TB3240

How to Use the TCM on A Cortex-M7 Based MCU with the XC32 Compiler

Introduction

The SAMS70/E70/V7x series of Microcontrollers (MCUs) from Microchip are high-performing MCUs with an Arm® Cortex®-M7 core. This series of MCUs offers a rich set of peripherals with a large built-in code and data memory. To ensure high-speed, low-latency, and deterministic access for time-critical code and data, the Arm Cortex-M7 core is connected to the Tightly-Coupled Memory (TCM).

This document explains how to use the TCM features in the SAM MCUs using the MPLAB® X IDE with the MPLAB XC32 compiler and MPLAB Harmony v3 software development framework.

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1. Tightly-Coupled Memory Overview

1.1 Tightly-Coupled Memory (TCM)

In Arm Cortex-M7 based architecture, the memory system includes support for the TCM. The TCM port connects a low-latency memory to the processor, and this TCM port has Instruction TCM (ITCM) and Data TCM (DTCM) interfaces. ITCM is a 64-bit memory interface and DTCM is a two 32-bit memory interfaces (D0TCM and D1TCM). Typically, RAM or RAM like memory (SRAM, FRAM etc.,) are connected to the TCM port.

DTCM is typically used to access Critical variables and Frequently updated variables. ITCM is typically used to access Critical functions, routines and Interrupt service routines.

Refer to ARM website for additional information on TCM implementation.

1.2 Implementation in SAMS/E/V7x MCUs

In the SAMS/E/V7x devices, a portion of the SRAM can be configured as TCM. This enables the TCM portion of the SRAM to be accessed with a deterministic latency (single clock cycle-read/write accesses). TCM runs at processor speed (Maximum CPU clock = 300 MHz).

The following sections describe how to use the TCM, and for additional information, refer to the device data sheet.

- ITCM and DTCM memory mapping:
    - The SRAM memory address and ITCM/DTCM memory address are different in the SAMS/E/V7x family of devices.

Figure 1-1. Memory Mapping
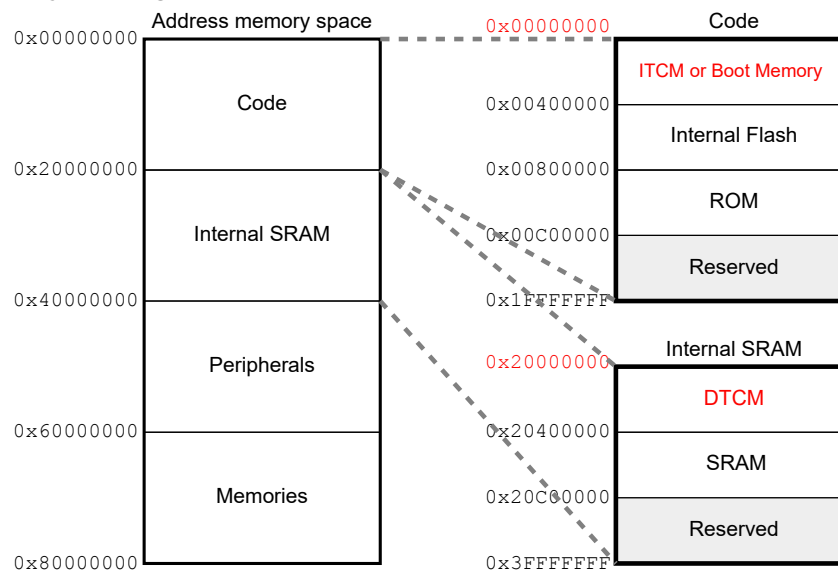
- Partition SRAM memory into System RAM and TCM memory
    - In the SAMS/E/V7x family of devices, separate memory is not available for the TCM. A portion of the SRAM is used for the TCM (DTCM and ITCM) and the remaining is used for the system RAM. Four TCM size configurations are possible in this device, and the size selection is made using the GPNVM (Fuse) bits.

