

Renesas RA Family

Booting Encrypted Image on RA4 using MCUboot and QSPI

Introduction

MCUboot is a secure bootloader for 32-bit MCUs. It defines a common infrastructure for the bootloader, defines system flash layout on microcontroller systems, and provides a secure bootloader that enables easy software update. MCUboot is independent of operating system and hardware and relies on hardware porting layers from the operating system it works with. The Renesas Flexible Software Package (FSP) integrates an MCUboot port starting from FSP v3.0.0. Users can benefit from using the FSP MCUboot Module to create a Root of Trust (RoT) for the system and perform secure booting and fail-safe application updates.

The MCUboot is maintained by Linaro in the GitHub mcu-tools page <https://github.com/mcu-tools/mcuboot>. There is a `\docs` folder that holds the documentation for MCUboot in `.md` file format. This application note refers to the above-mentioned documents wherever possible and is intended to provide additional information that is related to using the MCUboot module with Renesas RA FSP v3.0.0 or later.

To provide confidentiality of image data while in transport to the device or while residing on an external flash, MCUboot has support for encrypting/decrypting images on-the-fly while upgrading. When upgrading the image from the secondary slot to the primary slot, it is automatically decrypted after validation. Image encryption is supported by FSP v3.8.0 or later.

This application note walks the user through application project creation using the MCUboot module on Renesas EK-RA4M3 with external QSPI flash as the secondary image storage area. The application examples implemented image downloading to the QSPI secondary slot over USB PCDC. MCUboot with encryption also supports internal flash encryption. The operations are very similar to the QSPI usage and are not demonstrated in this application project.

For using MCUboot module with the internal flash in code flash linear mode without encryption support, user can reference application project (R11AN0869).

Required Resources

Development tools and software

- The e² studio IDE v2025-10 or later.
- Renesas Flexible Software Package (FSP) v6.2.0 or later.
- SEGGER J-link® USB driver.

The above three software components: the FSP, J-Link USB drivers and e² studio are bundled in a downloadable platform installer available on the FSP webpage at renesas.com/ra/fsp.

- Python v3.9 or later- <https://www.python.org/downloads/>

Hardware

- EK-RA4M3 Evaluation Kit for RA4M3 MCU Group (<http://www.renesas.com/ra/ek-ra4m3>).
- Workstation running Windows® 10/11 and Tera Term console, or similar application.
- Two USB device cables (type-A male to micro-B male).

Prerequisites and Intended Audience

This application note assumes you have some experience with the Renesas e² studio IDE and Arm® TrustZone® based development models with e² studio. Users are required to read the entire FSP User's Manual on the MCUboot Port section and review the RA4 Basic Secure Bootloader Design using MCUboot Application Project (R11AN0869) prior to moving forward with this application project. In addition, the application note assumes that you have some knowledge of cryptography. Prior knowledge of Python usage is also helpful.

The intended audience are product developers, product manufacturers, product support, or end users who are involved with designing application systems involving usage of a secure bootloader.

Using this Application Note

Section 1 covers the general overview of MCUboot and the application upgrade methods supported by the MCUboot. If you have worked with MCUboot module-based bootloader previously, this section can be bypassed.

Section 2 covers the general flow of architecting a system using FSP MCUboot module. If you have previously worked with the MCUboot system using FSP, this section can be bypassed.

Section 3 covers the walk throughs of running the initial example projects which do not include encryption support. These example projects use swap test update mode and internal code flash for both primary and secondary applications. Image downloader using XModem over USB PCDC is implemented in the primary and secondary applications. MCUboot provided example keys are used for image signing and encryption support.

Section 4 covers adding encryption support to the bootloader and applications using internal code flash for both the primary and secondary applications.

Section 5 covers updating the projects created in section 4 to use QSPI for secondary image storage. Note that for the user's convenience, an end solution for this section is provided for the user's reference.

Section 6 covers using custom image signing and image encryption keys in the projects created in Section 5.

Section 7 covers production-related topics.

