MICROCHIP

AN2565

SAM-BA® Monitor for ROMless Cortex™-M devices

Introduction

The SAM Boot Assistant (SAM-BA®) allows In-system Programming (ISP) using a USB or UART host without any external programming interface. In general, SAM-BA Monitor is factory programmed to ROM, if it exists. If ROM does not exist, by default, SAM-BA is not supported. To support SAM-BA in ROMless devices, the SAM-BA Monitor application can be loaded in the Flash memory.

This application note focuses on ROMless Cortex™-M devices and explains the SAM-BA Monitor and its interfaces on these devices. The SAM-BA Monitor is compatible with existing SAM-BA software tools, but has some differences compared to other Cortex-M devices. These differences are explained in this document.

Features

- Allows the end user to program, verify, and secure a device without a programmer
- Allows the end user to upgrade an application's firmware
- Provides a configurable Start condition using an I/O pin
- Supports USB-CDC and UART interfaces
- Source code is available, which can be customized to user requirements

Table of Contents

1. SAM-BA Introduction

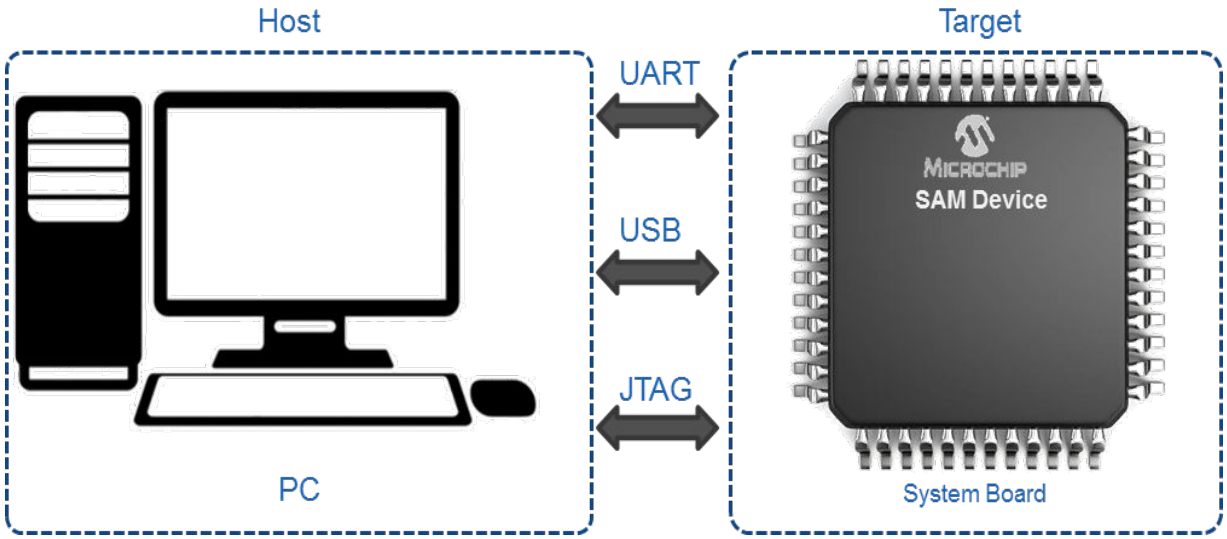
The SAM Boot Assistance (SAM-BA) software provides an open set of tools for programming Microchip SAM ARM® Thumb®-based microcontrollers. They are based on a common dynamic linked library (DLL), the AT91Boot_DLL, which is used by the SAM-BA and all ISP tools.

SAM-BA is used to establish a communication between a Host Graphical User Interface (SAM-BA GUI) running on a PC and a target device (Cortex-M device) from an existing system board.

The communication protocols used are as follows:

- USB
- UART
- JTAG

Figure 1-1. SAM-BA Connections Overview



1.1 Applet Introduction

To acknowledge the host requests, the target must be able to perform several functions when the host asks for a read/write/erase on a specific memory. Therefore, those functions, called *applets*, must be previously loaded into the RAM. An applet is a small program running on the target, which is used by SAM-BA to enable programming of non-volatile memories, low-level initialization, or other peripherals. For each SAM device, there is one dedicated applet to each memory device the chip interacts with.

1.2 SAM-BA Monitor

To communicate with the SAMB-BA GUI, a command interpreter, named as *SAM-BA Monitor*, must be placed in the target. Some SAM devices have the SAM-BA Monitor factory ROMed (see Figure 1-2), and some others do not have the SAM-BA Monitor; therefore, it must be loaded in the embedded Flash memory (see Figure 1-3). Those types of devices are called *ROMless* devices.

