run in STANDBY sleep mode
- Lock bypass disabled
- Fast wake up disabled
- Low power mode disabled
- Output frequency is 48MHz
- Reference clock frequency is 32768Hz
- Not divide reference clock

- Select REF0 as reference clock
- Set lock time to default mode
- Use default filter

Table 23-35. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to fill with default values

Function system_clock_source_dpll_set_config()

Configure the DPLL clock source.

```
void system_clock_source_dpll_set_config(
        struct system_clock_source_dpll_config *const config)
```

Configures the Digital Phase-Locked Loop clock source with the given configuration settings.

Note: The DPLL will be running when this function returns, as the DPLL module needs to be enabled in order to perform the module configuration.

Table 23-36. Parameters

Data direction	Parameter name	Description
[in]	config	DPLL configuration structure containing the new config

23.6.2.10. System Clock Initialization

Function system_clock_init()

Initialize clock system based on the configuration in conf_clocks.h.

```
void system_clock_init( void )
```

This function will apply the settings in conf_clocks.h when run from the user application. All clock sources and GCLK generators are running when this function returns.

Note: OSC48M is always enabled and if the user selects other clocks for GCLK generators, the OSC48M default enable can be disabled after system_clock_init. Make sure the clock switches successfully before disabling OSC48M.

23.6.2.11. System Flash Wait States

Function system_flash_set_waitstates()

Set flash controller wait states.

```
void system_flash_set_waitstates(
        uint8_t wait_states)
```

Will set the number of wait states that are used by the onboard flash memory. The number of wait states depend on both device supply voltage and CPU speed. The required number of wait states can be found in the electrical characteristics of the device.

Table 23-37. Parameters

Data direction	Parameter name	Description
[in]	wait_states	Number of wait states to use for internal flash

23.6.2.12. Generic Clock Management

Function system_gclk_init()

Initializes the GCLK driver.

```
void system_gclk_init( void )
```

Initializes the Generic Clock module, disabling and resetting all active Generic Clock Generators and Channels to their power-on default values.

23.6.2.13. Generic Clock Management (Generators)

Function system_gclk_gen_get_config_defaults()

Initializes a Generic Clock Generator configuration structure to defaults.

```
void system_gclk_gen_get_config_defaults(
        struct system_gclk_gen_config *const config)
```

Initializes a given Generic Clock Generator configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is:

- The clock is generated undivided from the source frequency
- The clock generator output is low when the generator is disabled
- The input clock is sourced from input clock channel 0
- The clock will be disabled during sleep
- The clock output will not be routed to a physical GPIO pin

Table 23-38. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_gclk_gen_set_config()

Writes a Generic Clock Generator configuration to the hardware module.

```
void system_gclk_gen_set_config(
        const uint8_t generator,
        struct system_gclk_gen_config *const config)
```

Writes out a given configuration of a Generic Clock Generator configuration to the hardware module.

Note: Changing the clock source on the fly (on a running generator) can take additional time if the clock source is configured to only run on-demand (ONDEMAND bit is set) and it is not currently running (no peripheral is requesting the clock source). In this case the GCLK will request the new clock while still keeping a request to the old clock source until the new clock source is ready.

Note: This function will not start a generator that is not already running; to start the generator, call system_gclk_gen_enable() after configuring a generator.

Table 23-39. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to configure
[in]	config	Configuration settings for the generator

Function system_gclk_gen_enable()

Enables a Generic Clock Generator that was previously configured.

```
void system_gclk_gen_enable(
        const uint8_t generator)
```

Starts the clock generation of a Generic Clock Generator that was previously configured via a call to system_gclk_gen_set_config().

Table 23-40. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to enable

Function system_gclk_gen_disable()

Disables a Generic Clock Generator that was previously enabled.

```
void system_gclk_gen_disable(
        const uint8_t generator)
```

Stops the clock generation of a Generic Clock Generator that was previously started via a call to system_gclk_gen_enable().

Table 23-41. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to disable

Function system_gclk_gen_is_enabled()

Determins if the specified Generic Clock Generator is enabled.

```
bool system_gclk_gen_is_enabled(
        const uint8_t generator)
```

Table 23-42. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index to check

Returns
The enabled status.

Table 23-43. Return Values

Return value	Description
true	The Generic Clock Generator is enabled
false	The Generic Clock Generator is disabled

23.6.2.14. Generic Clock Management (Channels)

Function system_gclk_chan_get_config_defaults()

Initializes a Generic Clock configuration structure to defaults.

```
void system_gclk_chan_get_config_defaults(
        struct system_gclk_chan_config *const config)
```

Initializes a given Generic Clock configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- The clock is sourced from the Generic Clock Generator channel 0
- The clock configuration will not be write-locked when set

Table 23-44. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_gclk_chan_set_config()

Writes a Generic Clock configuration to the hardware module.

```
void system_gclk_chan_set_config(
        const uint8_t channel,
        struct system_gclk_chan_config *const config)
```

Writes out a given configuration of a Generic Clock configuration to the hardware module. If the clock is currently running, it will be stopped.

Note: Once called the clock will not be running. To start the clock, call system_gclk_chan_enable() after configuring a clock channel.

Table 23-45. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to configure
[in]	config	Configuration settings for the clock

Function system_gclk_chan_enable()

Enables a Generic Clock that was previously configured.

```
void system_gclk_chan_enable(
        const uint8_t channel)
```

Starts the clock generation of a Generic Clock that was previously configured via a call to system_gclk_chan_set_config().

Table 23-46. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to enable

Function system_gclk_chan_disable()

Disables a Generic Clock that was previously enabled.

```
void system_gclk_chan_disable(
        const uint8_t channel)
```

Stops the clock generation of a Generic Clock that was previously started via a call to system_gclk_chan_enable().

Table 23-47. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to disable

Function system_gclk_chan_is_enabled()

Determins if the specified Generic Clock channel is enabled.

```
bool system_gclk_chan_is_enabled(
        const uint8_t channel)
```

Table 23-48. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns

The enabled status.

Table 23-49. Return Values

Return value	Description
true	The Generic Clock channel is enabled
false	The Generic Clock channel is disabled

Function system_gclk_chan_lock()

Locks a Generic Clock channel from further configuration writes.

```
void system_gclk_chan_lock(
        const uint8_t channel)
```

Locks a generic clock channel from further configuration writes. It is only possible to unlock the channel configuration through a power on reset.

Table 23-50. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock channel to enable

Function system_gclk_chan_is_locked()

Determins if the specified Generic Clock channel is locked.

```
bool system_gclk_chan_is_locked(
        const uint8_t channel)
```

Table 23-51. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns
The lock status.

Table 23-52. Return Values

Return value	Description
true	The Generic Clock channel is locked
false	The Generic Clock channel is not locked

23.6.2.15. Generic Clock Frequency Retrieval

Function system_gclk_gen_get_hz()

Retrieves the clock frequency of a Generic Clock generator.

```
uint32_t system_gclk_gen_get_hz(
        const uint8_t generator)
```

Determines the clock frequency (in Hz) of a specified Generic Clock generator, used as a source to a Generic Clock Channel module.

Table 23-53. Parameters

Data direction	Parameter name	Description
[in]	generator	Generic Clock Generator index

Returns
The frequency of the generic clock generator, in Hz.

Function system_gclk_chan_get_hz()

Retrieves the clock frequency of a Generic Clock channel.

```
uint32_t system_gclk_chan_get_hz(
        const uint8_t channel)
```

Determines the clock frequency (in Hz) of a specified Generic Clock channel, used as a source to a device peripheral module.

Table 23-54. Parameters

Data direction	Parameter name	Description
[in]	channel	Generic Clock Channel index

Returns
The frequency of the generic clock channel, in Hz.

23.6.3. Enumeration Definitions

23.6.3.1. Enum gclk_generator

List of Available GCLK generators. This enum is used in the peripheral device drivers to select the GCLK generator to be used for its operation.

The number of GCLK generators available is device dependent.

Table 23-55. Members

Enum value	Description
GCLK_GENERATOR_0	GCLK generator channel 0
GCLK_GENERATOR_1	GCLK generator channel 1
GCLK_GENERATOR_2	GCLK generator channel 2
GCLK_GENERATOR_3	GCLK generator channel 3
GCLK_GENERATOR_4	GCLK generator channel 4
GCLK_GENERATOR_5	GCLK generator channel 5
GCLK_GENERATOR_6	GCLK generator channel 6
GCLK_GENERATOR_7	GCLK generator channel 7
GCLK_GENERATOR_8	GCLK generator channel 8
GCLK_GENERATOR_9	GCLK generator channel 9
GCLK_GENERATOR_10	GCLK generator channel 10
GCLK_GENERATOR_11	GCLK generator channel 11
GCLK_GENERATOR_12	GCLK generator channel 12
GCLK_GENERATOR_13	GCLK generator channel 13
GCLK_GENERATOR_14	GCLK generator channel 14
GCLK_GENERATOR_15	GCLK generator channel 15
GCLK_GENERATOR_16	GCLK generator channel 16

23.6.3.2. Enum system_clock_apb_bus

Available bus clock domains on the APB bus.

Table 23-56. Members

Enum value	Description
SYSTEM_CLOCK_APB_APBA	Peripheral bus A on the APB bus
SYSTEM_CLOCK_APB_APBB	Peripheral bus B on the APB bus
SYSTEM_CLOCK_APB_APBC	Peripheral bus C on the APB bus

23.6.3.3. Enum system_clock_external

Available external clock source types.

Table 23-57. Members

Enum value	Description
SYSTEM_CLOCK_EXTERNAL_CRYSTAL	The external clock source is a crystal oscillator
SYSTEM_CLOCK_EXTERNAL_CLOCK	The connected clock source is an external logic level clock signal

23.6.3.4. Enum system_clock_source

Clock sources available to the GCLK generators

Table 23-58. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_OSC48M	Internal 48MHz RC oscillator
SYSTEM_CLOCK_SOURCE_OSC32K	Internal 32KHz RC oscillator
SYSTEM_CLOCK_SOURCE_XOSC	External oscillator
SYSTEM_CLOCK_SOURCE_XOSC32K	External 32KHz oscillator
SYSTEM_CLOCK_SOURCE_ULP32K	Internal Ultra Low Power 32KHz oscillator
SYSTEM_CLOCK_SOURCE_GCLKIN	Generator input pad
SYSTEM_CLOCK_SOURCE_GCLKGEN1	Generic clock generator one output
SYSTEM_CLOCK_SOURCE_DPLL	Digital Phase Locked Loop (DPLL)

23.6.3.5. Enum system_clock_source_dpll_filter

Table 23-59. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_DPLL_FILTER_DEFAULT	Default filter mode
SYSTEM_CLOCK_SOURCE_DPLL_FILTER_LOW_BANDWIDTH_FILTER	Low bandwidth filter

Enum value	Description
SYSTEM_CLOCK_SOURCE_DPLL_FILTER_HIGH_BANDWIDTH_FILTER	High bandwidth filter
SYSTEM_CLOCK_SOURCE_DPLL_FILTER_HIGH_DAMPING_FILTER	High damping filter

23.6.3.6. Enum system_clock_source_dpll_lock_time

Table 23-60. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_DPLL_LOCK_TIME_DEFAULT	Set no time-out as default
SYSTEM_CLOCK_SOURCE_DPLL_LOCK_TIME_8MS	Set time-out if no lock within 8ms
SYSTEM_CLOCK_SOURCE_DPLL_LOCK_TIME_9MS	Set time-out if no lock within 9ms
SYSTEM_CLOCK_SOURCE_DPLL_LOCK_TIME_10MS	Set time-out if no lock within 10ms
SYSTEM_CLOCK_SOURCE_DPLL_LOCK_TIME_11MS	Set time-out if no lock within 11ms

23.6.3.7. Enum system_clock_source_dpll_prescaler

Table 23-61. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_DPLL_DIV_1	DPLL output is divided by 1
SYSTEM_CLOCK_SOURCE_DPLL_DIV_2	DPLL output is divided by 2
SYSTEM_CLOCK_SOURCE_DPLL_DIV_4	DPLL output is divided by 4

23.6.3.8. Enum system_clock_source_dpll_reference_clock

Table 23-62. Members

Enum value	Description
SYSTEM_CLOCK_SOURCE_DPLL_REFERENCE_CLOCK_XOSC32K	Select XOSC32K as clock reference
SYSTEM_CLOCK_SOURCE_DPLL_REFERENCE_CLOCK_XOSC	Select XOSC as clock reference
SYSTEM_CLOCK_SOURCE_DPLL_REFERENCE_CLOCK_GCLK	Select GCLK as clock reference

23.6.3.9. Enum system_clock_xosc32k_failure_detector_prescaler

Available clock failure detector prescaler.

Table 23-63. Members

Enum value	Description
SYSTEM_CLOCK_XOSC32K_FAILURE_DETECTOR_PRESCALER_1	Divide OSCULP32K frequency by 1 for clock failure detector clock
SYSTEM_CLOCK_XOSC32K_FAILURE_DETECTOR_PRESCALER_2	Divide OSCULP32K frequency by 2 for clock failure detector clock

23.6.3.10. Enum system_clock_xosc_failure_detector_prescaler

Available clock failure detector prescaler.

Table 23-64. Members

Enum value	Description
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_1	Divide OSC48M frequency by 1 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_2	Divide OSC48M frequency by 2 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_4	Divide OSC48M frequency by 4 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_8	Divide OSC48M frequency by 8 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_16	Divide OSC48M frequency by 16 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_32	Divide OSC48M frequency by 32 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_64	Divide OSC48M frequency by 64 for clock failure detector clock
SYSTEM_CLOCK_XOSC_FAILURE_DETECTOR_PRESCALER_128	Divide OSC48M frequency by 128 for clock failure detector clock

23.6.3.11. Enum system_main_clock_div

Available division ratios for the CPU clocks.

Table 23-65. Members

Enum value	Description
SYSTEM_MAIN_CLOCK_DIV_1	Divide Main clock by one
SYSTEM_MAIN_CLOCK_DIV_2	Divide Main clock by two
SYSTEM_MAIN_CLOCK_DIV_4	Divide Main clock by four
SYSTEM_MAIN_CLOCK_DIV_8	Divide Main clock by eight
SYSTEM_MAIN_CLOCK_DIV_16	Divide Main clock by 16
SYSTEM_MAIN_CLOCK_DIV_32	Divide Main clock by 32
SYSTEM_MAIN_CLOCK_DIV_64	Divide Main clock by 64
SYSTEM_MAIN_CLOCK_DIV_128	Divide Main clock by 128

23.6.3.12. Enum system_osc32k_startup

Available internal 32KHz oscillator startup times, as a number of internal OSC32K clock cycles.

Table 23-66. Members

Enum value	Description
SYSTEM_OSC32K_STARTUP_3	Wait three clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_4	Wait four clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_6	Wait six clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_10	Wait ten clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_18	Wait 18 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_34	Wait 34 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_66	Wait 66 clock cycles until the clock source is considered stable
SYSTEM_OSC32K_STARTUP_130	Wait 130 clock cycles until the clock source is considered stable

23.6.3.13. Enum system_osc48m_div

Available prescalers for the internal 48MHz (nominal) system clock.

Table 23-67. Members

Enum value	Description
SYSTEM_OSC48M_DIV_1	Divide the 48MHz RC oscillator output by one
SYSTEM_OSC48M_DIV_2	Divide the 48MHz RC oscillator output by two
SYSTEM_OSC48M_DIV_3	Divide the 48MHz RC oscillator output by three
SYSTEM_OSC48M_DIV_4	Divide the 48MHz RC oscillator output by four

Enum value	Description
SYSTEM_OSC48M_DIV_5	Divide the 48MHz RC oscillator output by five
SYSTEM_OSC48M_DIV_6	Divide the 48MHz RC oscillator output by six
SYSTEM_OSC48M_DIV_7	Divide the 48MHz RC oscillator output by seven
SYSTEM_OSC48M_DIV_8	Divide the 48MHz RC oscillator output by eight
SYSTEM_OSC48M_DIV_9	Divide the 48MHz RC oscillator output by nine
SYSTEM_OSC48M_DIV_10	Divide the 48MHz RC oscillator output by ten
SYSTEM_OSC48M_DIV_11	Divide the 48MHz RC oscillator output by eleven
SYSTEM_OSC48M_DIV_12	Divide the 48MHz RC oscillator output by twelve
SYSTEM_OSC48M_DIV_13	Divide the 48MHz RC oscillator output by thirteen
SYSTEM_OSC48M_DIV_14	Divide the 48MHz RC oscillator output by fourteen
SYSTEM_OSC48M_DIV_15	Divide the 48MHz RC oscillator output by fifteen
SYSTEM_OSC48M_DIV_16	Divide the 48MHz RC oscillator output by sixteen

23.6.3.14. Enum system_osc48m_startup

Available internal 48MHz oscillator startup times, as a number of internal clock cycles.

Table 23-68. Members

Enum value	Description
SYSTEM_OSC48M_STARTUP_8	Wait 8 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_16	Wait 16 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_32	Wait 32 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_64	Wait 64 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_128	Wait 128 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_256	Wait 256 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_512	Wait 512 clock cycles until the clock source is considered stable
SYSTEM_OSC48M_STARTUP_1024	Wait 1024 clock cycles until the clock source is considered stable

23.6.3.15. Enum system_xosc32k_startup

Available external 32KHz oscillator startup times, as a number of external clock cycles.

Table 23-69. Members

Enum value	Description
SYSTEM_XOSC32K_STARTUP_2048	Wait 2048 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_4096	Wait 4096 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_16384	Wait 16384 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_32768	Wait 32768 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_65536	Wait 65536 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_131072	Wait 131072 clock cycles until the clock source is considered stable
SYSTEM_XOSC32K_STARTUP_262144	Wait 262144 clock cycles until the clock source is considered stable

23.6.3.16. Enum system_xosc_startup

Available external oscillator startup times, as a number of external clock cycles.

Table 23-70. Members

Enum value	Description
SYSTEM_XOSC_STARTUP_1	Wait one clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_2	Wait two clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_4	Wait four clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_8	Wait eight clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_16	Wait 16 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_32	Wait 32 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_64	Wait 64 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_128	Wait 128 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_256	Wait 256 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_512	Wait 512 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_1024	Wait 1024 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_2048	Wait 2048 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_4096	Wait 4096 clock cycles until the clock source is considered stable

Enum value	Description
SYSTEM_XOSC_STARTUP_8192	Wait 8192 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_16384	Wait 16384 clock cycles until the clock source is considered stable
SYSTEM_XOSC_STARTUP_32768	Wait 32768 clock cycles until the clock source is considered stable

23.7. Extra Information for SYSTEM CLOCK Driver

23.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
DFLL	Digital Frequency Locked Loop
MUX	Multiplexer
MCLK	Main Clock
OSC32K	Internal 32KHz Oscillator
OSC48M	Internal 48MHz Oscillator
PLL	Phase Locked Loop
OSC	Oscillator
XOSC	External Oscillator
XOSC32K	External 32KHz Oscillator
AHB	Advanced High-performance Bus
APB	Advanced Peripheral Bus
DPLL	Digital Phase Locked Loop

23.7.2. Dependencies

This driver has the following dependencies:

- None

23.7.3. Errata

There are no errata related to this driver.

23.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

23.8. Examples for System Clock Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM System Clock Management (SYSTEM CLOCK) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM CLOCK - Basic
- Quick Start Guide for SYSTEM CLOCK - GCLK Configuration

23.8.1. Quick Start Guide for SYSTEM CLOCK - Basic

In this case we apply the following configuration:

- RC8MHz (internal 8MHz RC oscillator)
  - Divide by four, giving a frequency of 2MHz
- DFLL (Digital frequency locked loop)
  - Open loop mode
  - 48MHz frequency
- CPU clock
  - Use two wait states when reading from flash memory
  - Use the DFLL, configured to 48MHz

23.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your application:

```
void configure_extosc32k(void)
{
    struct system_clock_source_xosc32k_config config_ext32k;
    system_clock_source_xosc32k_get_config_defaults(&config_ext32k);

    config_ext32k.startup_time = SYSTEM_XOSC32K_STARTUP_4096;

    system_clock_source_xosc32k_set_config(&config_ext32k);
}

#if (!SAMC21)
void configure_dfll_open_loop(void)
{
    struct system_clock_source_dfll_config config_dfll;
    system_clock_source_dfll_get_config_defaults(&config_dfll);

    system_clock_source_dfll_set_config(&config_dfll);
}
#endif
```

Workflow

1. Create a EXTOSC32K module configuration struct, which can be filled out to adjust the configuration of the external 32KHz oscillator channel.

```
struct system_clock_source_xosc32k_config config_ext32k;
```

2. Initialize the oscillator configuration struct with the module's default values.

```
system_clock_source_xosc32k_get_config_defaults(&config_ext32k);
```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the EXTOSC32K module configuration struct to require a start-up time of 4096 clock cycles.

```
config_ext32k.startup_time = SYSTEM_XOSC32K_STARTUP_4096;
```

4. Write the new configuration to the EXTOSC32K module.

```
system_clock_source_xosc32k_set_config(&config_ext32k);
```

5. Create a DFLL module configuration struct, which can be filled out to adjust the configuration of the external 32KHz oscillator channel.

```
struct system_clock_source_dfll_config config_dfll;
```

6. Initialize the DFLL oscillator configuration struct with the module's default values.

```
system_clock_source_dfll_get_config_defaults(&config_dfll);
```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

7. Write the new configuration to the DFLL module.

```
system_clock_source_dfll_set_config(&config_dfll);
```

23.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
/* Configure the external 32KHz oscillator */
configure_extosc32k();

/* Enable the external 32KHz oscillator */
enum status_code osc32k_status =
        system_clock_source_enable(SYSTEM_CLOCK_SOURCE_XOSC32K);

if (osc32k_status != STATUS_OK) {
    /* Error enabling the clock source */
}

#if (!SAMC21)
    /* Configure the DFLL in open loop mode using default values */
configure_dfll_open_loop();

/* Enable the DFLL oscillator */
enum status_code dfll_status =
        system_clock_source_enable(SYSTEM_CLOCK_SOURCE_DFLL);

if (dfll_status != STATUS_OK) {
    /* Error enabling the clock source */
}
```

```
/* Configure flash wait states before switching to high frequency clock */
system_flash_set_waitstates(2);

/* Change system clock to DFLL */
struct system_gclk_gen_config config_gclock_gen;
system_gclk_gen_get_config_defaults(&config_gclock_gen);
config_gclock_gen.source_clock    = SYSTEM_CLOCK_SOURCE_DFLL;
config_gclock_gen.division_factor = 1;
system_gclk_gen_set_config(GCLK_GENERATOR_0, &config_gclock_gen);
#endif
```

Workflow

1. Configure the external 32KHz oscillator source using the previously defined setup function.

   ```
   configure_extosc32k();
   ```

2. Enable the configured external 32KHz oscillator source.

   ```
   enum status_code osc32k_status =
           system_clock_source_enable(SYSTEM_CLOCK_SOURCE_XOSC32K);

   if (osc32k_status != STATUS_OK) {
       /* Error enabling the clock source */
   }
   ```

3. Configure the DFLL oscillator source using the previously defined setup function.

   ```
   configure_dfll_open_loop();
   ```

4. Enable the configured DFLL oscillator source.

   ```
   enum status_code dfll_status =
           system_clock_source_enable(SYSTEM_CLOCK_SOURCE_DFLL);

   if (dfll_status != STATUS_OK) {
       /* Error enabling the clock source */
   }
   ```

5. Configure the flash wait states to have two wait states per read, as the high speed DFLL will be used as the system clock. If insufficient wait states are used, the device may crash randomly due to misread instructions.

   ```
   system_flash_set_waitstates(2);
   ```

6. Switch the system clock source to the DFLL, by reconfiguring the main clock generator.

   ```
   struct system_gclk_gen_config config_gclock_gen;
   system_gclk_gen_get_config_defaults(&config_gclock_gen);
   config_gclock_gen.source_clock    = SYSTEM_CLOCK_SOURCE_DFLL;
   config_gclock_gen.division_factor = 1;
   system_gclk_gen_set_config(GCLK_GENERATOR_0, &config_gclock_gen);
   ```

23.8.2. Quick Start Guide for SYSTEM CLOCK - GCLK Configuration

In this use-case, the GCLK module is configured for:

- One generator attached to the internal 8MHz RC oscillator clock source
- Generator output equal to input frequency divided by a factor of 128
- One channel (connected to the TC0 module) enabled with the enabled generator selected

This use-case configures a clock channel to output a clock for a peripheral within the device, by first setting up a clock generator from a master clock source, and then linking the generator to the desired channel. This clock can then be used to clock a module within the device.

23.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_gclock_generator(void)
{
    struct system_gclk_gen_config gclock_gen_conf;
    system_gclk_gen_get_config_defaults(&gclock_gen_conf);

#if (SAML21) || (SAML22) || (SAMR30)
    gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC16M;
    gclock_gen_conf.division_factor = 128;
#elif (SAMC21)
    gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC48M;
    gclock_gen_conf.division_factor = 128;
#else
    gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC8M;
    gclock_gen_conf.division_factor = 128;
#endif

    system_gclk_gen_set_config(GCLK_GENERATOR_1, &gclock_gen_conf);

    system_gclk_gen_enable(GCLK_GENERATOR_1);
}

void configure_gclock_channel(void)
{
    struct system_gclk_chan_config gclk_chan_conf;
    system_gclk_chan_get_config_defaults(&gclk_chan_conf);

    gclk_chan_conf.source_generator = GCLK_GENERATOR_1;
#if (SAMD10) || (SAMD11) || SAMR30
    system_gclk_chan_set_config(TC1_GCLK_ID, &gclk_chan_conf);

    system_gclk_chan_enable(TC1_GCLK_ID);
#else
    system_gclk_chan_set_config(TC3_GCLK_ID, &gclk_chan_conf);

    system_gclk_chan_enable(TC3_GCLK_ID);
#endif
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_gclock_generator();
configure_gclock_channel();
```

Workflow

1. Create a GCLK generator configuration struct, which can be filled out to adjust the configuration of a single clock generator.

   ```
   struct system_gclk_gen_config gclock_gen_conf;
   ```

2. Initialize the generator configuration struct with the module's default values.

```
system_gclk_gen_get_config_defaults(&gclock_gen_conf);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request the master clock source channel 0 is used as the source of the generator, and set the generator output prescaler to divide the input clock by a factor of 128.

```
gclock_gen_conf.source_clock    = SYSTEM_CLOCK_SOURCE_OSC16M;
gclock_gen_conf.division_factor = 128;
```

4. Configure the generator using the configuration structure.

```
system_gclk_gen_set_config(GCLK_GENERATOR_1, &gclock_gen_conf);
```

Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

5. Enable the generator once it has been properly configured, to begin clock generation.

```
system_gclk_gen_enable(GCLK_GENERATOR_1);
```

6. Create a GCLK channel configuration struct, which can be filled out to adjust the configuration of a single generic clock channel.

```
struct system_gclk_chan_config gclk_chan_conf;
```

7. Initialize the channel configuration struct with the module's default values.

```
system_gclk_chan_get_config_defaults(&gclk_chan_conf);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

8. Adjust the configuration struct to request the previously configured and enabled clock generator is used as the clock source for the channel.

```
gclk_chan_conf.source_generator = GCLK_GENERATOR_1;
```

9. Configure the channel using the configuration structure.

```
system_gclk_chan_set_config(TC1_GCLK_ID, &gclk_chan_conf);
```

Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

10. Enable the channel once it has been properly configured, to output the clock to the channel's peripheral module consumers.

```
system_gclk_chan_enable(TC1_GCLK_ID);
```

23.8.2.2. Use-case

Code

Copy-paste the following code to your user application:

```
while (true) {
     /* Nothing to do */
}
```

Workflow

1. As the clock is generated asynchronously to the system core, no special extra application code is required.

24. SAM System Interrupt (SYSTEM INTERRUPT) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of internal software and hardware interrupts/exceptions.

The following peripheral is used by this module:

- NVIC (Nested Vector Interrupt Controller)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

24.1. Prerequisites

There are no prerequisites for this module.

24.2. Module Overview

The ARM® Cortex® M0+ core contains an interrupt and exception vector table, which can be used to configure the device's interrupt handlers; individual interrupts and exceptions can be enabled and disabled, as well as configured with a variable priority.

This driver provides a set of wrappers around the core interrupt functions, to expose a simple API for the management of global and individual interrupts within the device.

24.2.1. Critical Sections

In some applications it is important to ensure that no interrupts may be executed by the system whilst a critical portion of code is being run; for example, a buffer may be copied from one context to another - during which interrupts must be disabled to avoid corruption of the source buffer contents until the copy has completed. This driver provides a basic API to enter and exit nested critical sections, so that global interrupts can be kept disabled for as long as necessary to complete a critical application code section.

24.2.2. Software Interrupts

For some applications, it may be desirable to raise a module or core interrupt via software. For this reason, a set of APIs to set an interrupt or exception as pending are provided to the user application.

24.3. Special Considerations

Interrupts from peripherals in the SAM devices are on a per-module basis; an interrupt raised from any source within a module will cause a single, module-common handler to execute. It is the user application or driver's responsibility to de-multiplex the module-common interrupt to determine the exact interrupt cause.

24.4. Extra Information

For extra information, see Extra Information for SYSTEM INTERRUPT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

24.5. Examples

For a list of examples related to this driver, see Examples for SYSTEM INTERRUPT Driver.

24.6. API Overview

24.6.1. Function Definitions

24.6.1.1. Critical Section Management

Function system_interrupt_enter_critical_section()

Enters a critical section.

```
void system_interrupt_enter_critical_section( void )
```

Disables global interrupts. To support nested critical sections, an internal count of the critical section nesting will be kept, so that global interrupts are only re-enabled upon leaving the outermost nested critical section.

Function system_interrupt_leave_critical_section()

Leaves a critical section.

```
void system_interrupt_leave_critical_section( void )
```

Enables global interrupts. To support nested critical sections, an internal count of the critical section nesting will be kept, so that global interrupts are only re-enabled upon leaving the outermost nested critical section.

24.6.1.2. Interrupt Enabling/Disabling

Function system_interrupt_is_global_enabled()

Check if global interrupts are enabled.

```
bool system_interrupt_is_global_enabled( void )
```

Checks if global interrupts are currently enabled.

Returns
A boolean that identifies if the global interrupts are enabled or not.

Table 24-1. Return Values

Return value	Description
true	Global interrupts are currently enabled
false	Global interrupts are currently disabled

Function system_interrupt_enable_global()

Enables global interrupts.

```
void system_interrupt_enable_global( void )
```

Enables global interrupts in the device to fire any enabled interrupt handlers.

Function system_interrupt_disable_global()

Disables global interrupts.

```
void system_interrupt_disable_global( void )
```

Disabled global interrupts in the device, preventing any enabled interrupt handlers from executing.

Function system_interrupt_is_enabled()

Checks if an interrupt vector is enabled or not.

```
bool system_interrupt_is_enabled(
        const enum system_interrupt_vector vector)
```

Checks if a specific interrupt vector is currently enabled.

Table 24-2. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to check

Returns
A variable identifying if the requested interrupt vector is enabled.

Table 24-3. Return Values

Return value	Description
true	Specified interrupt vector is currently enabled
false	Specified interrupt vector is currently disabled

Function system_interrupt_enable()

Enable interrupt vector.

```
void system_interrupt_enable(
        const enum system_interrupt_vector vector)
```

Enables execution of the software handler for the requested interrupt vector.

Table 24-4. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to enable

Function system_interrupt_disable()

Disable interrupt vector.

```
void system_interrupt_disable(
        const enum system_interrupt_vector vector)
```

Disables execution of the software handler for the requested interrupt vector.

Table 24-5. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to disable

24.6.1.3. Interrupt State Management

Function system_interrupt_get_active()

Get active interrupt (if any).

```
enum system_interrupt_vector system_interrupt_get_active( void )
```

Return the vector number for the current executing software handler, if any.

Returns
Interrupt number that is currently executing.

Function system_interrupt_is_pending()

Check if a interrupt line is pending.

```
bool system_interrupt_is_pending(
        const enum system_interrupt_vector vector)
```

Checks if the requested interrupt vector is pending.

Table 24-6. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to check

Returns
A boolean identifying if the requested interrupt vector is pending.

Table 24-7. Return Values

Return value	Description
true	Specified interrupt vector is pending
false	Specified interrupt vector is not pending

Function system_interrupt_set_pending()

Set a interrupt vector as pending.

```
enum status_code system_interrupt_set_pending(
        const enum system_interrupt_vector vector)
```

Set the requested interrupt vector as pending (i.e. issues a software interrupt request for the specified vector). The software handler will be handled (if enabled) in a priority order based on vector number and configured priority settings.

Table 24-8. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number which is set as pending

Returns

Status code identifying if the vector was successfully set as pending.

Table 24-9. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

Function system_interrupt_clear_pending()

Clear pending interrupt vector.

```
enum status_code system_interrupt_clear_pending(
        const enum system_interrupt_vector vector)
```

Clear a pending interrupt vector, so the software handler is not executed.

Table 24-10. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector number to clear

Returns

A status code identifying if the interrupt pending state was successfully cleared.

Table 24-11. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

24.6.1.4. Interrupt Priority Management

Function system_interrupt_set_priority()

Set interrupt vector priority level.

```
enum status_code system_interrupt_set_priority(
        const enum system_interrupt_vector vector,
        const enum system_interrupt_priority_level priority_level)
```

Set the priority level of an external interrupt or exception.

Table 24-12. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector to change
[in]	priority_level	New vector priority level to set

Returns
Status code indicating if the priority level of the interrupt was successfully set.

Table 24-13. Return Values

Return value	Description
STATUS_OK	If no error was detected
STATUS_INVALID_ARG	If an unsupported interrupt vector number was given

Function system_interrupt_get_priority()

Get interrupt vector priority level.

```
enum system_interrupt_priority_level system_interrupt_get_priority(
        const enum system_interrupt_vector vector)
```

Retrieves the priority level of the requested external interrupt or exception.

Table 24-14. Parameters

Data direction	Parameter name	Description
[in]	vector	Interrupt vector of which the priority level will be read

Returns
Currently configured interrupt priority level of the given interrupt vector.

24.6.2. Enumeration Definitions

24.6.2.1. Enum system_interrupt_priority_level

Table of all possible interrupt and exception vector priorities within the device.

Table 24-15. Members

Enum value	Description
SYSTEM_INTERRUPT_PRIORITY_LEVEL_0	Priority level 0, the highest possible interrupt priority
SYSTEM_INTERRUPT_PRIORITY_LEVEL_1	Priority level 1
SYSTEM_INTERRUPT_PRIORITY_LEVEL_2	Priority level 2
SYSTEM_INTERRUPT_PRIORITY_LEVEL_3	Priority level 3, the lowest possible interrupt priority

24.6.2.2. Enum system_interrupt_vector_samc21

Table of all possible interrupt and exception vector indexes within the SAM C20/C21 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-16. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_SYSTEM	Interrupt vector index for MCLK, OSCCTRL, OSC32KCTRL, PAC, PM, SUPC, TAL peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_FREQM	Interrupt vector index for Frequency Meter peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).

24.6.2.3. Enum system_interrupt_vector_samd09

Table of all possible interrupt and exception vector indexes within the SAM D09 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-17. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt

24.6.2.4. Enum system_interrupt_vector_samd1x

Table of all possible interrupt and exception vector indexes within the SAM D10/D11 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-18. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception

Enum value	Description
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).

Enum value	Description
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt

24.6.2.5. Enum system_interrupt_vector_samd20

Table of all possible interrupt and exception vector indexes within the SAM D20 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-19. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC0`).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt

24.6.2.6. Enum system_interrupt_vector_samd21

Table of all possible interrupt and exception vector indexes within the SAM D21 device. Check peripherals configuration in SAM D21 datasheet for available vector index for specific device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-20. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt

Enum value	Description
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).

Enum value	Description
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt
SYSTEM_INTERRUPT_MODULE_I2S	Interrupt vector index for a Inter-IC Sound Interface peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AC1	Interrupt vector index for an Analog Comparator 1 peripheral interrupt

24.6.2.7. Enum system_interrupt_vector_samda1

Table of all possible interrupt and exception vector indexes within the SAM DA1 device. Check peripherals configuration in SAM DA1 datasheet for available vector index for specific device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-21. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt
SYSTEM_INTERRUPT_MODULE_I2S	Interrupt vector index for a Inter-IC Sound Interface peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AC1	Interrupt vector index for an Analog Comparator 1 peripheral interrupt

24.6.2.8. Enum system_interrupt_vector_saml21

Table of all possible interrupt and exception vector indexes within the SAM L21 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-22. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_SYSTEM	Interrupt vector index for MCLK, OSCCTRL, OSC32KCTRL, PAC, PM, SUPC, TAL peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_DAC	Interrupt vector index for a Digital-to-Analog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AES	Interrupt vector index for a AES peripheral interrupt
SYSTEM_INTERRUPT_MODULE_TRNG	Interrupt vector index for a TRNG peripheral interrupt

24.6.2.9. Enum system_interrupt_vector_saml22

Table of all possible interrupt and exception vector indexes within the SAM L22 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-23. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_SYSTEM	Interrupt vector index for MCLK, OSCCTRL, OSC32KCTRL, PAC, PM, SUPC, TAL peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_FREQM	Interrupt vector index for Frequency Meter peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).

Enum value	Description
SYSTEM_INTERRUPT_MODULE_TCC0	Interrupt vector index for a Timer/Counter Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SLCD	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt

24.6.2.10. Enum system_interrupt_vector_samr21

Table of all possible interrupt and exception vector indexes within the SAM R21 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-24. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_PM	Interrupt vector index for a Power Manager peripheral interrupt
SYSTEM_INTERRUPT_MODULE_SYSCTRL	Interrupt vector index for a System Control peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt

Enum value	Description
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt

24.6.2.11. Enum system_interrupt_vector_samr30

Table of all possible interrupt and exception vector indexes within the SAM L21 device.
Note: The actual enumeration name is "system_interrupt_vector".

Table 24-25. Members

Enum value	Description
SYSTEM_INTERRUPT_NON_MASKABLE	Interrupt vector index for a NMI interrupt
SYSTEM_INTERRUPT_HARD_FAULT	Interrupt vector index for a Hard Fault memory access exception

Enum value	Description
SYSTEM_INTERRUPT_SV_CALL	Interrupt vector index for a Supervisor Call exception
SYSTEM_INTERRUPT_PENDING_SV	Interrupt vector index for a Pending Supervisor interrupt
SYSTEM_INTERRUPT_SYSTICK	Interrupt vector index for a System Tick interrupt
SYSTEM_INTERRUPT_MODULE_SYSTEM	Interrupt vector index for MCLK, OSCCTRL, OSC32KCTRL, PAC, PM, SUPC, TAL peripheral interrupt
SYSTEM_INTERRUPT_MODULE_WDT	Interrupt vector index for a Watch Dog peripheral interrupt
SYSTEM_INTERRUPT_MODULE_RTC	Interrupt vector index for a Real Time Clock peripheral interrupt
SYSTEM_INTERRUPT_MODULE_EIC	Interrupt vector index for an External Interrupt peripheral interrupt
SYSTEM_INTERRUPT_MODULE_NVMCTRL	Interrupt vector index for a Non Volatile Memory Controller interrupt
SYSTEM_INTERRUPT_MODULE_DMA	Interrupt vector index for a Direct Memory Access interrupt
SYSTEM_INTERRUPT_MODULE_USB	Interrupt vector index for a Universal Serial Bus interrupt
SYSTEM_INTERRUPT_MODULE_EVSYS	Interrupt vector index for an Event System interrupt
SYSTEM_INTERRUPT_MODULE_SERCOMn	Interrupt vector index for a SERCOM peripheral interrupt. Each specific device may contain several SERCOM peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_SERCOM0`).
SYSTEM_INTERRUPT_MODULE_TCCn	Interrupt vector index for a Timer/Counter Control peripheral interrupt. Each specific device may contain several TCC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TCC0`).