Table 1-1. TCM Size Configurations

GPNVM Bits [8:7]	ITCM (KB)	DTCM (KB)	System SRAM for 384KB variant	System SRAM for 256KB variant
0	0	0	384	256

GPNVM Bits [8:7]	ITCM (KB)	DTCM (KB)	System SRAM for 384KB variant	System SRAM for 256KB variant
..........continued				
1	32	32	320	192
2	64	64	256	128
3	128	128	128	0

- Enabling and Disabling the ITCM and DTCM
  - ITCM and DTCM are enabled and disabled in the ITCMR and DTCMR registers in the Arm SCB
  - After reset, ITCM is disabled and DTCM is enabled

1.3 Configuring and Using TCM in MPLAB X IDE Project

In a typical GCC or any compiler environment, to use the TCM in the application, the following components must be configured:

- Linker script:
  - Memory sections for the ITCM and DTCM must be declared and defined.
- Startup code:
  - For the DTCM or ITCM, the content must be copied from the Flash to the TCM memory. This initialization must be done in the startup code before calling the `main()` function.

  Note: The data initialization is handled by the `pic32c_data_initialization()` function in the startup code.
- Application source file:
  - While declaring a variable, buffer, or defining a function in the code, users must apply the correct compiler attribute or compiler section name created in the linker script to place data or code in the TCM.

The MPLAB XC32 compiler has integrated support for the TCM, therefore the linker script and startup file configurations are taken care of by passing compiler configuration options.

The following section details the XC32 compiler options to configure TCM usage.

2. Using TCM with the XC32 Linker

The MPLAB XC32 compiler provides integrated TCM support. This makes it easier to use the TCM with any application. Additionally, the MPLAB Harmony v3 framework further simplifies TCM usage by automatically generating the necessary compiler flags. For example, to use the TCM in the MPLAB X SAMV7x project with the XC32 compiler, add the compiler flags, `mitcm=<size_in_bytes>` and `-mdtcm=<size_in_bytes>` to the global XC32 Options in the Project Properties window. The MPLAB X IDE Project Properties window provides options to configure DTCM and ITCM sizes as shown in the image below.

Figure 2-1. Compiler Flags
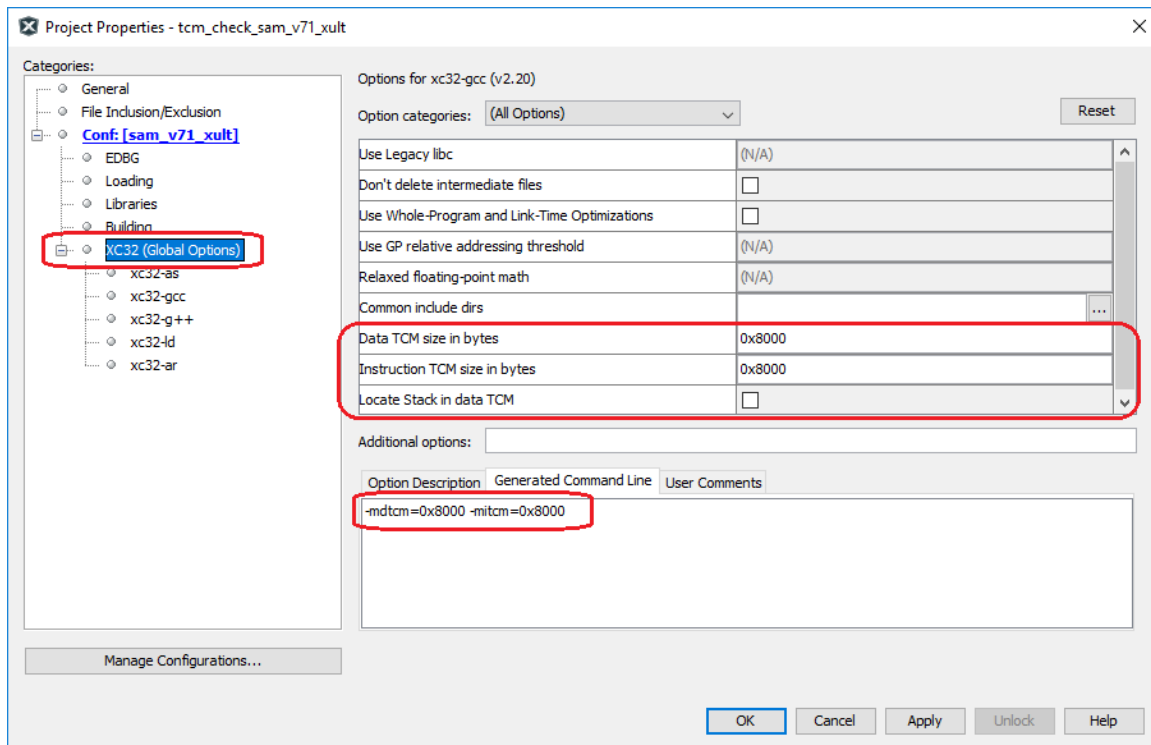
The device-specific startup code and device-specific linker script work together to set up and initialize the TCM at startup. Enabling TCM is not done by default startup code. Harmony v3 code generation adds code to enable TCM in startup code.