Figure 1-2. SAM ROM-based System Board

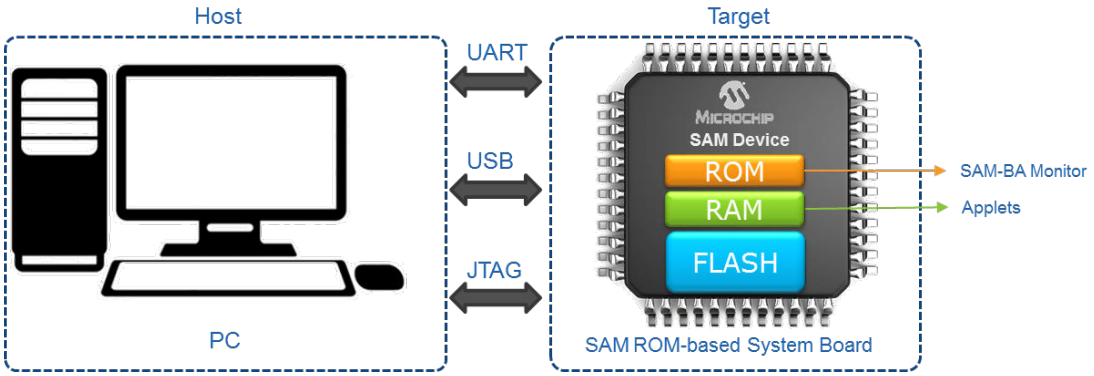
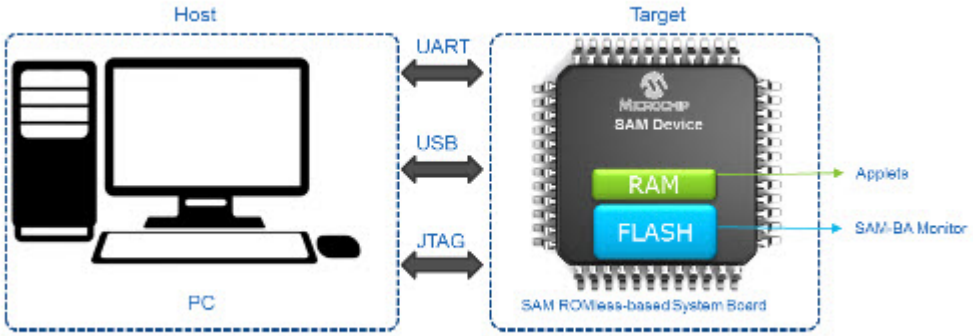


Figure 1-3. SAM ROMless-based System Board



The SAM-BA Monitor provides an easy way to program in-situ the on-chip Flash memory. The SAM-BA Monitor supports both USB-CDC and UART communications. The SAM-BA Monitor will continuously look for a Start condition on the UART and/or USB interfaces. When the Start condition is detected, SAM-BA Monitor enters into an infinite loop waiting for SAM-BA GUI commands.

The Start condition on the USB interface is enumeration completion. When the SAM-BA Monitor detects enumeration with the Host is completed, it will start waiting for SAM-BA commands.

The Start condition on the UART interface is '#'. When the SAM-BA Monitor receives this character, it will start waiting for SAM-BA commands.

2. ROMless Cortex-M Devices

The following table provides a list of current Cortex-M devices that *do not* have a ROMed or factory programmed (in Flash) SAM-BA Monitor. Microchip has provided a SAM-BA Monitor example for the dedicated XPlained Pro boards, but the SAM-BA Monitor remains an open source tool that can also be easily ported to any device of a ROMless product family.

Table 2-1. ROMless Cortex-M Devices

Product Family	Xplained Pro Board (On-board Device)	Core
SAM L22	SAML22 Xplained Pro (SAML22N18A)	Cortex-M0+
SAM L21	SAML21 Xplained Pro (SAML21J18B)	Cortex-M0+
SAM D21	SAMD21 Xplained Pro (SAMD21J18A)	Cortex-M0+
SAM C21	SAMC21 Xplained Pro (SAMC21J18A)	Cortex-M0+
SAM D5x/E5x	SAME54 Xplained Pro (SAME54P20A)	Cortex-M4

3. Hardware Requirements

The SAM-BA Monitor uses a general purpose I/O (Bootloader Entry Pin) to determine if the SAM-BA Monitor will start or execute application Flash.

The following table provides signals and their description in corresponding interfaces.

Table 3-1. SAM-BA Monitor UART Mode Connections

Signal Name	Description
UART RXD	Serial communication (115200-8-N-1) receive line
UART TXD	Serial communication (115200-8-N-1) transmit line
Bootloader Entry Pin	GPIO pin to determine execution (i.e., either to execute application or listen for SAM-BA host commands)

Table 3-2. SAM-BA Monitor USB Mode Connections

Signal Name	Description
USB D+	USB connection to Host
USB D-	USB connection to Host
Bootloader Entry Pin	GPIO pin to determine execution (i.e., either to execute application or listen for SAM-BA Host commands)

Note: For any device-specific requirements to enable Serial or USB communication, refer to the corresponding device's data sheet and/or schematic checklist section.

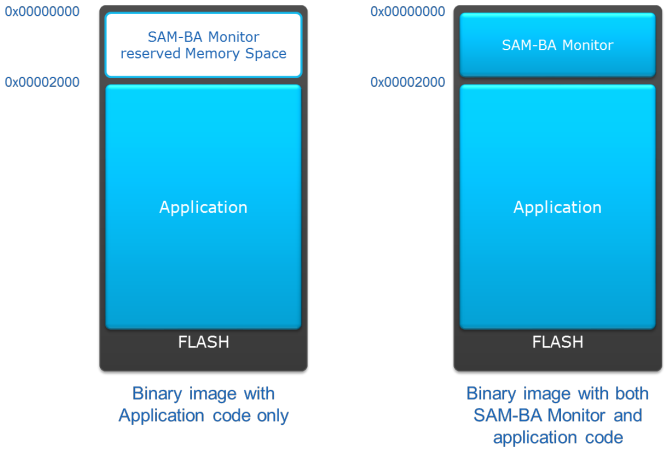
4. Software Implementation

This application note is provided with an example SAM-BA Monitor application that is based on Atmel® Studio. The full source code is available and it can be easily ported to IAR/KEIL, depending on user requirements.

4.1 Memory Map

A reserved space of Flash memory for the SAM-BA Monitor application is required. The size of this space is from 0x00000000, to the Application Start Address (0x00002000), to ensure consistency among various combinations of compilers (i.e., GCC/IAR and UART, and/or USB-CDC interface).