Enum value	Description
SYSTEM_INTERRUPT_MODULE_TCn	Interrupt vector index for a Timer/Counter peripheral interrupt. Each specific device may contain several TC peripherals; each module instance will have its own entry in the table, with the instance number substituted for "n" in the entry name (e.g. `SYSTEM_INTERRUPT_MODULE_TC3`).
SYSTEM_INTERRUPT_MODULE_AC	Interrupt vector index for an Analog Comparator peripheral interrupt
SYSTEM_INTERRUPT_MODULE_ADC	Interrupt vector index for an Analog-to-Digital peripheral interrupt
SYSTEM_INTERRUPT_MODULE_PTC	Interrupt vector index for a Peripheral Touch Controller peripheral interrupt

24.7. Extra Information for SYSTEM INTERRUPT Driver

24.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
ISR	Interrupt Service Routine
NMI	Non-maskable Interrupt
SERCOM	Serial Communication Interface

24.7.2. Dependencies

This driver has the following dependencies:

- None

24.7.3. Errata

There are no errata related to this driver.

24.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

24.8. Examples for SYSTEM INTERRUPT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM System Interrupt (SYSTEM INTERRUPT) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM INTERRUPT - Critical Section Use Case
- Quick Start Guide for SYSTEM INTERRUPT - Enable Module Interrupt Use Case

24.8.1. Quick Start Guide for SYSTEM INTERRUPT - Critical Section Use Case

In this case we perform a critical piece of code, disabling all interrupts while a global shared flag is read. During the critical section, no interrupts may occur.

24.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

24.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enter_critical_section();

if (is_ready == true) {
    /* Do something in response to the global shared flag */
    is_ready = false;
}

system_interrupt_leave_critical_section();
```

Workflow

1. Enter a critical section to disable global interrupts.

   ```
   system_interrupt_enter_critical_section();
   ```

   Note: Critical sections *may* be nested if desired; if nested, global interrupts will only be re-enabled once the outer-most critical section has completed.
2. Check a global shared flag and perform a response. This code may be any critical code that requires exclusive access to all resources without the possibility of interruption.

   ```
   if (is_ready == true) {
       /* Do something in response to the global shared flag */
       is_ready = false;
   }
   ```
3. Exit the critical section to re-enable global interrupts.

   ```
   system_interrupt_leave_critical_section();
   ```

24.8.2. Quick Start Guide for SYSTEM INTERRUPT - Enable Module Interrupt Use Case

In this case we enable interrupt handling for a specific module, as well as enable interrupts globally for the device.

24.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

24.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_RTC);

system_interrupt_enable_global();
```

Workflow

1. Enable interrupt handling for the device's RTC peripheral.

   ```
   system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_RTC);
   ```

2. Enable global interrupts, so that any enabled and active interrupt sources can trigger their respective handler functions.

   ```
   system_interrupt_enable_global();
   ```

25. SAM System Pin Multiplexer (SYSTEM PINMUX) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's physical I/O Pins, to alter the direction and input/drive characteristics as well as to configure the pin peripheral multiplexer selection.

The following peripheral is used by this module:

- PORT (Port I/O Management)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

25.1. Prerequisites

There are no prerequisites for this module.

25.2. Module Overview

The SAM devices contain a number of General Purpose I/O pins, used to interface the user application logic and internal hardware peripherals to an external system. The Pin Multiplexer (PINMUX) driver provides a method of configuring the individual pin peripheral multiplexers to select alternate pin functions.

25.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_SYSTEM_PINMUX_DRIVE_STRENGTH	SAM L21, SAM C20/C21

Note: The specific features are only available in the driver when the selected device supports those features.

25.2.2. Physical and Logical GPIO Pins

SAM devices use two naming conventions for the I/O pins in the device; one physical and one logical. Each physical pin on a device package is assigned both a physical port and pin identifier (e.g. "PORTA.

0") as well as a monotonically incrementing logical GPIO number (e.g. "GPIO0"). While the former is used to map physical pins to their physical internal device module counterparts, for simplicity the design of this driver uses the logical GPIO numbers instead.

25.2.3. Peripheral Multiplexing

SAM devices contain a peripheral MUX, which is individually controllable for each I/O pin of the device. The peripheral MUX allows you to select the function of a physical package pin - whether it will be controlled as a user controllable GPIO pin, or whether it will be connected internally to one of several peripheral modules (such as an I^2C module). When a pin is configured in GPIO mode, other peripherals connected to the same pin will be disabled.

25.2.4. Special Pad Characteristics

There are several special modes that can be selected on one or more I/O pins of the device, which alter the input and output characteristics of the pad.

25.2.4.1. Drive Strength

The Drive Strength configures the strength of the output driver on the pad. Normally, there is a fixed current limit that each I/O pin can safely drive, however some I/O pads offer a higher drive mode which increases this limit for that I/O pin at the expense of an increased power consumption.

25.2.4.2. Slew Rate

The Slew Rate configures the slew rate of the output driver, limiting the rate at which the pad output voltage can change with time.

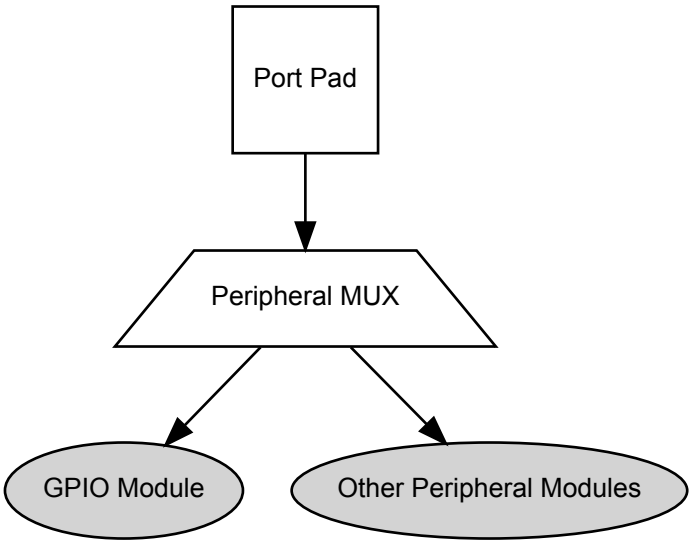
25.2.4.3. Input Sample Mode

The Input Sample Mode configures the input sampler buffer of the pad. By default, the input buffer is only sampled "on-demand", i.e. when the user application attempts to read from the input buffer. This mode is the most power efficient, but increases the latency of the input sample by two clock cycles of the port clock. To reduce latency, the input sampler can instead be configured to always sample the input buffer on each port clock cycle, at the expense of an increased power consumption.

25.2.5. Physical Connection

Figure 25-1 shows how this module is interconnected within the device:

Figure 25-1. Physical Connection



25.3. Special Considerations

The SAM port pin input sampling mode is set in groups of four physical pins; setting the sampling mode of any pin in a sub-group of eight I/O pins will configure the sampling mode of the entire sub-group.

High Drive Strength output driver mode is not available on all device pins - refer to your device specific datasheet.

25.4. Extra Information

For extra information, see Extra Information for SYSTEM PINMUX Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

25.5. Examples

For a list of examples related to this driver, see Examples for SYSTEM PINMUX Driver.

25.6. API Overview

25.6.1. Structure Definitions

25.6.1.1. Struct system_pinmux_config

Configuration structure for a port pin instance. This structure should be initialized by the system_pinmux_get_config_defaults() function before being modified by the user application.

Table 25-1. Members

Type	Name	Description
enum system_pinmux_pin_dir	direction	Port buffer input/output direction
enum system_pinmux_pin_pull	input_pull	Logic level pull of the input buffer
uint8_t	mux_position	MUX index of the peripheral that should control the pin, if peripheral control is desired. For GPIO use, this should be set to SYSTEM_PINMUX_GPIO.
bool	powersave	Enable lowest possible powerstate on the pin **Note:** All other configurations will be ignored, the pin will be disabled.

25.6.2. Macro Definitions

25.6.2.1. Macro FEATURE_SYSTEM_PINMUX_DRIVE_STRENGTH

```
#define FEATURE_SYSTEM_PINMUX_DRIVE_STRENGTH
```

Output Driver Strength Selection feature support

25.6.2.2. Macro SYSTEM_PINMUX_GPIO

```
#define SYSTEM_PINMUX_GPIO
```

Peripheral multiplexer index to select GPIO mode for a pin

25.6.3. Function Definitions

25.6.3.1. Configuration and Initialization

Function system_pinmux_get_config_defaults()

Initializes a Port pin configuration structure to defaults.

```
void system_pinmux_get_config_defaults(
        struct system_pinmux_config *const config)
```

Initializes a given Port pin configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Non peripheral (i.e. GPIO) controlled
- Input mode with internal pull-up enabled

Table 25-2. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function system_pinmux_pin_set_config()

Writes a Port pin configuration to the hardware module.

```
void system_pinmux_pin_set_config(
        const uint8_t gpio_pin,
        const struct system_pinmux_config *const config)
```

Writes out a given configuration of a Port pin configuration to the hardware module.

Note: If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 25-3. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure
[in]	config	Configuration settings for the pin

Function system_pinmux_group_set_config()

Writes a Port pin group configuration to the hardware module.

```
void system_pinmux_group_set_config(
        PortGroup *const port,
        const uint32_t mask,
        const struct system_pinmux_config *const config)
```

Writes out a given configuration of a Port pin group configuration to the hardware module.

Note: If the pin direction is set as an output, the pull-up/pull-down input configuration setting is ignored.

Table 25-4. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to configure
[in]	mask	Mask of the port pin(s) to configure
[in]	config	Configuration settings for the pin

25.6.3.2. Special Mode Configuration (Physical Group Orientated)

Function system_pinmux_get_group_from_gpio_pin()

Retrieves the PORT module group instance from a given GPIO pin number.

```
PortGroup * system_pinmux_get_group_from_gpio_pin(
        const uint8_t gpio_pin)
```

Retrieves the PORT module group instance associated with a given logical GPIO pin number.

Table 25-5. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to convert

Returns

Base address of the associated PORT module.

Function system_pinmux_group_set_input_sample_mode()

Configures the input sampling mode for a group of pins.

```
void system_pinmux_group_set_input_sample_mode(
        PortGroup *const port,
        const uint32_t mask,
        const enum system_pinmux_pin_sample mode)
```

Configures the input sampling mode for a group of pins, to control when the physical I/O pin value is sampled and stored inside the microcontroller.

Table 25-6. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to configure
[in]	mask	Mask of the port pin(s) to configure
[in]	mode	New pin sampling mode to configure

25.6.3.3. Special Mode Configuration (Logical Pin Orientated)

Function system_pinmux_pin_get_mux_position()

Retrieves the currently selected MUX position of a logical pin.

```
uint8_t system_pinmux_pin_get_mux_position(
        const uint8_t gpio_pin)
```

Retrieves the selected MUX peripheral on a given logical GPIO pin.

Table 25-7. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure

Returns

Currently selected peripheral index on the specified pin.

Function system_pinmux_pin_set_input_sample_mode()

Configures the input sampling mode for a GPIO pin.

```
void system_pinmux_pin_set_input_sample_mode(
        const uint8_t gpio_pin,
        const enum system_pinmux_pin_sample mode)
```

Configures the input sampling mode for a GPIO input, to control when the physical I/O pin value is sampled and stored inside the microcontroller.

Table 25-8. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure
[in]	mode	New pin sampling mode to configure

25.6.3.4. Function system_pinmux_group_set_output_strength()

Configures the output driver strength mode for a group of pins.

```
void system_pinmux_group_set_output_strength(
        PortGroup *const port,
        const uint32_t mask,
        const enum system_pinmux_pin_strength mode)
```

Configures the output drive strength for a group of pins, to control the amount of current the pad is able to sink/source.

Table 25-9. Parameters

Data direction	Parameter name	Description
[in]	port	Base of the PORT module to configure
[in]	mask	Mask of the port pin(s) to configure
[in]	mode	New output driver strength mode to configure

25.6.3.5. Function system_pinmux_pin_set_output_strength()

Configures the output driver strength mode for a GPIO pin.

```
void system_pinmux_pin_set_output_strength(
        const uint8_t gpio_pin,
        const enum system_pinmux_pin_strength mode)
```

Configures the output drive strength for a GPIO output, to control the amount of current the pad is able to sink/source.

Table 25-10. Parameters

Data direction	Parameter name	Description
[in]	gpio_pin	Index of the GPIO pin to configure
[in]	mode	New output driver strength mode to configure

25.6.4. Enumeration Definitions

25.6.4.1. Enum system_pinmux_pin_dir

Enum for the possible pin direction settings of the port pin configuration structure, to indicate the direction the pin should use.

Table 25-11. Members

Enum value	Description
SYSTEM_PINMUX_PIN_DIR_INPUT	The pin's input buffer should be enabled, so that the pin state can be read
SYSTEM_PINMUX_PIN_DIR_OUTPUT	The pin's output buffer should be enabled, so that the pin state can be set (but not read back)
SYSTEM_PINMUX_PIN_DIR_OUTPUT_WITH_READBACK	The pin's output and input buffers should both be enabled, so that the pin state can be set and read back

25.6.4.2. Enum system_pinmux_pin_pull

Enum for the possible pin pull settings of the port pin configuration structure, to indicate the type of logic level pull the pin should use.

Table 25-12. Members

Enum value	Description
SYSTEM_PINMUX_PIN_PULL_NONE	No logical pull should be applied to the pin
SYSTEM_PINMUX_PIN_PULL_UP	Pin should be pulled up when idle
SYSTEM_PINMUX_PIN_PULL_DOWN	Pin should be pulled down when idle

25.6.4.3. Enum system_pinmux_pin_sample

Enum for the possible input sampling modes for the port pin configuration structure, to indicate the type of sampling a port pin should use.

Table 25-13. Members

Enum value	Description
SYSTEM_PINMUX_PIN_SAMPLE_CONTINUOUS	Pin input buffer should continuously sample the pin state
SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND	Pin input buffer should be enabled when the IN register is read

25.6.4.4. Enum system_pinmux_pin_strength

Enum for the possible output drive strengths for the port pin configuration structure, to indicate the driver strength the pin should use.

Table 25-14. Members

Enum value	Description
SYSTEM_PINMUX_PIN_STRENGTH_NORMAL	Normal output driver strength
SYSTEM_PINMUX_PIN_STRENGTH_HIGH	High current output driver strength

25.7. Extra Information for SYSTEM PINMUX Driver

25.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
GPIO	General Purpose Input/Output
MUX	Multiplexer

25.7.2. Dependencies

This driver has the following dependencies:

- None

25.7.3. Errata

There are no errata related to this driver.

25.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Removed code of open drain, slew limit and drive strength features
Fixed broken sampling mode function implementations, which wrote corrupt configuration values to the device registers
Added missing NULL pointer asserts to the PORT driver functions
Initial Release

25.8. Examples for SYSTEM PINMUX Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM System Pin Multiplexer (SYSTEM PINMUX) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for SYSTEM PINMUX - Basic

25.8.1. Quick Start Guide for SYSTEM PINMUX - Basic

In this use case, the PINMUX module is configured for:

- One pin in input mode, with pull-up enabled, connected to the GPIO module
- Sampling mode of the pin changed to sample on demand

This use case sets up the PINMUX to configure a physical I/O pin set as an input with pull-up and changes the sampling mode of the pin to reduce power by only sampling the physical pin state when the user application attempts to read it.

25.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your application:

```
struct system_pinmux_config config_pinmux;
system_pinmux_get_config_defaults(&config_pinmux);

config_pinmux.mux_position = SYSTEM_PINMUX_GPIO;
config_pinmux.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
config_pinmux.input_pull   = SYSTEM_PINMUX_PIN_PULL_UP;

system_pinmux_pin_set_config(10, &config_pinmux);
```

Workflow

1. Create a PINMUX module pin configuration struct, which can be filled out to adjust the configuration of a single port pin.

   ```
   struct system_pinmux_config config_pinmux;
   ```

2. Initialize the pin configuration struct with the module's default values.

   ```
   system_pinmux_get_config_defaults(&config_pinmux);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to request an input pin with pull-up connected to the GPIO peripheral.

   ```
   config_pinmux.mux_position = SYSTEM_PINMUX_GPIO;
   config_pinmux.direction    = SYSTEM_PINMUX_PIN_DIR_INPUT;
   config_pinmux.input_pull   = SYSTEM_PINMUX_PIN_PULL_UP;
   ```

4. Configure GPIO10 with the initialized pin configuration struct, to enable the input sampler on the pin.

   ```
   system_pinmux_pin_set_config(10, &config_pinmux);
   ```

25.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_pinmux_pin_set_input_sample_mode(10,
        SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND);

while (true) {
    /* Infinite loop */
}
```

Workflow

1. Adjust the configuration of the pin to enable on-demand sampling mode.

```
system_pinmux_pin_set_input_sample_mode(10,
        SYSTEM_PINMUX_PIN_SAMPLE_ONDEMAND);
```

26. SAM Timer/Counter (TC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the timer modules within the device, for waveform generation and timing operations. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- TC (Timer/Counter)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21

The outline of this documentation is as follows:

26.1. Prerequisites

There are no prerequisites for this module.

26.2. Module Overview

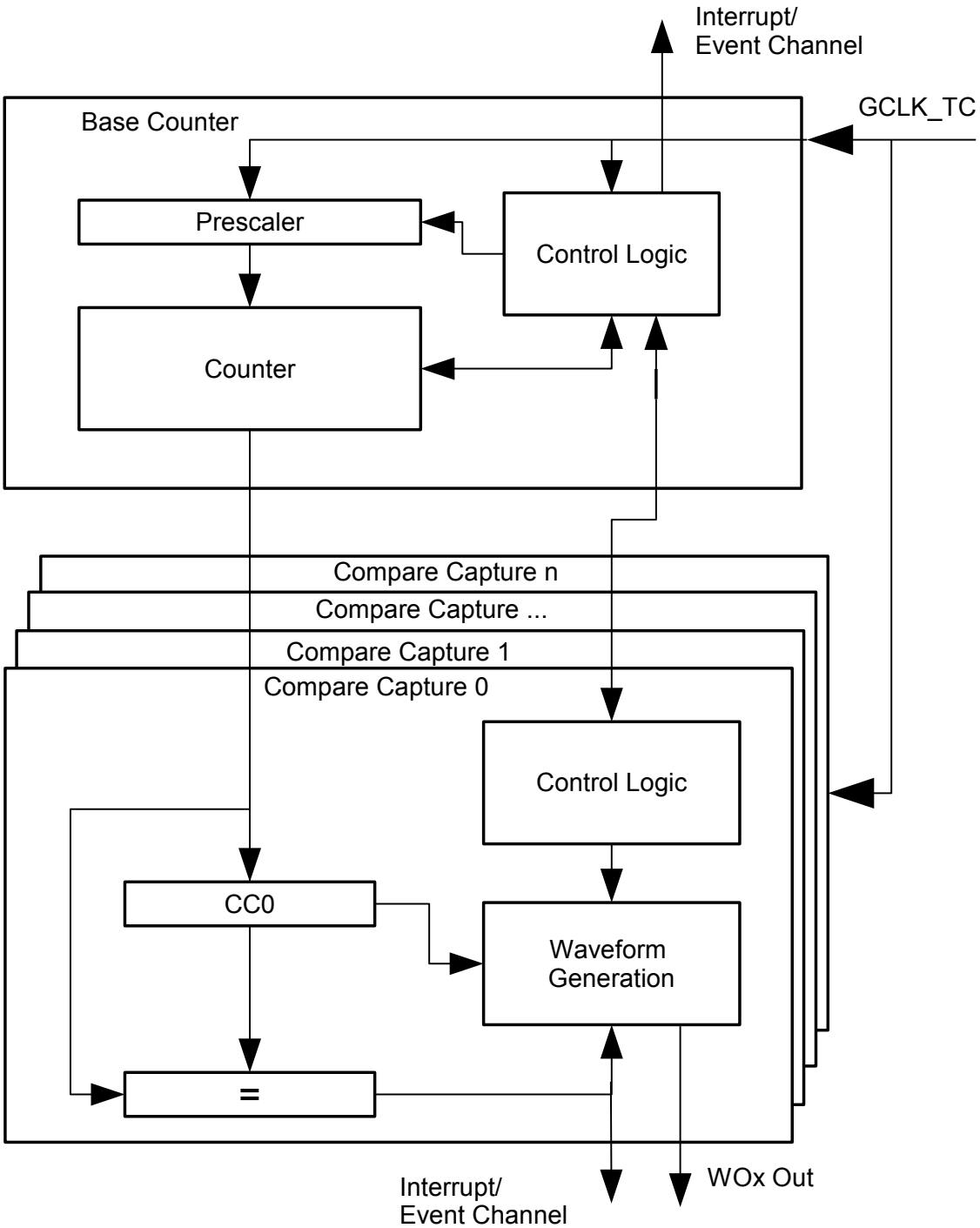
The Timer/Counter (TC) module provides a set of timing and counting related functionality, such as the generation of periodic waveforms, the capturing of a periodic waveform's frequency/duty cycle, and software timekeeping for periodic operations. TC modules can be configured to use an 8-, 16-, or 32-bit counter size.

This TC module for the SAM is capable of the following functions:

- Generation of PWM signals
- Generation of timestamps for events
- General time counting
- Waveform period capture
- Waveform frequency capture

Figure 26-1 shows the overview of the TC module design.

Figure 26-1. Basic Overview of the TC Module



26.2.1. Driver Feature Macro Definition

Driver Feature Macro	Supported devices
FEATURE_TC_DOUBLE_BUFFERED	SAM L21/L22/C20/C21
FEATURE_TC_SYNCBUSY_SCHEME_VERSION_2	SAM L21/L22/C20/C21
FEATURE_TC_STAMP_PW_CAPTURE	SAM L21/L22/C20/C21
FEATURE_TC_READ_SYNC	SAM L21/L22/C20/C21
FEATURE_TC_IO_CAPTURE	SAM L21/L22/C20/C21
FEATURE_TC_GENERATE_DMA_TRIGGER	SAM L21/L22

Note: The specific features are only available in the driver when the selected device supports those features.

26.2.2. Functional Description

Independent of the configured counter size, each TC module can be set up in one of two different modes; capture and compare.

In capture mode, the counter value is stored when a configurable event occurs. This mode can be used to generate timestamps used in event capture, or it can be used for the measurement of a periodic input signal's frequency/duty cycle.

In compare mode, the counter value is compared against one or more of the configured channel compare values. When the counter value coincides with a compare value an action can be taken automatically by the module, such as generating an output event or toggling a pin when used for frequency or Pulse Width Modulation (PWM) signal generation.

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the input event of another. For more information on event routing, refer to the event driver documentation.

26.2.3. Timer/Counter Size

Each timer module can be configured in one of three different counter sizes; 8-, 16-, and 32-bit. The size of the counter determines the maximum value it can count to before an overflow occurs and the count is reset back to zero. Table 26-1 shows the maximum values for each of the possible counter sizes.

Table 26-1. Timer Counter Sizes and Their Maximum Count Values

Counter size	Max. (hexadecimal)	Max. (decimal)
8-bit	0xFF	255
16-bit	0xFFFF	65,535
32-bit	0xFFFFFFFF	4,294,967,295

When using the counter in 16- or 32-bit count mode, Compare Capture register 0 (CC0) is used to store the period value when running in PWM generation match mode.

When using 32-bit counter size, two 16-bit counters are chained together in a cascade formation. Except in SAM D09/D10/D11. Even numbered TC modules (e.g. TC0, TC2) can be configured as 32-bit counters. The odd numbered counters will act as slaves to the even numbered masters, and will not be reconfigurable until the master timer is disabled. The pairing of timer modules for 32-bit mode is shown in Table 26-2.

Table 26-2. TC Master and Slave Module Pairings

Master TC module	Slave TC module
TC0	TC1
TC2	TC3
...	...
TCn-1	TCn

In SAM D09/D10/D11, odd numbered TC modules (e.g. TC1) can be configured as 32-bit counters. The even numbered (e.g. TC2) counters will act as slaves to the odd numbered masters.

26.2.4. Clock Settings

26.2.4.1. Clock Selection

Each TC peripheral is clocked asynchronously to the system clock by a GCLK (Generic Clock) channel. The GCLK channel connects to any of the GCLK generators. The GCLK generators are configured to use one of the available clock sources on the system such as internal oscillator, external crystals, etc. See the Generic Clock driver for more information.

26.2.4.2. Prescaler

Each TC module in the SAM has its own individual clock prescaler, which can be used to divide the input clock frequency used in the counter. This prescaler only scales the clock used to provide clock pulses for the counter to count, and does not affect the digital register interface portion of the module, thus the timer registers will synchronize to the raw GCLK frequency input to the module.

As a result of this, when selecting a GCLK frequency and timer prescaler value the user application should consider both the timer resolution required and the synchronization frequency, to avoid lengthy synchronization times of the module if a very slow GCLK frequency is fed into the TC module. It is preferable to use a higher module GCLK frequency as the input to the timer, and prescale this down as much as possible to obtain a suitable counter frequency in latency-sensitive applications.

26.2.4.3. Reloading

Timer modules also contain a configurable reload action, used when a re-trigger event occurs. Examples of a re-trigger event are the counter reaching the maximum value when counting up, or when an event from the event system tells the counter to re-trigger. The reload action determines if the prescaler should be reset, and when this should happen. The counter will always be reloaded with the value it is set to start counting from. The user can choose between three different reload actions, described in Table 26-3.

Table 26-3. TC Module Reload Actions

Reload action	Description
TC_RELOAD_ACTION_GCLK	Reload TC counter value on next GCLK cycle. Leave prescaler as-is.
TC_RELOAD_ACTION_PRESC	Reloads TC counter value on next prescaler clock. Leave prescaler as-is.
TC_RELOAD_ACTION_RESYNC	Reload TC counter value on next GCLK cycle. Clear prescaler to zero.

The reload action to use will depend on the specific application being implemented. One example is when an external trigger for a reload occurs; if the TC uses the prescaler, the counter in the prescaler should not have a value between zero and the division factor. The TC counter and the counter in the prescaler should both start at zero. When the counter is set to re-trigger when it reaches the maximum value on the other hand, this is not the right option to use. In such a case it would be better if the prescaler is left unaltered when the re-trigger happens, letting the counter reset on the next GCLK cycle.

26.2.5. Compare Match Operations

In compare match operation, Compare/Capture registers are used in comparison with the counter value. When the timer's count value matches the value of a compare channel, a user defined action can be taken.

26.2.5.1. Basic Timer

A Basic Timer is a simple application where compare match operations are used to determine when a specific period has elapsed. In Basic Timer operations, one or more values in the module's Compare/Capture registers are used to specify the time (as a number of prescaled GCLK cycles) when an action should be taken by the microcontroller. This can be an Interrupt Service Routine (ISR), event generator via the event system, or a software flag that is polled via the user application.

26.2.5.2. Waveform Generation

Waveform generation enables the TC module to generate square waves, or if combined with an external passive low-pass filter; analog waveforms.

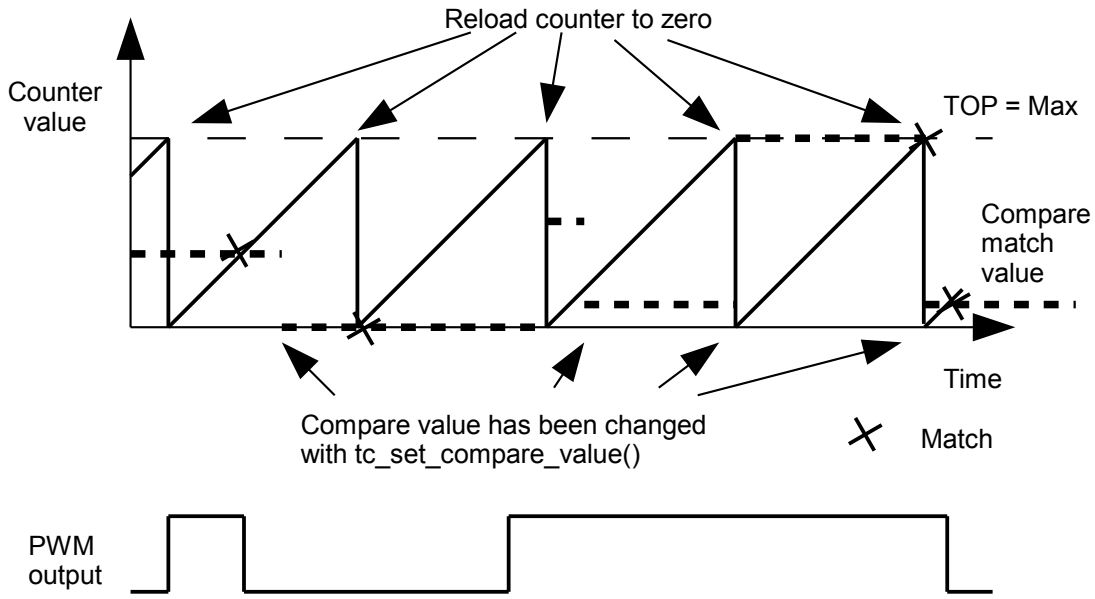
26.2.5.3. Waveform Generation - PWM

Pulse width modulation is a form of waveform generation and a signalling technique that can be useful in many situations. When PWM mode is used, a digital pulse train with a configurable frequency and duty cycle can be generated by the TC module and output to a GPIO pin of the device.

Often PWM is used to communicate a control or information parameter to an external circuit or component. Differing impedances of the source generator and sink receiver circuits are less of an issue when using PWM compared to using an analog voltage value, as noise will not generally affect the signal's integrity to a meaningful extent.

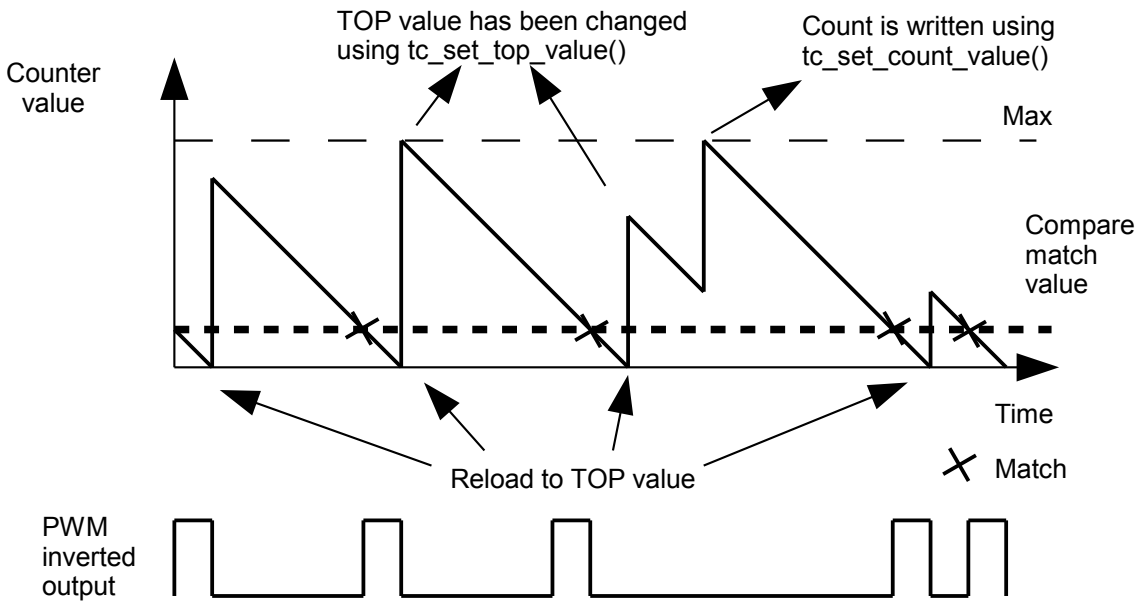
Figure 26-2 illustrates operations and different states of the counter and its output when running the counter in PWM normal mode. As can be seen, the TOP value is unchanged and is set to MAX. The compare match value is changed at several points to illustrate the resulting waveform output changes. The PWM output is set to normal (i.e. non-inverted) output mode.

Figure 26-2. Example of PWM in Normal Mode, and Different Counter Operations



In Figure 26-3, the counter is set to generate PWM in Match mode. The PWM output is inverted via the appropriate configuration option in the TC driver configuration structure. In this example, the counter value is changed once, but the compare match value is kept unchanged. As can be seen, it is possible to change the TOP value when running in PWM match mode.

Figure 26-3. Example of PWM in Match Mode and Different Counter Operations



26.2.5.4. Waveform Generation - Frequency

Frequency Generation mode is in many ways identical to PWM generation. However, in Frequency Generation a toggle only occurs on the output when a match on a capture channels occurs. When the

match is made, the timer value is reset, resulting in a variable frequency square wave with a fixed 50% duty cycle.

26.2.5.5. Capture Operations

In capture operations, any event from the event system or a pin change can trigger a capture of the counter value. This captured counter value can be used as a timestamp for the event, or it can be used in frequency and pulse width capture.

26.2.5.6. Capture Operations - Event

Event capture is a simple use of the capture functionality, designed to create timestamps for specific events. When the TC module's input capture pin is externally toggled, the current timer count value is copied into a buffered register which can then be read out by the user application.

Note that when performing any capture operation, there is a risk that the counter reaches its top value (MAX) when counting up, or the bottom value (zero) when counting down, before the capture event occurs. This can distort the result, making event timestamps to appear shorter than reality; the user application should check for timer overflow when reading a capture result in order to detect this situation and perform an appropriate adjustment.

Before checking for a new capture, TC_STATUS_COUNT_OVERFLOW should be checked. The response to an overflow error is left to the user application, however it may be necessary to clear both the capture overflow flag and the capture flag upon each capture reading.

26.2.5.7. Capture Operations - Pulse Width

Pulse Width Capture mode makes it possible to measure the pulse width and period of PWM signals. This mode uses two capture channels of the counter. This means that the counter module used for Pulse Width Capture can not be used for any other purpose. There are two modes for pulse width capture; Pulse Width Period (PWP) and Period Pulse Width (PPW). In PWP mode, capture channel 0 is used for storing the pulse width and capture channel 1 stores the observed period. While in PPW mode, the roles of the two capture channels are reversed.

As in the above example it is necessary to poll on interrupt flags to see if a new capture has happened and check that a capture overflow error has not occurred.

26.2.6. One-shot Mode

TC modules can be configured into a one-shot mode. When configured in this manner, starting the timer will cause it to count until the next overflow or underflow condition before automatically halting, waiting to be manually triggered by the user application software or an event signal from the event system.

26.2.6.1. Wave Generation Output Inversion

The output of the wave generation can be inverted by hardware if desired, resulting in the logically inverted value being output to the configured device GPIO pin.

26.3. Special Considerations

The number of capture compare registers in each TC module is dependent on the specific SAM device being used, and in some cases the counter size.

The maximum amount of capture compare registers available in any SAM device is two when running in 32-bit mode and four in 8- and 16-bit modes.

26.4. Extra Information

For extra information, see Extra Information for TC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

26.5. Examples

For a list of examples related to this driver, see Examples for TC Driver.

26.6. API Overview

26.6.1. Variable and Type Definitions

26.6.1.1. Waveform Inversion Mode

Type tc_callback_t

```
typedef void(* tc_callback_t )(struct tc_module *const module)
```

Type of the callback functions.

26.6.2. Structure Definitions

26.6.2.1. Struct tc_16bit_config

Table 26-4. Members

Type	Name	Description
uint16_t	compare_capture_channel[]	Value to be used for compare match on each channel
uint16_t	value	Initial timer count value

26.6.2.2. Struct tc_32bit_config

Table 26-5. Members

Type	Name	Description
uint32_t	compare_capture_channel[]	Value to be used for compare match on each channel
uint32_t	value	Initial timer count value

26.6.2.3. Struct tc_8bit_config

Table 26-6. Members

Type	Name	Description
uint8_t	compare_capture_channel[]	Value to be used for compare match on each channel
uint8_t	period	Where to count to or from depending on the direction on the counter
uint8_t	value	Initial timer count value

26.6.2.4. Struct tc_config

Configuration struct for a TC instance. This structure should be initialized by the tc_get_config_defaults function before being modified by the user application.

Table 26-7. Members

Type	Name	Description
union tc_config.@1	@1	Access the different counter size settings through this configuration member.
enum tc_clock_prescaler	clock_prescaler	Specifies the prescaler value for GCLK_TC
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
enum tc_count_direction	count_direction	Specifies the direction for the TC to count
enum tc_counter_size	counter_size	Specifies either 8-, 16-, or 32-bit counter size
bool	double_buffering_enabled	Set to `true` to enable double buffering write. When enabled any write through tc_set_top_value(), tc_set_compare_value() and will direct to the buffer register as buffered value, and the buffered value will be committed to effective register on UPDATE condition, if update is not locked.
bool	enable_capture_on_channel[]	Specifies which channel(s) to enable channel capture operation on
bool	enable_capture_on_IO[]	Specifies which channel(s) to enable I/O capture operation on
bool	oneshot	When `true`, one-shot will stop the TC on next hardware or software re-trigger event or overflow/underflow
struct tc_pwm_channel	pwm_channel[]	Specifies the PWM channel for TC

Type	Name	Description
enum tc_reload_action	reload_action	Specifies the reload or reset time of the counter and prescaler resynchronization on a re-trigger event for the TC
bool	run_in_standby	When `true` the module is enabled during standby
enum tc_wave_generation	wave_generation	Specifies which waveform generation mode to use
uint8_t	waveform_invert_output	Specifies which channel(s) to invert the waveform on. For SAM L21/L22/C20/C21, it's also used to invert I/O input pin.

26.6.2.5. Union tc_config.__unnamed__

Access the different counter size settings through this configuration member.

Table 26-8. Members

Type	Name	Description
struct tc_16bit_config	counter_16_bit	Struct for 16-bit specific timer configuration
struct tc_32bit_config	counter_32_bit	Struct for 32-bit specific timer configuration
struct tc_8bit_config	counter_8_bit	Struct for 8-bit specific timer configuration

26.6.2.6. Struct tc_events

Event flags for the tc_enable_events() and tc_disable_events().

Table 26-9. Members

Type	Name	Description
enum tc_event_action	event_action	Specifies which event to trigger if an event is triggered
bool	generate_event_on_compare_channel[]	Generate an output event on a compare channel match
bool	generate_event_on_overflow	Generate an output event on counter overflow
bool	invert_event_input	Specifies if the input event source is inverted, when used in PWP or PPW event action modes
bool	on_event_perform_action	Perform the configured event action when an incoming event is signalled

26.6.2.7. Struct tc_module

TC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

26.6.2.8. Struct tc_pwm_channel

Table 26-10. Members

Type	Name	Description
bool	enabled	When `true`, PWM output for the given channel is enabled
uint32_t	pin_mux	Specifies Multiplexer (MUX) setting for each output channel pin
uint32_t	pin_out	Specifies pin output for each channel

26.6.3. Macro Definitions

26.6.3.1. Macro FEATURE_TC_DOUBLE_BUFFERED

```
#define FEATURE_TC_DOUBLE_BUFFERED
```

Define port features set according to different device familyTC double buffered.