Note: With the `-mitcm` linker option enabled, the linker allocates the vector table to the ITCM, improving both interrupt latency and latency determinism. With the `-mstack-in-tcm` added to the linker option, the linker allocates the stack to the DTCM, and the startup code will transfer the stack from the System SRAM to the DTCM before calling the `main()` function.

2.1 Using MPLAB Harmony v3 for Configuring and Using TCM

In the MPLAB Harmony v3 project, TCM configurations are available under System module in the project graph. Set the TCM size in the configuration UI tree and generate the code.

Figure 2-2. Configuring TCM Size
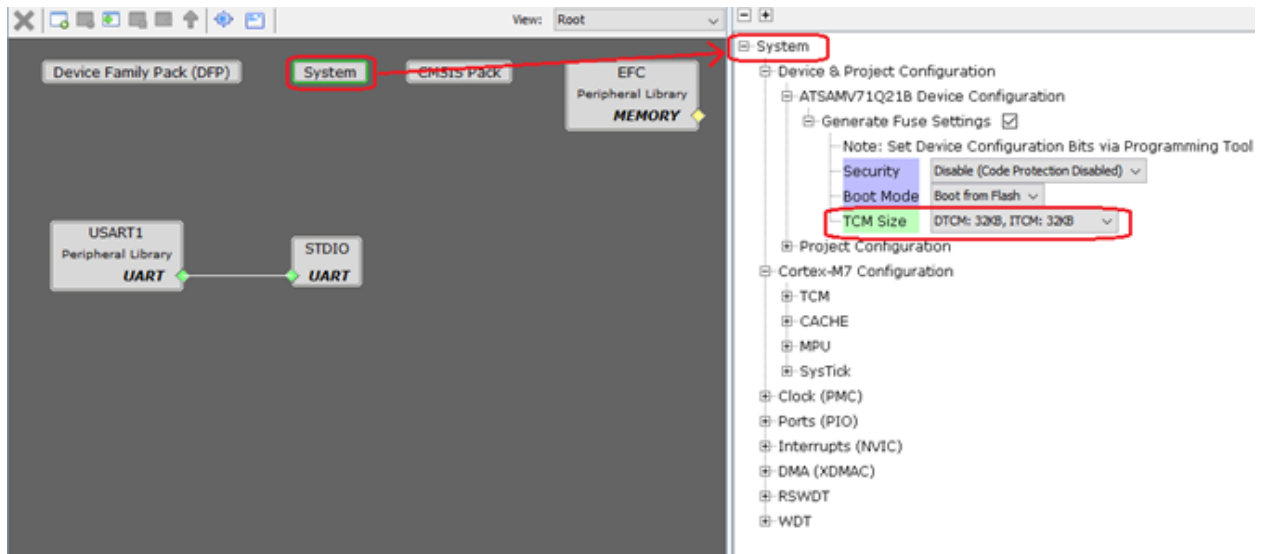
Note: Configuring the TCM size in the UI tree view, auto-populates the DTCM and ITCM `<size_in_bytes>` in the project properties settings.