Figure 4-1. Device Memory Map



4.2 Design Considerations

The following are the design considerations for this implementation:

- UART and USB drivers support most peripheral variants used in ROMless Cortex-M devices
- In this application note, Atmel Studio 7 must be used to program the SAM-BA Monitor into the device
- Tool versions used for development and testing are the latest release of Atmel Studio 7 and SAM-BA GUI 2.xx
- Compilation is performed using the ARM/GNU Compiler 6.2.1, with Optimization -Og, STACK_SIZE=0x280, --specs=nano.specs

4.3 Configurations

The SAM-BA Monitor application allows configurations to customize it for user needs. Following are the configurations for customization:

- Communication interface UART or USB, or both:
  - In case of UART, SERCOM instance on the device
- Bootloader Entry Pin that controls SAM-BA Monitor execution
- Application start address, changing application start address requires
  - Regenerating applets for the SAM-BA host

– Relocating application to the new start address

The following table provides configurations in the example application.

Table 4-1. SAM-BA Configurations in Example Application

Device	Configuration	Current Setting
SAM L22 (SAML22N18A)	Communication interface	Both USB and UART
	SERCOM instance	SERCOM4 (PC24D, PC25D)
	Bootloader Entry Pin	PC01
SAM L21 (SAML21J18B)	Communication interface	Both USB and UART
	SERCOM instance	SERCOM3 (PA22C and PA23C)
	Bootloader Entry Pin	PA02
SAM D21 (SAMD21J18A)	Communication interface	Both USB and UART
	SERCOM instance	SERCOM3 (PA22C and PA23C)
	Bootloader Entry Pin	PA15
SAM C21 (SAMC21J18A)	Communication interface	Both USB and UART
	SERCOM instance	SERCOM4 (PB10D, PB11D)
	Bootloader Entry Pin	PA28
SAM E54 (SAME54P20A)	Communication interface	Both USB and UART
	SERCOM instance	SERCOM2 (PB25D, PB24D)
	Bootloader Entry Pin	PB31

4.4 Memory Usage

The SAM-BA Monitor application is targeted to use limited Flash and SRAM, therefore, it can be ported to low footprint devices like 32K Flash and 4K SRAM. The following table illustrates Flash and SRAM consumption for different devices.

Note: Latest version of Atmel Studio, ARM/GNU Compiler 6.2.1, Optimization -Og, STACK_SIZE=0x280, --specs=nano.specs.

Table 4-2. SAM-BA Monitor Memory Usage

Device	USB + UART (Flash/ SRAM) in Bytes	USB Only (Flash/ SRAM) in Bytes	UART Only (Flash/ SRAM) in Bytes
SAML22N18A	4488/ 1168	3384/1160	2400 / 688
SAML21J18B	4508 / 1168	3404 / 1160	2420 / 688
SAMD21J18A	4524 / 1168	3436 / 1160	2464 / 688
SAME54P20A	4768 / 1168	3716 / 1160	2952 / 688

Note: This memory usage information may change if the development environment changes (i.e., Toolchain change, option changes, etc.).

5. Rebuilding SAM-BA Monitor

The source code for the SAM-BA Monitor is provided with this application note, which contains an Atmel Studio project configured for GCC. To use the SAM-BA Monitor for other devices or configurations, the SAM-BA Monitor project must be rebuilt with the required changes.

Use the following steps to rebuild for the SAM L22. Similar steps can be followed for any other ROMless Cortex-M devices.

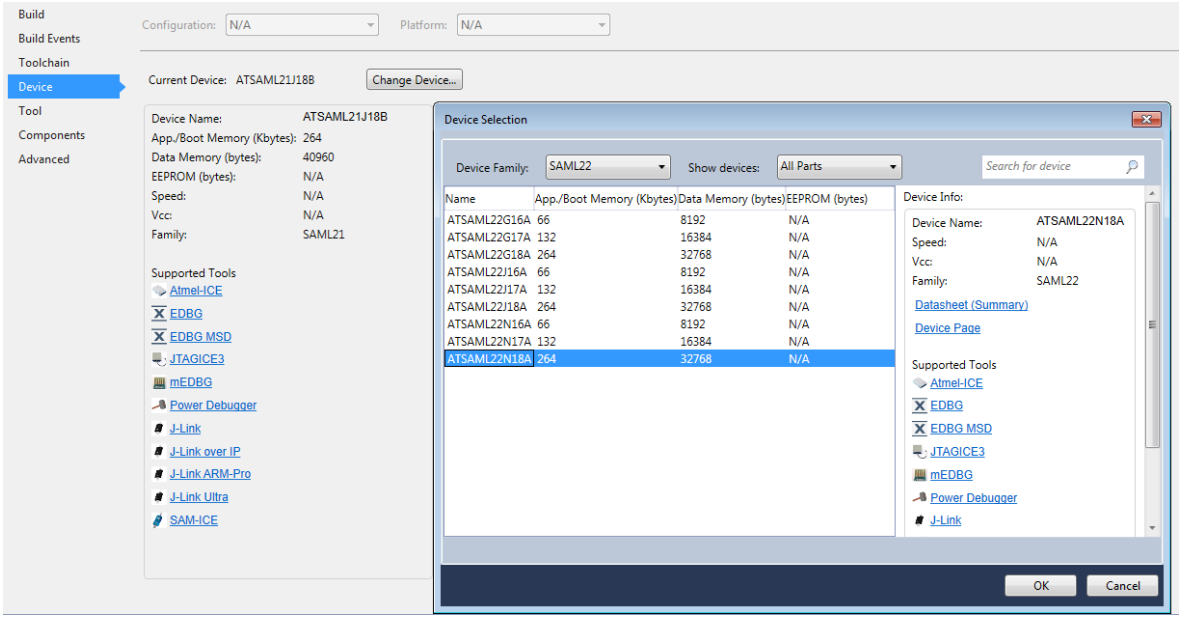
5.1 Example of Porting the SAM-BA Monitor to a SAM L22 Using Atmel Studio