26.6.3.2. Macro FEATURE_TC_SYNCBUSY_SCHEME_VERSION_2

```
#define FEATURE_TC_SYNCBUSY_SCHEME_VERSION_2
```

SYNCBUSY scheme version 2.

26.6.3.3. Macro FEATURE_TC_STAMP_PW_CAPTURE

```
#define FEATURE_TC_STAMP_PW_CAPTURE
```

TC time stamp capture and pulse width capture.

26.6.3.4. Macro FEATURE_TC_READ_SYNC

```
#define FEATURE_TC_READ_SYNC
```

Read synchronization of COUNT.

26.6.3.5. Macro FEATURE_TC_IO_CAPTURE

```
#define FEATURE_TC_IO_CAPTURE
```

I/O pin edge capture.

26.6.3.6. Macro FEATURE_TC_GENERATE_DMA_TRIGGER

```
#define FEATURE_TC_GENERATE_DMA_TRIGGER
```

Generate Direct Memory Access (DMA) triggers.

26.6.3.7. Module Status Flags

TC status flags, returned by tc_get_status() and cleared by tc_clear_status().

Macro TC_STATUS_CHANNEL_0_MATCH

```
#define TC_STATUS_CHANNEL_0_MATCH
```

Timer channel 0 has matched against its compare value, or has captured a new value.

Macro TC_STATUS_CHANNEL_1_MATCH

```
#define TC_STATUS_CHANNEL_1_MATCH
```

Timer channel 1 has matched against its compare value, or has captured a new value.

Macro TC_STATUS_SYNC_READY

```
#define TC_STATUS_SYNC_READY
```

Timer register synchronization has completed, and the synchronized count value may be read.

Macro TC_STATUS_CAPTURE_OVERFLOW

```
#define TC_STATUS_CAPTURE_OVERFLOW
```

A new value was captured before the previous value was read, resulting in lost data.

Macro TC_STATUS_COUNT_OVERFLOW

```
#define TC_STATUS_COUNT_OVERFLOW
```

The timer count value has overflowed from its maximum value to its minimum when counting upward, or from its minimum value to its maximum when counting downward.

Macro TC_STATUS_CHN0_BUFFER_VALID

```
#define TC_STATUS_CHN0_BUFFER_VALID
```

Channel 0 compare or capture buffer valid.

Macro TC_STATUS_CHN1_BUFFER_VALID

```
#define TC_STATUS_CHN1_BUFFER_VALID
```

Channel 1 compare or capture buffer valid.

Macro TC_STATUS_PERIOD_BUFFER_VALID

```
#define TC_STATUS_PERIOD_BUFFER_VALID
```

Period buffer valid.

26.6.3.8. TC Wave Generation Mode

Macro TC_WAVE_GENERATION_NORMAL_FREQ_MODE

```
#define TC_WAVE_GENERATION_NORMAL_FREQ_MODE
```

TC wave generation mode: normal frequency.

Macro TC_WAVE_GENERATION_MATCH_FREQ_MODE

```
#define TC_WAVE_GENERATION_MATCH_FREQ_MODE
```

TC wave generation mode: match frequency.

Macro TC_WAVE_GENERATION_NORMAL_PWM_MODE

```
#define TC_WAVE_GENERATION_NORMAL_PWM_MODE
```

TC wave generation mode: normal PWM.

Macro TC_WAVE_GENERATION_MATCH_PWM_MODE

```
#define TC_WAVE_GENERATION_MATCH_PWM_MODE
```

TC wave generation mode: match PWM.

26.6.3.9. Waveform Inversion Mode

Macro TC_WAVEFORM_INVERT_CC0_MODE

```
#define TC_WAVEFORM_INVERT_CC0_MODE
```

Waveform inversion CC0 mode.

Macro TC_WAVEFORM_INVERT_CC1_MODE

```
#define TC_WAVEFORM_INVERT_CC1_MODE
```

Waveform inversion CC1 mode.

26.6.4. Function Definitions

26.6.4.1. Driver Initialization and Configuration

Function tc_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool tc_is_syncing(
        const struct tc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 26-11. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Synchronization status of the underlying hardware module(s).

Table 26-12. Return Values

Return value	Description
false	If the module has completed synchronization
true	If the module synchronization is ongoing

Function tc_get_config_defaults()

Initializes config with predefined default values.

```
void tc_get_config_defaults(
        struct tc_config *const config)
```

This function will initialize a given TC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit counter size on the counter
- No prescaler
- Normal frequency wave generation
- GCLK reload action
- Don't run in standby
- Don't run on demand for SAM L21/L22/C20/C21
- No inversion of waveform output
- No capture enabled
- No I/O capture enabled for SAM L21/L22/C20/C21
- No event input enabled
- Count upward
- Don't perform one-shot operations
- No event action
- No channel 0 PWM output
- No channel 1 PWM output
- Counter starts on 0
- Capture compare channel 0 set to 0
- Capture compare channel 1 set to 0
- No PWM pin output enabled
- Pin and MUX configuration not set
- Double buffer disabled (if have this feature)

Table 26-13. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a TC module configuration structure to set

Function tc_init()

Initializes a hardware TC module instance.

```
enum status_code tc_init(
        struct tc_module *const module_inst,
        Tc *const hw,
        const struct tc_config *const config)
```

Enables the clock and initializes the TC module, based on the given configuration values.

Table 26-14. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the TC hardware module
[in]	config	Pointer to the TC configuration options struct

Returns
Status of the initialization procedure.

Table 26-15. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	Hardware module was busy when the initialization procedure was attempted
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied
STATUS_ERR_DENIED	Hardware module was already enabled, or the hardware module is configured in 32-bit slave mode

26.6.4.2. Event Management

Function tc_enable_events()

Enables a TC module event input or output.

```
void tc_enable_events(
        struct tc_module *const module_inst,
        struct tc_events *const events)
```

Enables one or more input or output events to or from the TC module. See tc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 26-16. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to enable

Function tc_disable_events()

Disables a TC module event input or output.

```
void tc_disable_events(
        struct tc_module *const module_inst,
        struct tc_events *const events)
```

Disables one or more input or output events to or from the TC module. See tc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 26-17. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to disable

26.6.4.3. Enable/Disable/Reset

Function tc_reset()

Resets the TC module.

```
enum status_code tc_reset(
        const struct tc_module *const module_inst)
```

Resets the TC module, restoring all hardware module registers to their default values and disabling the module. The TC module will not be accessible while the reset is being performed.

Note: When resetting a 32-bit counter only the master TC module's instance structure should be passed to the function.

Table 26-18. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns
Status of the procedure.

Table 26-19. Return Values

Return value	Description
STATUS_OK	The module was reset successfully
STATUS_ERR_UNSUPPORTED_DEV	A 32-bit slave TC module was passed to the function. Only use reset on master TC

Function tc_enable()

Enable the TC module.

```
void tc_enable(
        const struct tc_module *const module_inst)
```

Enables a TC module that has been previously initialized. The counter will start when the counter is enabled.

Note: When the counter is configured to re-trigger on an event, the counter will not start until the start function is used.

Table 26-20. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tc_disable()

Disables the TC module.

```
void tc_disable(
        const struct tc_module *const module_inst)
```

Disables a TC module and stops the counter.

Table 26-21. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

26.6.4.4. Get/Set Count Value

Function tc_get_count_value()

Get TC module count value.

```
uint32_t tc_get_count_value(
        const struct tc_module *const module_inst)
```

Retrieves the current count value of a TC module. The specified TC module may be started or stopped.

Table 26-22. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Count value of the specified TC module.

Function tc_set_count_value()

Sets TC module count value.

```
enum status_code tc_set_count_value(
        const struct tc_module *const module_inst,
        const uint32_t count)
```

Sets the current timer count value of a initialized TC module. The specified TC module may be started or stopped.

Table 26-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	count	New timer count value to set

Returns

Status of the count update procedure.

Table 26-24. Return Values

Return value	Description
STATUS_OK	The timer count was updated successfully
STATUS_ERR_INVALID_ARG	An invalid timer counter size was specified

26.6.4.5. Start/Stop Counter

Function tc_stop_counter()

Stops the counter.

```
void tc_stop_counter(
        const struct tc_module *const module_inst)
```

This function will stop the counter. When the counter is stopped the value in the count value is set to 0 if the counter was counting up, or maximum if the counter was counting down when stopped.

Table 26-25. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tc_start_counter()

Starts the counter.

```
void tc_start_counter(
        const struct tc_module *const module_inst)
```

Starts or restarts an initialized TC module's counter.

Table 26-26. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

26.6.4.6. Double Buffering

Function tc_update_double_buffer()

Update double buffer.

```
void tc_update_double_buffer(
        const struct tc_module *const module_inst)
```

Update double buffer.

Table 26-27. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

26.6.4.7. Count Read Synchronization

Function tc_sync_read_count()

Read synchronization of COUNT.

```
void tc_sync_read_count(
        const struct tc_module *const module_inst)
```

Read synchronization of COUNT.

Table 26-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

26.6.4.8. Generate TC DMA Triggers Command

Function tc_dma_trigger_command()

TC DMA Trigger.

```
void tc_dma_trigger_command(
        const struct tc_module *const module_inst)
```

TC DMA trigger command.

Table 26-29. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

26.6.4.9. Get Capture Set Compare

Function tc_get_capture_value()

Gets the TC module capture value.

```
uint32_t tc_get_capture_value(
        const struct tc_module *const module_inst,
        const enum tc_compare_capture_channel channel_index)
```

Retrieves the capture value in the indicated TC module capture channel.

Table 26-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the Compare Capture channel to read

Returns
Capture value stored in the specified timer channel.

Function tc_set_compare_value()

Sets a TC module compare value.

```
enum status_code tc_set_compare_value(
        const struct tc_module *const module_inst,
```

```
        const enum tc_compare_capture_channel channel_index,
        const uint32_t compare_value)
```

Writes a compare value to the given TC module compare/capture channel.

Table 26-31. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the compare channel to write to
[in]	compare	New compare value to set

Returns
Status of the compare update procedure.

Table 26-32. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied

26.6.4.10. Set Top Value

Function tc_set_top_value()

Set the timer TOP/period value.

```
enum status_code tc_set_top_value(
        const struct tc_module *const module_inst,
        const uint32_t top_value)
```

For 8-bit counter size this function writes the top value to the period register.

For 16- and 32-bit counter size this function writes the top value to Capture Compare register 0. The value in this register can not be used for any other purpose.

Note: This function is designed to be used in PWM or frequency match modes only, when the counter is set to 16- or 32-bit counter size. In 8-bit counter size it will always be possible to change the top value even in normal mode.

Table 26-33. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New timer TOP value to set

Returns
Status of the TOP set procedure.

Table 26-34. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	The configured TC module counter size in the module instance is invalid

26.6.4.11. Status Management

Function tc_get_status()

Retrieves the current module status.

```
uint32_t tc_get_status(
        struct tc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 26-35. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TC software instance struct

Returns
Bitmask of `TC_STATUS_*` flags.

Table 26-36. Return Values

Return value	Description
TC_STATUS_CHANNEL_0_MATCH	Timer channel 0 compare/capture match
TC_STATUS_CHANNEL_1_MATCH	Timer channel 1 compare/capture match
TC_STATUS_SYNC_READY	Timer read synchronization has completed
TC_STATUS_CAPTURE_OVERFLOW	Timer capture data has overflowed
TC_STATUS_COUNT_OVERFLOW	Timer count value has overflowed
TC_STATUS_CHN0_BUFFER_VALID	Timer count channel 0 compare/capture buffer valid
TC_STATUS_CHN1_BUFFER_VALID	Timer count channel 1 compare/capture buffer valid
TC_STATUS_PERIOD_BUFFER_VALID	Timer count period buffer valid

Function tc_clear_status()

Clears a module status flag.

```
void tc_clear_status(
        struct tc_module *const module_inst,
        const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 26-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TC software instance struct
[in]	status_flags	Bitmask of `TC_STATUS_*` flags to clear

26.6.5. Enumeration Definitions

26.6.5.1. Waveform Inversion Mode

Enum tc_waveform_invert_output

Output waveform inversion mode.

Table 26-38. Members

Enum value	Description
TC_WAVEFORM_INVERT_OUTPUT_NONE	No inversion of the waveform output
TC_WAVEFORM_INVERT_OUTPUT_CHANNEL_0	Invert output from compare channel 0
TC_WAVEFORM_INVERT_OUTPUT_CHANNEL_1	Invert output from compare channel 1

Enum tc_event_action

Event action to perform when the module is triggered by an event.

Table 26-39. Members

Enum value	Description
TC_EVENT_ACTION_OFF	No event action
TC_EVENT_ACTION_RETRIGGER	Re-trigger on event
TC_EVENT_ACTION_INCREMENT_COUNTER	Increment counter on event
TC_EVENT_ACTION_START	Start counter on event
TC_EVENT_ACTION_PPW	Store period in capture register 0, pulse width in capture register 1
TC_EVENT_ACTION_PWP	Store pulse width in capture register 0, period in capture register 1
TC_EVENT_ACTION_STAMP	Time stamp capture
TC_EVENT_ACTION_PW	Pulse width capture

26.6.5.2. Enum tc_callback

Enum for the possible callback types for the TC module.

Table 26-40. Members

Enum value	Description
TC_CALLBACK_OVERFLOW	Callback for TC overflow
TC_CALLBACK_ERROR	Callback for capture overflow error
TC_CALLBACK_CC_CHANNEL0	Callback for capture compare channel 0
TC_CALLBACK_CC_CHANNEL1	Callback for capture compare channel 1

26.6.5.3. Enum tc_clock_prescaler

This enum is used to choose the clock prescaler configuration. The prescaler divides the clock frequency of the TC module to make the counter count slower.

Table 26-41. Members

Enum value	Description
TC_CLOCK_PRESCALER_DIV1	Divide clock by 1
TC_CLOCK_PRESCALER_DIV2	Divide clock by 2
TC_CLOCK_PRESCALER_DIV4	Divide clock by 4
TC_CLOCK_PRESCALER_DIV8	Divide clock by 8
TC_CLOCK_PRESCALER_DIV16	Divide clock by 16
TC_CLOCK_PRESCALER_DIV64	Divide clock by 64
TC_CLOCK_PRESCALER_DIV256	Divide clock by 256
TC_CLOCK_PRESCALER_DIV1024	Divide clock by 1024

26.6.5.4. Enum tc_compare_capture_channel

This enum is used to specify which capture/compare channel to do operations on.

Table 26-42. Members

Enum value	Description
TC_COMPARE_CAPTURE_CHANNEL_0	Index of compare capture channel 0
TC_COMPARE_CAPTURE_CHANNEL_1	Index of compare capture channel 1

26.6.5.5. Enum tc_count_direction

Timer/Counter count direction.

Table 26-43. Members

Enum value	Description
TC_COUNT_DIRECTION_UP	Timer should count upward from zero to MAX
TC_COUNT_DIRECTION_DOWN	Timer should count downward to zero from MAX

26.6.5.6. Enum tc_counter_size

This enum specifies the maximum value it is possible to count to.

Table 26-44. Members

Enum value	Description
TC_COUNTER_SIZE_8BIT	The counter's maximum value is 0xFF, the period register is available to be used as top value
TC_COUNTER_SIZE_16BIT	The counter's maximum value is 0xFFFF. There is no separate period register, to modify top one of the capture compare registers has to be used. This limits the amount of available channels.
TC_COUNTER_SIZE_32BIT	The counter's maximum value is 0xFFFFFFFF. There is no separate period register, to modify top one of the capture compare registers has to be used. This limits the amount of available channels.

26.6.5.7. Enum tc_reload_action

This enum specify how the counter and prescaler should reload.

Table 26-45. Members

Enum value	Description
TC_RELOAD_ACTION_GCLK	The counter is reloaded/reset on the next GCLK and starts counting on the prescaler clock
TC_RELOAD_ACTION_PRESC	The counter is reloaded/reset on the next prescaler clock
TC_RELOAD_ACTION_RESYNC	The counter is reloaded/reset on the next GCLK, and the prescaler is restarted as well

26.6.5.8. Enum tc_wave_generation

This enum is used to select which mode to run the wave generation in.

Table 26-46. Members

Enum value	Description
TC_WAVE_GENERATION_NORMAL_FREQ	Top is maximum, except in 8-bit counter size where it is the PER register
TC_WAVE_GENERATION_MATCH_FREQ	Top is CC0, except in 8-bit counter size where it is the PER register

Enum value	Description
TC_WAVE_GENERATION_NORMAL_PWM	Top is maximum, except in 8-bit counter size where it is the PER register
TC_WAVE_GENERATION_MATCH_PWM	Top is CC0, except in 8-bit counter size where it is the PER register

26.7. Extra Information for TC Driver

26.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
DMA	Direct Memory Access
TC	Timer Counter
PWM	Pulse Width Modulation
PWP	Pulse Width Period
PPW	Period Pulse Width

26.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

26.7.3. Errata

There are no errata related to this driver.

26.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Added support for SAM D21 and do some modifications as below: • Clean up in the configuration structure, the counter size setting specific registers is accessed through the counter_8_bit, counter_16_bit, and counter_32_bit structures • All event related settings moved into the tc_event structure
Added automatic digital clock interface enable for the slave TC module when a timer is initialized in 32-bit mode
Initial release

26.8. Examples for TC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Timer/Counter (TC) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for TC - Basic
- Quick Start Guide for TC - Match Frequency Wave Generation
- Quick Start Guide for TC - Timer
- Quick Start Guide for TC - Callback
- Quick Start Guide for Using DMA with TC

26.8.1. Quick Start Guide for TC - Basic

In this use case, the TC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Capture compare channel 0 set to 0xFFFF/4

26.8.1.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

- SAM D21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM D20 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
```

```
#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

- SAM R21 Xplained Pro.

```
#define PWM_MODULE       EXT1_PWM_MODULE

#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

- SAM D11 Xplained Pro.

```
#define PWM_MODULE       EXT1_PWM_MODULE

#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

- SAM L21 Xplained Pro.

```
#define PWM_MODULE       EXT2_PWM_MODULE

#define PWM_OUT_PIN      EXT2_PWM_0_PIN

#define PWM_OUT_MUX      EXT2_PWM_0_MUX
```

- SAM L22 Xplained Pro.

```
#define PWM_MODULE       EXT1_PWM_MODULE

#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

- SAM DA1 Xplained Pro.

```
#define PWM_MODULE       EXT1_PWM_MODULE

#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

- SAM C21 Xplained Pro.

```
#define PWM_MODULE       EXT1_PWM_MODULE

#define PWM_OUT_PIN      EXT1_PWM_0_PIN

#define PWM_OUT_MUX      EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);
```

```
    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.
   1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   2. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   3. Alter the TC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

      ```
      config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
      config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
      config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF /
      4);
      ```

   4. Alter the TC settings to configure the PWM output on a physical device pin.

      ```
      config_tc.pwm_channel[0].enabled = true;
      config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
      config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
      ```

   5. Configure the TC module with the desired settings.

      ```
      tc_init(&tc_instance, PWM_MODULE, &config_tc);
      ```

   6. Enable the TC module to start the timer and begin PWM signal generation.

      ```
      tc_enable(&tc_instance);
      ```

26.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
     /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TC module.

```
while (true) {
     /* Infinite loop */
}
```

26.8.2. Quick Start Guide for TC - Match Frequency Wave Generation

In this use case, the TC will be used to generate a match frequency. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit resolution on the counter
- No prescaler
- Match frequency wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Capture compare channel 0 set to 4000

When system clock is 8MHz, and the compare channel 0 is 4000, the output frequency will be about 1KHz (8000000/4000/2).

26.8.2.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

- SAM D21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM D20 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_MATCH_FREQ;
    config_tc.counter_16_bit.compare_capture_channel[0] = 4000;

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

```
struct tc_module tc_instance;
```

Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.
    1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

```
struct tc_config config_tc;
```

    2. Initialize the TC configuration struct with the module's default values.

```
tc_get_config_defaults(&config_tc);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the TC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

```
config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
config_tc.wave_generation = TC_WAVE_GENERATION_MATCH_FREQ;
config_tc.counter_16_bit.compare_capture_channel[0] = 4000;
```

4. Alter the TC settings to configure the match frequency output on a physical device pin.

```
config_tc.pwm_channel[0].enabled = true;
config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
```

5. Configure the TC module with the desired settings.

```
tc_init(&tc_instance, PWM_MODULE, &config_tc);
```

6. Enable the TC module to start the timer and begin match frequency wave generation.

```
tc_enable(&tc_instance);
```

26.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the match frequency wave is generated via the TC module.

```
while (true) {
    /* Infinite loop */
}
```

26.8.3. Quick Start Guide for TC - Timer

In this use case, the TC will be used as a timer to generate overflow and compare match callbacks. In the callbacks the on-board LED is toggled.

The TC module will be set up as follows:

- GCLK generator 1 (GCLK 32K) clock source
- 16-bit resolution on the counter
- Prescaler is divided by 64
- GCLK reload action
- Count upward
- Don't run in standby
- No waveform outputs
- No capture enabled
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0

- Counter top set to 2000 (about 4s) and generate overflow callback
- Channel 0 is set to compare and match value 900 and generate callback
- Channel 1 is set to compare and match value 930 and generate callback

26.8.3.1. Quick Start

Prerequisites

For this use case, XOSC32K should be enabled and available through GCLK generator 1 clock source selection. Within Atmel Software Framework (ASF) it can be done through modifying *conf_clocks.h*. See System Clock Management Driver for more details about clock configuration.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D20 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM D21 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM R21 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM D11 Xplained Pro.

```
#define CONF_TC_MODULE TC1
```

- SAM L21 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM L22 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM DA1 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

- SAM C21 Xplained Pro.

```
#define CONF_TC_MODULE TC3
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following callback function code to your user application:

```
void tc_callback_to_toggle_led(
        struct tc_module *const module_inst)
{
    port_pin_toggle_output_level(LED0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);
```

```
    config_tc.counter_size = TC_COUNTER_SIZE_8BIT;
    config_tc.clock_source = GCLK_GENERATOR_1;
    config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV1024;
    config_tc.counter_8_bit.period = 100;
    config_tc.counter_8_bit.compare_capture_channel[0] = 50;
    config_tc.counter_8_bit.compare_capture_channel[1] = 54;

    tc_init(&tc_instance, CONF_TC_MODULE, &config_tc);

    tc_enable(&tc_instance);
}

void configure_tc_callbacks(void)
{
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_OVERFLOW);
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_CC_CHANNEL0);
    tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
            TC_CALLBACK_CC_CHANNEL1);

    tc_enable_callback(&tc_instance, TC_CALLBACK_OVERFLOW);
    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL1);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
configure_tc_callbacks();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.
   1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   2. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   3. Alter the TC settings to configure the GCLK source, prescaler, period, and compare channel values.

      ```
      config_tc.counter_size = TC_COUNTER_SIZE_8BIT;
      config_tc.clock_source = GCLK_GENERATOR_1;
      config_tc.clock_prescaler = TC_CLOCK_PRESCALER_DIV1024;
      config_tc.counter_8_bit.period = 100;
      config_tc.counter_8_bit.compare_capture_channel[0] = 50;
      config_tc.counter_8_bit.compare_capture_channel[1] = 54;
      ```

4. Configure the TC module with the desired settings.

```
tc_init(&tc_instance, CONF_TC_MODULE, &config_tc);
```

5. Enable the TC module to start the timer.

```
tc_enable(&tc_instance);
```

3. Configure the TC callbacks.
    1. Register the Overflow and Compare Channel Match callback functions with the driver.

```
tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
        TC_CALLBACK_OVERFLOW);
tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
        TC_CALLBACK_CC_CHANNEL0);
tc_register_callback(&tc_instance, tc_callback_to_toggle_led,
        TC_CALLBACK_CC_CHANNEL1);
```

    2. Enable the Overflow and Compare Channel Match callbacks so that it will be called by the driver when appropriate.

```
tc_enable_callback(&tc_instance, TC_CALLBACK_OVERFLOW);
tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL1);
```

26.8.3.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the timer is running.

```
while (true) {
}
```

26.8.4. Quick Start Guide for TC - Callback

In this use case, the TC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations

- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0

26.8.4.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

- SAM D21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM D20 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM R21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM D11 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM L21 Xplained Pro.

```
#define PWM_MODULE      EXT2_PWM_MODULE

#define PWM_OUT_PIN     EXT2_PWM_0_PIN

#define PWM_OUT_MUX     EXT2_PWM_0_MUX
```

- SAM L22 Xplained Pro.

```
#define PWM_MODULE      EXT3_PWM_MODULE

#define PWM_OUT_PIN     EXT3_PWM_0_PIN

#define PWM_OUT_MUX     EXT3_PWM_0_MUX
```

- SAM DA1 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

- SAM C21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

Copy-paste the following callback function code to your user application:

```
void tc_callback_to_change_duty_cycle(
        struct tc_module *const module_inst)
{
    static uint16_t i = 0;

    i += 128;
    tc_set_compare_value(module_inst, TC_COMPARE_CAPTURE_CHANNEL_0, i
+ 1);
}
```

Copy-paste the following setup code to your user application:

```
void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = 0xFFFF;

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
}

void configure_tc_callbacks(void)
{
    tc_register_callback(
            &tc_instance,
            tc_callback_to_change_duty_cycle,
            TC_CALLBACK_CC_CHANNEL0);

    tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
configure_tc_callbacks();
```

Workflow

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TC module.
   1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

      ```
      struct tc_config config_tc;
      ```

   2. Initialize the TC configuration struct with the module's default values.

      ```
      tc_get_config_defaults(&config_tc);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

   3. Alter the TC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

      ```
      config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
      config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
      config_tc.counter_16_bit.compare_capture_channel[0] = 0xFFFF;
      ```

   4. Alter the TC settings to configure the PWM output on a physical device pin.

      ```
      config_tc.pwm_channel[0].enabled = true;
      config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
      config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
      ```

   5. Configure the TC module with the desired settings.

      ```
      tc_init(&tc_instance, PWM_MODULE, &config_tc);
      ```

   6. Enable the TC module to start the timer and begin PWM signal generation.

      ```
      tc_enable(&tc_instance);
      ```

3. Configure the TC callbacks.
   1. Register the Compare Channel 0 Match callback functions with the driver.

      ```
      tc_register_callback(
              &tc_instance,
              tc_callback_to_change_duty_cycle,
              TC_CALLBACK_CC_CHANNEL0);
      ```

   2. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

      ```
      tc_enable_callback(&tc_instance, TC_CALLBACK_CC_CHANNEL0);
      ```

26.8.4.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TC module.

```
while (true) {
}
```

26.8.5. Quick Start Guide for Using DMA with TC

The supported kit list:

- SAM D21/R21/D11/L21/L22/DA1/C21 Xplained Pro

In this use case, the TC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. Once the counter value matches the values in the Compare/Capture Value register, an event will be tiggered for a DMA memory to memory transfer. The TC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- 16-bit resolution on the counter
- No prescaler
- Normal PWM wave generation
- GCLK reload action
- Don't run in standby
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Capture compare channel 0 set to 0xFFFF/4

The DMA module is configured for:

- Move data from memory to memory
- Using peripheral trigger of TC6 Match/Compare 0
- Using DMA priority level 0

26.8.5.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
#define PWM_OUT_PIN     EXT1_PWM_0_PIN
#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC6_DMAC_ID_MC_0
```

- SAM R21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
#define PWM_OUT_PIN     EXT1_PWM_0_PIN
#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC3_DMAC_ID_MC_0
```

- SAM D11 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
#define PWM_OUT_PIN     EXT1_PWM_0_PIN
#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC1_DMAC_ID_MC_0
```

- SAM L21 Xplained Pro.

```
#define PWM_MODULE      EXT2_PWM_MODULE
#define PWM_OUT_PIN     EXT2_PWM_0_PIN
#define PWM_OUT_MUX     EXT2_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC0_DMAC_ID_MC_0
```

- SAM L22 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
#define PWM_OUT_PIN     EXT1_PWM_0_PIN
#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC0_DMAC_ID_MC_0
```

- SAM DA1 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE
#define PWM_OUT_PIN     EXT1_PWM_0_PIN
#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC6_DMAC_ID_MC_0
```

- SAM C21 Xplained Pro.

```
#define PWM_MODULE      EXT1_PWM_MODULE

#define PWM_OUT_PIN     EXT1_PWM_0_PIN

#define PWM_OUT_MUX     EXT1_PWM_0_MUX
```

```
#define M2M_DMAC_TRIGGER_ID TC0_DMAC_ID_MC_0
```

Add to the main application source file, outside of any functions:

```
struct tc_module tc_instance;
```

```
struct dma_resource example_resource;
```

```
#define TRANSFER_SIZE    (16)
```

```
#define TRANSFER_COUNTER (32)
```

```
static uint8_t source_memory[TRANSFER_SIZE*TRANSFER_COUNTER];
```

```
static uint8_t destination_memory[TRANSFER_SIZE*TRANSFER_COUNTER];
```

```
static volatile bool transfer_is_done = false;
```

```
COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;
```

Copy-paste the following setup code to your user application:

```
#define TRANSFER_SIZE    (16)

#define TRANSFER_COUNTER (32)

static uint8_t source_memory[TRANSFER_SIZE*TRANSFER_COUNTER];

static uint8_t destination_memory[TRANSFER_SIZE*TRANSFER_COUNTER];

static volatile bool transfer_is_done = false;

COMPILER_ALIGNED(16)
DmacDescriptor example_descriptor SECTION_DMAC_DESCRIPTOR;

void configure_tc(void)
{
    struct tc_config config_tc;
    tc_get_config_defaults(&config_tc);

    config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
    config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
    config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);

    config_tc.pwm_channel[0].enabled = true;
    config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
    config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;

    tc_init(&tc_instance, PWM_MODULE, &config_tc);

    tc_enable(&tc_instance);
```

```
}

void transfer_done(struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}

void configure_dma_resource(struct dma_resource *resource)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);
    config.peripheral_trigger = M2M_DMAC_TRIGGER_ID;

    dma_allocate(resource, &config);
}

void setup_dma_descriptor(DmacDescriptor *descriptor)
{
    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = TRANSFER_SIZE;
    descriptor_config.source_address = (uint32_t)source_memory +
TRANSFER_SIZE;
    descriptor_config.destination_address =
            (uint32_t)destination_memory + TRANSFER_SIZE;

    dma_descriptor_create(descriptor, &descriptor_config);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tc();
```

Workflow

Create variables

1. Create a module software instance structure for the TC module to store the TC driver state while it is in use.

   ```
   struct tc_module tc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a module software instance structure for DMA resource to store the DMA resource state while it is in use.

   ```
   struct dma_resource example_resource;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

Configure TC

1. Create a TC module configuration struct, which can be filled out to adjust the configuration of a physical TC peripheral.

   ```
   struct tc_config config_tc;
   ```

2. Initialize the TC configuration struct with the module's default values.

```
tc_get_config_defaults(&config_tc);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the TC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

```
config_tc.counter_size    = TC_COUNTER_SIZE_16BIT;
config_tc.wave_generation = TC_WAVE_GENERATION_NORMAL_PWM;
config_tc.counter_16_bit.compare_capture_channel[0] = (0xFFFF / 4);
```

4. Alter the TC settings to configure the PWM output on a physical device pin.

```
config_tc.pwm_channel[0].enabled = true;
config_tc.pwm_channel[0].pin_out = PWM_OUT_PIN;
config_tc.pwm_channel[0].pin_mux = PWM_OUT_MUX;
```

5. Configure the TC module with the desired settings.

```
tc_init(&tc_instance, PWM_MODULE, &config_tc);
```

6. Enable the TC module to start the timer and begin PWM signal generation.

```
tc_enable(&tc_instance);
```

Configure DMA

1. Create a DMA resource configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_resource_config config;
```

2. Initialize the DMA resource configuration struct with the module's default values.

```
dma_get_config_defaults(&config);
config.peripheral_trigger = M2M_DMAC_TRIGGER_ID;
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Allocate a DMA resource with the configurations.

```
dma_allocate(resource, &config);
```

4. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

5. Initialize the DMA transfer descriptor configuration struct with the module's default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

6. Set the specific parameters for a DMA transfer with transfer size, source address, and destination address.

```
descriptor_config.block_transfer_count = TRANSFER_SIZE;
descriptor_config.source_address = (uint32_t)source_memory +
TRANSFER_SIZE;
```

```
descriptor_config.destination_address =
        (uint32_t)destination_memory + TRANSFER_SIZE;
```

7. Create the DMA transfer descriptor.

```
dma_descriptor_create(descriptor, &descriptor_config);
```

8. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&example_resource, &example_descriptor);
```

9. Register a callback to indicate transfer status.

```
dma_register_callback(&example_resource, transfer_done,
        DMA_CALLBACK_TRANSFER_DONE);
```

10. The transfer done flag is set in the registered callback function.

```
void transfer_done(struct dma_resource* const resource )
{
    UNUSED(resource);

    transfer_is_done = true;
}
```

Prepare data

1. Setup memory content for validate transfer.

```
for (i = 0; i < TRANSFER_SIZE*TRANSFER_COUNTER; i++) {
    source_memory[i] = i;
}
```

26.8.5.2. Use Case

Code

Copy-paste the following code to your user application:

```
for(i=0;i<TRANSFER_COUNTER;i++) {
    transfer_is_done = false;

    dma_start_transfer_job(&example_resource);

    while (!transfer_is_done) {
        /* Wait for transfer done */
    }

    example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
    example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
}

while(1);
```

Workflow

1. Start the loop for transfer.

```
for(i=0;i<TRANSFER_COUNTER;i++) {
    transfer_is_done = false;

    dma_start_transfer_job(&example_resource);

    while (!transfer_is_done) {
        /* Wait for transfer done */
    }
```

```
    example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
    example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
}
```

2. Set the transfer done flag as false.

```
transfer_is_done = false;
```

3. Start the transfer job.

```
dma_start_transfer_job(&example_resource);
```

4. Wait for transfer done.

```
while (!transfer_is_done) {
    /* Wait for transfer done */
}
```

5. Update the source and destination address for next transfer.

```
example_descriptor.SRCADDR.reg += TRANSFER_SIZE;
example_descriptor.DSTADDR.reg += TRANSFER_SIZE;
```

6. Enter endless loop.