Contents

1. MCUboot Functionalities Overview	5
1.1 Validate Application Before Booting and Updating	5
1.1.1 Encrypted Applications Update	6
2. Architecting an Application with MCUboot Module using FSP.....	6
2.1 MCU Memory Configuration using MCUboot Module with FSP	6
2.2 Application Image Format for Encrypted Image	7
2.3 Designing Bootloader and the Initial Primary Application Overview	7
2.4 General Guidelines using the MCUboot Module Across RA Family MCUs	7
2.5 Customize the Bootloader	8
2.6 Production Support.....	8
2.6.1 Key Provisioning	8
2.6.2 Make the bootloader immutable for enhanced security	8
2.6.3 Advance the device lifecycle states prior to the deploy the product to the field	8
3. Running the Initial Example Projects	9
3.1 Set Up the Python Image Signing Environment.....	13
3.2 Running the Initial Example Projects.....	13
3.2.1 Set Up the Hardware	14
3.2.2 Import the Projects	15
3.2.3 Configure the Python Signing Environment	15
3.2.4 Compile all the projects	16
3.2.5 Debug the Applications	17
3.2.6 Downloading and Running the Secondary Application	17
4. Add Encryption to the Initial Example Project.....	19
4.1 Configure the Bootloader for Encryption Support	20
4.2 Configure the Application Project for Encryption Support	24
5. Use QSPI as Secondary Storage Area	29
5.1 Configure the Bootloader to Use QSPI for Secondary Application Storage	30
5.2 Update the Primary Application Project to Support QSPI	34
6. Using Custom Signing Key and Encryption Key.....	36
7. Appendix	42
7.1 Making the Bootloader for Cortex®-M33 Immutable.....	42
7.2 Device Lifecycle Management for Renesas RA Cortex®-M33 MCUs	43
8. References	43
9. Website and Support	44

Revision History	45
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1. MCUboot Functionalities Overview

MCUboot handles the firmware authenticity check after start-up and the firmware switch part of the firmware update process. Downloading the new version of the firmware is out-of-scope for MCUboot. Typically, downloading the new version of the firmware is functionality that is provided by the application project itself. This application project provides an example of this functionality using XModem transfer protocol over USB PCDC port to download image to the external QSPI secondary image storage area.

1.1 Validate Application Before Booting and Updating

For applications using MCUboot, the MCU memory is separated into MCUboot, Primary App, Secondary App and the Scratch Area. The following is an example of the single image MCUboot memory map when using the internal code flash.

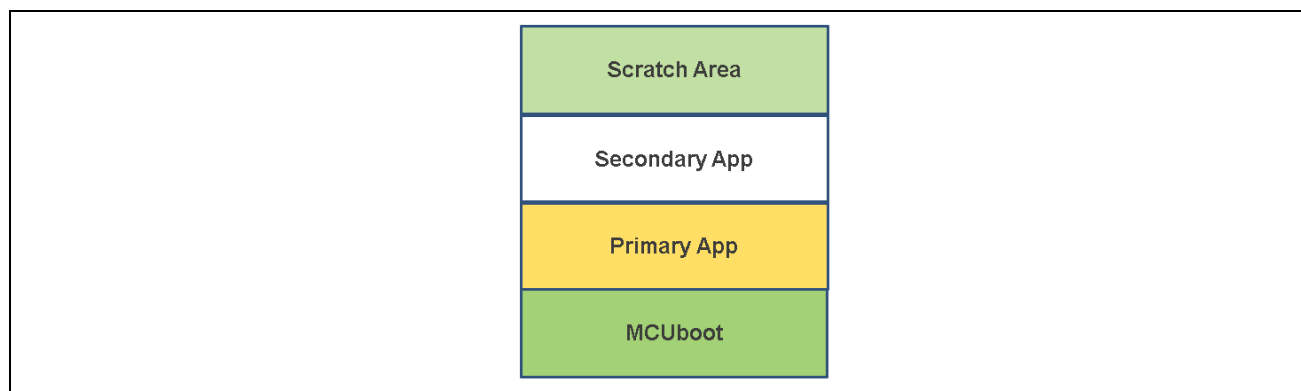


Figure 1. Single Image MCUboot Memory Code Flash Map

The following is an example of the single image MCUboot memory map when using external flash storage as the secondary storage area.