Code generation will generate relevant functions to configure the TCM size and enable the TCM in the startup file. These functions are called in the reset handler before the `main()` is called.

```
/**
 * \brief This is the code that gets called on processor reset.
 * To initialize the device, and call the main() routine.
 */
void __attribute__((optimize("-O1"), section(".text.Reset_Handler"), long_call))
Reset_Handler(void)
{
    uint32_t *pSrc;

    /* Call the optional application-provided _on_reset() function. */
    if (_on_reset)
    {
        _on_reset();
    }

    /* Reserved for use by MPLAB XC32. */
    if (__xc32_on_reset)
        __xc32_on_reset();

#if (__ARM_FP==14) || (__ARM_FP==4)
    /* Enable the FPU if the application is built with -mfloat-abi=softfp or -mfloat-abi=hard
*/
    FPU_Enable();
#endif

    TCM_Configure(1);
    /* Enable TCM   */
    TCM_Enable();

    /* Initialize data after TCM is enabled.
     * Data initialization from the XC32 .dinit template */
    __pic32c_data_initialization();
```

The `__pic32c_data_initialization()` routine copies the Flash contents to the ITCM portion of the SRAM and the initial values of the initialized data from the Flash to the DTCM portion of the SRAM.

2.2 Using the TCM for Allocating User Data and Code

To allocate the user data (variable or buffer) in the TCM, the following compiler attributes must be applied while declaring the variable or buffer: `__attribute__((tcm))`. The same compiler attribute can be used for placing the code in the TCM. Code or data will be placed into the instruction or data TCM as appropriate.

The following code example provides the usage of the `tcm` compiler attribute:

```
// ****************************************************************************
// ****************************************************************************
// Section: Included Files
// ****************************************************************************
// ****************************************************************************

#include <stddef.h>                    // Defines NULL
#include <stdbool.h>                   // Defines true
#include <stdlib.h>                    // Defines EXIT_FAILURE
#include "definitions.h"               // SYS function prototypes


static char __attribute__ ((tcm)) writeBuffer[] = "***************************** \r\n"
                           "        Data TCM Demo            \r\n"
                           "     Demo uses DTCM memory      \r\n"
                           "***************************** \r\n";

unsigned int __attribute__ ((tcm)) test_func(void)
{
    /* User Function Implementation
       can be made here */


}
```

The following figure shows the address of the `test_func()` routine and the location of the `writeBuffer[]` in the TCM memory. Other functions and variables are in the normal Flash and system RAM memory.

Figure 2-3. Variables Window While Debugging in MPLAB X IDE

Name	Type	Address	Value
☑ Ⓟ &test_func	function	0x168	0x2300B500
☑ Ⓟ &main	function	0x402F4C	0x2000B538
☑ ◇ i	unsigned int	0x2040000C	0x00000000
⊞ ☑ ◇ writeBuffer; file:../src/main_v71	unsigned char[133]	0x20000000	"\\0\\0\\0\\0\\0\\0\\0\\0\\0\\0\\
🗋 <Enter new watch>			

3.   References

1.   AT14971: SMART SAM E70 TCM Memory:
      http://ww1.microchip.com/downloads/en/AppNotes/atmel-42555-smart-sam-e70-tcm-memory_application%20note_at14971.pdf

2.   SAMS/E/V7x device data sheet:
      http://ww1.microchip.com/downloads/en/DeviceDoc/SAM-E70-S70-V70-V71-Family-Data-Sheet-DS60001527D.pdf

3.   ARM documentation on the Cortex-M7:
      http://infocenter.arm.com/help/index.jsp?topic=/com.arm.doc.ddi0489d/Chdeajag.html

4.   MPLAB X IDE:
      https://www.microchip.com/mplab/mplab-x-ide

5.   XC32 Compilers:
      https://www.microchip.com/mplab/compilers

6.   MPLAB Harmony v3:
      https://www.microchip.com/mplab/mplab-harmony/mplab-harmony-v3

7.   MPLAB Harmony GitHub:
      https://github.com/Microchip-MPLAB-Harmony

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