```
while(1);
```

27. SAM Timer Counter for Control Applications (TCC) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the TCC module within the device, for waveform generation and timing operations. It also provides extended options for control applications.

The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripheral is used by this module:

- TCC (Timer/Counter for Control Applications)

The following devices can use this module:

- Atmel | SMART SAM D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

27.1. Prerequisites

There are no prerequisites for this module.

27.2. Module Overview

The Timer/Counter for Control Applications (TCC) module provides a set of timing and counting related functionality, such as the generation of periodic waveforms, the capturing of a periodic waveform's frequency/duty cycle, software timekeeping for periodic operations, waveform extension control, fault detection etc.

The counter size of the TCC modules can be 16- or 24-bit depending on the TCC instance. Refer SAM TCC Feature List and SAM D10/D11 TCC Feature List for details on TCC instances.

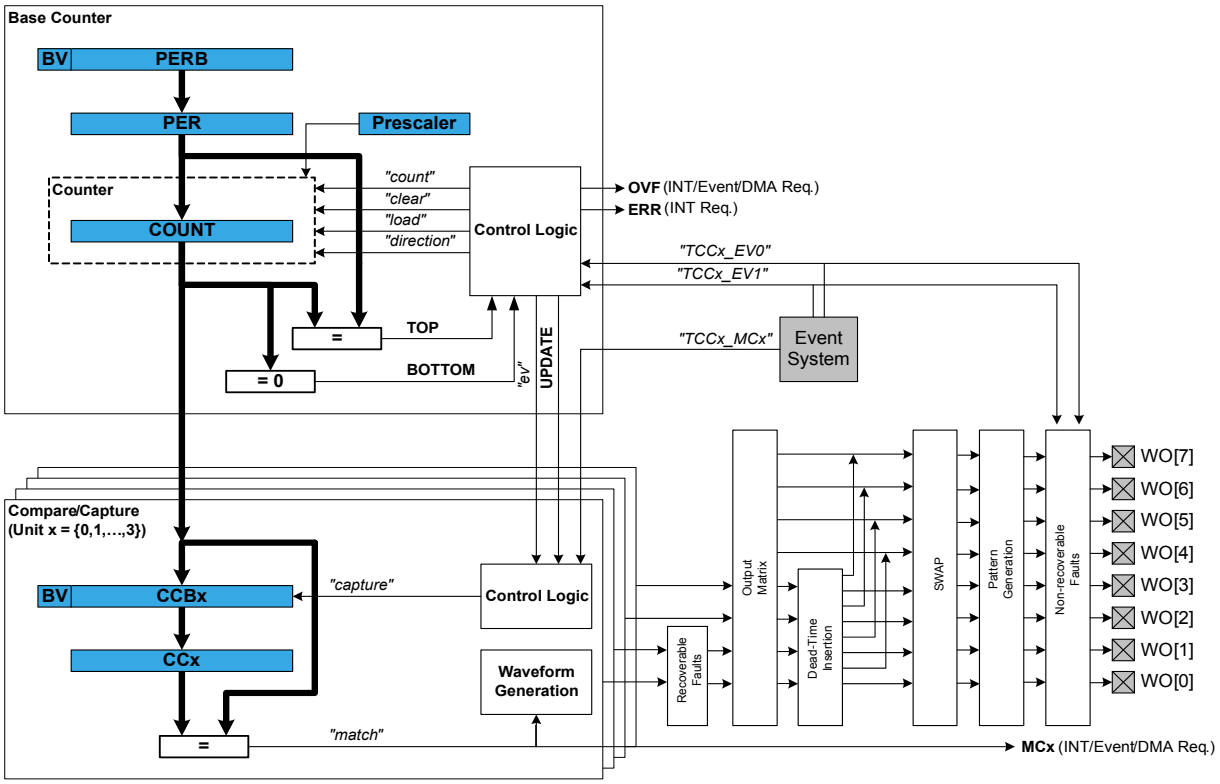
The TCC module for the SAM includes the following functions:

- Generation of PWM signals
- Generation of timestamps for events
- General time counting

- Waveform period capture
- Waveform frequency capture
- Additional control for generated waveform outputs
- Fault protection for waveform generation

Figure 27-1 shows the overview of the TCC Module.

Figure 27-1. Overview of the TCC Module



27.2.1. Functional Description

The TCC module consists of following sections:

- Base Counter
- Compare/Capture channels, with waveform generation
- Waveform extension control and fault detection
- Interface to the event system, DMAC, and the interrupt system

The base counter can be configured to either count a prescaled generic clock or events from the event system.(TCEx, with event action configured to counting). The counter value can be used by compare/capture channels which can be set up either in compare mode or capture mode.

In capture mode, the counter value is stored when a configurable event occurs. This mode can be used to generate timestamps used in event capture, or it can be used for the measurement of a periodic input signal's frequency/duty cycle.

In compare mode, the counter value is compared against one or more of the configured channels' compare values. When the counter value coincides with a compare value an action can be taken automatically by the module, such as generating an output event or toggling a pin when used for frequency or PWM signal generation.

Note: The connection of events between modules requires the use of the SAM Event System Driver (EVENTS) to route output event of one module to the the input event of another. For more information on event routing, refer to the event driver documentation.

In compare mode, when output signal is generated, extended waveform controls are available, to arrange the compare outputs into specific formats. The Output matrix can change the channel output routing. Pattern generation unit can overwrite the output signal line to specific state. The Fault protection feature of the TCC supports recoverable and non-recoverable faults.

27.2.2. Base Timer/Counter

27.2.2.1. Timer/Counter Size

Each TCC has a counter size of either 16- or 24-bits. The size of the counter determines the maximum value it can count to before an overflow occurs. Table 27-1 shows the maximum values for each of the possible counter sizes.

Table 27-1. Timer Counter Sizes and Their Maximum Count Values

Counter size	Max. (hexadecimal)	Max. (decimal)
16-bit	0xFFFF	65,535
24-bit	0xFFFFFF	16,777,215

The period/top value of the counter can be set, to define counting period. This will allow the counter to overflow when the counter value reaches the period/top value.

27.2.2.2. Timer/Counter Clock and Prescaler

TCC is clocked asynchronously to the system clock by a GCLK (Generic Clock) channel. The GCLK channel can be connected to any of the GCLK generators. The GCLK generators are configured to use one of the available clock sources in the system such as internal oscillator, external crystals, etc. See the Generic Clock driver for more information.

Each TCC module in the SAM has its own individual clock prescaler, which can be used to divide the input clock frequency used by the counter. This prescaler only scales the clock used to provide clock pulses for the counter to count, and does not affect the digital register interface portion of the module, thus the timer registers will be synchronized to the raw GCLK frequency input to the module.

As a result of this, when selecting a GCLK frequency and timer prescaler value, the user application should consider both the timer resolution required and the synchronization frequency to avoid lengthy synchronization times of the module if a very slow GCLK frequency is fed into the TCC module. It is preferable to use a higher module GCLK frequency as the input to the timer, and prescale this down as much as possible to obtain a suitable counter frequency in latency-sensitive applications.

27.2.2.3. Timer/Counter Control Inputs (Events)

The TCC can take several actions on the occurrence of an input event. The event actions are listed in Table 27-2.

Table 27-2. TCC Module Event Actions

Event action	Description	Applied event
TCC_EVENT_ACTION_OFF	No action on the event input	All
TCC_EVENT_ACTION_RETRIGGER	Re-trigger Counter on event	All
TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event	All
TCC_EVENT_ACTION_START	Counter start on event	EV0
TCC_EVENT_ACTION_DIR_CONTROL	Counter direction control	EV0
TCC_EVENT_ACTION_DECREMENT	Counter decrement on event	EV0
TCC_EVENT_ACTION_PERIOD_PULSE_WIDTH_CAPTURE	Capture pulse period and pulse width	EV0
TCC_EVENT_ACTION_PULSE_WIDTH_PERIOD_CAPTURE	Capture pulse width and pulse period	EV0
TCC_EVENT_ACTION_STOP	Counter stop on event	EV1
TCC_EVENT_ACTION_COUNT_EVENT	Counter count on event	EV1
TCC_EVENT_ACTION_INCREMENT	Counter increment on event	EV1
TCC_EVENT_ACTION_COUNT_DURING_ACTIVE	Counter count during active state of asynchronous event	EV1

27.2.2.4. Timer/Counter Reloading

The TCC also has a configurable reload action, used when a re-trigger event occurs. Examples of a re-trigger event could be the counter reaching the maximum value when counting up, or when an event from the event system makes the counter to re-trigger. The reload action determines if the prescaler should be reset, and on which clock. The counter will always be reloaded with the value it is set to start counting. The user can choose between three different reload actions, described in Table 27-3.

Table 27-3. TCC Module Reload Actions

Reload action	Description
TCC_RELOAD_ACTION_GCLK	Reload TCC counter value on next GCLK cycle. Leave prescaler as-is.
TCC_RELOAD_ACTION_PRESC	Reloads TCC counter value on next prescaler clock. Leave prescaler as-is.
TCC_RELOAD_ACTION_RESYNC	Reload TCC counter value on next GCLK cycle. Clear prescaler to zero.

The reload action to use will depend on the specific application being implemented. One example is when an external trigger for a reload occurs; if the TCC uses the prescaler, the counter in the prescaler should not have a value between zero and the division factor. The counter in the TCC module and the counter in the prescaler should both start at zero. If the counter is set to re-trigger when it reaches the maximum value, this is not the right option to use. In such a case it would be better if the prescaler is left unaltered when the re-trigger happens, letting the counter reset on the next GCLK cycle.

27.2.2.5. One-shot Mode

The TCC module can be configured in one-shot mode. When configured in this manner, starting the timer will cause it to count until the next overflow or underflow condition before automatically halting, waiting to be manually triggered by the user application software or an event from the event system.

27.2.3. Capture Operations

In capture operations, any event from the event system or a pin change can trigger a capture of the counter value. This captured counter value can be used as timestamps for the events, or it can be used in frequency and pulse width capture.

27.2.3.1. Capture Operations - Event

Event capture is a simple use of the capture functionality, designed to create timestamps for specific events. When the input event appears, the current counter value is copied into the corresponding compare/capture register, which can then be read by the user application.

Note that when performing any capture operation, there is a risk that the counter reaches its top value (MAX) when counting up, or the bottom value (zero) when counting down, before the capture event occurs. This can distort the result, making event timestamps to appear shorter than they really are. In this case, the user application should check for timer overflow when reading a capture result in order to detect this situation and perform an appropriate adjustment.

Before checking for a new capture, TCC_STATUS_COUNT_OVERFLOW should be checked. The response to an overflow error is left to the user application, however, it may be necessary to clear both the overflow flag and the capture flag upon each capture reading.

27.2.3.2. Capture Operations - Pulse Width

Pulse Width Capture mode makes it possible to measure the pulse width and period of PWM signals. This mode uses two capture channels of the counter. There are two modes for pulse width capture; Pulse Width Period (PWP) and Period Pulse Width (PPW). In PWP mode, capture channel 0 is used for storing the pulse width and capture channel 1 stores the observed period. While in PPW mode, the roles of the two capture channels are reversed.

As in the above example it is necessary to poll on interrupt flags to see if a new capture has happened and check that a capture overflow error has not occurred.

Refer to Timer/Counter Control Inputs (Events) to set up the input event to perform pulse width capture.

27.2.4. Compare Match Operation

In compare match operation, Compare/Capture registers are compared with the counter value. When the timer's count value matches the value of a compare channel, a user defined action can be taken.

27.2.4.1. Basic Timer

A Basic Timer is a simple application where compare match operation is used to determine when a specific period has elapsed. In Basic Timer operations, one or more values in the module's Compare/Capture registers are used to specify the time (in terms of the number of prescaled GCLK cycles, or input events) at which an action should be taken by the microcontroller. This can be an Interrupt Service Routine (ISR), event generation via the event system, or a software flag that is polled from the user application.

27.2.4.2. Waveform Generation

Waveform generation enables the TCC module to generate square waves, or, if combined with an external passive low-pass filter, analog waveforms.

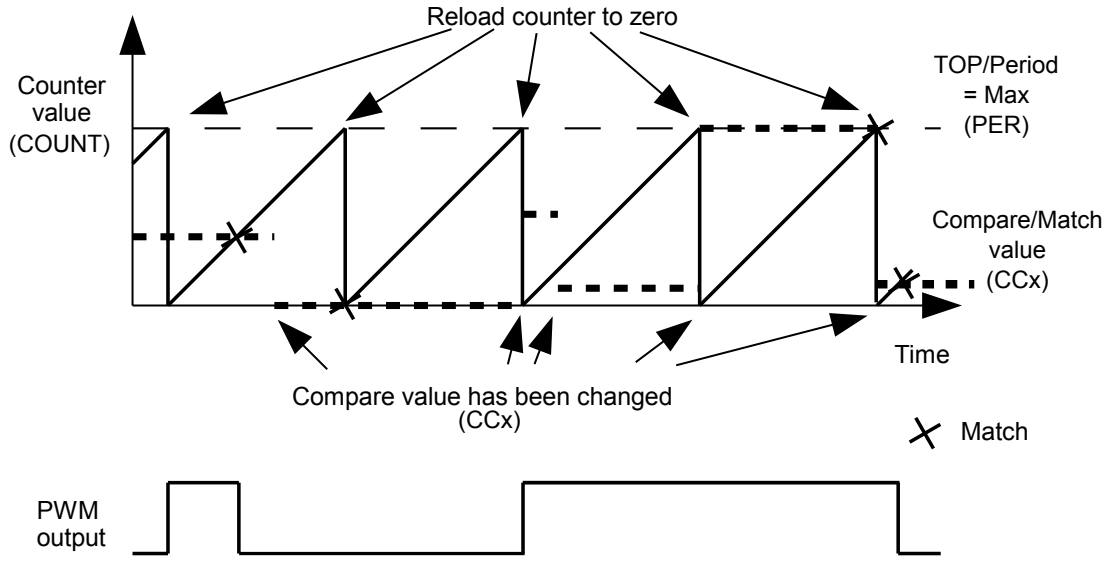
27.2.4.3. Waveform Generation - PWM

Pulse width modulation is a form of waveform generation and a signalling technique that can be useful in many applications. When PWM mode is used, a digital pulse train with a configurable frequency and duty cycle can be generated by the TCC module and output to a GPIO pin of the device.

Often PWM is used to communicate a control or information parameter to an external circuit or component. Differing impedances of the source generator and sink receiver circuits is less of an issue when using PWM compared to using an analog voltage value, as noise will not generally affect the signal's integrity to a meaningful extent.

Figure 27-2 illustrates operations and different states of the counter and its output when using the timer in Normal PWM mode (Single Slope). As can be seen, the TOP/PERIOD value is unchanged and is set to MAX. The compare match value is changed at several points to illustrate the resulting waveform output changes. The PWM output is set to normal (i.e. non-inverted) output mode.

Figure 27-2. Example Of PWM In Single-Slope Mode, and Different Counter Operations



Several PWM modes are supported by the TCC module, refer to datasheet for the details on PWM waveform generation.

27.2.4.4. Waveform Generation - Frequency

Normal Frequency Generation is in many ways identical to PWM generation. However, only in Frequency Generation, a toggle occurs on the output when a match on a compare channels occurs.

When the Match Frequency Generation is used, the timer value is reset on match condition, resulting in a variable frequency square wave with a fixed 50% duty cycle.

27.2.5. Waveform Extended Controls

27.2.5.1. Pattern Generation

Pattern insertion allows the TCC module to change the actual pin output level without modifying the compare/match settings.

Table 27-4. TCC Module Output Pattern Generation

Pattern	Description
TCC_OUTPUT_PATTERN_DISABLE	Pattern disabled, generate output as is
TCC_OUTPUT_PATTERN_0	Generate pattern 0 on output (keep the output LOW)
TCC_OUTPUT_PATTERN_1	Generate pattern 1 on output (keep the output HIGH)

27.2.5.2. Recoverable Faults

The recoverable faults can trigger one or several of following fault actions:

1. *Halt* action: The recoverable faults can halt the TCC timer/counter, so that the final output wave is kept at a defined state. When the fault state is removed it is possible to recover the counter and waveform generation. The halt action is defined as:

Table 27-5. TCC Module Recoverable Fault Halt Actions

Action	Description
TCC_FAULT_HALT_ACTION_DISABLE	Halt action is disabled
TCC_FAULT_HALT_ACTION_HW_HALT	The timer/counter is halted as long as the corresponding fault is present
TCC_FAULT_HALT_ACTION_SW_HALT	The timer/counter is halted until the corresponding fault is removed and fault state cleared by software
TCC_FAULT_HALT_ACTION_NON_RECOVERABLE	Force all the TCC output pins to a pre-defined level, as what Non-Recoverable Fault do

2. *Restart* action: When enabled, the recoverable faults can restart the TCC timer/counter.
3. *Keep* action: When enabled, the recoverable faults can keep the corresponding channel output to zero when the fault condition is present.
4. *Capture* action: When the recoverable fault occurs, the capture action can time stamps the corresponding fault. The following capture mode is supported:

Table 27-6. TCC Module Recoverable Fault Capture Actions

Action	Description
TCC_FAULT_CAPTURE_DISABLE	Capture action is disabled
TCC_FAULT_CAPTURE_EACH	Equivalent to standard capture operation, on each fault occurrence the time stamp is captured
TCC_FAULT_CAPTURE_MINIMUM	Get the minimum time stamped value in all time stamps
TCC_FAULT_CAPTURE_MAXIMUM	Get the maximum time stamped value in all time stamps
TCC_FAULT_CAPTURE_SMALLER	Time stamp the fault input if the value is smaller than last one
TCC_FAULT_CAPTURE_BIGGER	Time stamp the fault input if the value is bigger than last one
TCC_FAULT_CAPTURE_CHANGE	Time stamp the fault input if the time stamps changes its increment direction

In TCC module, only the first two compare channels (CC0 and CC1) can work with recoverable fault inputs. The corresponding event inputs (TCCx MC0 and TCCx MC1) are then used as fault inputs respectively. The faults are called Fault A and Fault B.

The recoverable fault can be filtered or effected by corresponding channel output. On fault condition there are many other settings that can be chosen. Refer to data sheet for more details about the recoverable fault operations.

27.2.5.3. Non-Recoverable Faults

The non-recoverable faults force all the TCC output pins to a pre-defined level (can be forced to 0 or 1). The input control signal of non-recoverable fault is from timer/counter event (TCCx EV0 and TCCx EV1). To enable non-recoverable fault, corresponding TCEx event action must be set to non-recoverable fault action (TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT). Refer to Timer/Counter Control Inputs (Events) to see the available event input action.

27.2.6. Double and Circular Buffering

The pattern, period, and the compare channels registers are double buffered. For these options there are effective registers (PATT, PER, and CCx) and buffer registers (PATTB, PERB, and CCx). When writing to the buffer registers, the values are buffered and will be committed to effective registers on UPDATE condition.

Usually the buffered value is cleared after it is committed, but there is also an option to circular the register buffers. The period (PER) and four lowest compare channels register (CCx, x is 0 ~ 3) support this function. When circular buffer is used, on UPDATE the previous period or compare values are copied back into the corresponding period buffer and compare buffers. This way, the register value and its buffer register value is actually switched on UPDATE condition, and will be switched back on next UPDATE condition.

For input capture, the buffer register (CCBx) and the corresponding capture channel register (CCx) act like a FIFO. When regular register (CCx) is empty or read, any content in the buffer register is passed to regular one.

In TCC module driver, when the double buffering write is enabled, any write through tcc_set_top_value(), tcc_set_compare_value(), and tcc_set_pattern() will be done to the corresponding buffer register. Then the value in the buffer register will be transferred to the regular register on the next UPDATE condition or by a force UPDATE using tcc_force_double_buffer_update().

27.2.7. Sleep Mode

TCC modules can be configured to operate in any sleep mode, with its "run in standby" function enabled. It can wake up the device using interrupts or perform internal actions with the help of the Event System.

27.3. Special Considerations

27.3.1. Driver Feature Macro Definition

Table 27-7 shows some specific features of the TCC Module.

Table 27-7. TCC Module Specific Features

Driver Feature Macro	Supported devices
FEATURE_TCC_GENERATE_DMA_TRIGGER	SAM L21/L22/R30

Note: The specific features are only available in the driver when the selected device supports those features.

27.3.2. Module Features

The features of TCC, such as timer/counter size, number of compare capture channels, and number of outputs, are dependent on the TCC module instance being used.

27.3.2.1. SAM TCC Feature List

For SAM D21/R21/L21/L22/DA1/C21/R30, the TCC features are:

Table 27-8. TCC module features for SAM D21/R21/L21/L22/DA1/C21/R30

TCC#	Match/ Capture channels	Wave outputs	Counter size [bits]	Fault	Dithering	Output matrix	Dead-Time insertion	SWAP	Pattern
0	4	8	24	Y	Y	Y	Y	Y	Y
1	2	4	24	Y	Y				Y
2	2	2	16	Y					

27.3.2.2. SAM D10/D11 TCC Feature List

For SAM D10/D11, the TCC features are:

Table 27-9. TCC Module Features For SAM D10/D11

TCC#	Match/ Capture channels	Wave outputs	Counter size [bits]	Fault	Dithering	Output matrix	Dead-Time insertion	SWAP	Pattern
0	4	8	24	Y	Y	Y	Y	Y	Y

27.3.3. Channels vs. Pinouts

As the TCC module may have more waveform output pins than the number of compare/capture channels, the free pins (with number higher than number of channels) will reuse the waveform generated by channels subsequently. E.g., if the number of channels is four and the number of wave output pins is eight, channel 0 output will be available on out pin 0 and 4, channel 1 output on wave out pin 1 and 5, and so on.

27.4. Extra Information

For extra information, see Extra Information for TCC Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

27.5. Examples

For a list of examples related to this driver, see Examples for TCC Driver.

27.6. API Overview

27.6.1. Variable and Type Definitions

27.6.1.1. Type tcc_callback_t

```
typedef void(* tcc_callback_t )(struct tcc_module *const module)
```

Type definition for the TCC callback function.

27.6.2. Structure Definitions

27.6.2.1. Struct tcc_capture_config

Structure used when configuring TCC channels in capture mode.

Table 27-10. Members

Type	Name	Description
enum tcc_channel_function	channel_function[]	Channel functions selection (capture/match)

27.6.2.2. Struct tcc_config

Configuration struct for a TCC instance. This structure should be initialized by the tcc_get_config_defaults function before being modified by the user application.

Table 27-11. Members

Type	Name	Description
union tcc_config.@1	@1	TCC match/capture configurations
struct tcc_counter_config	counter	Structure for configuring TCC base timer/ counter
bool	double_buffering_enabled	Set to `true` to enable double buffering write. When enabled any write through tcc_set_top_value(), tcc_set_compare_value() and tcc_set_pattern() will direct to the buffer register as buffered value, and the buffered value will be committed to effective register on UPDATE condition, if update is not locked. **Note:** The init values in tcc_config for tcc_init are always filled to effective registers, no matter if double buffering is enabled or not.
struct tcc_pins_config	pins	Structure for configuring TCC output pins
bool	run_in_standby	When `true` the module is enabled during standby
struct tcc_wave_extension_config	wave_ext	Structure for configuring TCC waveform extension

27.6.2.3. Union tcc_config.__unnamed__

TCC match/capture configurations

Table 27-12. Members

Type	Name	Description
struct tcc_capture_config	capture	Helps to configure a TCC channel in capture mode
struct tcc_match_wave_config	compare	For configuring a TCC channel in compare mode
struct tcc_match_wave_config	wave	Serves the same purpose as compare. Used as an alias for compare, when a TCC channel is configured for wave generation

27.6.2.4. Struct tcc_counter_config

Structure for configuring a TCC as a counter.

Table 27-13. Members

Type	Name	Description
enum tcc_clock_prescaler	clock_prescaler	Specifies the prescaler value for GCLK_TCC
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
uint32_t	count	Value to initialize the count register
enum tcc_count_direction	direction	Specifies the direction for the TCC to count
enum tcc_count_overflow_dma_trigger_mode	dma_trigger_mode	Counter overflow trigger a DMA request mode
bool	oneshot	When `true`, the counter will be stopped on the next hardware or software re-trigger event or overflow/underflow
uint32_t	period	Period/top and period/top buffer values for counter
enum tcc_reload_action	reload_action	Specifies the reload or reset time of the counter and prescaler resynchronization on a re-trigger event for the TCC

27.6.2.5. Struct tcc_events

Event flags for the tcc_enable_events() and tcc_disable_events().

Table 27-14. Members

Type	Name	Description
bool	generate_event_on_channel[]	Generate an output event on a channel capture/match. Specify which channels will generate events
bool	generate_event_on_counter_event	Generate an output event on counter boundary. See tcc_event_output_action.
bool	generate_event_on_counter_overflow	Generate an output event on counter overflow/underflow
bool	generate_event_on_counter_retrigger	Generate an output event on counter retrigger
struct tcc_input_event_config	input_config[]	Input events configuration
bool	on_event_perform_channel_action[]	Perform the configured event action when an incoming channel event is signalled
bool	on_input_event_perform_action[]	Perform the configured event action when an incoming event is signalled
struct tcc_output_event_config	output_config	Output event configuration

27.6.2.6. Struct tcc_input_event_config

For configuring an input event.

Table 27-15. Members

Type	Name	Description
enum tcc_event_action	action	Event action on incoming event
bool	invert	Invert incoming event input line
bool	modify_action	Modify event action

27.6.2.7. Struct tcc_match_wave_config

The structure, which helps to configure a TCC channel for compare operation and wave generation.

Table 27-16. Members

Type	Name	Description
enum tcc_channel_function	channel_function[]	Channel functions selection (capture/match)
uint32_t	match[]	Value to be used for compare match on each channel
enum tcc_wave_generation	wave_generation	Specifies which waveform generation mode to use

Type	Name	Description
enum tcc_wave_polarity	wave_polarity[]	Specifies polarity for match output waveform generation
enum tcc_ramp	wave_ramp	Specifies Ramp mode for waveform generation

27.6.2.8. Struct tcc_module

TCC software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved only for module-internal use.

Table 27-17. Members

Type	Name	Description
tcc_callback_t	callback[]	Array of callbacks
bool	double_buffering_enabled	Set to `true` to write to buffered registers
uint32_t	enable_callback_mask	Bit mask for callbacks enabled
Tcc *	hw	Hardware module pointer of the associated Timer/Counter peripheral.
uint32_t	register_callback_mask	Bit mask for callbacks registered

27.6.2.9. Struct tcc_non_recoverable_fault_config

Table 27-18. Members

Type	Name	Description
uint8_t	filter_value	Fault filter value applied on TCEx event input line (0x0 ~ 0xF). Must be 0 when TCEx event is used as synchronous event.
enum tcc_fault_state_output	output	Output

27.6.2.10. Struct tcc_output_event_config

Structure used for configuring an output event.

Table 27-19. Members

Type	Name	Description
enum tcc_event_generation_selection	generation_selection	It decides which part of the counter cycle the counter event output is generated
bool	modify_generation_selection	A switch to allow enable/disable of events, without modifying the event output configuration

27.6.2.11. Struct tcc_pins_config

Structure which is used when taking wave output from TCC.

Table 27-20. Members

Type	Name	Description
bool	enable_wave_out_pin[]	When `true`, PWM output pin for the given channel is enabled
uint32_t	wave_out_pin[]	Specifies pin output for each channel
uint32_t	wave_out_pin_mux[]	Specifies MUX setting for each output channel pin

27.6.2.12. Struct tcc_recoverable_fault_config

Table 27-21. Members

Type	Name	Description
enum tcc_fault_blanking	blanking	Fault Blanking Start Point for recoverable Fault
uint8_t	blanking_cycles	Fault blanking value (0 ~ 255), disable input source for several TCC clocks after the detection of the waveform edge
enum tcc_fault_capture_action	capture_action	Capture action for recoverable Fault
enum tcc_fault_capture_channel	capture_channel	Channel triggered by recoverable Fault
uint8_t	filter_value	Fault filter value applied on MCEx event input line (0x0 ~ 0xF). Must be 0 when MCEx event is used as synchronous event. Apply to both recoverable and non-recoverable fault.
enum tcc_fault_halt_action	halt_action	Halt action for recoverable Fault
bool	keep	Set to `true` to enable keep action (keep until end of TCC cycle)
bool	qualification	Set to `true` to enable input qualification (disable input when output is inactive)
bool	restart	Set to `true` to enable restart action
enum tcc_fault_source	source	Specifies if the event input generates recoverable Fault. The event system channel connected to MCEx event input must be configured as asynchronous.

27.6.2.13. Struct tcc_wave_extension_config

This structure is used to specify the waveform extension features for TCC.

Table 27-22. Members

Type	Name	Description
bool	invert[]	Invert waveform final outputs lines
struct tcc_non_recoverable_fault_config	non_recoverable_fault[]	Configuration for non-recoverable faults
struct tcc_recoverable_fault_config	recoverable_fault[]	Configuration for recoverable faults

27.6.3. Macro Definitions

27.6.3.1. Driver Feature Definition

Define port features set according to different device family.

Macro FEATURE_TCC_GENERATE_DMA_TRIGGER

```
#define FEATURE_TCC_GENERATE_DMA_TRIGGER
```

Generate DMA triggers

27.6.3.2. Module Status Flags

TCC status flags, returned by tcc_get_status() and cleared by tcc_clear_status().

Macro TCC_STATUS_CHANNEL_MATCH_CAPTURE

```
#define TCC_STATUS_CHANNEL_MATCH_CAPTURE(ch)
```

Timer channel `ch` (0 ~ 3) has matched against its compare value, or has captured a new value.

Macro TCC_STATUS_CHANNEL_OUTPUT

```
#define TCC_STATUS_CHANNEL_OUTPUT(ch)
```

Timer channel `ch` (0 ~ 3) match/compare output state.

Macro TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR

```
#define TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(x)
```

A Non-Recoverable Fault `x` (0 ~ 1) has occurred.

Macro TCC_STATUS_RECOVERABLE_FAULT_OCCUR

```
#define TCC_STATUS_RECOVERABLE_FAULT_OCCUR(n)
```

A Recoverable Fault `n` (0 ~ 1 representing A ~ B) has occured.

Macro TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT

```
#define TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT(x)
```

The Non-Recoverable Fault `x` (0 ~ 1) input is present.

Macro TCC_STATUS_RECOVERABLE_FAULT_PRESENT

```
#define TCC_STATUS_RECOVERABLE_FAULT_PRESENT(n)
```

A Recoverable Fault `n` (0 ~ 1 representing A ~ B) is present.

Macro TCC_STATUS_SYNC_READY

```
#define TCC_STATUS_SYNC_READY
```

Timer registers synchronization has completed, and the synchronized count value may be read.

Macro TCC_STATUS_CAPTURE_OVERFLOW

```
#define TCC_STATUS_CAPTURE_OVERFLOW
```

A new value was captured before the previous value was read, resulting in lost data.

Macro TCC_STATUS_COUNTER_EVENT

```
#define TCC_STATUS_COUNTER_EVENT
```

A counter event occurred.

Macro TCC_STATUS_COUNTER_RETRIGGERED

```
#define TCC_STATUS_COUNTER_RETRIGGERED
```

A counter retrigger occurred.

Macro TCC_STATUS_COUNT_OVERFLOW

```
#define TCC_STATUS_COUNT_OVERFLOW
```

The timer count value has overflowed from its maximum value to its minimum when counting upward, or from its minimum value to its maximum when counting downward.

Macro TCC_STATUS_RAMP_CYCLE_INDEX

```
#define TCC_STATUS_RAMP_CYCLE_INDEX
```

Ramp period cycle index. In ramp operation, each two period cycles are marked as cycle A and B, the index 0 represents cycle A and 1 represents cycle B.

Macro TCC_STATUS_STOPPED

```
#define TCC_STATUS_STOPPED
```

The counter has been stopped (due to disable, stop command, or one-shot).

27.6.3.3. Macro _TCC_CHANNEL_ENUM_LIST

```
#define _TCC_CHANNEL_ENUM_LIST(type)
```

Generates table enum list entries for all channels of a given type and channel number on TCC module.

27.6.3.4. Macro _TCC_ENUM

```
#define _TCC_ENUM(n, type)
```

Generates a table enum list entry for a given type and index (e.g. "TCC_CALLBACK_MC_CHANNEL_0,").

27.6.3.5. Macro _TCC_WO_ENUM_LIST

```
#define _TCC_WO_ENUM_LIST(type)
```

Generates table enum list entries for all output of a given type and waveform output number on TCC module.

27.6.3.6. Macro TCC_NUM_CHANNELS

```
#define TCC_NUM_CHANNELS
```

Maximum number of channels supported by the driver (Channel index from 0 to `TCC_NUM_CHANNELS` - 1).

27.6.3.7. Macro TCC_NUM_FAULTS

```
#define TCC_NUM_FAULTS
```

Maximum number of (recoverable) faults supported by the driver.

27.6.3.8. Macro TCC_NUM_WAVE_OUTPUTS

```
#define TCC_NUM_WAVE_OUTPUTS
```

Maximum number of wave outputs lines supported by the driver (Output line index from 0 to `TCC_NUM_WAVE_OUTPUTS` - 1).

27.6.4. Function Definitions

27.6.4.1. Driver Initialization and Configuration

Function tcc_is_syncing()

Determines if the hardware module is currently synchronizing to the bus.

```
bool tcc_is_syncing(
        const struct tcc_module *const module_inst)
```

Checks to see if the underlying hardware peripheral module is currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Table 27-23. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns

Synchronization status of the underlying hardware module.

Table 27-24. Return Values

Return value	Description
false	If the module has completed synchronization
true	If the module synchronization is ongoing

Function tcc_get_config_defaults()

Initializes config with predefined default values.

```
void tcc_get_config_defaults(
        struct tcc_config *const config,
        Tcc *const hw)
```

This function will initialize a given TCC configuration structure to a set of known default values. This function should be called on any new instance of the configuration structures before being modified by the user application.

The default configuration is as follows:

- Don't run in standby
- When setting top, compare, or pattern by API, do double buffering write
- The base timer/counter configurations:
  - GCLK generator 0 clock source
  - No prescaler
  - GCLK reload action
  - Count upward
  - Don't perform one-shot operations
  - Counter starts on 0
  - Period/top value set to maximum
- The match/capture configurations:
  - All Capture compare channel value set to 0
  - No capture enabled (all channels use compare function)
  - Normal frequency wave generation
  - Waveform generation polarity set to 0
  - Don't perform ramp on waveform
- The waveform extension configurations:
  - No recoverable fault is enabled, fault actions are disabled, filter is set to 0
  - No non-recoverable fault state output is enabled and filter is 0
  - No inversion of waveform output
- No channel output enabled
- No PWM pin output enabled
- Pin and MUX configuration not set

Table 27-25. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to a TCC module configuration structure to set
[in]	hw	Pointer to the TCC hardware module

Function tcc_init()

Initializes a hardware TCC module instance.

```
enum status_code tcc_init(
        struct tcc_module *const module_inst,
        Tcc *const hw,
        const struct tcc_config *const config)
```

Enables the clock and initializes the given TCC module, based on the given configuration values.

Table 27-26. Parameters

Data direction	Parameter name	Description
[in, out]	module_inst	Pointer to the software module instance struct
[in]	hw	Pointer to the TCC hardware module
[in]	config	Pointer to the TCC configuration options struct

Returns
Status of the initialization procedure.

Table 27-27. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_BUSY	The hardware module was busy when the initialization procedure was attempted
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied
STATUS_ERR_DENIED	The hardware module was already enabled

27.6.4.2. Event Management

Function tcc_enable_events()

Enables the TCC module event input or output.

```
enum status_code tcc_enable_events(
        struct tcc_module *const module_inst,
        struct tcc_events *const events)
```

Enables one or more input or output events to or from the TCC module. See tcc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 27-28. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to enable or configure

Returns
Status of the events setup procedure.

Table 27-29. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid configuration option or argument was supplied

Function tcc_disable_events()

Disables the event input or output of a TCC instance.

```
void tcc_disable_events(
        struct tcc_module *const module_inst,
        struct tcc_events *const events)
```

Disables one or more input or output events for the given TCC module. See tcc_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 27-30. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	events	Struct containing flags of events to disable

27.6.4.3. Enable/Disable/Reset

Function tcc_enable()

Enable the TCC module.

```
void tcc_enable(
        const struct tcc_module *const module_inst)
```

Enables a TCC module that has been previously initialized. The counter will start when the counter is enabled.

Note: When the counter is configured to re-trigger on an event, the counter will not start until the next incoming event appears. Then it restarts on any following event.

Table 27-31. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_disable()

Disables the TCC module.

```
void tcc_disable(
        const struct tcc_module *const module_inst)
```

Disables a TCC module and stops the counter.

Table 27-32. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_reset()

Resets the TCC module.

```
void tcc_reset(
        const struct tcc_module *const module_inst)
```

Resets the TCC module, restoring all hardware module registers to their default values and disabling the module. The TCC module will not be accessible while the reset is being performed.

Note: When resetting a 32-bit counter only the master TCC module's instance structure should be passed to the function.

Table 27-33. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

27.6.4.4. Set/Toggle Count Direction

Function tcc_set_count_direction()

Sets the TCC module count direction.

```
void tcc_set_count_direction(
        const struct tcc_module *const module_inst,
        enum tcc_count_direction dir)
```

Sets the count direction of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 27-34. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	dir	New timer count direction to set

Function tcc_toggle_count_direction()

Toggles the TCC module count direction.

```
void tcc_toggle_count_direction(
        const struct tcc_module *const module_inst)
```

Toggles the count direction of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 27-35. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

27.6.4.5. Get/Set Count Value

Function tcc_get_count_value()

Get count value of the given TCC module.

```
uint32_t tcc_get_count_value(
        const struct tcc_module *const module_inst)
```

Retrieves the current count value of a TCC module. The specified TCC module can remain running or stopped.

Table 27-36. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Returns
Count value of the specified TCC module.

Function tcc_set_count_value()

Sets count value for the given TCC module.

```
enum status_code tcc_set_count_value(
        const struct tcc_module *const module_inst,
        const uint32_t count)
```

Sets the timer count value of an initialized TCC module. The specified TCC module can remain running or stopped.

Table 27-37. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	count	New timer count value to set

Returns
Status which indicates whether the new value is set.

Table 27-38. Return Values

Return value	Description
STATUS_OK	The timer count was updated successfully
STATUS_ERR_INVALID_ARG	An invalid timer counter size was specified

27.6.4.6. Stop/Restart Counter

Function tcc_stop_counter()

Stops the counter.

```
void tcc_stop_counter(
        const struct tcc_module *const module_inst)
```

This function will stop the counter. When the counter is stopped the value in the count register is set to 0 if the counter was counting up, or maximum or the top value if the counter was counting down.

Table 27-39. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

Function tcc_restart_counter()

Starts the counter from beginning.

```
void tcc_restart_counter(
        const struct tcc_module *const module_inst)
```

Restarts an initialized TCC module's counter.

Table 27-40. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

27.6.4.7. Generate TCC DMA Triggers Command

Function tcc_dma_trigger_command()

TCC DMA Trigger.

```
void tcc_dma_trigger_command(
        const struct tcc_module *const module_inst)
```

TCC DMA trigger command.

Table 27-41. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct

27.6.4.8. Get/Set Compare/Capture Register

Function tcc_get_capture_value()

Gets the TCC module capture value.

```
uint32_t tcc_get_capture_value(
        const struct tcc_module *const module_inst,
        const enum tcc_match_capture_channel channel_index)
```

Retrieves the capture value in the indicated TCC module capture channel.

Table 27-42. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the Compare Capture channel to read

Returns
Capture value stored in the specified timer channel.

Function tcc_set_compare_value()

Sets a TCC module compare value.

```
enum status_code tcc_set_compare_value(
        const struct tcc_module *const module_inst,
        const enum tcc_match_capture_channel channel_index,
        const uint32_t compare)
```

Writes a compare value to the given TCC module compare/capture channel.

If double buffering is enabled it always write to the buffer register. The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

Table 27-43. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the compare channel to write to
[in]	compare	New compare value to set

Returns
Status of the compare update procedure.

Table 27-44. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or compare value exceed resolution

27.6.4.9. Set Top Value

Function tcc_set_top_value()

Set the timer TOP/PERIOD value.

```
enum status_code tcc_set_top_value(
        const struct tcc_module *const module_inst,
        const uint32_t top_value)
```

This function writes the given value to the PER/PERB register.

If double buffering is enabled it always write to the buffer register (PERB). The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

When using MFRQ, the top value is defined by the CC0 register value and the PER value is ignored, so tcc_set_compare_value (module,channel_0,value) must be used instead of this function to change the actual top value in that case. For all other waveforms operation the top value is defined by PER register value.

Table 27-45. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New value to be loaded into the PER/PERB register

Returns
Status of the TOP set procedure.

Table 27-46. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or top/period value exceed resolution

27.6.4.10. Set Output Pattern

Function tcc_set_pattern()

Sets the TCC module waveform output pattern.

```
enum status_code tcc_set_pattern(
        const struct tcc_module *const module_inst,
        const uint32_t line_index,
        const enum tcc_output_pattern pattern)
```

Force waveform output line to generate specific pattern (0, 1, or as is).

If double buffering is enabled it always write to the buffer register. The value will then be updated immediately by calling tcc_force_double_buffer_update(), or be updated when the lock update bit is cleared and the UPDATE condition happen.

Table 27-47. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	line_index	Output line index
[in]	pattern	Output pattern to use (tcc_output_pattern)

Returns
Status of the pattern set procedure.

Table 27-48. Return Values

Return value	Description
STATUS_OK	The PATT register is updated successfully
STATUS_ERR_INVALID_ARG	An invalid line index was supplied

27.6.4.11. Set Ramp Index

Function tcc_set_ramp_index()

Sets the TCC module ramp index on next cycle.

```
void tcc_set_ramp_index(
        const struct tcc_module *const module_inst,
        const enum tcc_ramp_index ramp_index)
```

In RAMP2 and RAMP2A operation, we can force either cycle A or cycle B at the output, on the next clock cycle. When ramp index command is disabled, cycle A and cycle B will appear at the output, on alternate clock cycles. See tcc_ramp.

Table 27-49. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	ramp_index	Ramp index (tcc_ramp_index) of the next cycle

27.6.4.12. Status Management

Function tcc_is_running()

Checks if the timer/counter is running.

```
bool tcc_is_running(
        struct tcc_module *const module_inst)
```

Table 27-50. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Returns
Status which indicates whether the module is running.

Table 27-51. Return Values

Return value	Description
true	The timer/counter is running
false	The timer/counter is stopped

Function tcc_get_status()

Retrieves the current module status.

```
uint32_t tcc_get_status(
        struct tcc_module *const module_inst)
```

Retrieves the status of the module, giving overall state information.

Table 27-52. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Returns
Bitmask of `TCC_STATUS_*` flags.

Table 27-53. Return Values

Return value	Description
TCC_STATUS_CHANNEL_MATCH_CAPTURE(n)	Channel n match/capture has occured
TCC_STATUS_CHANNEL_OUTPUT(n)	Channel n match/capture output state
TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(x)	Non-recoverable fault x has occured
TCC_STATUS_RECOVERABLE_FAULT_OCCUR(n)	Recoverable fault n has occured
TCC_STATUS_NON_RECOVERABLE_FAULT_PRESENT(x)	Non-recoverable fault x input present
TCC_STATUS_RECOVERABLE_FAULT_PRESENT(n)	Recoverable fault n input present
TCC_STATUS_SYNC_READY	None of register is syncing
TCC_STATUS_CAPTURE_OVERFLOW	Timer capture data has overflowed
TCC_STATUS_COUNTER_EVENT	Timer counter event has occurred
TCC_STATUS_COUNT_OVERFLOW	Timer count value has overflowed
TCC_STATUS_COUNTER_RETRIGGERED	Timer counter has been retriggered
TCC_STATUS_STOP	Timer counter has been stopped
TCC_STATUS_RAMP_CYCLE_INDEX	Wave ramp index for cycle

Function tcc_clear_status()

Clears a module status flag.

```
void tcc_clear_status(
        struct tcc_module *const module_inst,
        const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 27-54. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct
[in]	status_flags	Bitmask of `TCC_STATUS_*` flags to clear

27.6.4.13. Double Buffering Management

Function tcc_enable_double_buffering()

Enable TCC double buffering write.

```
void tcc_enable_double_buffering(
        struct tcc_module *const module_inst)
```

When double buffering write is enabled, the following function will write values to buffered registers instead of effective ones (buffered):

- PERB: through tcc_set_top_value()
- CCBx(x is 0~3): through tcc_set_compare_value()
- PATTB: through tcc_set_pattern()

Then, on UPDATE condition the buffered registers are committed to regular ones to take effect.