1. Open *samba_monitor.atsln* from the zip archive provided with this application note.
2. Create a device-specific configuration file similar to the existing device configuration files in the *device_config* folder. In this case it is *device_config_saml22n18a.h*. Include this new configuration file in *device_config\device_config.h* when the device is defined.
   - 2.1. The following configurations are used for SAML22:
     - 2.1.1. Communication interface - Both USB and UART, choose `SAM_BA_INTERFACE` as `SAM_BA_BOTH_INTERFACES`
     - 2.1.2. Default `APP_START_ADDRESS` (i.e., 0x00002000)
     - 2.1.3. Add SAML22N18A support in *device_config.h* as shown in the following code example:

```
#elif defined (__SAML22N18A__)
#include "device_config_saml22n18a.h"
#define SAM_BA_INTERFACE   SAM_BA_BOTH_INTERFACES
#define APP_START_ADDRESS  DEFAULT_APP_START_ADDRESS
```

   - 2.2. Revisit all other macros and in-line functions in *device_config_saml22n18a.h* and ensure they match the current device settings. Refer to the specific device data sheet for configuration details.

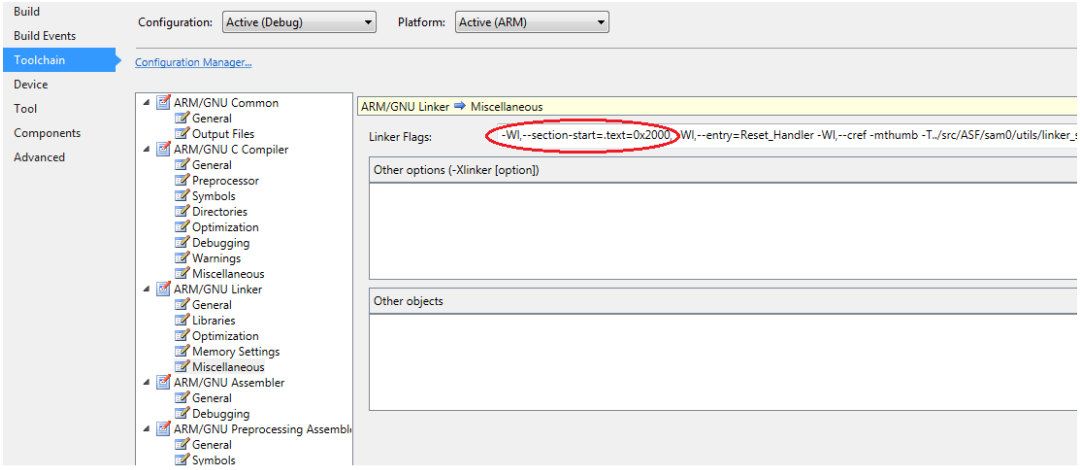
   Note: Updated *device_config.h* and *device_config_saml22n18a.h* files are provided with this application.
3. Open properties by selecting *Project* > *Properties*, and then navigate to:
   - 3.1. *Device* > *Change Device*
     - 3.1.1. Select **New Device**. The *Device_Startup* folder should be updated for the new device.



4. Rebuild the project. The new hex and bin files are ready to use in the output folder.

5.2 Relocating Application to the New Start Address

1. Open the application project and relocate it to the new address configured in samba_monitor. In this case it is 0x00002000.
   1.1. Open Properties, by selecting *Project* > *Properties* and then navigate to *Tool chain* > *ARM/GNU Linker* > *Miscellaneous.*
      1.1.1. Add `-Wl,--section-start=.text=0x2000,.`

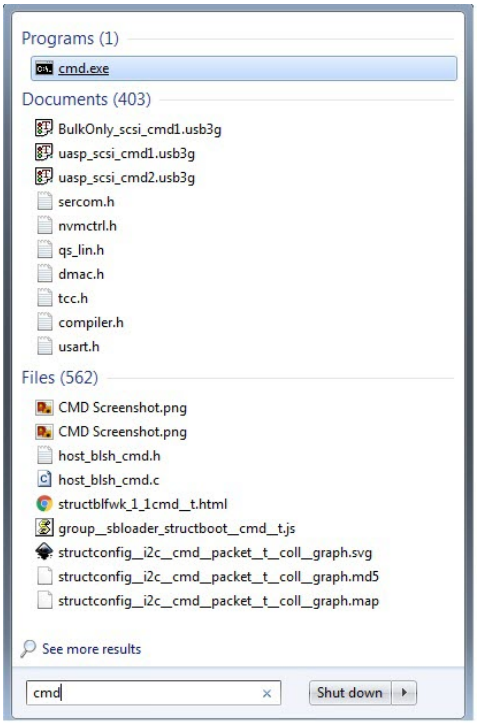


2. For an application that is using the same USART or USB interface, it may need to reinitialize as per application needs. Otherwise, the application may continue using configurations from the SAM-BA Monitor.
3. Rebuild the project. The application hex and bin files should be ready to use in the Debug/Release folder.