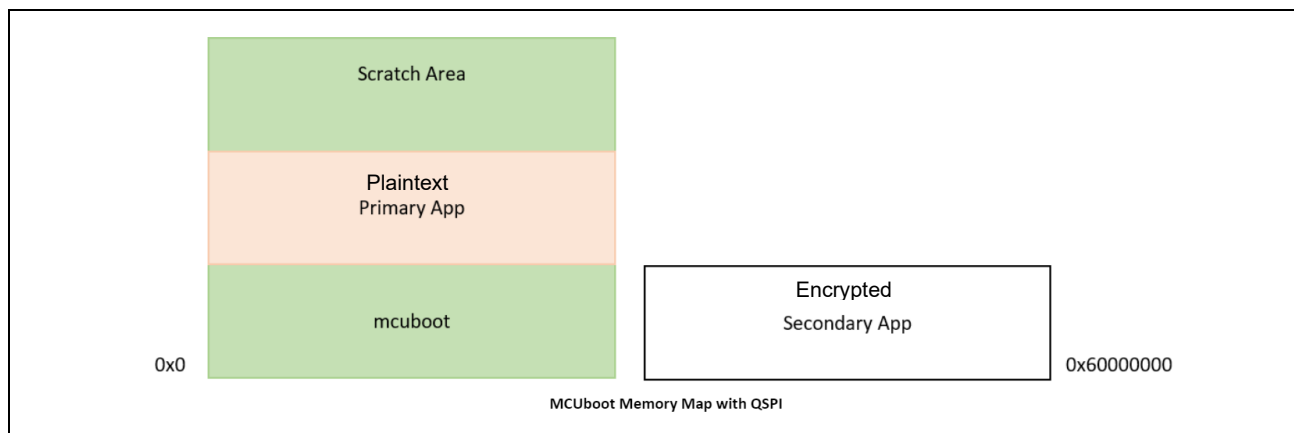


Figure 2. Single Image MCUboot Flash Memory Map with QSPI

For more information on the MCUboot memory layout, refer to the [Flash Map section](#) of the reference MCUboot website.

The functionality of the MCUboot during booting and updating follows the process below:

The bootloader starts when CPU is released from reset. For TrustZone®-based MCUs, MCUboot is designed to run in Secure mode with all access privileges available to it. If there are images in the Secondary App memory marked as to be updated, the bootloader performs the following actions:

1. The bootloader will authenticate the Secondary image.
2. Upon successful authentication, the bootloader will switch to the new image based on the selected update method. Available update methods are introduced in section 1.1.1.
3. The bootloader will boot the new image.

If there is no new image in the Secondary App memory region, the bootloader will authenticate the Primary applications and boot the Primary image.

The authentication of the application is configurable in terms of the authentication methods and whether the authentication is to be performed with MCUboot. If authentication is to be performed, the available methods are RSA or ECDSA. The firmware image is authenticated by hash (SHA-256) and digital signature validation. The public key used for digital signature validation can be built into the bootloader image or provisioned into the MCU during manufacturing. In the examples included in this application project, the public key is built into the bootloader images.

The image header needs to flag this image as ENCRYPTED (0x04) and a TLV with the key must be present in the image.

There is a signing tool included with the MCUboot: [imgtool.py](#). This tool provides services for creating Root keys, key management, and signing and packaging an image with version controls. User needs to read the MCUboot documentation to use and understand these operations.

1.1.1 Encrypted Applications Update

The major use case for encrypted image update is for external flash update image storage. External flash content is prone to theft in many ways. It is critical to secure the external flash secondary image storage area via encryption. Another relatively rare use case is the internal flash update image storage if the image is downloaded via insecure channel.

Encrypted image boot is supported with swap and overwrite upgrade mode on all RA MCUs via FSP. Direct XIP upgrade mode is not supported. The cryptographic operation for RA MCU is supported by MbedCrypto and TinyCrypt. User can reference Table 1 for the selection of the cryptographic library.

We recommend acquiring more details on the upgrade mode by reviewing the corresponding sections in application project (R11AN0869) as well as the MCUboot design page:

<https://github.com/mcu-tools/mcuboot/blob/master/docs/design.md>.

If swap upgrades are enabled, the image located in the primary slot, also having the ENCRYPTED flag set and the corresponding Type Length Value (TLV) field present, the primary image is re-encrypted while swapping to the secondary slot.