Table 27-55. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_disable_double_buffering()

Disable TCC double buffering Write.

```
void tcc_disable_double_buffering(
        struct tcc_module *const module_inst)
```

When double buffering write is disabled, following function will write values to effective registers (not buffered):

- PER: through tcc_set_top_value()
- CCx(x is 0~3): through tcc_set_compare_value()
- PATT: through tcc_set_pattern()

Note: This function does not lock double buffer update, which means on next UPDATE condition the last written buffered values will be committed to take effect. Invoke tcc_lock_double_buffer_update() before this function to disable double buffering update, if this change is not expected.

Table 27-56. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_lock_double_buffer_update()

Lock the TCC double buffered registers updates.

```
void tcc_lock_double_buffer_update(
        struct tcc_module *const module_inst)
```

Locks the double buffered registers so they will not be updated through their buffered values on UPDATE conditions.

Table 27-57. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_unlock_double_buffer_update()

Unlock the TCC double buffered registers updates.

```
void tcc_unlock_double_buffer_update(
        struct tcc_module *const module_inst)
```

Unlock the double buffered registers so they will be updated through their buffered values on UPDATE conditions.

Table 27-58. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_force_double_buffer_update()

Force the TCC double buffered registers to update once.

```
void tcc_force_double_buffer_update(
        struct tcc_module *const module_inst)
```

Table 27-59. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_enable_circular_buffer_top()

Enable Circular option for double buffered Top/Period Values.

```
void tcc_enable_circular_buffer_top(
        struct tcc_module *const module_inst)
```

Enable circular option for the double buffered top/period values. On each UPDATE condition, the contents of PERB and PER are switched, meaning that the contents of PERB are transferred to PER and the contents of PER are transferred to PERB.

Table 27-60. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_disable_circular_buffer_top()

Disable Circular option for double buffered Top/Period Values.

```
void tcc_disable_circular_buffer_top(
        struct tcc_module *const module_inst)
```

Stop circularing the double buffered top/period values.

Table 27-61. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct

Function tcc_set_double_buffer_top_values()

Set the timer TOP/PERIOD value and buffer value.

```
enum status_code tcc_set_double_buffer_top_values(
        const struct tcc_module *const module_inst,
        const uint32_t top_value,
        const uint32_t top_buffer_value)
```

This function writes the given value to the PER and PERB register. Usually as preparation for double buffer or circulared double buffer (circular buffer).

When using MFRQ, the top values are defined by the CC0 and CCB0, the PER and PERB values are ignored, so tcc_set_double_buffer_compare_values (module,channel_0,value,buffer) must be used instead of this function to change the actual top values in that case. For all other waveforms operation the top values are defined by PER and PERB registers values.

Table 27-62. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	top_value	New value to be loaded into the PER register
[in]	top_buffer_value	New value to be loaded into the PERB register

Returns

Status of the TOP set procedure.

Table 27-63. Return Values

Return value	Description
STATUS_OK	The timer TOP value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or top/period value exceed resolution

Function tcc_enable_circular_buffer_compare()

Enable circular option for double buffered compare values.

```
enum status_code tcc_enable_circular_buffer_compare(
        struct tcc_module *const module_inst,
        enum tcc_match_capture_channel channel_index)
```

Enable circular option for the double buffered channel compare values. On each UPDATE condition, the contents of CCBx and CCx are switched, meaning that the contents of CCBx are transferred to CCx and the contents of CCx are transferred to CCBx.

Table 27-64. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct
[in]	channel_index	Index of the compare channel to set up to

Table 27-65. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid channel index is supplied

Function tcc_disable_circular_buffer_compare()

Disable circular option for double buffered compare values.

```
enum status_code tcc_disable_circular_buffer_compare(
        struct tcc_module *const module_inst,
        enum tcc_match_capture_channel channel_index)
```

Stop circularing the double buffered compare values.

Table 27-66. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TCC software instance struct
[in]	channel_index	Index of the compare channel to set up to

Table 27-67. Return Values

Return value	Description
STATUS_OK	The module was initialized successfully
STATUS_INVALID_ARG	An invalid channel index is supplied

Function tcc_set_double_buffer_compare_values()

Sets a TCC module compare value and buffer value.

```
enum status_code tcc_set_double_buffer_compare_values(
        struct tcc_module *const module_inst,
        enum tcc_match_capture_channel channel_index,
        const uint32_t compare,
        const uint32_t compare_buffer)
```

Writes compare value and buffer to the given TCC module compare/capture channel. Usually as preparation for double buffer or circulared double buffer (circular buffer).

Table 27-68. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the software module instance struct
[in]	channel_index	Index of the compare channel to write to
[in]	compare	New compare value to set
[in]	compare_buffer	New compare buffer value to set

Returns
Status of the compare update procedure.

Table 27-69. Return Values

Return value	Description
STATUS_OK	The compare value was updated successfully
STATUS_ERR_INVALID_ARG	An invalid channel index was supplied or compare value exceed resolution

27.6.5. Enumeration Definitions

27.6.5.1. Enum tcc_callback

Enum for the possible callback types for the TCC module.

Table 27-70. Members

Enum value	Description
TCC_CALLBACK_OVERFLOW	Callback for TCC overflow
TCC_CALLBACK_RETRIGGER	Callback for TCC Retrigger
TCC_CALLBACK_COUNTER_EVENT	Callback for TCC counter event
TCC_CALLBACK_ERROR	Callback for capture overflow error
TCC_CALLBACK_FAULTA	Callback for Recoverable Fault A
TCC_CALLBACK_FAULTB	Callback for Recoverable Fault B
TCC_CALLBACK_FAULT0	Callback for Non-Recoverable Fault 0
TCC_CALLBACK_FAULT1	Callback for Non-Recoverable Fault 1
TCC_CALLBACK_CHANNEL_n	Channel callback type table for TCC Each TCC module may contain several callback types for channels; each channel will have its own callback type in the table, with the channel index number substituted for "n" in the channel callback type (e.g. `TCC_MATCH_CAPTURE_CHANNEL_0`).

27.6.5.2. Enum tcc_channel_function

To set a timer channel either in compare or in capture mode.

Table 27-71. Members

Enum value	Description
TCC_CHANNEL_FUNCTION_COMPARE	TCC channel performs compare operation
TCC_CHANNEL_FUNCTION_CAPTURE	TCC channel performs capture operation

27.6.5.3. Enum tcc_clock_prescaler

This enum is used to choose the clock prescaler configuration. The prescaler divides the clock frequency of the TCC module to operate TCC at a slower clock rate.

Table 27-72. Members

Enum value	Description
TCC_CLOCK_PRESCALER_DIV1	Divide clock by 1
TCC_CLOCK_PRESCALER_DIV2	Divide clock by 2
TCC_CLOCK_PRESCALER_DIV4	Divide clock by 4
TCC_CLOCK_PRESCALER_DIV8	Divide clock by 8
TCC_CLOCK_PRESCALER_DIV16	Divide clock by 16
TCC_CLOCK_PRESCALER_DIV64	Divide clock by 64
TCC_CLOCK_PRESCALER_DIV256	Divide clock by 256
TCC_CLOCK_PRESCALER_DIV1024	Divide clock by 1024

27.6.5.4. Enum tcc_count_direction

Used when selecting the Timer/Counter count direction.

Table 27-73. Members

Enum value	Description
TCC_COUNT_DIRECTION_UP	Timer should count upward
TCC_COUNT_DIRECTION_DOWN	Timer should count downward

27.6.5.5. Enum tcc_count_overflow_dma_trigger_mode

Used when selecting the Timer/Counter overflow DMA request mode.

Table 27-74. Members

Enum value	Description
TCC_COUNT_OVERFLOW_DMA_TRIGGER_MODE_CONTINUE	TCC generates a DMA request on each cycle when an update condition is detected
TCC_COUNT_OVERFLOW_DMA_TRIGGER_MODE_ONE_SHOT	When an update condition is detected, the TCC generates a DMA trigger on the cycle following the DMA One-Shot Command written to the Control B register

27.6.5.6. Enum tcc_event0_action

Event action to perform when the module is triggered by event0.

Table 27-75. Members

Enum value	Description
TCC_EVENT0_ACTION_OFF	No event action
TCC_EVENT0_ACTION_RETRIGGER	Re-trigger Counter on event
TCC_EVENT0_ACTION_COUNT_EVENT	Count events (increment or decrement, depending on count direction)
TCC_EVENT0_ACTION_START	Start counter on event
TCC_EVENT0_ACTION_INCREMENT	Increment counter on event
TCC_EVENT0_ACTION_COUNT_DURING_ACTIVE	Count during active state of asynchronous event
TCC_EVENT0_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event

27.6.5.7. Enum tcc_event1_action

Event action to perform when the module is triggered by event1.

Table 27-76. Members

Enum value	Description
TCC_EVENT1_ACTION_OFF	No event action
TCC_EVENT1_ACTION_RETRIGGER	Re-trigger Counter on event
TCC_EVENT1_ACTION_DIR_CONTROL	The event source must be an asynchronous event, and the input value will override the direction settings. If TCEINVx is 0 and input event is LOW: counter will count up. If TCEINVx is 0 and input event is HIGH: counter will count down.

Enum value	Description
TCC_EVENT1_ACTION_STOP	Stop counter on event
TCC_EVENT1_ACTION_DECREMENT	Decrement on event
TCC_EVENT1_ACTION_PERIOD_PULSE_WIDTH_CAPTURE	Store period in capture register 0, pulse width in capture register 1
TCC_EVENT1_ACTION_PULSE_WIDTH_PERIOD_CAPTURE	Store pulse width in capture register 0, period in capture register 1
TCC_EVENT1_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event

27.6.5.8. Enum tcc_event_action

Event action to perform when the module is triggered by events.

Table 27-77. Members

Enum value	Description
TCC_EVENT_ACTION_OFF	No event action
TCC_EVENT_ACTION_STOP	Stop counting, the counter will maintain its current value, waveforms are set to a defined Non-Recoverable State output (tcc_non_recoverable_state_output).
TCC_EVENT_ACTION_RETRIGGER	Re-trigger counter on event, may generate an event if the re-trigger event output is enabled. **Note:** When re-trigger event action is enabled, enabling the counter will not start until the next incoming event appears.
TCC_EVENT_ACTION_START	Start counter when previously stopped. Start counting on the event rising edge. Further events will not restart the counter; the counter keeps on counting using prescaled GCLK_TCCx, until it reaches TOP or Zero depending on the direction.
TCC_EVENT_ACTION_COUNT_EVENT	Count events; i.e. Increment or decrement depending on count direction.

Enum value	Description
TCC_EVENT_ACTION_DIR_CONTROL	The event source must be an asynchronous event, input value will overrides the direction settings (input low: counting up, input high: counting down).
TCC_EVENT_ACTION_INCREMENT	Increment the counter on event, irrespective of count direction
TCC_EVENT_ACTION_DECREMENT	Decrement the counter on event, irrespective of count direction
TCC_EVENT_ACTION_COUNT_DURING_ACTIVE	Count during active state of asynchronous event. In this case, depending on the count direction, the count will be incremented or decremented on each prescaled GCLK_TCCx, as long as the input event remains active.
TCC_EVENT_ACTION_PERIOD_PULSE_WIDTH_CAPTURE	Store period in capture register 0, pulse width in capture register 1
TCC_EVENT_ACTION_PULSE_WIDTH_PERIOD_CAPTURE	Store pulse width in capture register 0, period in capture register 1
TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT	Generate Non-Recoverable Fault on event

27.6.5.9. Enum tcc_event_generation_selection

This enum is used to define the point at which the counter event is generated.

Table 27-78. Members

Enum value	Description
TCC_EVENT_GENERATION_SELECTION_START	Counter Event is generated when a new counter cycle starts
TCC_EVENT_GENERATION_SELECTION_END	Counter Event is generated when a counter cycle ends
TCC_EVENT_GENERATION_SELECTION_BETWEEN	Counter Event is generated when a counter cycle ends, except for the first and last cycles
TCC_EVENT_GENERATION_SELECTION_BOUNDARY	Counter Event is generated when a new counter cycle starts or ends

27.6.5.10. Enum tcc_fault_blanking

Table 27-79. Members

Enum value	Description
TCC_FAULT_BLANKING_DISABLE	No blanking
TCC_FAULT_BLANKING_RISING_EDGE	Blanking applied from rising edge of the output waveform
TCC_FAULT_BLANKING_FALLING_EDGE	Blanking applied from falling edge of the output waveform
TCC_FAULT_BLANKING_BOTH_EDGE	Blanking applied from each toggle of the output waveform

27.6.5.11. Enum tcc_fault_capture_action

Table 27-80. Members

Enum value	Description
TCC_FAULT_CAPTURE_DISABLE	Capture disabled
TCC_FAULT_CAPTURE_EACH	Capture on Fault, each value is captured
TCC_FAULT_CAPTURE_MINIMUM	Capture the minimum detection, but notify on smaller ones
TCC_FAULT_CAPTURE_MAXIMUM	Capture the maximum detection, but notify on bigger ones
TCC_FAULT_CAPTURE_SMALLER	Capture if the value is smaller than last, notify event or interrupt if previous stamp is confirmed to be "local minimum" (not bigger than current stamp).
TCC_FAULT_CAPTURE_BIGGER	Capture if the value is bigger than last, notify event or interrupt if previous stamp is confirmed to be "local maximum" (not smaller than current stamp).
TCC_FAULT_CAPTURE_CHANGE	Capture if the time stamps changes its increment direction

27.6.5.12. Enum tcc_fault_capture_channel

Table 27-81. Members

Enum value	Description
TCC_FAULT_CAPTURE_CHANNEL_0	Recoverable fault triggers channel 0 capture operation
TCC_FAULT_CAPTURE_CHANNEL_1	Recoverable fault triggers channel 1 capture operation
TCC_FAULT_CAPTURE_CHANNEL_2	Recoverable fault triggers channel 2 capture operation
TCC_FAULT_CAPTURE_CHANNEL_3	Recoverable fault triggers channel 3 capture operation

27.6.5.13. Enum tcc_fault_halt_action

Table 27-82. Members

Enum value	Description
TCC_FAULT_HALT_ACTION_DISABLE	Halt action disabled.
TCC_FAULT_HALT_ACTION_HW_HALT	Hardware halt action, counter is halted until restart
TCC_FAULT_HALT_ACTION_SW_HALT	Software halt action, counter is halted until fault bit cleared
TCC_FAULT_HALT_ACTION_NON_RECOVERABLE	Non-Recoverable fault, force output to pre-defined level

27.6.5.14. Enum tcc_fault_keep

Table 27-83. Members

Enum value	Description
TCC_FAULT_KEEP_DISABLE	Disable keeping, wave output released as soon as fault is released
TCC_FAULT_KEEP_TILL_END	Keep wave output until end of TCC cycle

27.6.5.15. Enum tcc_fault_qualification

Table 27-84. Members

Enum value	Description
TCC_FAULT_QUALIFICATION_DISABLE	The input is not disabled on compare condition
TCC_FAULT_QUALIFICATION_BY_OUTPUT	The input is disabled when match output signal is at inactive level

27.6.5.16. Enum tcc_fault_restart

Table 27-85. Members

Enum value	Description
TCC_FAULT_RESTART_DISABLE	Restart Action disabled
TCC_FAULT_RESTART_ENABLE	Restart Action enabled

27.6.5.17. Enum tcc_fault_source

Table 27-86. Members

Enum value	Description
TCC_FAULT_SOURCE_DISABLE	Fault input is disabled
TCC_FAULT_SOURCE_ENABLE	Match Capture Event x (x=0,1) input

Enum value	Description
TCC_FAULT_SOURCE_INVERT	Inverted MCEx (x=0,1) event input
TCC_FAULT_SOURCE_ALTFAULT	Alternate fault (A or B) state at the end of the previous period

27.6.5.18. Enum tcc_fault_state_output

Table 27-87. Members

Enum value	Description
TCC_FAULT_STATE_OUTPUT_OFF	Non-recoverable fault output is tri-stated
TCC_FAULT_STATE_OUTPUT_0	Non-recoverable fault force output 0
TCC_FAULT_STATE_OUTPUT_1	Non-recoverable fault force output 1

27.6.5.19. Enum tcc_match_capture_channel

This enum is used to specify which capture/match channel to do operations on.

Table 27-88. Members

Enum value	Description
TCC_MATCH_CAPTURE_CHANNEL_n	Match capture channel index table for TCC Each TCC module may contain several match capture channels; each channel will have its own index in the table, with the index number substituted for "n" in the index name (e.g. `TCC_MATCH_CAPTURE_CHANNEL_0`).

27.6.5.20. Enum tcc_output_invertion

Used when enabling or disabling output inversion.

Table 27-89. Members

Enum value	Description
TCC_OUTPUT_INVERTION_DISABLE	Output inversion not to be enabled
TCC_OUTPUT_INVERTION_ENABLE	Invert the output from WO[x]

27.6.5.21. Enum tcc_output_pattern

Used when disabling output pattern or when selecting a specific pattern.

Table 27-90. Members

Enum value	Description
TCC_OUTPUT_PATTERN_DISABLE	SWAP output pattern is not used
TCC_OUTPUT_PATTERN_0	Pattern 0 is applied to SWAP output
TCC_OUTPUT_PATTERN_1	Pattern 1 is applied to SWAP output

27.6.5.22. Enum tcc_ramp

Ramp operations which are supported in single-slope PWM generation.

Table 27-91. Members

Enum value	Description
TCC_RAMP_RAMP1	Default timer/counter PWM operation
TCC_RAMP_RAMP2A	Uses a single channel (CC0) to control both CC0/CC1 compare outputs. In cycle A, the channel 0 output is disabled, and in cycle B, the channel 1 output is disabled.
TCC_RAMP_RAMP2	Uses channels CC0 and CC1 to control compare outputs. In cycle A, the channel 0 output is disabled, and in cycle B, the channel 1 output is disabled.

27.6.5.23. Enum tcc_ramp_index

In ramp operation, each two period cycles are marked as cycle A and B, the index 0 represents cycle A and 1 represents cycle B.

Table 27-92. Members

Enum value	Description
TCC_RAMP_INDEX_DEFAULT	Default, cycle index toggles.
TCC_RAMP_INDEX_FORCE_B	Force next cycle to be cycle B (set to 1)
TCC_RAMP_INDEX_FORCE_A	Force next cycle to be cycle A (clear to 0)
TCC_RAMP_INDEX_FORCE_KEEP	Force next cycle keeping the same as current

27.6.5.24. Enum tcc_reload_action

This enum specify how the counter is reloaded and whether the prescaler should be restarted.

Table 27-93. Members

Enum value	Description
TCC_RELOAD_ACTION_GCLK	The counter is reloaded/reset on the next GCLK and starts counting on the prescaler clock
TCC_RELOAD_ACTION_PRESC	The counter is reloaded/reset on the next prescaler clock
TCC_RELOAD_ACTION_RESYNC	The counter is reloaded/reset on the next GCLK, and the prescaler is restarted as well

27.6.5.25. Enum tcc_wave_generation

This enum is used to specify the waveform generation mode.

Table 27-94. Members

Enum value	Description
TCC_WAVE_GENERATION_NORMAL_FREQ	Normal Frequency: Top is the PER register, output toggled on each compare match
TCC_WAVE_GENERATION_MATCH_FREQ	Match Frequency: Top is CC0 register, output toggles on each update condition
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM	Single-Slope PWM: Top is the PER register, CCx controls duty cycle (output active when count is greater than CCx)
TCC_WAVE_GENERATION_DOUBLE_SLOPE_CRITICAL	Double-slope (count up and down), non centre-aligned: Top is the PER register, CC[x] controls duty cycle while counting up and CC[x+N/2] controls it while counting down
TCC_WAVE_GENERATION_DOUBLE_SLOPE_BOTTOM	Double-slope (count up and down), interrupt/event at Bottom (Top is the PER register, output active when count is greater than CCx)
TCC_WAVE_GENERATION_DOUBLE_SLOPE_BOTH	Double-slope (count up and down), interrupt/event at Bottom and Top: (Top is the PER register, output active when count is lower than CCx)
TCC_WAVE_GENERATION_DOUBLE_SLOPE_TOP	Double-slope (count up and down), interrupt/event at Top (Top is the PER register, output active when count is greater than CCx)

27.6.5.26. Enum tcc_wave_output

This enum is used to specify which wave output to do operations on.

Table 27-95. Members

Enum value	Description
TCC_WAVE_OUTPUT_n	Waveform output index table for TCC Each TCC module may contain several wave outputs; each output will have its own index in the table, with the index number substituted for "n" in the index name (e.g. `TCC_WAVE_OUTPUT_0`).

27.6.5.27. Enum tcc_wave_polarity

Specifies whether the wave output needs to be inverted or not.

Table 27-96. Members

Enum value	Description
TCC_WAVE_POLARITY_0	Wave output is not inverted
TCC_WAVE_POLARITY_1	Wave output is inverted

27.7. Extra Information for TCC Driver

27.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
DMA	Direct Memory Access
TCC	Timer Counter for Control Applications
PWM	Pulse Width Modulation
PWP	Pulse Width Period
PPW	Period Pulse Width

27.7.2. Dependencies

This driver has the following dependencies:

- System Pin Multiplexer Driver

27.7.3. Errata

There are no errata related to this driver.

27.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Add double buffering functionality
Add fault handling functionality
Initial Release

27.8. Examples for TCC Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Timer Counter for Control Applications (TCC) Driver. QSGs are simple examples with step-by-step instructions to

configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for TCC - Basic
- Quick Start Guide for TCC - Double Buffering and Circular
- Quick Start Guide for TCC - Timer
- Quick Start Guide for TCC - Callback
- Quick Start Guide for TCC - Non-Recoverable Fault
- Quick Start Guide for TCC - Recoverable Fault
- Quick Start Guide for Using DMA with TCC

27.8.1. Quick Start Guide for TCC - Basic

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width is set to one quarter of the period. When the PWM signal connects to LED, LED will light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM R21 Xpro	PA19	LED0
SAM L21 Xpro	PB10	LED0
SAM L22 Xpro	PC27	LED0
SAM DA1 Xpro	PB30	LED0
SAM C21 Xpro	PA15	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- Prescaler is set to 256
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action

- No event generation enabled
- Counter starts on 0
- Counter top set to 0xFFFF
- Capture compare channel 0 set to 0xFFFF/4

27.8.1.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#if SAMR30

#define CONF_PWM_MODULE      LED_0_PWM3CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM3CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM3CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM3CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM3CTRL_MUX
#else

#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
#endif
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV256;
    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = (0xFFFF / 4);

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

```
    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the TCC module.
   1. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

      ```
      struct tcc_config config_tcc;
      ```
   2. Initialize the TCC configuration struct with the module's default values.

      ```
      tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   3. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

      ```
      config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV256;
      config_tcc.counter.period = 0xFFFF;
      config_tcc.compare.wave_generation =
      TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
      config_tcc.compare.match[CONF_PWM_CHANNEL] = (0xFFFF / 4);
      ```
   4. Alter the TCC settings to configure the PWM output on a physical device pin.

      ```
      config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
      config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
      CONF_PWM_OUT_PIN;
      config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
      CONF_PWM_OUT_MUX;
      ```
   5. Configure the TCC module with the desired settings.

      ```
      tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
      ```
   6. Enable the TCC module to start the timer and begin PWM signal generation.

      ```
      tcc_enable(&tcc_instance);
      ```

27.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
    /* Infinite loop */
}
```

27.8.2. Quick Start Guide for TCC - Double Buffering and Circular

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width alters in one quarter and three quarter of the period. When the PWM signal connects to LED, LED will light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM R21 Xpro	PA19	LED0
SAM L21 Xpro	PB10	LED0
SAM L22 Xpro	PC27	LED0
SAM DA1 Xpro	PB30	LED0
SAM C21 Xpro	PA15	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- Prescaler is set to 1024
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Counter top set to 8000
- Capture compare channel set to 8000/4

- Capture compare channel buffer set to 8000*3/4
- Circular option for compare channel is enabled so that the compare values keep switching on update condition

27.8.2.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#if SAMR30

#define CONF_PWM_MODULE      LED_0_PWM3CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM3CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM3CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM3CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM3CTRL_MUX
#else

#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
#endif
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
    config_tcc.counter.period = 8000;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = (8000 / 4);

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    tcc_set_compare_value(&tcc_instance,
            (enum tcc_match_capture_channel)CONF_PWM_CHANNEL, 8000*3/4);
```

```
    tcc_enable_circular_buffer_compare(&tcc_instance,
            (enum tcc_match_capture_channel)CONF_PWM_CHANNEL);

    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the TCC module.
   1. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

      ```
      struct tcc_config config_tcc;
      ```
   2. Initialize the TCC configuration struct with the module's default values.

      ```
      tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
   3. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

      ```
      config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
      config_tcc.counter.period = 8000;
      config_tcc.compare.wave_generation =
      TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
      config_tcc.compare.match[CONF_PWM_CHANNEL] = (8000 / 4);
      ```
   4. Alter the TCC settings to configure the PWM output on a physical device pin.

      ```
      config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
      config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
      CONF_PWM_OUT_PIN;
      config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
      CONF_PWM_OUT_MUX;
      ```
   5. Configure the TCC module with the desired settings.

      ```
      tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
      ```
   6. Set to compare buffer value and enable circular of double buffered compare values.

      ```
      tcc_set_compare_value(&tcc_instance,
              (enum tcc_match_capture_channel)CONF_PWM_CHANNEL,
      8000*3/4);
      tcc_enable_circular_buffer_compare(&tcc_instance,
              (enum tcc_match_capture_channel)CONF_PWM_CHANNEL);
      ```
   7. Enable the TCC module to start the timer and begin PWM signal generation.

      ```
      tcc_enable(&tcc_instance);
      ```

27.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
     /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
     /* Infinite loop */
}
```

27.8.3. Quick Start Guide for TCC - Timer

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro
- SAM D11 Xplained Pro

In this use case, the TCC will be used as a timer, to generate overflow and compare match callbacks. In the callbacks the on-board LED is toggled.

The TCC module will be set up as follows:

- GCLK generator 1 (GCLK 32K) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- Prescaler is divided by 64
- GCLK reload action
- Count upward
- Don't run in standby
- No waveform outputs
- No capture enabled
- Don't perform one-shot operations
- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Counter top set to 2000 (about 4s) and generate overflow callback
- Channel 0 is set to compare and match value 900 and generate callback
- Channel 1 is set to compare and match value 930 and generate callback
- Channel 2 is set to compare and match value 1100 and generate callback
- Channel 3 is set to compare and match value 1250 and generate callback

27.8.3.1. Quick Start

Prerequisites

For this use case, XOSC32K should be enabled and available through GCLK generator 1 clock source selection. Within Atmel Software Framework (ASF) it can be done through modifying *conf_clocks.h*. See System Clock Management Driver for more details about clock configuration.

Code

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_toggle_led(
        struct tcc_module *const module_inst)
{
    port_pin_toggle_output_level(LED0_PIN);
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, TCC0);

    config_tcc.counter.clock_source = GCLK_GENERATOR_1;
    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV64;
    config_tcc.counter.period =   2000;
    config_tcc.compare.match[0] =  900;
    config_tcc.compare.match[1] =  930;
    config_tcc.compare.match[2] = 1100;
    config_tcc.compare.match[3] = 1250;

    tcc_init(&tcc_instance, TCC0, &config_tcc);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_OVERFLOW);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_0);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_1);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_2);
    tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
            TCC_CALLBACK_CHANNEL_3);

    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_OVERFLOW);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_0);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_1);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_2);
    tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_3);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

```
struct tcc_module tcc_instance;
```

Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Configure the TCC module.
    1. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

```
struct tcc_config config_tcc;
```

    2. Initialize the TCC configuration struct with the module's default values.

```
tcc_get_config_defaults(&config_tcc, TCC0);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    3. Alter the TCC settings to configure the GCLK source, prescaler, period, and compare channel values.

```
config_tcc.counter.clock_source = GCLK_GENERATOR_1;
config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV64;
config_tcc.counter.period =   2000;
config_tcc.compare.match[0] =  900;
config_tcc.compare.match[1] =  930;
config_tcc.compare.match[2] = 1100;
config_tcc.compare.match[3] = 1250;
```

    4. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, TCC0, &config_tcc);
```

    5. Enable the TCC module to start the timer.

```
tcc_enable(&tcc_instance);
```

3. Configure the TCC callbacks.
    1. Register the Overflow and Compare Channel Match callback functions with the driver.

```
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_OVERFLOW);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_0);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_1);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_2);
tcc_register_callback(&tcc_instance, tcc_callback_to_toggle_led,
        TCC_CALLBACK_CHANNEL_3);
```

    2. Enable the Overflow and Compare Channel Match callbacks so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_OVERFLOW);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_0);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_1);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_2);
tcc_enable_callback(&tcc_instance, TCC_CALLBACK_CHANNEL_3);
```

27.8.3.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the timer is running.

```
while (true) {
}
```

27.8.4. Quick Start Guide for TCC - Callback

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. When the PWM signal connects to LED, LED will light. To see the waveform, you may need an oscilloscope.

The PWM output is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM R21 Xpro	PA19	LED0
SAM L21 Xpro	PB10	LED0
SAM L22 Xpro	PC27	LED0
SAM DA1 Xpro	PB30	LED0
SAM C21 Xpro	PA15	LED0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No faults or waveform extensions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations

- No event input enabled
- No event action
- No event generation enabled
- Counter starts on 0

27.8.4.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

```
#if SAMR30

#define CONF_PWM_MODULE      LED_0_PWM3CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM3CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM3CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM3CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM3CTRL_MUX
#else

#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
#endif
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
    tcc_set_compare_value(module_inst,
            (enum tcc_match_capture_channel)
                    (TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL),
            i + 1);
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));

    tcc_enable_callback(&tcc_instance,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();
```

Workflow

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Configure the TCC module.
   1. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

      ```
      struct tcc_config config_tcc;
      ```
   2. Initialize the TCC configuration struct with the module's default values.

      ```
      tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

```
config_tcc.counter.period = 0xFFFF;
config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
```

4. Alter the TCC settings to configure the PWM output on a physical device pin.

```
config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;
```

5. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

6. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

3. Configure the TCC callbacks.
   1. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
        tcc_callback_to_change_duty_cycle,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));
```

   2. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));
```

27.8.4.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

27.8.5. Quick Start Guide for TCC - Non-Recoverable Fault

The supported kit list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. There is a non-recoverable fault input which controls PWM output. When this fault is active (low) the PWM output will be forced to be high. When fault is released (input high) the PWM output will go on.

When the PWM signal connects to LED, LED will light. If fault input is from a button, the LED will be off when the button is down and on when the button is up. To see the PWM waveform, you may need an oscilloscope.

The PWM output and fault input is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM D21 Xpro	PA15	SW0
SAM R21 Xpro	PA19	LED0
SAM R21 Xpro	PA28	SW0
SAM L21 Xpro	PB10	LED0
SAM L21 Xpro	PA16	SW0
SAM L22 Xpro	PC27	LED0
SAM L22 Xpro	PC01	SW0
SAM DA1 Xpro	PB30	LED0
SAM DA1 Xpro	PA15	SW0
SAM C21 Xpro	PA15	LED0
SAM C21 Xpro	PA28	SW0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No waveform extentions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input except TCC event0 enabled
- No event action except TCC event0 acts as Non-Recoverable Fault
- No event generation enabled

- Counter starts on 0

27.8.5.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions:

- SAM D21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

- SAM R21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_8
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

- SAM L21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
```

```
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_2
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

- SAM L22 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_9
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

- SAM DA1 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

- SAM C21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
```

```
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN

#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX

#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE

#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_8

#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

Add to the main application source file, before any functions:

```
#include <string.h>
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
struct events_resource event_resource;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
    tcc_set_compare_value(module_inst,
            (enum tcc_match_capture_channel)
                    (TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL),
            i + 1);
}
```

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(0));
    }
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
```

```
    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
    config_tcc.wave_ext.non_recoverable_fault[0].output =
TCC_FAULT_STATE_OUTPUT_1;
    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events;
    memset(&events, 0, sizeof(struct tcc_events));

    events.on_input_event_perform_action[0] = true;
    events.input_config[0].modify_action = true;
    events.input_config[0].action =
TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT;

    tcc_enable_events(&tcc_instance, &events);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));

    tcc_enable_callback(&tcc_instance,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));
}
```

```
static void configure_eic(void)
{
    struct extint_chan_conf config;
    extint_chan_get_config_defaults(&config);
    config.filter_input_signal = true;
    config.detection_criteria  = EXTINT_DETECT_BOTH;
    config.gpio_pin     = CONF_FAULT_EIC_PIN;
    config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
    extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);

    struct extint_events events;
    memset(&events, 0, sizeof(struct extint_events));
    events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
    extint_enable_events(&events);

    extint_register_callback(eic_callback_to_clear_halt,
            CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}
```

```
static void configure_event(void)
{
```

```
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator = CONF_FAULT_EVENT_GENERATOR;
    config.path      = EVENTS_PATH_ASYNCHRONOUS;

    events_allocate(&event_resource, &config);

    events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();

configure_eic();
configure_event();
```

Workflow

Configure TCC

1. Create a module software instance struct for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

   ```
   struct tcc_config config_tcc;
   ```
3. Initialize the TCC configuration struct with the module's default values.

   ```
   tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
4. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value and fault options. Here the Non-Recoverable Fault output is enabled and set to high level (1).

   ```
   config_tcc.counter.period = 0xFFFF;
   config_tcc.compare.wave_generation =
   TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
   config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
   ```

   ```
   config_tcc.wave_ext.non_recoverable_fault[0].output =
   TCC_FAULT_STATE_OUTPUT_1;
   ```
5. Alter the TCC settings to configure the PWM output on a physical device pin.

   ```
   config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
   config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
   CONF_PWM_OUT_PIN;
   config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
   CONF_PWM_OUT_MUX;
   ```

6. Configure the TCC module with the desired settings.

```
tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
```

7. Create a TCC events configuration struct, which can be filled out to enable/disable events and configure event settings. Reset all fields to zero.

```
struct tcc_events events;
memset(&events, 0, sizeof(struct tcc_events));
```

8. Alter the TCC events settings to enable/disable desired events, to change event generating options and modify event actions. Here TCC event0 will act as Non-Recoverable Fault input.

```
events.on_input_event_perform_action[0] = true;
events.input_config[0].modify_action = true;
events.input_config[0].action = TCC_EVENT_ACTION_NON_RECOVERABLE_FAULT;
```

9. Enable and apply events settings.

```
tcc_enable_events(&tcc_instance, &events);
```

10. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

11. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
        tcc_callback_to_change_duty_cycle,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));
```

12. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));
```

Configure EXTINT for fault input

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

```
struct extint_chan_conf config;
```

2. Initialize the channel configuration struct with the module's default values.

```
extint_chan_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config.filter_input_signal = true;
config.detection_criteria  = EXTINT_DETECT_BOTH;
config.gpio_pin     = CONF_FAULT_EIC_PIN;
config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);
```

5. Create a TXTINT events configuration struct, which can be filled out to enable/disable events. Reset all fields to zero.

```
struct extint_events events;
memset(&events, 0, sizeof(struct extint_events));
```

6. Adjust the configuration struct, set the channels to be enabled to `true`. Here the channel to the board button is used.

```
events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
```

7. Enable the events.

```
extint_enable_events(&events);
```

8. Define the EXTINT callback that will be fired when a detection event occurs. For this example, when fault line is released, the TCC fault state is cleared to go on PWM generating.

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_NON_RECOVERABLE_FAULT_OCCUR(0));
    }
}
```

9. Register a callback function `eic_callback_to_clear_halt()` to handle detections from the External Interrupt Controller (EIC).

```
extint_register_callback(eic_callback_to_clear_halt,
        CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
```

10. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

Configure EVENTS for fault input

1. Create an event resource instance struct for the EVENTS module to store.

```
struct events_resource event_resource;
```

Note: This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

```
struct events_config config;
```

3. Initialize the event channel configuration struct with the module's default values.

```
events_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the configuration struct to request that the channel will be attached to the specified event generator, and that the asynchronous event path will be used. Here the EIC channel connected to board button is the event generator.

```
config.generator = CONF_FAULT_EVENT_GENERATOR;
config.path      = EVENTS_PATH_ASYNCHRONOUS;
```

5. Allocate and configure the channel using the configuration structure.

```
events_allocate(&event_resource, &config);
```

Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Attach a user to the channel. Here the user is TCC event0, which has been configured as input of Non-Recoverable Fault.

```
events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
```

27.8.5.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

27.8.6. Quick Start Guide for TCC - Recoverable Fault

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal, with a varying duty cycle. Here the pulse width is increased each time the timer count matches the set compare value. There is a recoverable fault input which controls PWM output. When this fault is active (low) the PWM output will be frozen (could be off or on, no light changing). When fault is released (input high) the PWM output will go on.

When the PWM signal connects to LED, LED will light. If fault input is from a button, the LED will be frozen and not changing it's light when the button is down and will go on when the button is up. To see the PWM waveform, you may need an oscilloscope.

The PWM output and fault input is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM D21 Xpro	PA15	SW0
SAM R21 Xpro	PA06	EXT1 Pin 3

Board	Pin	Connect to
SAM R21 Xpro	PA28	SW0
SAM L21 Xpro	PB10	LED0
SAM L21 Xpro	PA16	SW0
SAM L22 Xpro	PB18	EXT3 Pin 9
SAM L22 Xpro	PC01	SW0
SAM DA1 Xpro	PB30	LED0
SAM DA1 Xpro	PA15	SW0
SAM C21 Xpro	PA15	LED0
SAM C21 Xpro	PA28	SW0

The TCC module will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- No prescaler
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No waveform extentions
- No inversion of waveform output
- No capture enabled
- Count upward
- Don't perform one-shot operations
- No event input except channel 0 event enabled
- No event action
- No event generation enabled
- Counter starts on 0
- Recoverable Fault A is generated from channel 0 event input, fault halt acts as software halt, other actions or options are all disabled

27.8.6.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
```

```
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_MC_0
```

- SAM R21 Xplained Pro

```
#define CONF_PWM_MODULE      TCC1
#define CONF_PWM_CHANNEL     0
#define CONF_PWM_OUTPUT      0
#define CONF_PWM_OUT_PIN     PIN_PA06E_TCC1_WO0
#define CONF_PWM_OUT_MUX     MUX_PA06E_TCC1_WO0
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_8
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC1_MC_0
```

- SAM L21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_2
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_MC_0
```

- SAM L22 Xplained Pro

```
#define CONF_PWM_MODULE      TCC0
#define CONF_PWM_CHANNEL     0
#define CONF_PWM_OUTPUT      0
#define CONF_PWM_OUT_PIN     PIN_PB18F_TCC0_WO0
#define CONF_PWM_OUT_MUX     MUX_PB18F_TCC0_WO0
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_9
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_MC_0
```

- SAM DA1 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_15
#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_MC_0
```

- SAM C21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_FAULT_EIC_PIN       SW0_EIC_PIN
#define CONF_FAULT_EIC_PIN_MUX   SW0_EIC_PINMUX
#define CONF_FAULT_EIC_LINE      SW0_EIC_LINE
```

```
#define CONF_FAULT_EVENT_GENERATOR EVSYS_ID_GEN_EIC_EXTINT_8

#define CONF_FAULT_EVENT_USER      EVSYS_ID_USER_TCC0_EV_0
```

Add to the main application source file, before any functions:

```
#include <string.h>
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
struct events_resource event_resource;
```

Copy-paste the following callback function code to your user application:

```
static void tcc_callback_to_change_duty_cycle(
        struct tcc_module *const module_inst)
{
    static uint32_t delay = 10;
    static uint32_t i = 0;

    if (--delay) {
        return;
    }
    delay = 10;
    i = (i + 0x0800) & 0xFFFF;
    tcc_set_compare_value(module_inst,
            (enum tcc_match_capture_channel)
                    (TCC_MATCH_CAPTURE_CHANNEL_0 + CONF_PWM_CHANNEL),
            i + 1);
}
```

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_RECOVERABLE_FAULT_OCCUR(CONF_PWM_CHANNEL));
    }
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.period = 0xFFFF;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
    config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].source =
            TCC_FAULT_SOURCE_ENABLE;

config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].halt_action =
            TCC_FAULT_HALT_ACTION_SW_HALT;
    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;
```

```
    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events;
    memset(&events, 0, sizeof(struct tcc_events));

    events.on_event_perform_channel_action[CONF_PWM_CHANNEL] = true;

    tcc_enable_events(&tcc_instance, &events);

    tcc_enable(&tcc_instance);
}

static void configure_tcc_callbacks(void)
{
    tcc_register_callback(
            &tcc_instance,
            tcc_callback_to_change_duty_cycle,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));

    tcc_enable_callback(&tcc_instance,
            (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 +
CONF_PWM_CHANNEL));
}
```

```
static void configure_eic(void)
{
    struct extint_chan_conf config;
    extint_chan_get_config_defaults(&config);
    config.filter_input_signal = true;
    config.detection_criteria  = EXTINT_DETECT_BOTH;
    config.gpio_pin     = CONF_FAULT_EIC_PIN;
    config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
    extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);

    struct extint_events events;
    memset(&events, 0, sizeof(struct extint_events));
    events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
    extint_enable_events(&events);

    extint_register_callback(eic_callback_to_clear_halt,
            CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
    extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
            EXTINT_CALLBACK_TYPE_DETECT);
}
```

```
static void configure_event(void)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator = CONF_FAULT_EVENT_GENERATOR;
    config.path      = EVENTS_PATH_ASYNCHRONOUS;

    events_allocate(&event_resource, &config);

    events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
configure_tcc_callbacks();
```

```
configure_eic();
configure_event();
```

Workflow

Configure TCC

1. Create a module software instance struct for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.

2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

   ```
   struct tcc_config config_tcc;
   ```

3. Initialize the TCC configuration struct with the module's default values.

   ```
   tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value and fault options. Here the Recoverable Fault input is enabled and halt action is set to software mode (must use software to clear halt state).