5.3 Regenerating Applets for the SAM-BA Host

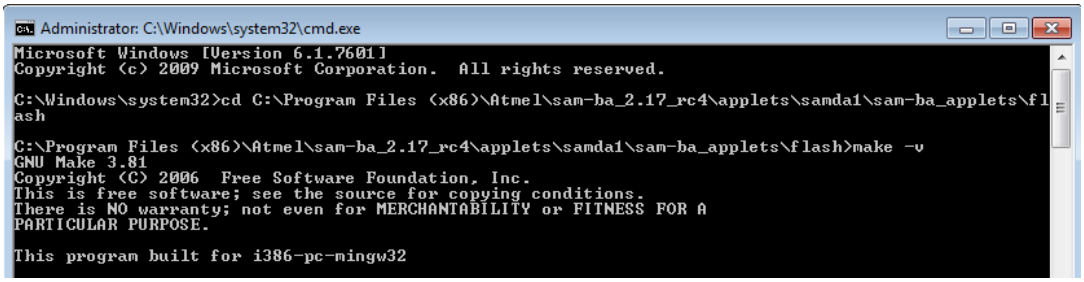
Use the following steps to change the start address of the application. Refer to http://www.microchip.com//wwwAppNotes/AppNotes.aspx?appnote=en591431, for a complete details on how to customize and regenerate applets for the SAM-BA Host.

1. Go to the SAM-BA installation directory, by default it is located in *Program files (x86)/Atmel/sam-ba.*
2. Locate the *applets\samda1\sam-ba_applets\flash\ flash_app_main.c* file.
   - 2.1. Edit the `MONITOR_SIZE` macro in the C file to match the Application Start address in the customized SAM-BA Monitor and save the file.
   - 2.2. Open a CMD window with administrator privileges.
     - 2.2.1. In *search programs and files*, type **cmd**.
     - 2.2.2. Use Ctrl+Shift+Enter to open instead of Enter (with administrator privileges).
   - 2.3. Navigate to the *applets\samda1\sam-ba_applets\flash* folder by using the *cd* command.
   - 2.4. In this folder, enter the *make –v* command to display the make version. If not, refer to the **GNU Make 3.81** section in the application note, available for download at: http://www.microchip.com//wwwAppNotes/AppNotes.aspx?appnote=en591431.

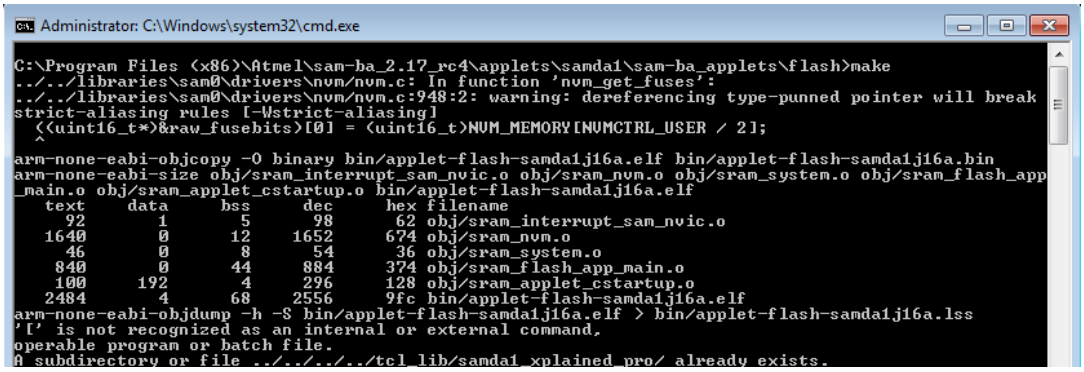


Ctrl+Shift+Enter

Select Yes



   - 2.5. Open the *cmd* window and Run *make*.



2.6. The updated bin file should be generated in the *bin* folder.

2.6.1. Go to the *tcl-lib\saml22_xplained_pro* folder and copy the bin file.

2.6.2. Restart the SAM-BA host utility to use the updated bin file.

Once all of the steps above are completed successfully, the SAM-BA Monitor and SAM-BA host should be ready for the SAM L22 device.

Note: Updated applets source code, bin, and tcl files are provided for all the ROMless Cortex-M devices folder.