- The image is encrypted using AES-CTR-128, with a counter that starts from zero (over the payload blocks) and increments by 1 for each 16-byte block. AES-CTR was chosen for speed/simplicity and allowing for any block to be encrypted/decrypted without requiring knowledge of any other block (allowing for simple resume operations on swap interruptions). MCUboot also supports AES-CTR-256, this is not supported from FSP side.

2. Architecting an Application with MCUboot Module using FSP

This section provides an overview of the FSP MCUboot module, which integrates MCUboot as a module into the FSP. The available upgrade modes and memory architecture design are discussed. In addition, signing and mastering new images are discussed.

2.1 MCU Memory Configuration using MCUboot Module with FSP

For the general support information, the user can reference the MCUboot port section of the FSP User's Manual.

It is also highly recommended that the user reviews the MCUboot encrypted image page for background on the encryption scheme.

https://github.com/mcu-tools/mcuboot/blob/main/docs/encrypted_images.md

Users can gain hands on experience in configuring the memory regions using the MCUboot module in the walkthrough section in section 3, section 4 and section 5.

2.2 Application Image Format for Encrypted Image

Figure 3 is a more detailed application image format that can be referenced to understand the booting process.

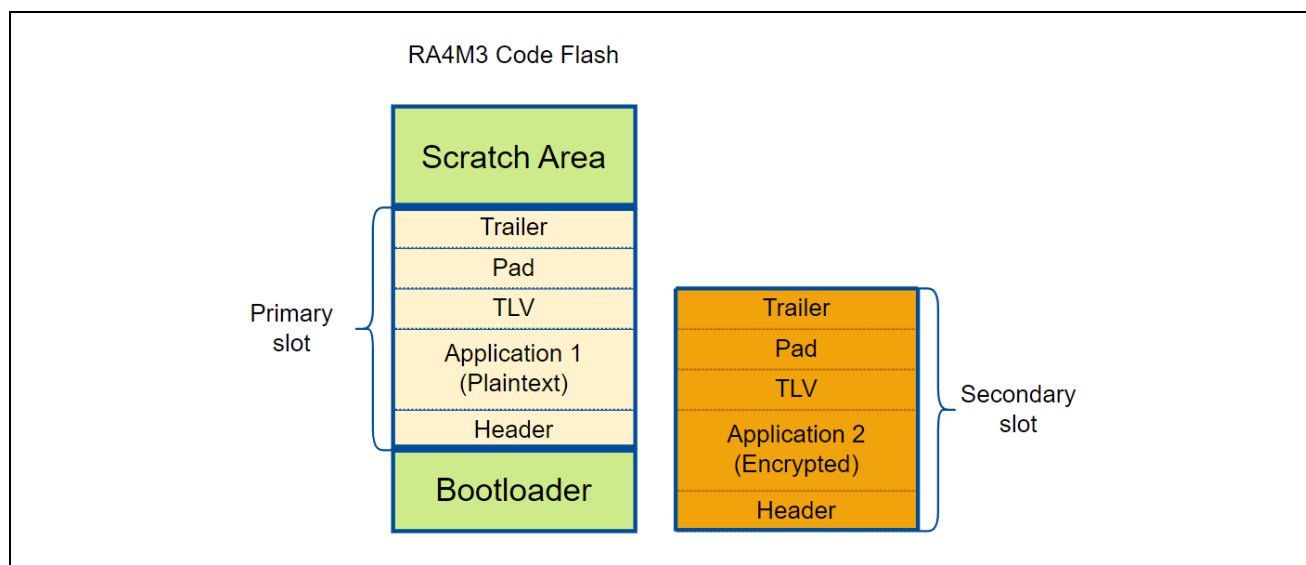


Figure 3. Application Image Format

To signal the bootloader as an encrypted image, the application adds the ENCRYPTED flag in the header area. In addition, the image encryption key is stored in encrypted form within the trailer area. The key that is used to encrypt the image encryption key is shared between the image encryption process and the image decryption process via ECIES P256 or RSA OAEP 2048.

2.3 Designing Bootloader and the Initial Primary Application Overview

A bootloader is typically designed with an existing initial primary application. The following are the general guidelines for designing the bootloader with the initial primary application.