   ```
   config_tcc.counter.period = 0xFFFF;
   config_tcc.compare.wave_generation =
   TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
   config_tcc.compare.match[CONF_PWM_CHANNEL] = 0xFFFF;
   ```

   ```
   config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].source =
           TCC_FAULT_SOURCE_ENABLE;
   config_tcc.wave_ext.recoverable_fault[CONF_PWM_CHANNEL].halt_action =
           TCC_FAULT_HALT_ACTION_SW_HALT;
   ```

5. Alter the TCC settings to configure the PWM output on a physical device pin.

   ```
   config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
   config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
   CONF_PWM_OUT_PIN;
   config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
   CONF_PWM_OUT_MUX;
   ```

6. Configure the TCC module with the desired settings.

   ```
   tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
   ```

7. Create a TCC events configuration struct, which can be filled out to enable/disable events and configure event settings. Reset all fields to zero.

   ```
   struct tcc_events events;
   memset(&events, 0, sizeof(struct tcc_events));
   ```

8. Alter the TCC events settings to enable/disable desired events, to change event generating options and modify event actions. Here channel event 0 input is enabled as source of recoverable fault.

   ```
   events.on_event_perform_channel_action[CONF_PWM_CHANNEL] = true;
   ```

9. Enable and apply events settings.

```
tcc_enable_events(&tcc_instance, &events);
```

10. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

11. Register the Compare Channel 0 Match callback functions with the driver.

```
tcc_register_callback(
        &tcc_instance,
        tcc_callback_to_change_duty_cycle,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));
```

12. Enable the Compare Channel 0 Match callback so that it will be called by the driver when appropriate.

```
tcc_enable_callback(&tcc_instance,
        (enum tcc_callback)(TCC_CALLBACK_CHANNEL_0 + CONF_PWM_CHANNEL));
```

Configure EXTINT for fault input

1. Create an EXTINT module channel configuration struct, which can be filled out to adjust the configuration of a single external interrupt channel.

```
struct extint_chan_conf config;
```

2. Initialize the channel configuration struct with the module's default values.

```
extint_chan_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to configure the pin MUX (to route the desired physical pin to the logical channel) to the board button, and to configure the channel to detect both rising and falling edges.

```
config.filter_input_signal = true;
config.detection_criteria  = EXTINT_DETECT_BOTH;
config.gpio_pin     = CONF_FAULT_EIC_PIN;
config.gpio_pin_mux = CONF_FAULT_EIC_PIN_MUX;
```

4. Configure external interrupt channel with the desired channel settings.

```
extint_chan_set_config(CONF_FAULT_EIC_LINE, &config);
```

5. Create a TXTINT events configuration struct, which can be filled out to enable/disable events. Reset all fields to zero.

```
struct extint_events events;
memset(&events, 0, sizeof(struct extint_events));
```

6. Adjust the configuration struct, set the channels to be enabled to `true`. Here the channel to the board button is used.

```
events.generate_event_on_detect[CONF_FAULT_EIC_LINE] = true;
```

7. Enable the events.

```
extint_enable_events(&events);
```

8. Define the EXTINT callback that will be fired when a detection event occurs. For this example, when fault line is released, the TCC fault state is cleared to go on PWM generating.

```
static void eic_callback_to_clear_halt(void)
{
    if (port_pin_get_input_level(CONF_FAULT_EIC_PIN)) {
        tcc_clear_status(&tcc_instance,
                TCC_STATUS_RECOVERABLE_FAULT_OCCUR(CONF_PWM_CHANNEL));
    }
}
```

9. Register a callback function `eic_callback_to_clear_halt()` to handle detections from the External Interrupt Controller (EIC).

```
extint_register_callback(eic_callback_to_clear_halt,
        CONF_FAULT_EIC_LINE, EXTINT_CALLBACK_TYPE_DETECT);
```

10. Enable the registered callback function for the configured External Interrupt channel, so that it will be called by the module when the channel detects an edge.

```
extint_chan_enable_callback(CONF_FAULT_EIC_LINE,
        EXTINT_CALLBACK_TYPE_DETECT);
```

Configure EVENTS for fault input

1. Create an event resource instance struct for the EVENTS module to store.

```
struct events_resource event_resource;
```

Note: This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event channel configuration struct, which can be filled out to adjust the configuration of a single event channel.

```
struct events_config config;
```

3. Initialize the event channel configuration struct with the module's default values.

```
events_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the configuration struct to request that the channel will be attached to the specified event generator, and that the asynchronous event path will be used. Here the EIC channel connected to board button is the event generator.

```
config.generator = CONF_FAULT_EVENT_GENERATOR;
config.path      = EVENTS_PATH_ASYNCHRONOUS;
```

5. Allocate and configure the channel using the configuration structure.

```
events_allocate(&event_resource, &config);
```

Note: The existing configuration struct may be re-used, as long as any values that have been altered from the default settings are taken into account by the user application.

6. Attach a user to the channel. Here the user is TCC channel 0 event, which has been configured as input of Recoverable Fault.

```
events_attach_user(&event_resource, CONF_FAULT_EVENT_USER);
```

27.8.6.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable_global();

while (true) {
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
}
```

27.8.7. Quick Start Guide for Using DMA with TCC

The supported board list:

- SAM D21/R21/L21/L22/DA1/C21 Xplained Pro

In this use case, the TCC will be used to generate a PWM signal. Here the pulse width varies through the following values with the help of DMA transfer: one quarter of the period, half of the period, and three quarters of the period. The PWM output can be used to drive a LED. The waveform can also be viewed using an oscilloscope. The output signal is also fed back to another TCC channel by event system, the event stamps are captured and transferred to a buffer by DMA.

The PWM output is set up as follows:

Board	Pin	Connect to
SAM D21 Xpro	PB30	LED0
SAM R21 Xpro	PA19	LED0
SAM L21 Xpro	PB10	LED0
SAM L22 Xpro	PC27	LED0
SAM DA1 Xpro	PB30	LED0
SAM C21 Xpro	PA15	LED0

The TCC module will be setup as follows:

- GCLK generator 0 (GCLK main) clock source
- Use double buffering write when set top, compare, or pattern through API
- No dithering on the counter or compare
- Prescaler is set to 1024
- Single Slope PWM wave generation
- GCLK reload action
- Don't run in standby
- No fault or waveform extensions
- No inversion of waveform output
- No capture enabled

- Count upward
- Don't perform one-shot operations
- Counter starts on 0
- Counter top set to 0x1000
- Channel 0 (on SAM D21 Xpro) or 3 (on SAM R21 Xpro) is set to compare and match value 0x1000*3/4 and generate event
- Channel 1 is set to capture on input event

The event resource of EVSYS module will be setup as follows:

- TCC match capture channel 0 (on SAM D21 Xpro) or 3 (on SAM R21 Xpro) is selected as event generator
- Event generation is synchronous, with rising edge detected
- TCC match capture channel 1 is the event user

The DMA resource of DMAC module will be setup as follows:

- Two DMA resources are used
- Both DMA resources use peripheral trigger
- Both DMA resources perform beat transfer on trigger
- Both DMA resources use beat size of 16 bits
- Both DMA resources are configured to transfer three beats and then repeat again in same buffer
- On DMA resource which controls the compare value
  - TCC0 overflow triggers DMA transfer
  - The source address increment is enabled
  - The destination address is fixed to TCC channel 0 Compare/Capture register
- On DMA resource which reads the captured value
  - TCC0 capture on channel 1 triggers DMA transfer
  - The source address is fixed to TCC channel 1 Compare/Capture register
  - The destination address increment is enabled
  - The captured value is transferred to an array in SRAM

27.8.7.1. Quick Start

Prerequisites

There are no prerequisites for this use case.

Code

Add to the main application source file, before any functions, according to the kit used:

- SAM D21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE

#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL

#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT

#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN

#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1

#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0
```

```
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

```
#define CONF_CAPTURE_TRIGGER TCC0_DMAC_ID_MC_1
```

- SAM R21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1
#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_3
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

```
#define CONF_CAPTURE_TRIGGER TCC0_DMAC_ID_MC_1
```

- SAM L21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1
#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

- SAM L22 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
```

```
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1
#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

- SAM DA1 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1
#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

```
#define CONF_CAPTURE_TRIGGER TCC0_DMAC_ID_MC_1
```

- SAM C21 Xplained Pro

```
#define CONF_PWM_MODULE      LED_0_PWM4CTRL_MODULE
#define CONF_PWM_CHANNEL     LED_0_PWM4CTRL_CHANNEL
#define CONF_PWM_OUTPUT      LED_0_PWM4CTRL_OUTPUT
#define CONF_PWM_OUT_PIN     LED_0_PWM4CTRL_PIN
#define CONF_PWM_OUT_MUX     LED_0_PWM4CTRL_MUX
```

```
#define CONF_TCC_CAPTURE_CHANNEL      1
#define CONF_TCC_EVENT_GENERATOR      EVSYS_ID_GEN_TCC0_MCX_0
#define CONF_TCC_EVENT_USER           EVSYS_ID_USER_TCC0_MC_1
```

```
#define CONF_COMPARE_TRIGGER TCC0_DMAC_ID_OVF
```

Add to the main application source file, outside of any functions:

```
struct tcc_module tcc_instance;
```

```
uint16_t capture_values[3] = {0, 0, 0};
struct dma_resource capture_dma_resource;
```

```
COMPILER_ALIGNED(16) DmacDescriptor capture_dma_descriptor
SECTION_DMAC_DESCRIPTOR;
struct events_resource capture_event_resource;
```

```
uint16_t compare_values[3] = {
    (0x1000 / 4), (0x1000 * 2 / 4), (0x1000 * 3 / 4)
};
struct dma_resource compare_dma_resource;
COMPILER_ALIGNED(16) DmacDescriptor compare_dma_descriptor
SECTION_DMAC_DESCRIPTOR;
```

Copy-paste the following setup code to your user application:

```
static void config_event_for_capture(void)
{
    struct events_config config;

    events_get_config_defaults(&config);

    config.generator      = CONF_TCC_EVENT_GENERATOR;
    config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
    config.path           = EVENTS_PATH_SYNCHRONOUS;
    config.clock_source   = GCLK_GENERATOR_0;

    events_allocate(&capture_event_resource, &config);

    events_attach_user(&capture_event_resource, CONF_TCC_EVENT_USER);
}
```

```
static void config_dma_for_capture(void)
{
    struct dma_resource_config config;

    dma_get_config_defaults(&config);

    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
    config.peripheral_trigger = CONF_CAPTURE_TRIGGER;

    dma_allocate(&capture_dma_resource, &config);

    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 3;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.step_selection = DMA_STEPSEL_SRC;
    descriptor_config.src_increment_enable = false;
    descriptor_config.source_address =
            (uint32_t)&CONF_PWM_MODULE->CC[CONF_TCC_CAPTURE_CHANNEL];
    descriptor_config.destination_address =
            (uint32_t)capture_values + sizeof(capture_values);

    dma_descriptor_create(&capture_dma_descriptor, &descriptor_config);

    dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
    dma_add_descriptor(&capture_dma_resource, &capture_dma_descriptor);
    dma_start_transfer_job(&capture_dma_resource);
}
```

```
static void config_dma_for_wave(void)
{
    struct dma_resource_config config;
```

```
    dma_get_config_defaults(&config);
    config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
    config.peripheral_trigger = CONF_COMPARE_TRIGGER;
    dma_allocate(&compare_dma_resource, &config);

    struct dma_descriptor_config descriptor_config;

    dma_descriptor_get_config_defaults(&descriptor_config);

    descriptor_config.block_transfer_count = 3;
    descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
    descriptor_config.dst_increment_enable = false;
    descriptor_config.source_address =
            (uint32_t)compare_values + sizeof(compare_values);
#if (SAMR21) || (SAMD21) || (SAMDA1)
    descriptor_config.destination_address =
            (uint32_t)&CONF_PWM_MODULE->CC[CONF_PWM_CHANNEL];
#else
    descriptor_config.destination_address =
            (uint32_t)&CONF_PWM_MODULE->CCBUF[CONF_PWM_CHANNEL];
#endif

    dma_descriptor_create(&compare_dma_descriptor, &descriptor_config);

    dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
    dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
    dma_start_transfer_job(&compare_dma_resource);
}
```

```
static void configure_tcc(void)
{
    struct tcc_config config_tcc;
    tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);

    config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
    config_tcc.counter.period = 0x1000;
    config_tcc.compare.channel_function[CONF_TCC_CAPTURE_CHANNEL] =
            TCC_CHANNEL_FUNCTION_CAPTURE;
    config_tcc.compare.wave_generation =
TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
    config_tcc.compare.wave_polarity[CONF_PWM_CHANNEL] =
TCC_WAVE_POLARITY_0;
    config_tcc.compare.match[CONF_PWM_CHANNEL] = compare_values[2];

    config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
    config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
CONF_PWM_OUT_PIN;
    config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
CONF_PWM_OUT_MUX;

    tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);

    struct tcc_events events_tcc = {
        .input_config[0].modify_action = false,
        .input_config[1].modify_action = false,
        .output_config.modify_generation_selection = false,
        .generate_event_on_channel[CONF_PWM_CHANNEL] = true,
        .on_event_perform_channel_action[CONF_TCC_CAPTURE_CHANNEL] =
true
    };
    tcc_enable_events(&tcc_instance, &events_tcc);

    config_event_for_capture();
```

```
    config_dma_for_capture();
    config_dma_for_wave();

    tcc_enable(&tcc_instance);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tcc();
```

Workflow

Configure the TCC

1. Create a module software instance structure for the TCC module to store the TCC driver state while it is in use.

   ```
   struct tcc_module tcc_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a TCC module configuration struct, which can be filled out to adjust the configuration of a physical TCC peripheral.

   ```
   struct tcc_config config_tcc;
   ```
3. Initialize the TCC configuration struct with the module's default values.

   ```
   tcc_get_config_defaults(&config_tcc, CONF_PWM_MODULE);
   ```

   Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
4. Alter the TCC settings to configure the counter width, wave generation mode, and the compare channel 0 value.

   ```
   config_tcc.counter.clock_prescaler = TCC_CLOCK_PRESCALER_DIV1024;
   config_tcc.counter.period = 0x1000;
   config_tcc.compare.channel_function[CONF_TCC_CAPTURE_CHANNEL] =
           TCC_CHANNEL_FUNCTION_CAPTURE;
   config_tcc.compare.wave_generation =
   TCC_WAVE_GENERATION_SINGLE_SLOPE_PWM;
   config_tcc.compare.wave_polarity[CONF_PWM_CHANNEL] =
   TCC_WAVE_POLARITY_0;
   config_tcc.compare.match[CONF_PWM_CHANNEL] = compare_values[2];
   ```
5. Alter the TCC settings to configure the PWM output on a physical device pin.

   ```
   config_tcc.pins.enable_wave_out_pin[CONF_PWM_OUTPUT] = true;
   config_tcc.pins.wave_out_pin[CONF_PWM_OUTPUT]        =
   CONF_PWM_OUT_PIN;
   config_tcc.pins.wave_out_pin_mux[CONF_PWM_OUTPUT]    =
   CONF_PWM_OUT_MUX;
   ```
6. Configure the TCC module with the desired settings.

   ```
   tcc_init(&tcc_instance, CONF_PWM_MODULE, &config_tcc);
   ```
7. Configure and enable the desired events for the TCC module.

   ```
   struct tcc_events events_tcc = {
       .input_config[0].modify_action = false,
       .input_config[1].modify_action = false,
       .output_config.modify_generation_selection = false,
       .generate_event_on_channel[CONF_PWM_CHANNEL] = true,
   ```

```
    .on_event_perform_channel_action[CONF_TCC_CAPTURE_CHANNEL] = true
};
tcc_enable_events(&tcc_instance, &events_tcc);
```

Configure the Event System

Configure the EVSYS module to wire channel 0 event to channel 1.

1. Create an event resource instance.

```
struct events_resource capture_event_resource;
```

Note: This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create an event resource configuration struct.

```
struct events_config config;
```

3. Initialize the event resource configuration struct with default values.

```
events_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the event resource configuration to desired values.

```
config.generator      = CONF_TCC_EVENT_GENERATOR;
config.edge_detect    = EVENTS_EDGE_DETECT_RISING;
config.path           = EVENTS_PATH_SYNCHRONOUS;
config.clock_source   = GCLK_GENERATOR_0;
```

5. Allocate and configure the resource using the configuration structure.

```
events_allocate(&capture_event_resource, &config);
```

6. Attach a user to the resource.

```
events_attach_user(&capture_event_resource, CONF_TCC_EVENT_USER);
```

Configure the DMA for Capture TCC Channel 1

Configure the DMAC module to obtain captured value from TCC channel 1.

1. Create a DMA resource instance.

```
struct dma_resource capture_dma_resource;
```

Note: This should never go out of scope as long as the resource is in use. In most cases, this should be global.

2. Create a DMA resource configuration struct.

```
struct dma_resource_config config;
```

3. Initialize the DMA resource configuration struct with default values.

```
dma_get_config_defaults(&config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

4. Adjust the DMA resource configurations.

```
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
config.peripheral_trigger = CONF_CAPTURE_TRIGGER;
```

5. Allocate a DMA resource with the configurations.

```
dma_allocate(&capture_dma_resource, &config);
```

6. Prepare DMA transfer descriptor.
    1. Create a DMA transfer descriptor.

```
COMPILER_ALIGNED(16) DmacDescriptor capture_dma_descriptor
SECTION_DMAC_DESCRIPTOR;
```

Note: When multiple descriptors are linked, the linked item should never go out of scope before it is loaded (to DMA Write-Back memory section). In most cases, if more than one descriptors are used, they should be global except the very first one.

    2. Create a DMA transfer descriptor struct.
    3. Create a DMA transfer descriptor configuration structure, which can be filled out to adjust the configuration of a single DMA transfer.

```
struct dma_descriptor_config descriptor_config;
```

    4. Initialize the DMA transfer descriptor configuration struct with default values.

```
dma_descriptor_get_config_defaults(&descriptor_config);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    5. Adjust the DMA transfer descriptor configurations.

```
descriptor_config.block_transfer_count = 3;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.step_selection = DMA_STEPSEL_SRC;
descriptor_config.src_increment_enable = false;
descriptor_config.source_address =
        (uint32_t)&CONF_PWM_MODULE->CC[CONF_TCC_CAPTURE_CHANNEL];
descriptor_config.destination_address =
        (uint32_t)capture_values + sizeof(capture_values);
```

    6. Create the DMA transfer descriptor with the given configuration.

```
dma_descriptor_create(&capture_dma_descriptor,
&descriptor_config);
```

7. Start DMA transfer job with prepared descriptor.
    1. Add the DMA transfer descriptor to the allocated DMA resource.

```
dma_add_descriptor(&capture_dma_resource,
&capture_dma_descriptor);
dma_add_descriptor(&capture_dma_resource,
&capture_dma_descriptor);
```

Note: When adding multiple descriptors, the last one added is linked at the end of the descriptor queue. If ringed list is needed, just add the first descriptor again to build the circle.

    2. Start the DMA transfer job with the allocated DMA resource and transfer descriptor.

```
dma_start_transfer_job(&capture_dma_resource);
```

Configure the DMA for Compare TCC Channel 0

Configure the DMAC module to update TCC channel 0 compare value. The flow is similar to last DMA configure step for capture.

1. Allocate and configure the DMA resource.

```
struct dma_resource compare_dma_resource;
```

```
struct dma_resource_config config;
dma_get_config_defaults(&config);
config.trigger_action = DMA_TRIGGER_ACTION_BEAT;
config.peripheral_trigger = CONF_COMPARE_TRIGGER;
dma_allocate(&compare_dma_resource, &config);
```

2. Prepare DMA transfer descriptor.

```
COMPILER_ALIGNED(16) DmacDescriptor compare_dma_descriptor
SECTION_DMAC_DESCRIPTOR;
```

```
struct dma_descriptor_config descriptor_config;

dma_descriptor_get_config_defaults(&descriptor_config);

descriptor_config.block_transfer_count = 3;
descriptor_config.beat_size = DMA_BEAT_SIZE_HWORD;
descriptor_config.dst_increment_enable = false;
descriptor_config.source_address =
        (uint32_t)compare_values + sizeof(compare_values);
#if (SAMR21) || (SAMD21) || (SAMDA1)
    descriptor_config.destination_address =
        (uint32_t)&CONF_PWM_MODULE->CC[CONF_PWM_CHANNEL];
#else
descriptor_config.destination_address =
        (uint32_t)&CONF_PWM_MODULE->CCBUF[CONF_PWM_CHANNEL];
#endif

dma_descriptor_create(&compare_dma_descriptor, &descriptor_config);
```

3. Start DMA transfer job with prepared descriptor.

```
dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
dma_add_descriptor(&compare_dma_resource, &compare_dma_descriptor);
dma_start_transfer_job(&compare_dma_resource);
```

4. Enable the TCC module to start the timer and begin PWM signal generation.

```
tcc_enable(&tcc_instance);
```

27.8.7.2. Use Case

Code

Copy-paste the following code to your user application:

```
while (true) {
    /* Infinite loop */
}
```

Workflow

1. Enter an infinite loop while the PWM wave is generated via the TCC module.

```
while (true) {
    /* Infinite loop */
}
```

28. SAM Temperature Sensor (TSENS) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Configurable Custom Logic functionality.

The following peripheral is used by this module:

- TSENS (Temperature Sensor)

The following devices can use this module:

- Atmel | SMART SAM C21

The outline of this documentation is as follows:

28.1. Prerequisites

There are no prerequisites for this module.

28.2. Module Overview

The Temperature Sensor (TSENS) can be used to accurately measure the operating temperature of the device. TSENS accurately measures the operating temperature of the device by comparing the difference in two temperature dependent frequencies to a known frequency. The frequency of the temperature dependent oscillator (TOSC) is measured twice: first with the min configuration and next with the maximum configuration. The resulting signed value is proportional to the temperature and is corrected for offset by the contents of the OFFSET register.

Accurately measures a temperature:

- ±1°C over 0°C ~ 60°C
- ±3°C over -40°C ~ 85°C
- ±5°C over -40°C ~ 105°C

The number of periods of GCLK_TSENS used for the measurement is defined by the GAIN register. The width of the resulting pulse is measured using a counter clocked by GCLK_TSENS in the up direction for the 1st phase and in the down 2nd phase. Register GAIN and OFFSET is loaded from NVM, or can also be fixed by user.

$$VALUE = OFFSET + \left(\frac{f_{TOSCMIN} - f_{TOSCMAX}}{f_{GCLK}}\right) \times GAIN$$

Note: If fix this bitfield, the relationship between GCLK frequency, GAIN and resolution as below:

Resolution (#/°C)	GAIN@48MHz	GAIN@40MHz
1 (1°C)	960	800
10 (0.1°C)	9600	8000
100 (0.01°C)	96000	80000

28.2.1. Window Monitor

The TSENS module window monitor function can be used to automatically compare the conversion result against a predefined pair of upper and lower threshold values.

28.2.2. Events

Event generation and event actions are configurable in the TSENS.

The TSENS has one actions that can be triggered upon event reception:

- Start conversion

The TSENS can generate the following output event:

- Window monitor

If the event actions are enabled in the configuration, any incoming event will trigger the action.

If the window monitor event is enabled, an event will be generated when the configured window condition is detected.

28.3. Special Considerations

There are no special considerations for this module.

28.4. Extra Information

For extra information, see Extra Information for TSENS Driver. This includes:

- Acronym
- Dependencies
- Errata
- Module History

28.5. Examples

For a list of examples related to this driver, see Examples for TSENS Driver.

28.6. API Overview

28.6.1. Variable and Type Definitions

28.6.1.1. Type tsens_callback_t

```
typedef void(* tsens_callback_t )(enum tsens_callback)
```

Type of the callback functions.

28.6.2. Structure Definitions

28.6.2.1. Struct tsens_calibration

Calibration configuration structure.

Table 28-1. Members

Type	Name	Description
uint32_t	gain	Time amplifier gain
int32_t	offset	Offset correction

28.6.2.2. Struct tsens_config

Configuration structure for an TSENS instance. This structure should be initialized by the tsens_get_config_defaults() function before being modified by the user application.

Table 28-2. Members

Type	Name	Description
struct tsens_calibration	calibration	Calibration value
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral
enum tsens_event_action	event_action	Event action to take on incoming event
bool	free_running	Enables free running mode if true
bool	run_in_standby	Enables TSENS in standby sleep mode if true
struct tsens_window_config	window	Window monitor configuration structure

28.6.2.3. Struct tsens_events

Event flags for the TSENS module. This is used to enable and disable events via tsens_enable_events() and tsens_disable_events().

Table 28-3. Members

Type	Name	Description
bool	generate_event_on_window_monitor	Enable event generation on window monitor

28.6.2.4. Struct tsens_module

TSENS software instance structure, used to retain software state information of an associated hardware module instance.

Note: The fields of this structure should not be altered by the user application; they are reserved for module-internal use only.

28.6.2.5. Struct tsens_window_config

Window monitor configuration structure.

Table 28-4. Members

Type	Name	Description
int32_t	window_lower_value	Lower window value
enum tsens_window_mode	window_mode	Selected window mode
int32_t	window_upper_value	Upper window value

28.6.3. Macro Definitions

28.6.3.1. Module Status Flags

TSENS status flags, returned by tsens_get_status() and cleared by tsens_clear_status().

Macro TSENS_STATUS_RESULT_READY

```
#define TSENS_STATUS_RESULT_READY
```

TSENS result ready.

Macro TSENS_STATUS_OVERRUN

```
#define TSENS_STATUS_OVERRUN
```

TSENS result overwritten before read.

Macro TSENS_STATUS_WINDOW

```
#define TSENS_STATUS_WINDOW
```

Window monitor match.

Macro TSENS_STATUS_OVERFLOW

```
#define TSENS_STATUS_OVERFLOW
```

TSENS result overflows.

28.6.3.2. Macro ERRATA_14476

```
#define ERRATA_14476
```

The magnitude of the temperature measurement value decreases with increasing temperature, i.e. it has a negative temperature coefficient. Errata reference: 14476.

28.6.4. Function Definitions

28.6.4.1. Driver Initialization and Configuration

Function tsens_init()

Initializes the TSENS.

```
enum status_code tsens_init(
        struct tsens_config * config)
```

Initializes the TSENS device struct and the hardware module based on the given configuration struct values.

Table 28-5. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to the configuration struct

Returns
Status of the initialization procedure.

Table 28-6. Return Values

Return value	Description
STATUS_OK	The initialization was successful
STATUS_ERR_INVALID_ARG	Invalid argument(s) were provided
STATUS_BUSY	The module is busy with a reset operation
STATUS_ERR_DENIED	The module is enabled

Function tsens_get_config_defaults()

Initializes an TSENS configuration structure to defaults.

```
void tsens_get_config_defaults(
        struct tsens_config *const config)
```

Initializes a given TSENS configuration struct to a set of known default values. This function should be called on any new instance of the configuration struct before being modified by the user application.

The default configuration is as follows:

- GCLK generator 0 (GCLK main) clock source
- All events (input and generation) disabled
- Free running disabled
- Run in standby disabled
- Window monitor disabled
- Register GAIN value
- Register OFFSET value

Note: Register GAIN and OFFSET is loaded from NVM, or can also be fixed. If this bitfield is to be fixed, pay attention to the relationship between GCLK frequency, GAIN, and resolution. See Chapter Module Overview.

Table 28-7. Parameters

Data direction	Parameter name	Description
[out]	config	Pointer to configuration struct to initialize to default values

28.6.4.2. Status Management

Function tsens_get_status()

Retrieves the current module status.

```
uint32_t tsens_get_status( void )
```

Retrieves the status of the module, giving overall state information.

Returns
Bit mask of TSENS status flags.

Table 28-8. Return Values

Return value	Description
TSENS_STATUS_RESULT_READY	TSENS result is ready to be read
TSENS_STATUS_OVERRUN	TSENS result overwritten before read
TSENS_STATUS_WINDOW	TSENS has detected a value inside the set window range
TSENS_STATUS_OVERFLOW	TSENS result overflows

Function tsens_clear_status()

Clears a module status flag.

```
void tsens_clear_status(
        const uint32_t status_flags)
```

Clears the given status flag of the module.

Table 28-9. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TSENS software instance struct
[in]	status_flags	Bitmask of `TSENS_STATUS_*` flags to clear

28.6.4.3. Enable, Disable, and Reset TSENS Module, Start Conversion and Read Result

Function tsens_is_syncing()

Determines if the hardware module is currently synchronizing to the bus.

```
bool tsens_is_syncing( void )
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns
Synchronization status of the underlying hardware module(s).

Table 28-10. Return Values

Return value	Description
true	If the module synchronization is ongoing
false	If the module has completed synchronization

Function tsens_enable()

Enables the TSENS module.

```
void tsens_enable( void )
```

Enables an TSENS module that has previously been configured.

Function tsens_disable()

Disables the TSENS module.

```
void tsens_disable( void )
```

Disables an TSENS module that was previously enabled.

Function tsens_reset()

Resets the TSENS module.

```
void tsens_reset( void )
```

Resets an TSENS module, clearing all module state and registers to their default values.

Function tsens_enable_events()

Enables an TSENS event output.

```
void tsens_enable_events(
        struct tsens_events *const events)
```

Enables one or more input or output events to or from the TSENS module. See tsens_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 28-11. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to enable

Function tsens_disable_events()

Disables an TSENS event output.

```
void tsens_disable_events(
        struct tsens_events *const events)
```

Disables one or more output events to or from the TSENS module. See tsens_events for a list of events this module supports.

Note: Events cannot be altered while the module is enabled.

Table 28-12. Parameters

Data direction	Parameter name	Description
[in]	events	Struct containing flags of events to disable

Function tsens_start_conversion()

Start a TSENS conversion.

```
void tsens_start_conversion( void )
```

Start a new TSENS conversion.

Function tsens_read()

Reads the TSENS result.

```
enum status_code tsens_read(
        int32_t * result)
```

Reads the result from a TSENS conversion that was previously started.

Table 28-13. Parameters

Data direction	Parameter name	Description
[out]	result	Pointer to store the result value in

Returns
Status of the TSENS read request.

Table 28-14. Return Values

Return value	Description
STATUS_OK	The result was retrieved successfully
STATUS_BUSY	A conversion result was not ready
STATUS_ERR_OVERFLOW	The result register has been overwritten by the TSENS module before the result was read by the software

28.6.4.4. Callback Management

Function tsens_register_callback()

Registers a callback.

```
enum status_code tsens_register_callback(
        struct tsens_module *const module,
        tsens_callback_t callback_func,
        enum tsens_callback callback_type)
```

Registers a callback function which is implemented by the user.

Note: The callback must be enabled by for the interrupt handler to call it when the condition for the callback is met.

Table 28-15. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to TSENS software instance struct
[in]	callback_func	Pointer to callback function
[in]	callback_type	Callback type given by an enum

Function tsens_unregister_callback()

Unregisters a callback.

```
enum status_code tsens_unregister_callback(
        struct tsens_module *const module,
        enum tsens_callback callback_type)
```

Unregisters a callback function which is implemented by the user.

Table 28-16. Parameters

Data direction	Parameter name	Description
[in]	module	Pointer to TSENS software instance struct
[in]	callback_type	Callback type given by an enum

Function tsens_enable_callback()

Enables callback.

```
void tsens_enable_callback(
        enum tsens_callback callback_type)
```

Enables the callback function registered by tsens_register_callback. The callback function will be called from the interrupt handler when the conditions for the callback type are met.

Table 28-17. Parameters

Data direction	Parameter name	Description
[in]	callback_type	Callback type given by an enum

Function tsens_disable_callback()

Disables callback.

```
void tsens_disable_callback(
        enum tsens_callback callback_type)
```

Disables the callback function registered by the tsens_register_callback.

Table 28-18. Parameters

Data direction	Parameter name	Description
[in]	callback_type	Callback type given by an enum

Function tsens_read_job()

Read result from TSENS.

```
void tsens_read_job(
        struct tsens_module *const module_inst,
        int32_t * result)
```

Table 28-19. Parameters

Data direction	Parameter name	Description
[in]	module_inst	Pointer to the TSENS software instance struct
[out]	result	Pointer to store the TSENS result

28.6.5. Enumeration Definitions

28.6.5.1. Enum tsens_callback

Callback types for TSENS callback driver.

Table 28-20. Members

Enum value	Description
TSENS_CALLBACK_RESULT_READY	Callback for result ready
TSENS_CALLBACK_OVERRUN	Callback when result overwritten before read
TSENS_CALLBACK_WINDOW	Callback when window is hit
TSENS_CALLBACK_OVF	Callback when the result overflows

28.6.5.2. Enum tsens_event_action

Enum for the possible actions to take on an incoming event.

Table 28-21. Members

Enum value	Description
TSENS_EVENT_ACTION_DISABLED	Event action disabled
TSENS_EVENT_ACTION_START_CONV	Start conversion

28.6.5.3. Enum tsens_window_mode

Enum for the possible window monitor modes for the TSENS.

Table 28-22. Members

Enum value	Description
TSENS_WINDOW_MODE_DISABLE	No window mode
TSENS_WINDOW_MODE_ABOVE	RESULT > WINLT
TSENS_WINDOW_MODE_BELOW	RESULT < WINUT

Enum value	Description
TSENS_WINDOW_MODE_INSIDE	WINLT < RESULT < WINUT
TSENS_WINDOW_MODE_OUTSIDE	!(WINLT < RESULT < WINUT)
TSENS_WINDOW_MODE_HYST_ABOVE	VALUE > WINUT with hysteresis to WINLT
TSENS_WINDOW_MODE_HYST_BELOW	VALUE < WINLT with hysteresis to WINUT

28.7. Extra Information for TSENS Driver

28.7.1. Acronym

Below is a table listing the acronym used in this module, along with their intended meaning.

Acronym	Description
TSENS	Temperature Sensor

28.7.2. Dependencies

This driver has no dependencies.

28.7.3. Errata

Errata reference: 14476.

The magnitude of the temperature measurement value decreases with increasing temperature, i.e. it has a negative temperature coefficient.

28.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

28.8. Examples for TSENS Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Temperature Sensor (TSENS) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for TSENS - Basic
- Quick Start Guide for TSENS - Callback

28.8.1. Quick Start Guide for TSENS - Basic

In this use case, the TSENS will be configured with the following settings:

- GCLK generator 0 (GCLK main) clock source
- Free running disabled
- Run in standby
- Window monitor disabled
- All events (input and generation) disabled
- Calibration value which read from NVM or user set

28.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Copy-paste the following setup code to your user application:

```
void configure_tsens(void)
{
    struct tsens_config config_tsens;
    tsens_get_config_defaults(&config_tsens);

    tsens_init(&config_tsens);

    tsens_enable();
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tsens();
```

Workflow

1. Configure the TSENS module.
    1. Create a TSENS module configuration struct, which can be filled out to adjust the configuration of a physical TSENS peripheral.

        ```
        struct tsens_config config_tsens;
        ```

    2. Initialize the TSENS configuration struct with the module's default values.

        ```
        tsens_get_config_defaults(&config_tsens);
        ```

        Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.
    3. Set TSENS configurations.

        ```
        tsens_init(&config_tsens);
        ```

    4. Enable the TSENS module so that conversions can be made.

        ```
        tsens_enable();
        ```

28.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
int32_t result;

tsens_start_conversion();

do {
    /* Wait for conversion to be done and read out result */
```

```
} while (tsens_read(&result) != STATUS_OK);

while (1) {
     /* Infinite loop */
}
```

Workflow

1. Start conversion.

```
tsens_start_conversion();
```

2. Wait until conversion is done and read result.

```
int32_t result;

tsens_start_conversion();

do {
     /* Wait for conversion to be done and read out result */
} while (tsens_read(&result) != STATUS_OK);
```

3. Enter an infinite loop once the conversion is complete.

```
while (1) {
     /* Infinite loop */
}
```

28.8.2. Quick Start Guide for TSENS - Callback

In this use case, the TSENS will measure the temperature using interrupt driven conversion. When the temperature value has been measured, a callback will be called that signals the main application that the conversion is complete.

The TSENS will be set up as follows:

- GCLK generator 0 (GCLK main) clock source
- Free running disabled
- Run in standby
- Window monitor disabled
- All events (input and generation) disabled
- Calibration value which read from NVM or user set

28.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Add to the main application source file, outside of any functions:

```
struct tsens_module tsens_instance;
```

```
int32_t tsens_result;
```

Callback function:

```
volatile bool tsens_read_done = false;

static void tsens_complete_callback(enum tsens_callback i)
{
```

```
    tsens_read_done = true;
}
```

Copy-paste the following setup code to your user application:

```
static void configure_tsens(void)
{
    struct tsens_config config_tsens;
    tsens_get_config_defaults(&config_tsens);

    tsens_init(&config_tsens);

    tsens_enable();
}

static void configure_tsens_callbacks(void)
{
    tsens_register_callback(&tsens_instance,
            tsens_complete_callback, TSENS_CALLBACK_RESULT_READY);
    tsens_enable_callback(TSENS_CALLBACK_RESULT_READY);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_tsens();
configure_tsens_callbacks();
```

Workflow

1. Create a module software instance structure for the TSENS module to store the TSENS driver state while it is in use.

   ```
   struct tsens_module tsens_instance;
   ```

   Note: This should never go out of scope as long as the module is in use. In most cases, this should be global.
2. Create a variable for the TSENS sample to be stored in by the driver asynchronously.

   ```
   int32_t tsens_result;
   ```
3. Create a callback function that will be called each time the TSENS completes an asynchronous read job.

   ```
   volatile bool tsens_read_done = false;

   static void tsens_complete_callback(enum tsens_callback i)
   {
       tsens_read_done = true;
   }
   ```
4. Configure the TSENS module.
   1. Create a TSENS module configuration struct, which can be filled out to adjust the configuration of a physical TSENS peripheral.

      ```
      struct tsens_config config_tsens;
      ```
   2. Initialize the TSENS configuration struct with the module's default values.

      ```
      tsens_get_config_defaults(&config_tsens);
      ```

      Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Set TSENS configurations.