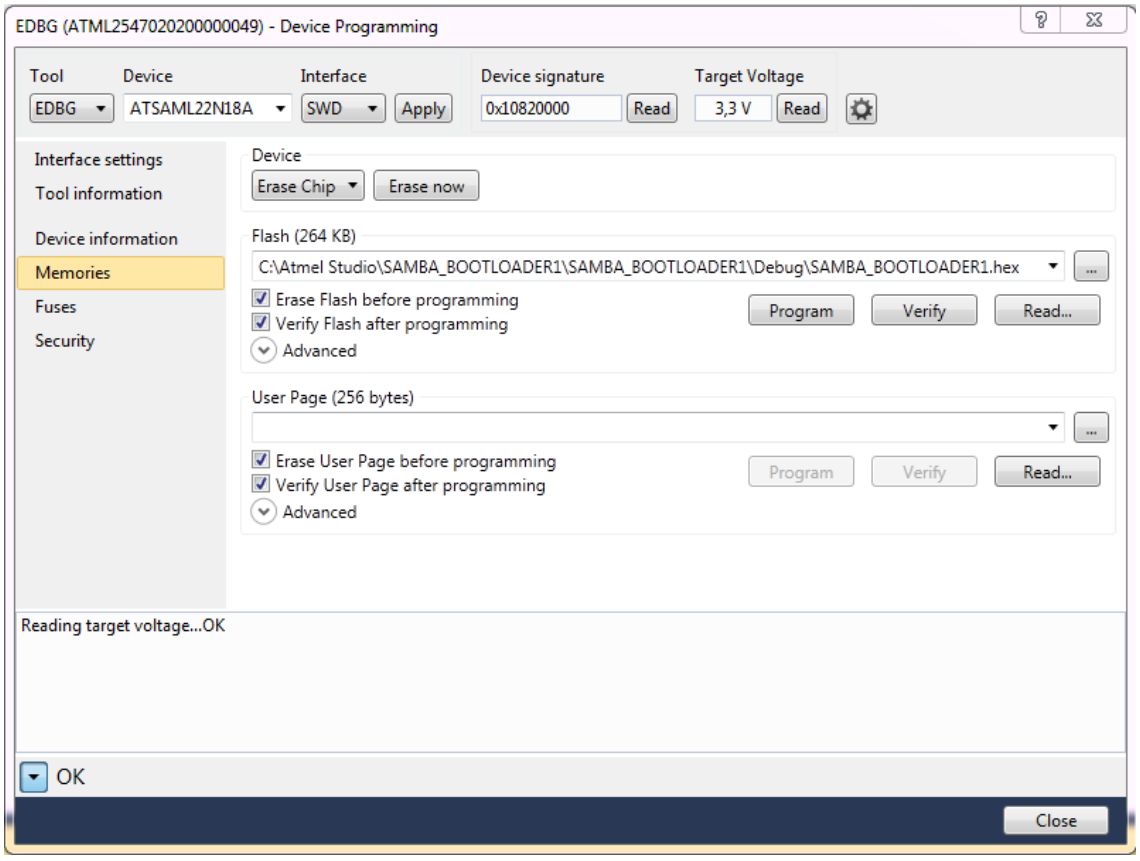
6. Using SAM-BA Monitor

6.1 Programming SAM-BA Monitor

Programming the SAM-BA Monitor can be done using a Serial Wire Debug (SWD) probe:

1. In Atmel Studio, select *Tools* > *Device Programming*.
2. Select the Tool, and then click **Apply**.
3. From the Memories tab, erase the chip by clicking **Erase now**.
4. Specify the path to the SAM-BA Monitor image in the Flash field and click **Program**.

Figure 6-1. Device Programming



5. Alternatively, the command-line programming tool, *atprogram*, can also be used for programming the hex file. The following example can be used to program the SAML22N18A device which is available on the SAM L22 Xplained board.

```
atprogram -t edbg -i swd -d atsaml22n18a program -f
samd21_sam_ba_both_interfaces.hex
```

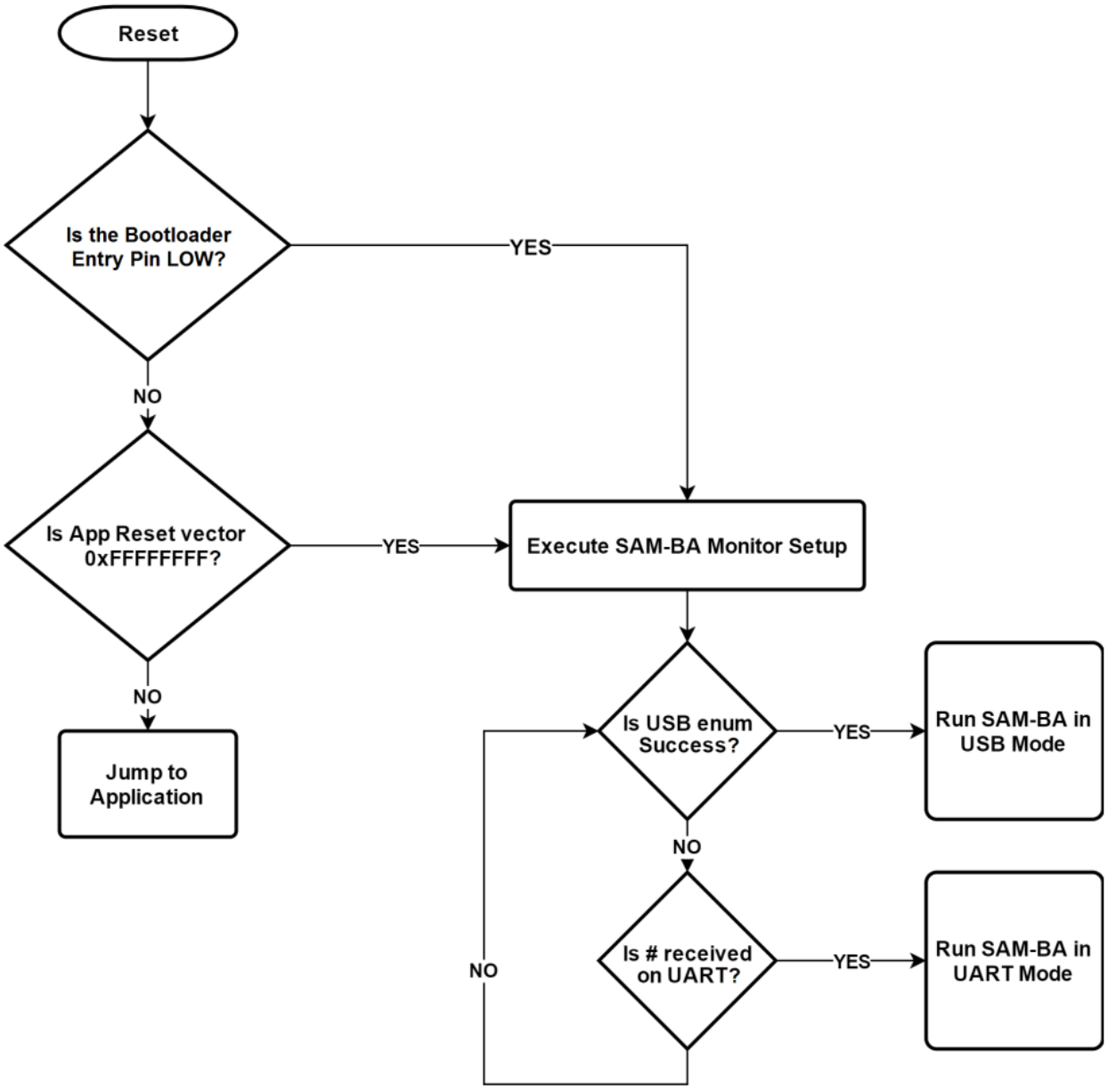
6.2 Entering the SAM-BA Monitor

SAM-BA Bootloader activation can be requested using any one of the following conditions:

External Condition: Pull the Bootloader Entry Pin low while releasing the device from the Reset condition. A common usage is to use a push button accessible by the user as a SAM-BA Monitor trigger. The user must press and hold the push button when powering up or resetting the device.

Internal Condition: On erased devices or when the application reset vector (@APP_START_ADDRESS + 4) is blank (0xFFFFFFFF).

Figure 6-2. SAM-BA Monitor Boot Process



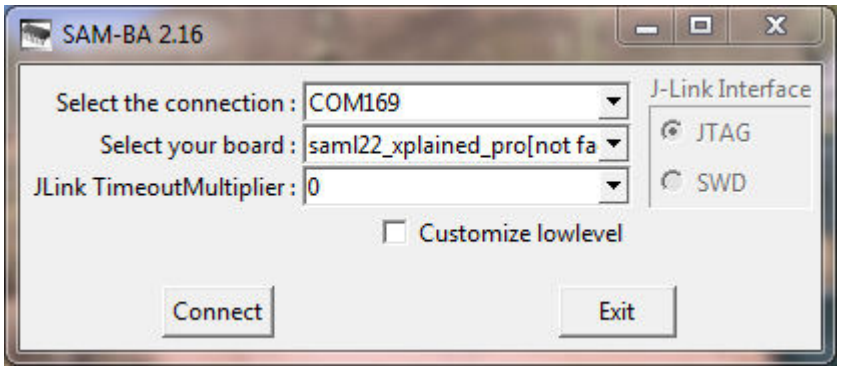
7. Running SAM-BA on Windows®

This section presents the basic steps to run the SAM-BA GUI on a Windows® PC. For complete details, refer to the SAM-BA User guide (*<samba-install-directory>\doc\sam-ba user guide.pdf*).

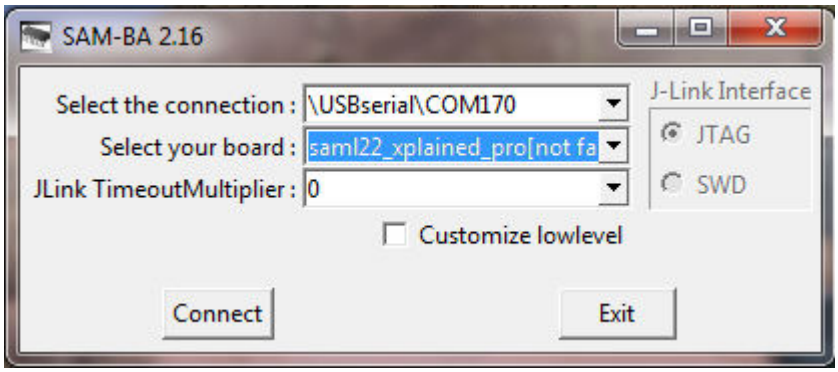
7.1 Connecting to SAM-BA GUI

To use the SAM-BA Monitor with the UART interface, connect the hardware to the PC through the detected COM port or the selected serial port.

Note: For the SAM L22 Xplained Pro, the UART interface is output using the *DEBUG USB* port.



To use the SAM-BA monitor with the USB interface, connect the hardware to the PC through the *TARGET USB* port.



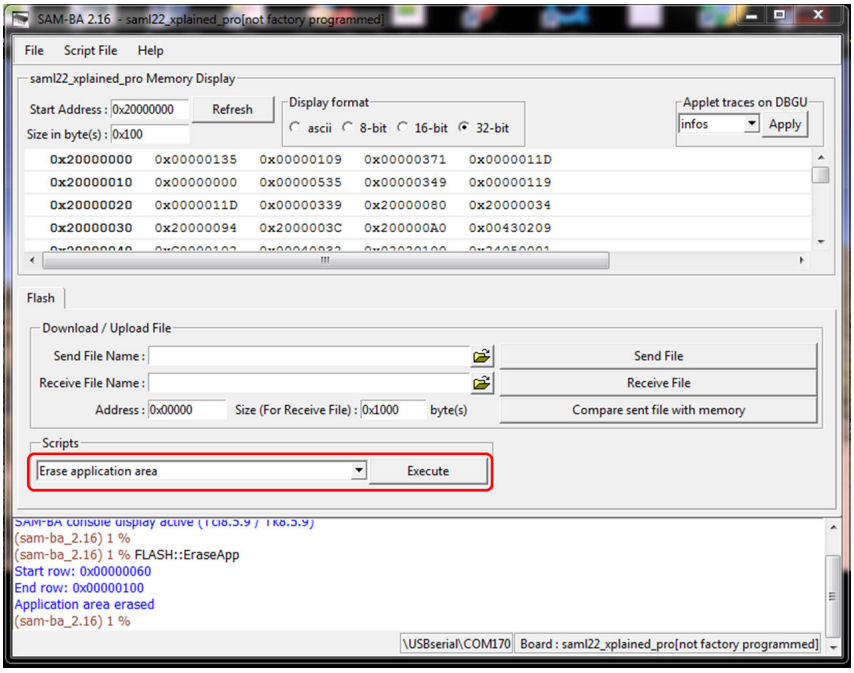
Click **Connect** to establish connection with the device.