- Develop the bootloader and analyze the MCU memory resource allocation needed for the bootloader and the application. The bootloader memory usage is influenced by the application image update mode, signature type and whether to validate the Primary Image.
- The bootloader maintains a memory map of all the different images. User needs to perform the memory usage analysis of the application and update the bootloader defined memory map for consistency and adjust as needed.
- When changing the image authentication and image update mode, the bootloader memory allocation may need to be adjusted.

Most of these design aspects are addressed in the walk-through in this application note.

2.4 General Guidelines using the MCUboot Module Across RA Family MCUs

The MCUboot module is supported on all RA Family MCUs.

The cryptographic support is provided via MbedTLS (Crypto Only) module and TinyCrypt module. Both crypto modules are supported on all RA MCUs either through software or MCU hardware. The MbedTLS (Crypto Only) module is supported by the MCU hardware if the corresponding algorithms are supported by the hardware crypto engine, otherwise MbedTLS software stack will be used. The MbedTLS offers more crypto algorithms, is generally faster and has a larger memory footprint. On the other hand, the TinyCrypt module offers a smaller number of algorithms, is slower but has a much smaller memory footprint. Users can consider disable the image validation of the primary image prior to execution at MCU reset to reduce the boot time.

Table 1 is the typical cryptographic selection recommendations when using MCUboot with RA MCUs. If memory footprint is a priority, users can choose the TinyCrypt module over the MbedTLS Crypto Only module for some of these use cases. To improve the verification speed and reduce boot time when using Tiny Crypt, user can consider disable image validation to improve verification and boot time performance.

Table 1. Typical Cryptographic Selection Recommendations for RA MCUs

Crypto Stack	RA2 No Encryption	RA2 with Encryption	RA4E1, RA6E1, RA4W1, RA4M1, RA6T2 No Encryption	RA4E1, RA6E1, RA4W1, RA4M1, RA6T2 with Encryption	RA6M1/M2/M3, RA6T1, RA4M2/M3, RA6M4/M5 with or without Encryption	RA8M1, RA8D1, RA8T1, with or without Encryption
MbedTLS (Crypto Only)					x	x
Tiny Crypt (HW AES)		x		x		
Tiny Crypt (SW Only)	x		x			

2.5 Customize the Bootloader

The following are some aspects that need to be considered when customizing the bootloader in a product design.

- Customized method to download the application.
- Adjust the flash memory allocation in the bootloader project for the bootloader as well as the application image.

Porting the EK-RA4M3 example bootloader and application projects to EK-RA4M2:

- The user is recommended to recreate the projects with all the stack components in e² studio. In this step, the bootloader size and image size can be adjusted based on the MCU flash memory size and the application image size.
- There is no code update needed when porting the included example projects to RA4M2. After the configurator stack is created, the user can copy over the application source code under \src folder to the newly created project \src folder.

2.6 Production Support

2.6.1 Key Provisioning

By default, the public key is embedded in the bootloader code, and its hash is added to the image manifest as a `KEYHASH TLV` entry. See section 6 for more details about the public key and private key which are used for testing purposes. For production support, the user needs to follow the example shown in `key.c` to add their public key. A more secure solution is to inject the image verification public key. In addition, the user needs to update the private key for application image signing. This application project provides examples of how to use `imgtool.py` to create custom image signing keys and encryption keys in section 6.

As an alternative, the bootloader can be made independent of the included test keys by setting the `MCUBOOT_HW_KEY` option. In this case the hash of the public key must be provisioned to the target device and MCUboot must be able to retrieve the key-hash from there. For this reason, the target must provide a definition of the `boot_retrieve_public_key_hash()` function that is declared in `boot/bootutil/include/bootutil/sign_key.h`. It is also required to use the full option for the `-public-key-format` `imgtool` argument in order to add the whole public key (`PUBKEY TLV`) to the image manifest instead of its hash (`KEYHASH TLV`).

During boot, the public key is validated before it is used for signature verification. MCUboot calculates the hash of the public key from the TLV area and compares it with the key-hash that was retrieved from the device. This way, MCUboot is independent from the public key(s). The key(s) can be provisioned any time and by different parties.

2.6.2 Make the bootloader immutable for enhanced security

For Cortex®-M33 MCU, refer to section 7.1 to make the bootloader immutable.