```
tsens_init(&config_tsens);
```

4. Enable the TSENS module so that conversions can be made.

```
tsens_enable();
```

5. Register and enable the TSENS read complete callback handler.
    1. Register the user-provided read complete callback function with the driver, so that it will be run when an asynchronous read job completes.

```
tsens_register_callback(&tsens_instance,
        tsens_complete_callback, TSENS_CALLBACK_RESULT_READY);
```

    2. Enable the read complete callback so that it will generate callbacks.

```
tsens_enable_callback(TSENS_CALLBACK_RESULT_READY);
```

28.8.2.2. Use Case

Code

Copy-paste the following code to your user application:

```
system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_TSENS);
system_interrupt_enable_global();

tsens_read_job(&tsens_instance, &tsens_result);

while (tsens_read_done == false) {
    /* Wait for asynchronous TSENS read to complete */
}

while (1) {
    /* Infinite loop */
}
```

Workflow

1. Enable interrupts, so that callbacks can be generated by the driver.

```
system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_TSENS);
system_interrupt_enable_global();
```

2. Start an asynchronous TSENS conversion, to store TSENS sample into the variable and generate a callback when complete.

```
tsens_read_job(&tsens_instance, &tsens_result);
```

3. Wait until the asynchronous conversion is complete.

```
while (tsens_read_done == false) {
    /* Wait for asynchronous TSENS read to complete */
}
```

4. Enter an infinite loop once the conversion is complete.

```
while (1) {
    /* Infinite loop */
}
```

29. SAM Watchdog (WDT) Driver

This driver for Atmel® | SMART ARM®-based microcontrollers provides an interface for the configuration and management of the device's Watchdog Timer module, including the enabling, disabling, and kicking within the device. The following driver API modes are covered by this manual:

- Polled APIs
- Callback APIs

The following peripherals are used by this module:

- WDT (Watchdog Timer)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D09/D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM DA1
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM R30

The outline of this documentation is as follows:

29.1. Prerequisites

There are no prerequisites for this module.

29.2. Module Overview

The Watchdog module (WDT) is designed to give an added level of safety in critical systems, to ensure a system reset is triggered in the case of a deadlock or other software malfunction that prevents normal device operation.

At a basic level, the Watchdog is a system timer with a fixed period; once enabled, it will continue to count ticks of its asynchronous clock until it is periodically reset, or the timeout period is reached. In the event of a Watchdog timeout, the module will trigger a system reset identical to a pulse of the device's reset pin, resetting all peripherals to their power-on default states and restarting the application software from the reset vector.

In many systems, there is an obvious upper bound to the amount of time each iteration of the main application loop can be expected to run, before a malfunction can be assumed (either due to a deadlock waiting on hardware or software, or due to other means). When the Watchdog is configured with a

timeout period equal to this upper bound, a malfunction in the system will force a full system reset to allow for a graceful recovery.

29.2.1. Locked Mode

The Watchdog configuration can be set in the device fuses and locked in hardware, so that no software changes can be made to the Watchdog configuration. Additionally, the Watchdog can be locked on in software if it is not already locked, so that the module configuration cannot be modified until a power on reset of the device.

The locked configuration can be used to ensure that faulty software does not cause the Watchdog configuration to be changed, preserving the level of safety given by the module.

29.2.2. Window Mode

Just as there is a reasonable upper bound to the time the main program loop should take for each iteration, there is also in many applications a lower bound, i.e. a *minimum* time for which each loop iteration should run for under normal circumstances. To guard against a system failure resetting the Watchdog in a tight loop (or a failure in the system application causing the main loop to run faster than expected) a "Window" mode can be enabled to disallow resetting of the Watchdog counter before a certain period of time. If the Watchdog is not reset *after* the window opens but not *before* the Watchdog expires, the system will reset.

29.2.3. Early Warning

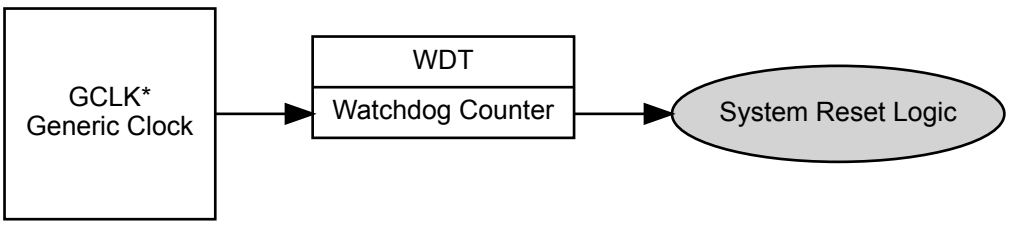
In some cases it is desirable to receive an early warning that the Watchdog is about to expire, so that some system action (such as saving any system configuration data for failure analysis purposes) can be performed before the system reset occurs. The Early Warning feature of the Watchdog module allows such a notification to be requested; after the configured early warning time (but before the expiry of the Watchdog counter) the Early Warning flag will become set, so that the user application can take an appropriate action.

Note: It is important to note that the purpose of the Early Warning feature is *not* to allow the user application to reset the Watchdog; doing so will defeat the safety the module gives to the user application. Instead, this feature should be used purely to perform any tasks that need to be undertaken before the system reset occurs.

29.2.4. Physical Connection

Figure 29-1 shows how this module is interconnected within the device.

Figure 29-1. Physical Connection



Note: Watchdog Counter of SAM L21/L22/R30 is *not* provided by GCLK, but it uses an internal 1KHz OSCULP32K output clock.

29.3. Special Considerations

On some devices the Watchdog configuration can be fused to be always on in a particular configuration; if this mode is enabled the Watchdog is not software configurable and can have its count reset and early warning state checked/cleared only.

29.4. Extra Information

For extra information, see Extra Information for WDT Driver. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

29.5. Examples

For a list of examples related to this driver, see Examples for WDT Driver.

29.6. API Overview

29.6.1. Variable and Type Definitions

29.6.1.1. Callback Configuration and Initialization

Type wdt_callback_t

```
typedef void(* wdt_callback_t )(void)
```

Type definition for a WDT module callback function.

29.6.2. Structure Definitions

29.6.2.1. Struct wdt_conf

Configuration structure for a Watchdog Timer instance. This structure should be initialized by the wdt_get_config_defaults() function before being modified by the user application.

Table 29-1. Members

Type	Name	Description
bool	always_on	If `true`, the Watchdog will be locked to the current configuration settings when the Watchdog is enabled
enum gclk_generator	clock_source	GCLK generator used to clock the peripheral except SAM L21/L22/C21/C20/R30
enum wdt_period	early_warning_period	Number of Watchdog timer clock ticks until the early warning flag is set

Type	Name	Description
bool	enable	Enable/Disable the Watchdog Timer
enum wdt_period	timeout_period	Number of Watchdog timer clock ticks until the Watchdog expires
enum wdt_period	window_period	Number of Watchdog timer clock ticks until the reset window opens

29.6.3. Function Definitions

29.6.3.1. Configuration and Initialization

Function wdt_is_syncing()

Determines if the hardware module(s) are currently synchronizing to the bus.

```
bool wdt_is_syncing( void )
```

Checks to see if the underlying hardware peripheral module(s) are currently synchronizing across multiple clock domains to the hardware bus. This function can be used to delay further operations on a module until such time that it is ready, to prevent blocking delays for synchronization in the user application.

Returns
Synchronization status of the underlying hardware module(s).

Table 29-2. Return Values

Return value	Description
false	If the module has completed synchronization
true	If the module synchronization is ongoing

Function wdt_get_config_defaults()

Initializes a Watchdog Timer configuration structure to defaults.

```
void wdt_get_config_defaults(
        struct wdt_conf *const config)
```

Initializes a given Watchdog Timer configuration structure to a set of known default values. This function should be called on all new instances of these configuration structures before being modified by the user application.

The default configuration is as follows:

- Not locked, to allow for further (re-)configuration
- Enable WDT
- Watchdog timer sourced from Generic Clock Channel 4
- A timeout period of 16384 clocks of the Watchdog module clock
- No window period, so that the Watchdog count can be reset at any time
- No early warning period to indicate the Watchdog will soon expire

Table 29-3. Parameters

Data direction	Parameter name	Description
[out]	config	Configuration structure to initialize to default values

Function wdt_set_config()

Sets up the WDT hardware module based on the configuration.

```
enum status_code wdt_set_config(
        const struct wdt_conf *const config)
```

Writes a given configuration of a WDT configuration to the hardware module, and initializes the internal device struct.

Table 29-4. Parameters

Data direction	Parameter name	Description
[in]	config	Pointer to the configuration struct

Returns
Status of the configuration procedure.

Table 29-5. Return Values

Return value	Description
STATUS_OK	If the module was configured correctly
STATUS_ERR_INVALID_ARG	If invalid argument(s) were supplied
STATUS_ERR_IO	If the Watchdog module is locked to be always on

Function wdt_is_locked()

Determines if the Watchdog timer is currently locked in an enabled state.

```
bool wdt_is_locked( void )
```

Determines if the Watchdog timer is currently enabled and locked, so that it cannot be disabled or otherwise reconfigured.

Returns
Current Watchdog lock state.

29.6.3.2. Timeout and Early Warning Management

Function wdt_clear_early_warning()

Clears the Watchdog timer early warning period elapsed flag.

```
void wdt_clear_early_warning( void )
```

Clears the Watchdog timer early warning period elapsed flag, so that a new early warning period can be detected.

Function wdt_is_early_warning()

Determines if the Watchdog timer early warning period has elapsed.

```
bool wdt_is_early_warning( void )
```

Determines if the Watchdog timer early warning period has elapsed.

Note: If no early warning period was configured, the value returned by this function is invalid.

Returns
Current Watchdog Early Warning state.

Function wdt_reset_count()

Resets the count of the running Watchdog Timer that was previously enabled.

```
void wdt_reset_count( void )
```

Resets the current count of the Watchdog Timer, restarting the timeout period count elapsed. This function should be called after the window period (if one was set in the module configuration) but before the timeout period to prevent a reset of the system.

29.6.3.3. Callback Configuration and Initialization

Function wdt_register_callback()

Registers an asynchronous callback function with the driver.

```
enum status_code wdt_register_callback(
        const wdt_callback_t callback,
        const enum wdt_callback type)
```

Registers an asynchronous callback with the WDT driver, fired when a given criteria (such as an Early Warning) is met. Callbacks are fired once for each event.

Table 29-6. Parameters

Data direction	Parameter name	Description
[in]	callback	Pointer to the callback function to register
[in]	type	Type of callback function to register

Returns
Status of the registration operation.

Table 29-7. Return Values

Return value	Description
STATUS_OK	The callback was registered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

Function wdt_unregister_callback()

Unregisters an asynchronous callback function with the driver.

```
enum status_code wdt_unregister_callback(
        const enum wdt_callback type)
```

Unregisters an asynchronous callback with the WDT driver, removing it from the internal callback registration table.

Table 29-8. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to unregister

Returns
Status of the de-registration operation.

Table 29-9. Return Values

Return value	Description
STATUS_OK	The callback was Unregistered successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

29.6.3.4. Callback Enabling and Disabling

Function wdt_enable_callback()

Enables asynchronous callback generation for a given type.

```
enum status_code wdt_enable_callback(
        const enum wdt_callback type)
```

Enables asynchronous callbacks for a given callback type. This must be called before an external interrupt channel will generate callback events.

Table 29-10. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to enable

Returns
Status of the callback enable operation.

Table 29-11. Return Values

Return value	Description
STATUS_OK	The callback was enabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

Function wdt_disable_callback()

Disables asynchronous callback generation for a given type.

```
enum status_code wdt_disable_callback(
        const enum wdt_callback type)
```

Disables asynchronous callbacks for a given callback type.

Table 29-12. Parameters

Data direction	Parameter name	Description
[in]	type	Type of callback function to disable

Returns
Status of the callback disable operation.

Table 29-13. Return Values

Return value	Description
STATUS_OK	The callback was disabled successfully
STATUS_ERR_INVALID_ARG	If an invalid callback type was supplied

29.6.4. Enumeration Definitions

29.6.4.1. Callback Configuration and Initialization

Enum wdt_callback

Enum for the possible callback types for the WDT module.

Table 29-14. Members

Enum value	Description
WDT_CALLBACK_EARLY_WARNING	Callback type for when an early warning callback from the WDT module is issued

29.6.4.2. Enum wdt_period

Enum for the possible period settings of the Watchdog timer module, for values requiring a period as a number of Watchdog timer clock ticks.

Table 29-15. Members

Enum value	Description
WDT_PERIOD_NONE	No Watchdog period. This value can only be used when setting the Window and Early Warning periods; its use as the Watchdog Reset Period is invalid.
WDT_PERIOD_8CLK	Watchdog period of 8 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_16CLK	Watchdog period of 16 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_32CLK	Watchdog period of 32 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_64CLK	Watchdog period of 64 clocks of the Watchdog Timer Generic Clock

Enum value	Description
WDT_PERIOD_128CLK	Watchdog period of 128 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_256CLK	Watchdog period of 256 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_512CLK	Watchdog period of 512 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_1024CLK	Watchdog period of 1024 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_2048CLK	Watchdog period of 2048 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_4096CLK	Watchdog period of 4096 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_8192CLK	Watchdog period of 8192 clocks of the Watchdog Timer Generic Clock
WDT_PERIOD_16384CLK	Watchdog period of 16384 clocks of the Watchdog Timer Generic Clock

29.7. Extra Information for WDT Driver

29.7.1. Acronyms

The table below presents the acronyms used in this module:

Acronym	Description
WDT	Watchdog Timer

29.7.2. Dependencies

This driver has the following dependencies:

- System Clock Driver

29.7.3. Errata

There are no errata related to this driver.

29.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Driver updated to follow driver type convention: • wdt_init, wdt_enable, wdt_disable functions removed • wdt_set_config function added • WDT module enable state moved inside the configuration struct
Initial Release

29.8. Examples for WDT Driver

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Watchdog (WDT) Driver. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for WDT - Basic
- Quick Start Guide for WDT - Callback

29.8.1. Quick Start Guide for WDT - Basic

In this use case, the Watchdog module is configured for:

- System reset after 2048 clocks of the Watchdog generic clock
- Always on mode disabled
- Basic mode, with no window or early warning periods

This use case sets up the Watchdog to force a system reset after every 2048 clocks of the Watchdog's Generic Clock channel, unless the user periodically resets the Watchdog counter via a button before the timer expires. If the Watchdog resets the device, a LED on the board is turned off.

29.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_wdt(void)
{
    /* Create a new configuration structure for the Watchdog settings and fill
    * with the default module settings. */
    struct wdt_conf config_wdt;
    wdt_get_config_defaults(&config_wdt);

    /* Set the Watchdog configuration settings */
    config_wdt.always_on      = false;
#if !((SAML21) || (SAMC21) || (SAML22) || (SAMR30))
    config_wdt.clock_source   = GCLK_GENERATOR_4;
#endif
    config_wdt.timeout_period = WDT_PERIOD_2048CLK;

    /* Initialize and enable the Watchdog with the user settings */
    wdt_set_config(&config_wdt);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_wdt();
```

Workflow

1. Create a Watchdog module configuration struct, which can be filled out to adjust the configuration of the Watchdog.

   ```
   struct wdt_conf config_wdt;
   ```

2. Initialize the Watchdog configuration struct with the module's default values.

```
wdt_get_config_defaults(&config_wdt);
```

Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

3. Adjust the configuration struct to set the timeout period and lock mode of the Watchdog.

```
config_wdt.always_on      = false;
#if !((SAML21) || (SAMC21) || (SAML22) || (SAMR30))
    config_wdt.clock_source   = GCLK_GENERATOR_4;
#endif
    config_wdt.timeout_period = WDT_PERIOD_2048CLK;
```

4. Setups the WDT hardware module with the requested settings.

```
wdt_set_config(&config_wdt);
```

29.8.1.2. Quick Start Guide for WDT - Basic

Code

Copy-paste the following code to your user application:

```
enum system_reset_cause reset_cause = system_get_reset_cause();

if (reset_cause == SYSTEM_RESET_CAUSE_WDT) {
    port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
}
else {
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}

while (true) {
    if (port_pin_get_input_level(BUTTON_0_PIN) == false) {
        port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);

        wdt_reset_count();
    }
}
```

Workflow

1. Retrieve the cause of the system reset to determine if the Watchdog module was the cause of the last reset.

```
enum system_reset_cause reset_cause = system_get_reset_cause();
```

2. Turn on or off the board LED based on whether the Watchdog reset the device.

```
if (reset_cause == SYSTEM_RESET_CAUSE_WDT) {
    port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
}
else {
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}
```

3. Enter an infinite loop to hold the main program logic.

```
while (true) {
```

4. Test to see if the board button is currently being pressed.

```
if (port_pin_get_input_level(BUTTON_0_PIN) == false) {
```

5. If the button is pressed, turn on the board LED and reset the Watchdog timer.

```
port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);

wdt_reset_count();
```

29.8.2. Quick Start Guide for WDT - Callback

In this use case, the Watchdog module is configured for:

- System reset after 4096 clocks of the Watchdog generic clock
- Always on mode disabled
- Early warning period of 2048 clocks of the Watchdog generic clock

This use case sets up the Watchdog to force a system reset after every 4096 clocks of the Watchdog's Generic Clock channel, with an Early Warning callback being generated every 2048 clocks. Each time the Early Warning interrupt fires the board LED is turned on, and each time the device resets the board LED is turned off, giving a periodic flashing pattern.

29.8.2.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void watchdog_early_warning_callback(void)
{
    port_pin_set_output_level(LED_0_PIN, LED_0_ACTIVE);
}

void configure_wdt(void)
{
    /* Create a new configuration structure for the Watchdog settings and fill
    * with the default module settings. */
    struct wdt_conf config_wdt;
    wdt_get_config_defaults(&config_wdt);

    /* Set the Watchdog configuration settings */
    config_wdt.always_on            = false;
#if !((SAML21) || (SAMC21) || (SAML22) || (SAMR30))
    config_wdt.clock_source         = GCLK_GENERATOR_4;
#endif
    config_wdt.timeout_period       = WDT_PERIOD_4096CLK;
    config_wdt.early_warning_period = WDT_PERIOD_2048CLK;

    /* Initialize and enable the Watchdog with the user settings */
    wdt_set_config(&config_wdt);
}

void configure_wdt_callbacks(void)
{
    wdt_register_callback(watchdog_early_warning_callback,
        WDT_CALLBACK_EARLY_WARNING);

    wdt_enable_callback(WDT_CALLBACK_EARLY_WARNING);
}
```

Add to user application initialization (typically the start of `main()`):

```
configure_wdt();
configure_wdt_callbacks();
```

Workflow

1. Configure and enable the Watchdog driver.
    1. Create a Watchdog module configuration struct, which can be filled out to adjust the configuration of the Watchdog.

        ```
        struct wdt_conf config_wdt;
        ```

    2. Initialize the Watchdog configuration struct with the module's default values.

        ```
        wdt_get_config_defaults(&config_wdt);
        ```

        Note: This should always be performed before using the configuration struct to ensure that all values are initialized to known default settings.

    3. Adjust the configuration struct to set the timeout and early warning periods of the Watchdog.

        ```
        config_wdt.always_on            = false;
        #if !((SAML21) || (SAMC21) || (SAML22) || (SAMR30))
            config_wdt.clock_source         = GCLK_GENERATOR_4;
        #endif
            config_wdt.timeout_period       = WDT_PERIOD_4096CLK;
        config_wdt.early_warning_period = WDT_PERIOD_2048CLK;
        ```

    4. Sets up the WDT hardware module with the requested settings.

        ```
        wdt_set_config(&config_wdt);
        ```

2. Register and enable the Early Warning callback handler.
    1. Register the user-provided Early Warning callback function with the driver, so that it will be run when an Early Warning condition occurs.

        ```
        wdt_register_callback(watchdog_early_warning_callback,
            WDT_CALLBACK_EARLY_WARNING);
        ```

    2. Enable the Early Warning callback so that it will generate callbacks.

        ```
        wdt_enable_callback(WDT_CALLBACK_EARLY_WARNING);
        ```

29.8.2.2. Quick Start Guide for WDT - Callback

Code

Copy-paste the following code to your user application:

```
port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);

system_interrupt_enable_global();

while (true) {
    /* Wait for callback */
}
```

Workflow

1. Turn off the board LED when the application starts.

    ```
    port_pin_set_output_level(LED_0_PIN, LED_0_INACTIVE);
    ```

2. Enable global interrupts so that callbacks can be generated.

```
system_interrupt_enable_global();
```

3. Enter an infinite loop to hold the main program logic.

```
while (true) {
     /* Wait for callback */
}
```

30. SAM EEPROM Emulator (EEPROM) Service

This driver for Atmel® | SMART ARM®-based microcontrollers provides an emulated EEPROM memory space in the device's FLASH memory, for the storage and retrieval of user-application configuration data into and out of non-volatile memory.

The following peripherals are used by this module:

- NVM (Non-Volatile Memory Controller)

The following devices can use this module:

- Atmel | SMART SAM D20/D21
- Atmel | SMART SAM R21
- Atmel | SMART SAM D10/D11
- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM DA1

The outline of this documentation is as follows:

30.1. Prerequisites

The SAM device fuses must be configured via an external programmer or debugger, so that an EEPROM section is allocated in the main NVM flash memory contents. If a NVM section is not allocated for the EEPROM emulator, or if insufficient space for the emulator is reserved, the module will fail to initialize.

30.2. Module Overview

As the SAM devices do not contain any physical EEPROM memory, the storage of non-volatile user data is instead emulated using a special section of the device's main FLASH memory. The use of FLASH memory technology over EEPROM presents several difficulties over true EEPROM memory; data must be written as a number of physical memory pages (of several bytes each) rather than being individually byte addressable, and entire rows of FLASH must be erased before new data may be stored. To help abstract these characteristics away from the user application an emulation scheme is implemented to present a more user-friendly API for data storage and retrieval.

This module provides an EEPROM emulation layer on top of the device's internal NVM controller, to provide a standard interface for the reading and writing of non-volatile configuration data. This data is placed into the EEPROM emulated section of the device's main FLASH memory storage section, the size of which is configured using the device's fuses. Emulated EEPROM is exempt from the usual device NVM region lock bits, so that it may be read from or written to at any point in the user application.

There are many different algorithms that may be employed for EEPROM emulation using FLASH memory, to tune the write and read latencies, RAM usage, wear levelling and other characteristics. As a

result, multiple different emulator schemes may be implemented, so that the most appropriate scheme for a specific application's requirements may be used.

30.2.1. Implementation Details

The following information is relevant for **EEPROM Emulator scheme 1, version 1.0.0**, as implemented by this module. Other revisions or emulation schemes may vary in their implementation details and may have different wear-leveling, latency, and other characteristics.

30.2.1.1. Emulator Characteristics

This emulator is designed for **best reliability, with a good balance of available storage and write-cycle limits**. It is designed to ensure that page data is automatically updated so that in the event of a failed update the previous data is not lost (when used correctly). With the exception of a system reset with data cached to the internal write-cache buffer, at most only the latest write to physical non-volatile memory will be lost in the event of a failed write.

This emulator scheme is tuned to give best write-cycle longevity when writes are confined to the same logical EEPROM page (where possible) and when writes across multiple logical EEPROM pages are made in a linear fashion through the entire emulated EEPROM space.

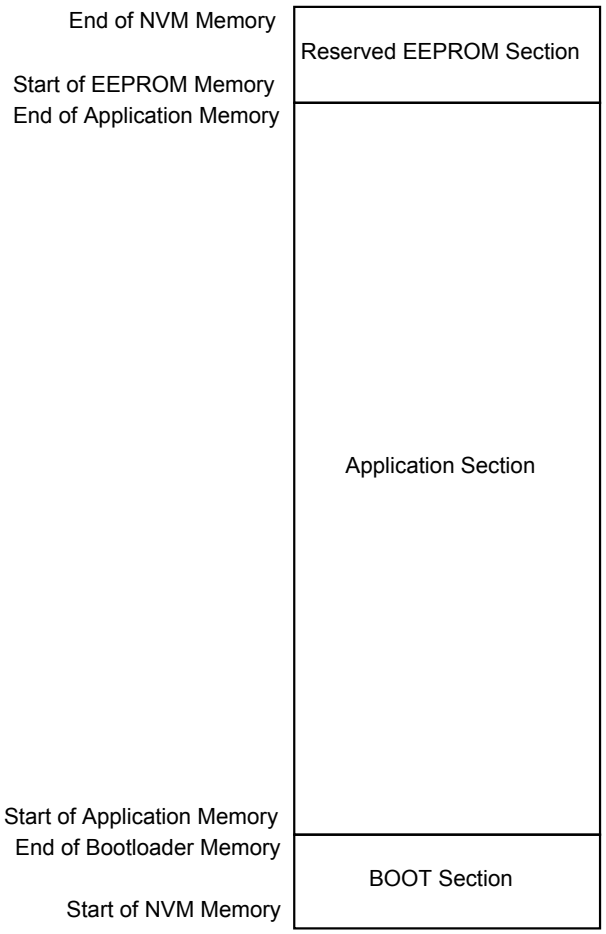
30.2.1.2. Physical Memory

The SAM non-volatile FLASH is divided into a number of physical rows, each containing four identically sized flash pages. Pages may be read or written to individually, however pages must be erased before being reprogrammed and the smallest granularity available for erasure is one single row.

This discrepancy results in the need for an emulator scheme that is able to handle the versioning and moving of page data to different physical rows as needed, erasing old rows ready for re-use by future page write operations.

Physically, the emulated EEPROM segment is located at the end of the physical FLASH memory space, as shown in Figure 30-1.

Figure 30-1. Physical Memory



30.2.1.3. Master Row

One physical FLASH row at the end of the emulated EEPROM memory space is reserved for use by the emulator to store configuration data. The master row is not user-accessible, and is reserved solely for internal use by the emulator.

30.2.1.4. Spare Row

As data needs to be preserved between row erasures, a single FLASH row is kept unused to act as destination for copied data when a write request is made to an already full row. When the write request is made, any logical pages of data in the full row that need to be preserved are written to the spare row along with the new (updated) logical page data, before the old row is erased and marked as the new spare.

30.2.1.5. Row Contents

Each physical FLASH row initially stores the contents of two logical EEPROM memory pages. This halves the available storage space for the emulated EEPROM but reduces the overall number of row erases that are required, by reserving two pages within each row for updated versions of the logical page contents. See Figure 30-3 for a visual layout of the EEPROM Emulator physical memory.

As logical pages within a physical row are updated, the new data is filled into the remaining unused pages in the row. Once the entire row is full, a new write request will copy the logical page not being written to in the current row to the spare row with the new (updated) logical page data, before the old row is erased.

This system allows for the same logical page to be updated up to three times into physical memory before a row erasure procedure is needed. In the case of multiple versions of the same logical EEPROM page being stored in the same physical row, the right-most (highest physical FLASH memory page address) version is considered to be the most current.

30.2.1.6. Write Cache

As a typical EEPROM use case is to write to multiple sections of the same EEPROM page sequentially, the emulator is optimized with a single logical EEPROM page write cache to buffer writes before they are written to the physical backing memory store. The cache is automatically committed when a new write request to a different logical EEPROM memory page is requested, or when the user manually commits the write cache.

Without the write cache, each write request to an EEPROM memory page would require a full page write, reducing the system performance and significantly reducing the lifespan of the non-volatile memory.

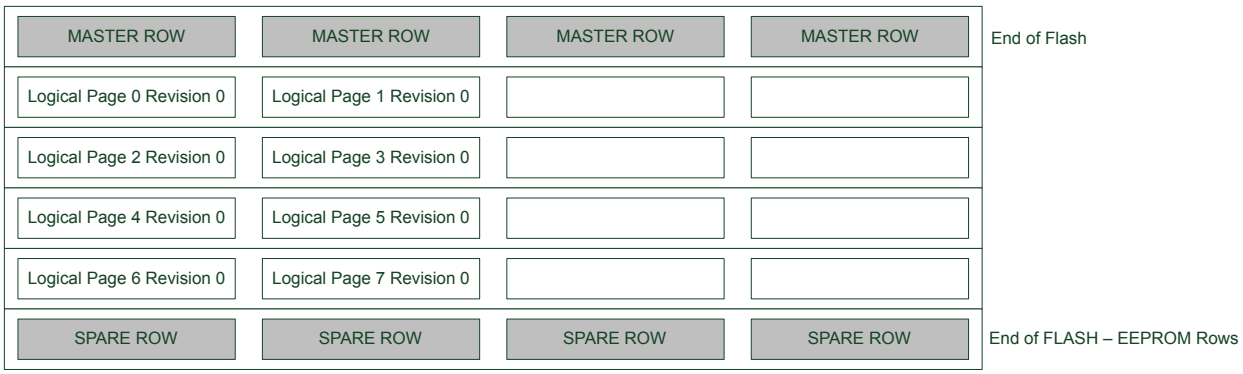
30.2.2. Memory Layout

A single logical EEPROM page is physically stored as the page contents and a header inside a single physical FLASH page, as shown in Figure 30-2.

Figure 30-2. Internal Layout of An Emulated EEPROM Page

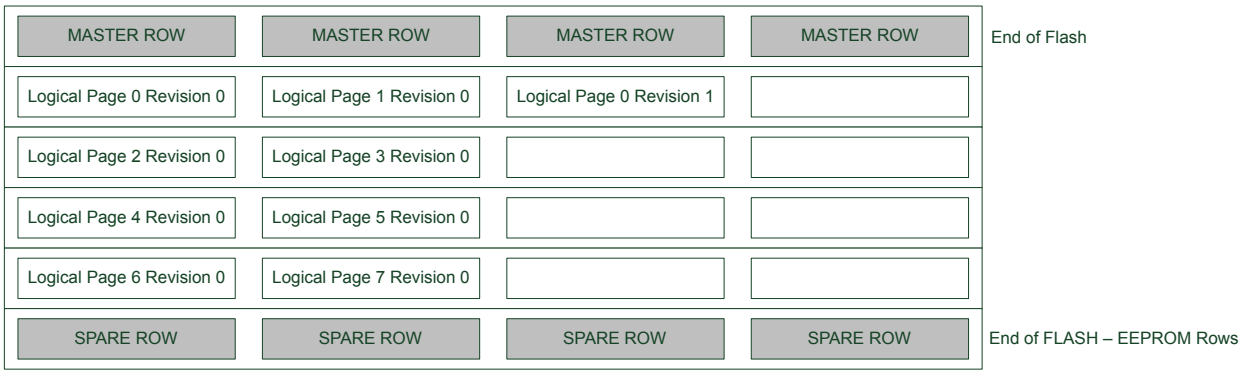
Within the EEPROM memory reservation section at the top of the NVM memory space, this emulator will produce the layout as shown in Figure 30-3 when initialized for the first time.

Figure 30-3. Initial Physical Layout of The Emulated EEPROM Memory



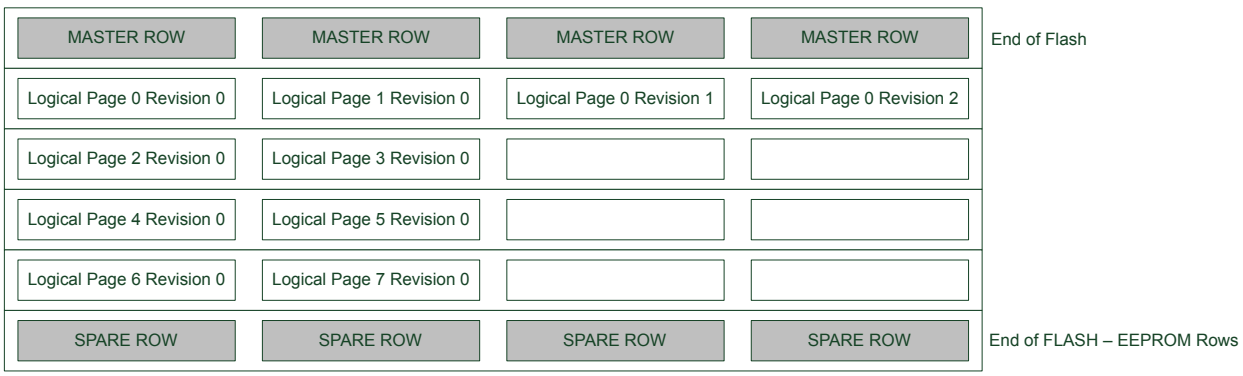
When an EEPROM page needs to be committed to physical memory, the next free FLASH page in the same row will be chosen - this makes recovery simple, as the right-most version of a logical page in a row is considered the most current. With four pages to a physical NVM row, this allows for up to three updates to the same logical page to be made before an erase is needed. Figure 30-4 shows the result of the user writing an updated version of logical EEPROM page `N-1` to the physical memory.

Figure 30-4. First Write to Logical EEPROM Page N-1



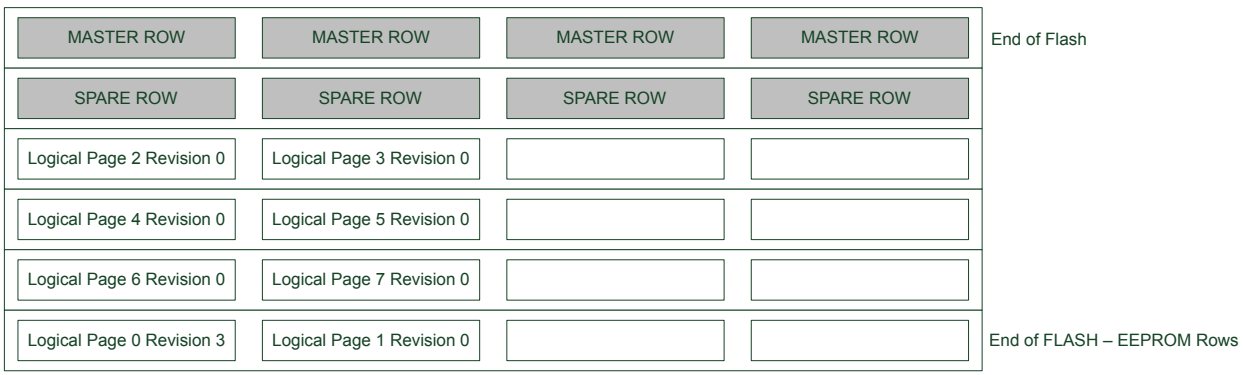
A second write of the same logical EEPROM page results in the layout shown in Figure 30-5.

Figure 30-5. Second Write to Logical EEPROM Page N-1



A third write of the same logical page requires that the EEPROM emulator erase the row, as it has become full. Prior to this, the contents of the unmodified page in the same row as the page being updated will be copied into the spare row, along with the new version of the page being updated. The old (full) row is then erased, resulting in the layout shown in Figure 30-6.

Figure 30-6. Third Write to Logical EEPROM Page N-1



30.3. Special Considerations

30.3.1. NVM Controller Configuration

The EEPROM Emulator service will initialize the NVM controller as part of its own initialization routine; the NVM controller will be placed in Manual Write mode, so that explicit write commands must be sent to the controller to commit a buffered page to physical memory. The manual write command must thus be

issued to the NVM controller whenever the user application wishes to write to a NVM page for its own purposes.

30.3.2. Logical EEPROM Page Size

As a small amount of information needs to be stored in a header before the contents of a logical EEPROM page in memory (for use by the emulation service), the available data in each EEPROM page is less than the total size of a single NVM memory page by several bytes.

30.3.3. Committing of the Write Cache

A single-page write cache is used internally to buffer data written to pages in order to reduce the number of physical writes required to store the user data, and to preserve the physical memory lifespan. As a result, it is important that the write cache is committed to physical memory **as soon as possible after a BOD low power condition**, to ensure that enough power is available to guarantee a completed write so that no data is lost.

The write cache must also be manually committed to physical memory if the user application is to perform any NVM operations using the NVM controller directly.

30.4. Extra Information

For extra information, see Extra Information. This includes:

- Acronyms
- Dependencies
- Errata
- Module History

30.5. Examples

For a list of examples related to this driver, see Examples for Emulated EEPROM Service.

30.6. API Overview

30.6.1. Structure Definitions

30.6.1.1. Struct eeprom_emulator_parameters

Structure containing the memory layout parameters of the EEPROM emulator module.

Table 30-1. Members

Type	Name	Description
uint16_t	eeprom_number_of_pages	Number of emulated pages of EEPROM.
uint8_t	page_size	Number of bytes per emulated EEPROM page.

30.6.2. Macro Definitions

30.6.2.1. EEPROM Emulator Information

Macro EEPROM_EMULATOR_ID

```
#define EEPROM_EMULATOR_ID
```

Emulator scheme ID, identifying the scheme used to emulated EEPROM storage.

Macro EEPROM_MAJOR_VERSION

```
#define EEPROM_MAJOR_VERSION
```

Emulator major version number, identifying the emulator major version.

Macro EEPROM_MINOR_VERSION

```
#define EEPROM_MINOR_VERSION
```

Emulator minor version number, identifying the emulator minor version.

Macro EEPROM_REVISION

```
#define EEPROM_REVISION
```

Emulator revision version number, identifying the emulator revision.

Macro EEPROM_PAGE_SIZE

```
#define EEPROM_PAGE_SIZE
```

Size of the user data portion of each logical EEPROM page, in bytes.

30.6.3. Function Definitions

30.6.3.1. Configuration and Initialization

Function eeprom_emulator_init()

Initializes the EEPROM Emulator service.

```
enum status_code eeprom_emulator_init( void )
```

Initializes the emulated EEPROM memory space; if the emulated EEPROM memory has not been previously initialized, it will need to be explicitly formatted via eeprom_emulator_erase_memory(). The EEPROM memory space will **not** be automatically erased by the initialization function, so that partial data may be recovered by the user application manually if the service is unable to initialize successfully.

Returns

Status code indicating the status of the operation.

Table 30-2. Return Values

Return value	Description
STATUS_OK	EEPROM emulation service was successfully initialized
STATUS_ERR_NO_MEMORY	No EEPROM section has been allocated in the device

Return value	Description
STATUS_ERR_BAD_FORMAT	Emulated EEPROM memory is corrupt or not formatted
STATUS_ERR_IO	EEPROM data is incompatible with this version or scheme of the EEPROM emulator

Function eeprom_emulator_erase_memory()

Erases the entire emulated EEPROM memory space.

```
void eeprom_emulator_erase_memory( void )
```

Erases and re-initializes the emulated EEPROM memory space, destroying any existing data.

Function eeprom_emulator_get_parameters()

Retrieves the parameters of the EEPROM Emulator memory layout.