7.2 Flash Programming

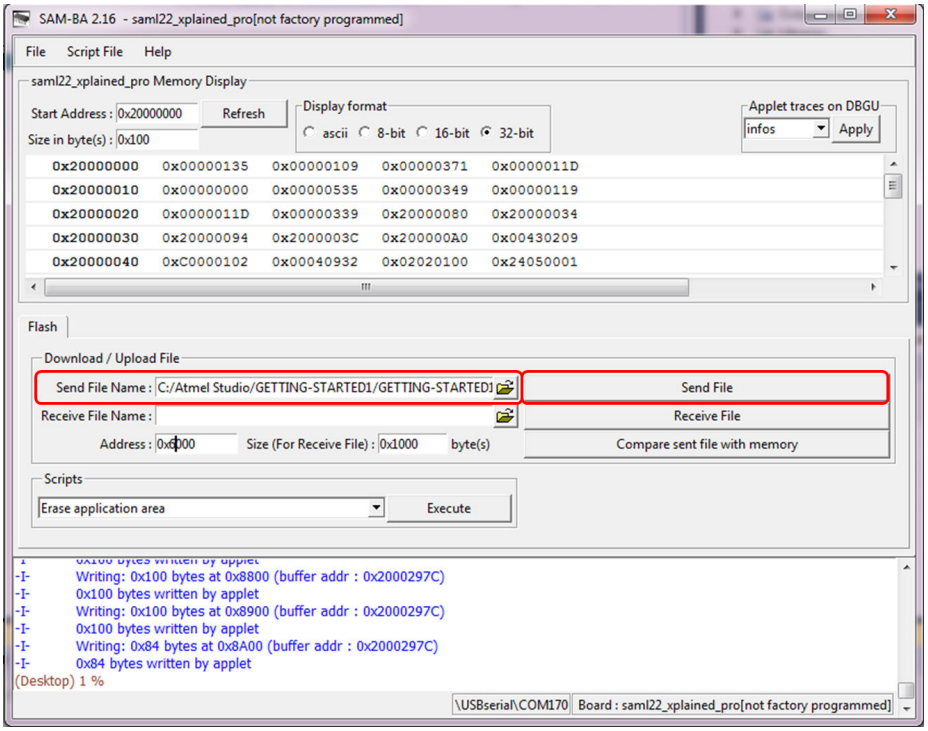
On successful connection to the device, the following SAM-BA screen will be displayed, which allows various interactions with the device. For upgrading an application, the user need to erase existing application and then download or upload the file. The contents of the Flash are loaded using the Flash tab. While uploading a program to Flash memory, the start address must match the configured value in the SAM-BA Monitor and applet (in the example SAM-BA Monitor it is 0x2000); otherwise, the transfer process will be aborted.

Flash Programming

1. Erase the application by choosing the *Erase application area* script and then click **Execute**.



2. Select the file to download to device Flash and then change the *Address* to **0x02000**.



3. Click **Send File**.

7.3 Scripts

The following predefined scripts are available with SAM-BA Host.

Table 7-1. Predefined Scripts

Script Name	Description
Set Security Bit	Set the security bit to secure the device. Refer to "NVMCTRL" chapter in the specific device data sheet for more information.
Read Security Bit	Read the current security state
Erase application area	Erase all application code (SAM-BA Monitor region will not be erased).
Invalidate application	Erase first page of application.
Read Fuses	Returns the values of fuse settings. Refer to the "NVM User Row Mapping" section in the specific device data sheet for more information.
Read Lock Fuses	Read the current lock settings
Read Device ID	Read the Device Identification register
Set Lock Bit [0:15]	Set the specified lock bit to prevent any erasure of Flash memory region. Refer to the "NVMCTRL" chapter in the specific device data sheet for more information.
Unlock all	Unlock all Flash memory regions.

8. Other Solutions

The SAM-BA Monitor is also provided in various other options. The following table presents various options and use cases.

Table 8-1.

SAM-BA Monitor Option	Description
ASF-based SAM-BA Monitor	SAM-BA Monitor is developed using the Atmel Software Framework (ASF). It is easy to port to various devices as it takes care of drivers porting for various SERCOM or USB instances or variants on the device. Due to the ASF, it is a little higher in footprint. (24 KB in ASF 3.32).
ROM-based SAM-BA Monitor	On some devices, such as the Cortex-M3 / M4 / M7 series SAM devices, where ROM is available, the SAM-BA Monitor is loaded into ROM. It will be activated based on the GPNVM bit setting on the reset. Refer to the specific device data sheet for details.
Legacy IAR Projects	The following Legacy Projects are also included in this application note zip folder: • Atmel-42238-UART-based-SAM-BA-Bootloader-for-SAM-D20_AP-Note_AT04189.zip • Atmel-42366-SAM-BA-Bootloader-for-SAM-D21_ApplicationNote_AT07175.zip

9. References

- Atmel-42438-SAM-BA-Overview-and-Customization-Process_ApplicationNote_AT09423.pdf
- Atmel-42728-Using-SAM-BA-for-Linux-on-SMART-ARM-based-Microcontrollers_ApplicationNotes_AT15004.pdf
- SAM-BA User Guide: *<samba_install_dir>\doc\sam-ba user guide.pdf*

10. Revision History

Table 10-1. Rev. A - 11/2017

Description
This is the initial release of this document.

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