2.6.3 Advance the device lifecycle states prior to the deploy the product to the field

For Cortex®-M33 MCU, user can refer to section 7.2 for the device lifecycle management of the MCU.

3. Running the Initial Example Projects

This section provides a walkthrough of running the included initial example projects. The initial projects use internal flash for both primary and secondary applications. To demonstrate the image encryption support, instructions on how to add encryption support to these projects and change the secondary slot from the internal flash to external QSPI are provided in the next section.

To learn how to establish a system using MCUboot module from scratch, user can reference application project R11AN0869. Prior to signing the application project, the Python package needs to be installed. The instructions on how to install the Python components used for MCUboot is included in section 3.3.3.

Unzip MCUboot_Encryption_Initial_Projects.zip you can see there are four projects:

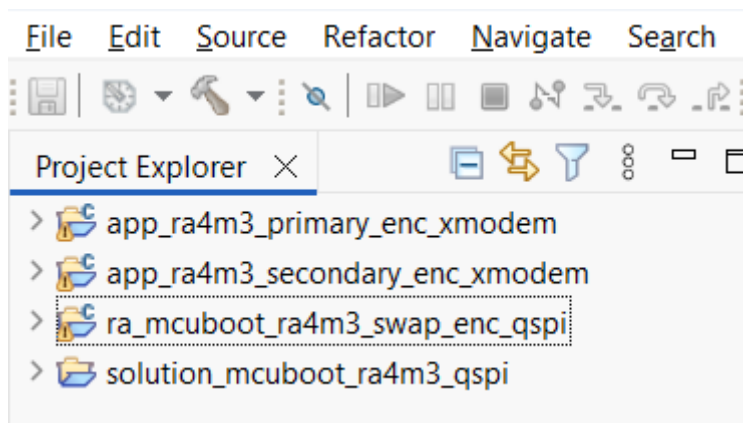


Figure 4. Initial Example Projects

The description of these projects is provided in the following table.

Table 2. Description of the Initial Example Projects

Projects	Description
app_ra4m3_primary_enc_xmodem	Primary application: <ul style="list-style-type: none"> Blinky thread blinks three LEDs (red, green, blue). Downloader thread implemented XModem over USB PCDC support.
app_ra4m3_secondary_enc_xmodem	Secondary application: <ul style="list-style-type: none"> Blinky thread blinks blue LED. Downloader thread implemented XModem over USB PCDC support.
ra_mcuboot_ra4m3_swap_enc_qspi	The bootloader project: <ul style="list-style-type: none"> The bootloader is configured with swap upgrade mode. Swap test mode is enabled in the secondary application. The maximum application image size is configured. All application images are plaintext. The secondary slot is in the internal code flash. Code flash is linear mode.
solution_mcuboot_ra4m3_qspi	The FSP Solution Project (Advanced), supported from FSP v6.0.0: <ul style="list-style-type: none"> The FSP Solution Project (Advanced) is a chain of projects that includes both the bootloader and the primary application project. It manages the Clock configuration and Memories settings for both the bootloader and the primary application project.

In this section, we will run the example projects through the following stages.

First, we will erase the MCU. Then we will download the primary application to the internal flash.

In the next stage, we can use the image downloader implemented in the primary application to download the secondary image to the secondary slot. Upon the next reboot, the secondary image will be booted.