```
enum status_code eeprom_emulator_get_parameters(
        struct eeprom_emulator_parameters *const parameters)
```

Retrieves the configuration parameters of the EEPROM Emulator, after it has been initialized.

Table 30-3. Parameters

Data direction	Parameter name	Description
[out]	parameters	EEPROM Emulator parameter struct to fill

Returns
Status of the operation.

Table 30-4. Return Values

Return value	Description
STATUS_OK	If the emulator parameters were retrieved successfully
STATUS_ERR_NOT_INITIALIZED	If the EEPROM Emulator is not initialized

30.6.3.2. Logical EEPROM Page Reading/Writing

Function eeprom_emulator_commit_page_buffer()

Commits any cached data to physical non-volatile memory.

```
enum status_code eeprom_emulator_commit_page_buffer( void )
```

Commits the internal SRAM caches to physical non-volatile memory, to ensure that any outstanding cached data is preserved. This function should be called prior to a system reset or shutdown to prevent data loss.

Note: This should be the first function executed in a BOD33 Early Warning callback to ensure that any outstanding cache data is fully written to prevent data loss.

Note: This function should also be called before using the NVM controller directly in the user-application for any other purposes to prevent data loss.

Returns
Status code indicating the status of the operation.

Function eeprom_emulator_write_page()

Writes a page of data to an emulated EEPROM memory page.

```
enum status_code eeprom_emulator_write_page(
        const uint8_t logical_page,
        const uint8_t *const data)
```

Writes an emulated EEPROM page of data to the emulated EEPROM memory space.

Note: Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the eeprom_emulator_commit_page_buffer() function should be called.

Table 30-5. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical EEPROM page number to write to
[in]	data	Pointer to the data buffer containing source data to write

Returns
Status code indicating the status of the operation.

Table 30-6. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

Function eeprom_emulator_read_page()

Reads a page of data from an emulated EEPROM memory page.

```
enum status_code eeprom_emulator_read_page(
        const uint8_t logical_page,
        uint8_t *const data)
```

Reads an emulated EEPROM page of data from the emulated EEPROM memory space.

Table 30-7. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical EEPROM page number to read from
[out]	data	Pointer to the destination data buffer to fill

Returns
Status code indicating the status of the operation.

Table 30-8. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

30.6.3.3. Buffer EEPROM Reading/Writing

Function eeprom_emulator_write_buffer()

Writes a buffer of data to the emulated EEPROM memory space.

```
enum status_code eeprom_emulator_write_buffer(
        const uint16_t offset,
        const uint8_t *const data,
        const uint16_t length)
```

Writes a buffer of data to a section of emulated EEPROM memory space. The source buffer may be of any size, and the destination may lie outside of an emulated EEPROM page boundary.

Note: Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the eeprom_emulator_commit_page_buffer() function should be called.

Table 30-9. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to write to, in emulated EEPROM memory space
[in]	data	Pointer to the data buffer containing source data to write
[in]	length	Length of the data to write, in bytes

Returns

Status code indicating the status of the operation.

Table 30-10. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

Function eeprom_emulator_read_buffer()

Reads a buffer of data from the emulated EEPROM memory space.

```
enum status_code eeprom_emulator_read_buffer(
        const uint16_t offset,
        uint8_t *const data,
        const uint16_t length)
```

Reads a buffer of data from a section of emulated EEPROM memory space. The destination buffer may be of any size, and the source may lie outside of an emulated EEPROM page boundary.

Table 30-11. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to read from, in emulated EEPROM memory space
[out]	data	Pointer to the data buffer containing source data to read
[in]	length	Length of the data to read, in bytes

Returns
Status code indicating the status of the operation.

Table 30-12. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated EEPROM memory space was supplied

30.7. Extra Information

30.7.1. Acronyms

Below is a table listing the acronyms used in this module, along with their intended meanings.

Acronym	Description
EEPROM	Electronically Erasable Read-Only Memory
NVM	Non-Volatile Memory

30.7.2. Dependencies

This driver has the following dependencies:

- Non-Volatile Memory Controller Driver

30.7.3. Errata

There are no errata related to this driver.

30.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Fix warnings
Initial Release

30.8. Examples for Emulated EEPROM Service

This is a list of the available Quick Start guides (QSGs) and example applications for SAM EEPROM Emulator (EEPROM) Service. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that QSGs can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the Emulated EEPROM Module - Basic Use Case

30.8.1. Quick Start Guide for the Emulated EEPROM Module - Basic Use Case

In this use case, the EEPROM emulator module is configured and a sample page of data read and written. The first byte of the first EEPROM page is toggled, and a LED is turned on or off to reflect the new state. Each time the device is reset, the LED should toggle to a different state to indicate correct non-volatile storage and retrieval.

30.8.1.1. Prerequisites

The device's fuses must be configured to reserve a sufficient number of FLASH memory rows for use by the EEPROM emulator service, before the service can be used. That is:
`NVMCTRL_FUSES_EEPROM_SIZE` has to be set to less than 0x5 in the fuse setting, then there will be more than 8 pages size for EEPROM. Atmel Studio can be used to set this fuse(Tools->Device Programming).

30.8.1.2. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_eeprom(void)
{
     /* Setup EEPROM emulator service */
     enum status_code error_code = eeprom_emulator_init();

     if (error_code == STATUS_ERR_NO_MEMORY) {
          while (true) {
               /* No EEPROM section has been set in the device's fuses */
          }
     }
     else if (error_code != STATUS_OK) {
          /* Erase the emulated EEPROM memory (assume it is unformatted or
         * irrecoverably corrupt) */
          eeprom_emulator_erase_memory();
          eeprom_emulator_init();
     }
}

#if (SAMD || SAMR21)
```

```
void SYSCTRL_Handler(void)
{
    if (SYSCTRL->INTFLAG.reg & SYSCTRL_INTFLAG_BOD33DET) {
        SYSCTRL->INTFLAG.reg = SYSCTRL_INTFLAG_BOD33DET;
        eeprom_emulator_commit_page_buffer();
    }
}
#endif
static void configure_bod(void)
{
#if (SAMD || SAMR21)
    struct bod_config config_bod33;
    bod_get_config_defaults(&config_bod33);
    config_bod33.action = BOD_ACTION_INTERRUPT;
    /* BOD33 threshold level is about 3.2V */
    config_bod33.level = 48;
    bod_set_config(BOD_BOD33, &config_bod33);
    bod_enable(BOD_BOD33);

    SYSCTRL->INTENSET.reg = SYSCTRL_INTENCLR_BOD33DET;
    system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_SYSCTRL);
#endif

}
```

Add to user application initialization (typically the start of `main()`):

```
configure_eeprom();
```

Workflow

1. Attempt to initialize the EEPROM emulator service, storing the error code from the initialization function into a temporary variable.

   ```
   enum status_code error_code = eeprom_emulator_init();
   ```

2. Check if the emulator failed to initialize due to the device fuses not being configured to reserve enough of the main FLASH memory rows for emulated EEPROM usage - abort if the fuses are mis-configured.

   ```
   if (error_code == STATUS_ERR_NO_MEMORY) {
       while (true) {
           /* No EEPROM section has been set in the device's fuses */
       }
   }
   ```

3. Check if the emulator service failed to initialize for any other reason; if so assume the emulator physical memory is unformatted or corrupt and erase/re-try initialization.

   ```
   else if (error_code != STATUS_OK) {
       /* Erase the emulated EEPROM memory (assume it is unformatted or
       * irrecoverably corrupt) */
       eeprom_emulator_erase_memory();
       eeprom_emulator_init();
   }
   ```

   Config BOD to give an early warning, so that we could prevent data loss.

   ```
   configure_bod();
   ```

30.8.1.3. Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t page_data[EEPROM_PAGE_SIZE];
eeprom_emulator_read_page(0, page_data);

page_data[0] = !page_data[0];
port_pin_set_output_level(LED_0_PIN, page_data[0]);

eeprom_emulator_write_page(0, page_data);
eeprom_emulator_commit_page_buffer();

page_data[1]=0x1;
eeprom_emulator_write_page(0, page_data);

while (true) {

}
```

Workflow

1. Create a buffer to hold a single emulated EEPROM page of memory, and read out logical EEPROM page zero into it.

   ```
   uint8_t page_data[EEPROM_PAGE_SIZE];
   eeprom_emulator_read_page(0, page_data);
   ```

2. Toggle the first byte of the read page.

   ```
   page_data[0] = !page_data[0];
   ```

3. Output the toggled LED state onto the board LED.

   ```
   port_pin_set_output_level(LED_0_PIN, page_data[0]);
   ```

4. Write the modified page back to logical EEPROM page zero, flushing the internal emulator write cache afterwards to ensure it is immediately written to physical non-volatile memory.

   ```
   eeprom_emulator_write_page(0, page_data);
   eeprom_emulator_commit_page_buffer();
   ```

5. Modify data and write back to logical EEPROM page zero. The data is not committed and should call `eeprom_emulator_commit_page_buffer` to ensure that any outstanding cache data is fully written to prevent data loss when detecting a BOD early warning.

   ```
   page_data[1]=0x1;
   eeprom_emulator_write_page(0, page_data);
   ```

31. SAM Read While Write EEPROM (RWW EEPROM) Emulator Service

This driver for Atmel® | SMART ARM®-based microcontrollers provides an RWW emulated EEPROM memory area, for the storage and retrieval of user-application configuration data into and out of non-volatile memory. The main array can therefore run code while EEPROM data is written.

The following peripheral is used by this module:

- NVM (Non-Volatile Memory Controller)

The following devices can use this module:

- Atmel | SMART SAM L21/L22
- Atmel | SMART SAM D21
- Atmel | SMART SAM C20/C21
- Atmel | SMART SAM DA1

The outline of this documentation is as follows:

31.1. Prerequisites

There are no prerequisites for this module.

31.2. Module Overview

SAM devices embeds a separate read while write EEPROM emulation (RWWEE) array that can be programmed while the main array is not blocked. To use RWWEE memory, data must be written as a number of physical memory pages (of several bytes each) rather than being individually byte addressable, and entire rows of RWWEE must be erased before new data may be stored. To help abstract these characteristics away from the user application an emulation scheme is implemented to present a more user-friendly API for data storage and retrieval.

This module provides an RWW EEPROM emulation layer on top of the device's internal NVM controller, to provide a standard interface for the reading and writing of non-volatile configuration data. This data is placed into the RWW EEPROM emulated section. Emulated EEPROM is exempt from the usual device NVM region lock bits, so that it may be read from or written to at any point in the user application.

There are many different algorithms that may be employed for EEPROM emulation, to tune the write and read latencies, RAM usage, wear levelling, and other characteristics. As a result, multiple different emulator schemes may be implemented, so that the most appropriate scheme for a specific application's requirements may be used.

31.2.1. Implementation Details

The following information is relevant for **RWW EEPROM Emulator scheme 1, version 1.0.0**, as implemented by this module. Other revisions or emulation schemes may vary in their implementation details and may have different wear-leveling, latency, and other characteristics.

31.2.1.1. Emulator Characteristics

This emulator is designed for **best reliability, with a good balance of available storage and write-cycle limits**. It is designed to ensure that page data is updated by an atomic operation, so that in the event of a failed update the previous data is not lost (when used correctly). With the exception of a system reset with data cached to the internal write-cache buffer, at most only the latest write to physical non-volatile memory will be lost in the event of a failed write.

This emulator scheme is tuned to give best write-cycle longevity when writes are confined to the same logical RWW EEPROM page (where possible) and when writes across multiple logical RWW EEPROM pages are made in a linear fashion through the entire emulated RWW EEPROM space.

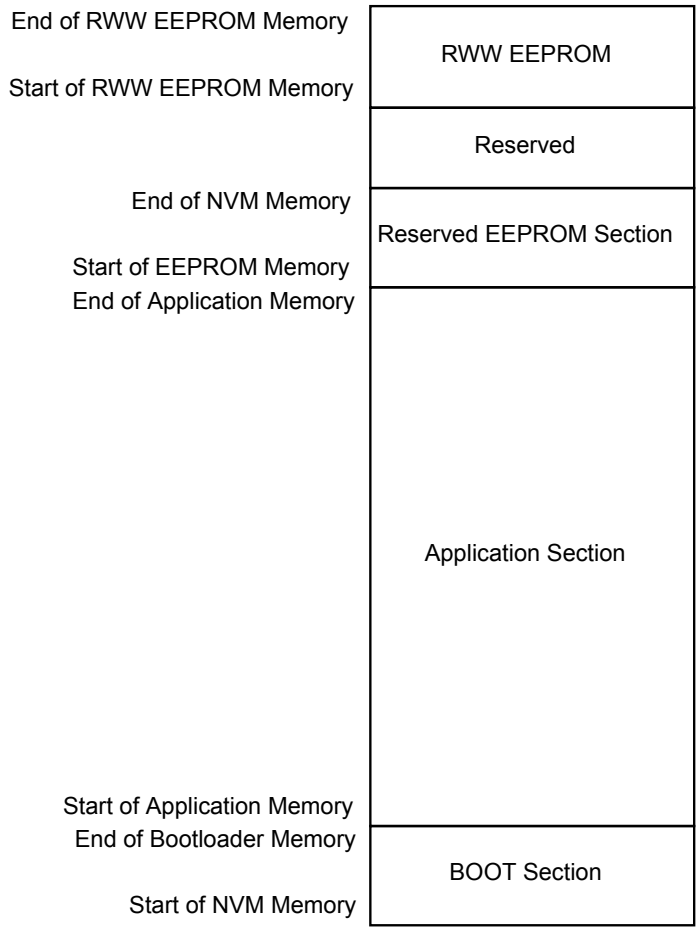
31.2.1.2. Physical Memory

RWW EEPROM emulator is divided into a number of physical rows, each containing four identically sized pages. Pages may be read or written to individually, however, pages must be erased before being reprogrammed and the smallest granularity available for erasure is one single row.

This discrepancy results in the need for an emulator scheme that is able to handle the versioning and moving of page data to different physical rows as needed, erasing old rows ready for re-use by future page write operations.

Physically, the emulated RWW EEPROM segment is a dedicated space that are memory mapped, as shown in Figure 31-1.

Figure 31-1. Physical Memory



31.2.1.3. Master Row

One physical row at the end of the emulated RWW EEPROM memory space is reserved for use by the emulator to store configuration data. The master row is not user-accessible, and is reserved solely for internal use by the emulator.

31.2.1.4. Spare Row

As data needs to be preserved between row erasures, a single row is kept unused to act as destination for copied data when a write request is made to an already full row. When the write request is made, any logical pages of data in the full row that need to be preserved are written to the spare row along with the new (updated) logical page data, before the old row is erased and marked as the new spare.

31.2.1.5. Row Contents

Each physical row initially stores the contents of one or two logical RWW EEPROM memory pages (it depends on application configuration file). This quarters or halves the available storage space for the emulated RWW EEPROM but reduces the overall number of row erases that are required, by reserving two or three pages within each row for updated versions of the logical page contents. See Figure 31-2 for a visual layout of the RWW EEPROM Emulator physical memory.

As logical pages within a physical row are updated, the new data is filled into the remaining unused pages in the row. Once the entire row is full, a new write request will copy the logical page not being written to in the current row to the spare row with the new (updated) logical page data, before the old row is erased.

When it is configured, each physical row stores the contents of one logical RWW EEPROM memory page. This system will allow for the same logical page to be updated up to four times into the physical memory before a row erasure procedure is needed. In the case of multiple versions of the same logical RWW EEPROM page being stored in the same physical row, the right-most (highest physical memory page address) version is considered to be the most current.

31.2.1.6. Write Cache

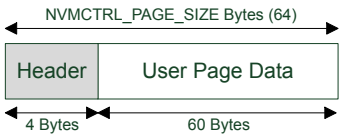
As a typical EEPROM use case is to write to multiple sections of the same EEPROM page sequentially, the emulator is optimized with a single logical RWW EEPROM page write cache to buffer writes before they are written to the physical backing memory store. The cache is automatically committed when a new write request to a different logical RWW EEPROM memory page is requested, or when the user manually commits the write cache.

Without the write cache, each write request to an EEPROM memory page would require a full page write, reducing the system performance and significantly reducing the lifespan of the non-volatile memory.

31.2.2. Memory Layout

A single logical RWW EEPROM page is physically stored as the page content and a header inside a single physical page, as shown in Figure 31-2.

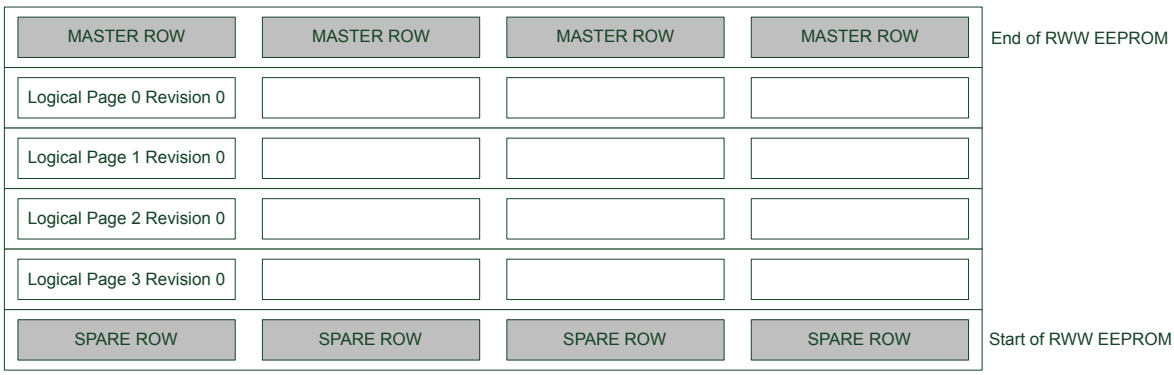
Figure 31-2. Internal Layout of an Emulated RWW EEPROM Page



Note: In the following memory layout example, each physical row stores the contents of one logical RWW EEPROM page. Refer to "AT03265: SAM EEPROM Emulator Service (EEPROM)" for the example of two logical EEPROM pages in one row.

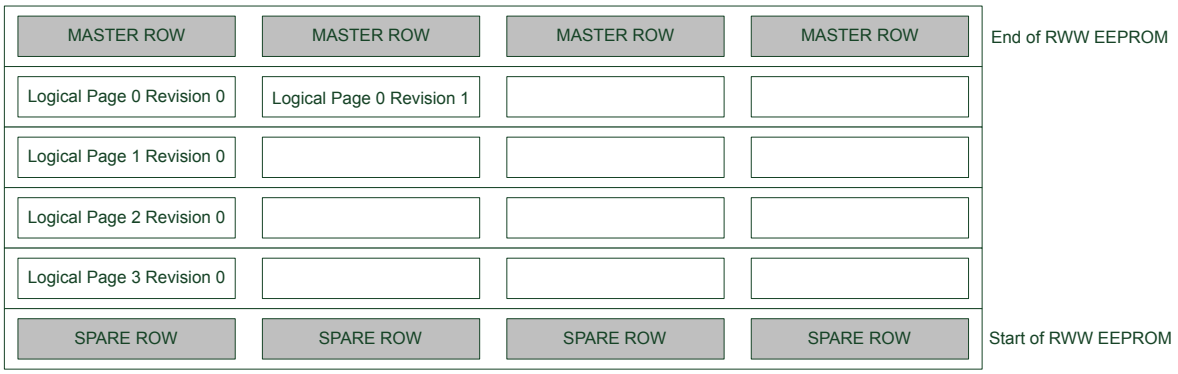
Within the RWW EEPROM memory reservation section at the top of the NVM memory space, this emulator will produce the layout as shown in Figure 31-3 when initialized for the first time.

Figure 31-3. Initial Physical Layout of the Emulated RWW EEPROM Memory



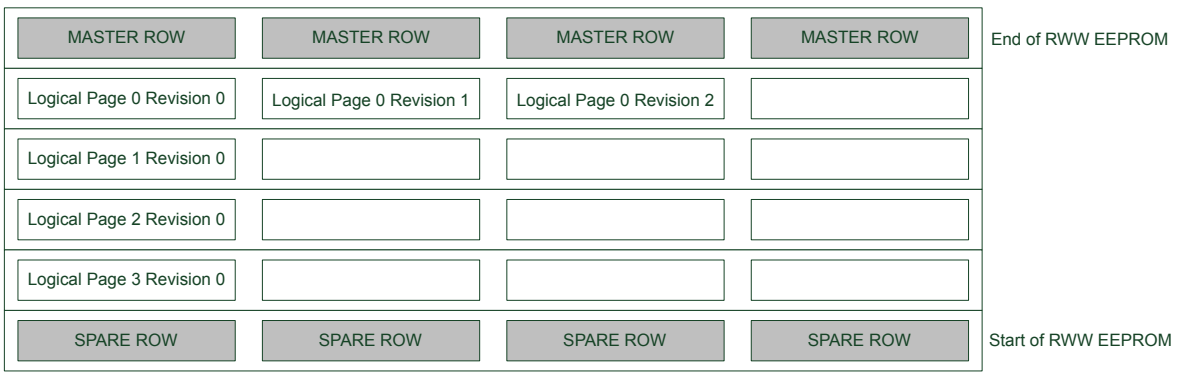
When an RWW EEPROM page needs to be committed to physical memory, the next free page in the same row will be chosen. This makes recovery simple, as the right-most version of a logical page in a row is considered the most current. With four pages to a physical NVM row, this allows for up to four updates to the same logical page to be made before an erase is needed. Figure 31-4 shows the result of the user writing an updated version of logical EEPROM page `N-1` to the physical memory.

Figure 31-4. First Write to Logical RWW EEPROM Page N-1



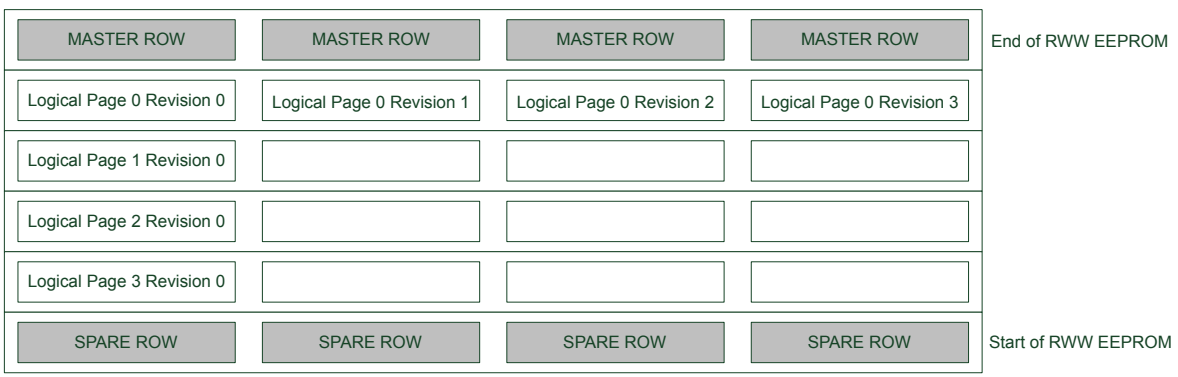
A second write of the same logical RWW EEPROM page results in the layout shown in Figure 31-5.

Figure 31-5. Second Write to Logical RWW EEPROM Page N-1



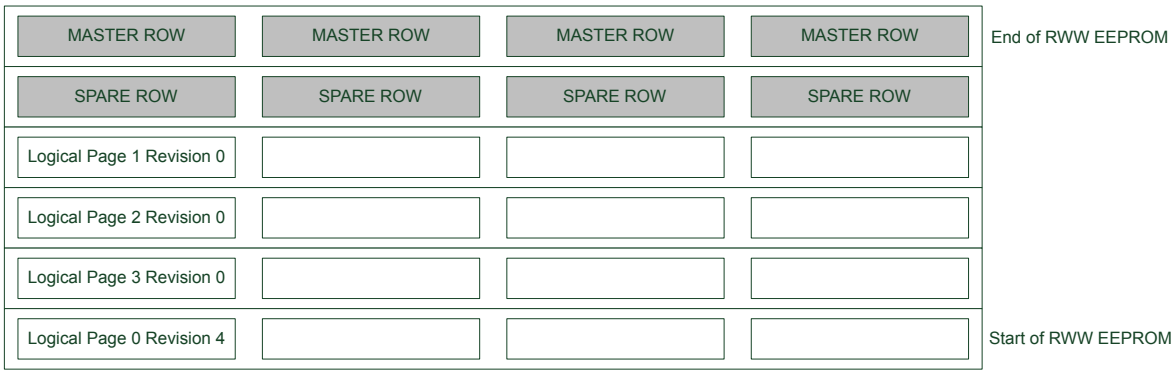
A third write of the same logical RWW EEPROM page results in the layout shown in Figure 31-6.

Figure 31-6. Third Write to Logical RWW EEPROM Page N-1



A fourth write of the same logical page requires that the RWW EEPROM emulator erase the row, as it has become full. Prior to this, the content of the unmodified page in the same row as the page being updated will be copied into the spare row, along with the new version of the page being updated. The old (full) row is then erased, resulting in the layout shown in Figure 31-7.

Figure 31-7. Third Write to Logical RWW EEPROM Page N-1



31.3. Special Considerations

31.3.1. NVM Controller Configuration

The RWW EEPROM Emulator service will initialize the NVM controller as part of its own initialization routine; the NVM controller will be placed in Manual Write mode, so that explicit write commands must be sent to the controller to commit a buffered page to physical memory. The manual write command must thus be issued to the NVM controller whenever the user application wishes to write to a NVM page for its own purposes.

31.3.2. Logical RWW EEPROM Page Size

As a small amount of information needs to be stored in a header before the content of a logical EEPROM page in memory (for use by the emulation service), the available data in each RWW EEPROM page is less than the total size of a single NVM memory page by several bytes.

31.3.3. Committing of the Write Cache

A single-page write cache is used internally to buffer data written to pages in order to reduce the number of physical writes required to store the user data, and to preserve the physical memory lifespan. As a result, it is important that the write cache is committed to physical memory **as soon as possible after a BOD low power condition**, to ensure that enough power is available to guarantee a completed write so that no data is lost.

The write cache must also be manually committed to physical memory if the user application is to perform any NVM operations using the NVM controller directly.

31.3.4. RWW EEPROM Page Checksum

For each page, a checksum function is used to verify the integrity of the page data. When reading the page data, using rww_eeprom_emulator_read_page(). When its checksum is not correct, an error can be detected. This function can be enabled or disabled through the configuration file.

31.4. Extra Information

For extra information, see Extra Information. This includes:

- Acronyms
- Dependencies

- Errata
- Module History

31.5. Examples

For a list of examples related to this driver, see Examples for Emulated RWW EEPROM Service.

31.6. API Overview

31.6.1. Structure Definitions

31.6.1.1. Struct rww_eeprom_emulator_parameters

Structure containing the memory layout parameters of the EEPROM emulator module.

Table 31-1. Members

Type	Name	Description
uint16_t	eeprom_number_of_pages	Number of emulated pages of EEPROM
uint8_t	page_size	Number of bytes per emulated EEPROM page

31.6.2. Macro Definitions

31.6.2.1. RWW EEPROM Emulator Information

Macro RWW_EEPROM_EMULATOR_ID

```
#define RWW_EEPROM_EMULATOR_ID
```

Emulator scheme ID, identifying the scheme used to emulated EEPROM storage.

Macro RWW_EEPROM_MAJOR_VERSION

```
#define RWW_EEPROM_MAJOR_VERSION
```

Emulator major version number, identifying the emulator major version.

Macro RWW_EEPROM_MINOR_VERSION

```
#define RWW_EEPROM_MINOR_VERSION
```

Emulator minor version number, identifying the emulator minor version.

Macro RWW_EEPROM_REVISION

```
#define RWW_EEPROM_REVISION
```

Emulator revision version number, identifying the emulator revision.

Macro RWW_EEPROM_PAGE_SIZE

```
#define RWW_EEPROM_PAGE_SIZE
```

Size of the user data portion of each logical EEPROM page, in bytes.

31.6.3. Function Definitions

31.6.3.1. Configuration and Initialization

Function rww_eeprom_emulator_init()

Initializes the RWW EEPROM Emulator service.

```
enum status_code rww_eeprom_emulator_init( void )
```

Initializes the emulated RWW EEPROM memory space. If the emulated RWW EEPROM memory has not been previously initialized, it will need to be explicitly formatted via rww_eeprom_emulator_erase_memory(). The RWW EEPROM memory space will **not** be automatically erased by the initialization function. Partial data may be recovered by the user application manually if the service is unable to initialize successfully.

Returns
Status code indicating the status of the operation.

Table 31-2. Return Values

Return value	Description
STATUS_OK	RWW EEPROM emulation service was successfully initialized
STATUS_ERR_BAD_FORMAT	Emulated RWW EEPROM memory is corrupt or not formatted
STATUS_ERR_IO	RWW EEPROM data is incompatible with this version or scheme of the RWW EEPROM emulator
STATUS_ERR_INVALID_ARG	Invalid logical page configuration

Function rww_eeprom_emulator_erase_memory()

Erases the entire emulated RWW EEPROM memory space.

```
void rww_eeprom_emulator_erase_memory( void )
```

Erases and re-initializes the emulated RWW EEPROM memory space, destroying any existing data.

Function rww_eeprom_emulator_get_parameters()

Retrieves the parameters of the RWW EEPROM Emulator memory layout.

```
enum status_code rww_eeprom_emulator_get_parameters(
        struct rww_eeprom_emulator_parameters *const parameters)
```

Retrieves the configuration parameters of the RWW EEPROM Emulator, after it has been initialized.

Table 31-3. Parameters

Data direction	Parameter name	Description
[out]	parameters	RWW EEPROM Emulator parameter struct to fill

Returns
Status of the operation.

Table 31-4. Return Values

Return value	Description
STATUS_OK	If the emulator parameters were retrieved successfully
STATUS_ERR_NOT_INITIALIZED	If the RWW EEPROM Emulator is not initialized

31.6.3.2. Logical RWW EEPROM Page Reading/Writing

Function rww_eeprom_emulator_commit_page_buffer()

Commits any cached data to physical non-volatile memory.

```
enum status_code rww_eeprom_emulator_commit_page_buffer( void )
```

Commits the internal SRAM caches to physical non-volatile memory, to ensure that any outstanding cached data is preserved. This function should be called prior to a system reset or shutdown to prevent data loss.

Note: This should be the first function executed in a BOD33 Early Warning callback to ensure that any outstanding cache data is fully written to prevent data loss.

Note: This function should also be called before using the NVM controller directly in the user-application for any other purposes to prevent data loss.

Returns
Status code indicating the status of the operation.

Function rww_eeprom_emulator_write_page()

Writes a page of data to an emulated RWW EEPROM memory page.

```
enum status_code rww_eeprom_emulator_write_page(
        const uint8_t logical_page,
        const uint8_t *const data)
```

Writes an emulated RWW EEPROM page of data to the emulated RWW EEPROM memory space.

Note: Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the rww_eeprom_emulator_commit_page_buffer() function should be called.

Table 31-5. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical RWW EEPROM page number to write to
[in]	data	Pointer to the data buffer containing source data to write

Returns
Status code indicating the status of the operation.

Table 31-6. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the RWW EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated RWW EEPROM memory space was supplied

Function rww_eeprom_emulator_read_page()

Reads a page of data from an emulated RWW EEPROM memory page.

```
enum status_code rww_eeprom_emulator_read_page(
        const uint8_t logical_page,
        uint8_t *const data)
```

Reads an emulated RWW EEPROM page of data from the emulated RWW EEPROM memory space.

Table 31-7. Parameters

Data direction	Parameter name	Description
[in]	logical_page	Logical RWW EEPROM page number to read from
[out]	data	Pointer to the destination data buffer to fill

Returns

Status code indicating the status of the operation.

Table 31-8. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the RWW EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated RWW EEPROM memory space was supplied
STATUS_ERR_BAD_FORMAT	Page data checksum is not correct, maybe data is damaged

31.6.3.3. Buffer RWW EEPROM Reading/Writing

Function rww_eeprom_emulator_write_buffer()

Writes a buffer of data to the emulated RWW EEPROM memory space.

```
enum status_code rww_eeprom_emulator_write_buffer(
        const uint16_t offset,
        const uint8_t *const data,
        const uint16_t length)
```

Writes a buffer of data to a section of emulated RWW EEPROM memory space. The source buffer may be of any size, and the destination may lie outside of an emulated RWW EEPROM page boundary.

Note: Data stored in pages may be cached in volatile RAM memory; to commit any cached data to physical non-volatile memory, the rww_eeprom_emulator_commit_page_buffer() function should be called.

Table 31-9. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to write to, in emulated RWW EEPROM memory space
[in]	data	Pointer to the data buffer containing source data to write
[in]	length	Length of the data to write, in bytes

Returns
Status code indicating the status of the operation.

Table 31-10. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the RWW EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated RWW EEPROM memory space was supplied

Function rww_eeprom_emulator_read_buffer()

Reads a buffer of data from the emulated RWW EEPROM memory space.

```
enum status_code rww_eeprom_emulator_read_buffer(
        const uint16_t offset,
        uint8_t *const data,
        const uint16_t length)
```

Reads a buffer of data from a section of emulated RWW EEPROM memory space. The destination buffer may be of any size, and the source may lie outside of an emulated RWW EEPROM page boundary.

Table 31-11. Parameters

Data direction	Parameter name	Description
[in]	offset	Starting byte offset to read from, in emulated RWW EEPROM memory space
[out]	data	Pointer to the data buffer containing source data to read
[in]	length	Length of the data to read, in bytes

Returns
Status code indicating the status of the operation.

Table 31-12. Return Values

Return value	Description
STATUS_OK	If the page was successfully read
STATUS_ERR_NOT_INITIALIZED	If the RWW EEPROM emulator is not initialized
STATUS_ERR_BAD_ADDRESS	If an address outside the valid emulated RWW EEPROM memory space was supplied

31.6.4. Enumeration Definitions

31.6.4.1. Enum rwwee_logical_page_num_in_row

Enum for the possible logical pages that are stored in each physical row.

Table 31-13. Members

Enum value	Description
RWWEE_LOGICAL_PAGE_NUM_1	One logical page stored in a physical row
RWWEE_LOGICAL_PAGE_NUM_2	Two logical pages stored in a physical row

31.7. Extra Information

31.7.1. Acronyms

Acronym	Description
EEPROM	Electronically Erasable Read-Only Memory
RWWEE	Read While Write EEPROM
RWW	Read While Write
NVM	Non-Volatile Memory

31.7.2. Dependencies

This driver has the following dependencies:

- Non-Volatile Memory Controller Driver

31.7.3. Errata

There are no errata related to this driver.

31.7.4. Module History

An overview of the module history is presented in the table below, with details on the enhancements and fixes made to the module since its first release. The current version of this corresponds to the newest version in the table.

Changelog
Initial Release

31.8. Examples for Emulated RWW EEPROM Service

This is a list of the available Quick Start guides (QSGs) and example applications for SAM Read While Write EEPROM (RWW EEPROM) Emulator Service. QSGs are simple examples with step-by-step instructions to configure and use this driver in a selection of use cases. Note that a QSG can be compiled as a standalone application or be added to the user application.

- Quick Start Guide for the Emulated RWW EEPROM Module - Basic Use Case

31.8.1. Quick Start Guide for the Emulated RWW EEPROM Module - Basic Use Case

In this use case, the RWW EEPROM emulator module is configured, and a sample page is read and written. The first byte of the first RWW EEPROM page is toggled, and a LED is turned ON or OFF to reflect the new state. Each time the device is reset, the LED should toggle to a different state to indicate correct non-volatile storage and retrieval.

31.8.1.1. Setup

Prerequisites

There are no special setup requirements for this use-case.

Code

Copy-paste the following setup code to your user application:

```
void configure_eeprom(void)
{
    /* Setup EEPROM emulator service */
    enum status_code error_code = rww_eeprom_emulator_init();

    if (error_code == STATUS_ERR_NO_MEMORY) {
        while (true) {
            /* No EEPROM section has been set in the device's fuses */
        }
    }
    else if (error_code != STATUS_OK) {
        /* Erase the emulated EEPROM memory (assume it is unformatted or
        * irrecoverably corrupt) */
        rww_eeprom_emulator_erase_memory();
        rww_eeprom_emulator_init();
    }
}

#if (SAMD21) || (SAMDA1)
void SYSCTRL_Handler(void)
{
    if (SYSCTRL->INTFLAG.reg & SYSCTRL_INTFLAG_BOD33DET) {
        SYSCTRL->INTFLAG.reg = SYSCTRL_INTFLAG_BOD33DET;
        rww_eeprom_emulator_commit_page_buffer();
    }
}
#endif
static void configure_bod(void)
{
#if (SAMD21) || (SAMDA1)
```

```
    struct bod_config config_bod33;
    bod_get_config_defaults(&config_bod33);
    config_bod33.action = BOD_ACTION_INTERRUPT;
    /* BOD33 threshold level is about 3.2V */
    config_bod33.level = 48;
    bod_set_config(BOD_BOD33, &config_bod33);
    bod_enable(BOD_BOD33);

    SYSCTRL->INTENSET.reg = SYSCTRL_INTENCLR_BOD33DET;
    system_interrupt_enable(SYSTEM_INTERRUPT_MODULE_SYSCTRL);
#endif

}
```

Add to user application initialization (typically the start of `main()`):

```
configure_eeprom();
```

Workflow

1. Attempt to initialize the RWW EEPROM emulator service, storing the error code from the initialization function into a temporary variable.

   ```
   enum status_code error_code = rww_eeprom_emulator_init();
   ```

2. Check if the emulator service failed to initialize for any other reason; if so, assume the emulator physical memory is unformatted or corrupt and erase/re-try initialization.

   ```
   else if (error_code != STATUS_OK) {
       /* Erase the emulated EEPROM memory (assume it is unformatted or
       * irrecoverably corrupt) */
       rww_eeprom_emulator_erase_memory();
       rww_eeprom_emulator_init();
   }
   ```

   Config BOD to give an early warning to prevent data loss.

   ```
   configure_bod();
   ```

31.8.1.2. Use Case

Code

Copy-paste the following code to your user application:

```
uint8_t page_data[RWW_EEPROM_PAGE_SIZE];
rww_eeprom_emulator_read_page(0, page_data);

page_data[0] = !page_data[0];
port_pin_set_output_level(LED_0_PIN, page_data[0]);

rww_eeprom_emulator_write_page(0, page_data);
rww_eeprom_emulator_commit_page_buffer();

page_data[1]=0x1;
rww_eeprom_emulator_write_page(0, page_data);

while (true) {

}
```

Workflow

1. Create a buffer to hold a single emulated RWW EEPROM page of memory, and read out logical RWW EEPROM page zero into it.

```
uint8_t page_data[RWW_EEPROM_PAGE_SIZE];
rww_eeprom_emulator_read_page(0, page_data);
```

2. Toggle the first byte of the read page.

```
page_data[0] = !page_data[0];
```

3. Output the toggled LED state onto the board LED.

```
port_pin_set_output_level(LED_0_PIN, page_data[0]);
```

4. Write the modified page back to logical RWW EEPROM page zero, flushing the internal emulator write cache afterwards to ensure it is immediately written to physical non-volatile memory.

```
rww_eeprom_emulator_write_page(0, page_data);
rww_eeprom_emulator_commit_page_buffer();
```

5. Modify data and write back to logical EEPROM page zero. The data is not committed and should call `rww_eeprom_emulator_commit_page_buffer` to ensure that any outstanding cache data is fully written to prevent data loss when detecting a BOD early warning.

```
page_data[1]=0x1;
rww_eeprom_emulator_write_page(0, page_data);
```

32. Document Revision History

Doc. Rev.	Date	Comments
42698A	09/2016	Initial document release

Atmel | Enabling Unlimited Possibilities®

Atmel Corporation 1600 Technology Drive, San Jose, CA 95110 USA **T:** (+1)(408) 441.0311 **F:** (+1)(408) 436.4200 | **www.atmel.com**