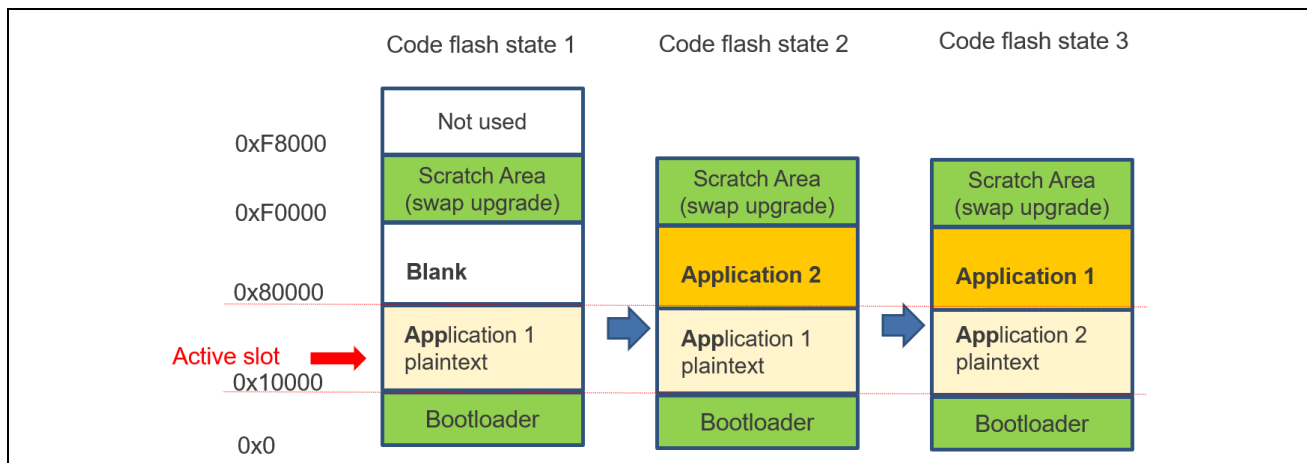


Figure 5. Operational Flow with Swap Update Mode

Note that in the initial application projects, the application image size is defined as 0x70000 which is the maximum application image size based on the example bootloader included when using internal flash for primary and secondary image storage with code flash linear mode.

3.1 Memory Partition using the Solution Project

Although the provided sample projects are ready-to-run, this chapter briefly explains the memory partition configuration in the **FSP Solution project**. Starting from FSP v6.0.0, an FSP Solution Project is required to define the bootloader slots.

The **Renesas FSP Solution project (Advanced)** is a chain of projects, specifically consisting of the bootloader and the application project. For instructions on how to create a **Renesas FSP Solution Project (Advanced)**, refer to the application project R11AN1048.

After creating the **Solution project**, the bootloader slots can be configured from the **Memories** tab in `solution.xml`. Figure 6 illustrates the default **Memories** tab generated during the creation of the **Solution project**.

Memories							
Name	Start	Size	Core	Security			
> RAM	0x20000000	0x20000				Add Partition	
▼ FLASH	0x00000000	0x100000				Remove Partition	
FLASH_CM33_B	0x00000000	0x8000	CM33	Secure		Clear Partitions	
FLASH_CM33_S	0x00008000	0x8000	CM33	Secure			
FLASH_CM33_C	0x00010000	0x0	CM33	Non-secure Callable		Sort Partitions	
> DATA_FLASH	0x08000000	0x2000					
> QSPI_FLASH	0x60000000	0x4000000					
> OPTION_SETTING_OFS0	0x0100A100	0x4		Secure			
> OPTION_SETTING_OFS1	0x0100A180	0x4		Non-secure			
> OPTION_SETTING_BANKSEL	0x0100A190	0x4		Non-secure			
> OPTION_SETTING_BPS	0x0100A1C0	0x8		Non-secure			
> OPTION_SETTING_PBPS	0x0100A1E0	0x8		Non-secure			
> OPTION_SETTING_OFS1_SEC	0x0100A200	0x4		Secure			
> OPTION_SETTING_BANKSEL_SEC	0x0100A210	0x4		Secure			
> OPTION_SETTING_BPS_SEC	0x0100A240	0x8		Secure			
> OPTION_SETTING_PBPS_SEC	0x0100A260	0x8		Secure			
> OPTION_SETTING_OFS1_SEL	0x0100A280	0x4		Secure			
> OPTION_SETTING_BANKSEL_SEL	0x0100A290	0x4		Secure			
> OPTION_SETTING_BPS_SEL	0x0100A2C0	0x8		Secure			
Summary						BSP	
						Clocks	
						Pins	
						Memories	
						Adjustments	

Figure 6. The Default Memories Tab in `solution.xml`

The bootloader slots definitions shown in Table 3, which are used in the `MCUboot_Encryption_Initial_Projects` sample, will be used to illustrate how to build a complete **FLASH** map for an MCUboot project using the following steps. The same procedure can be applied to create a **QSPI_FLASH** partition.

1. Open `solution.xml` then navigate to **Memories** tab and select the **FLASH** region.
2. Click **Add Partition**, as shown in Figure 7. The **New Partition** dialog appears.

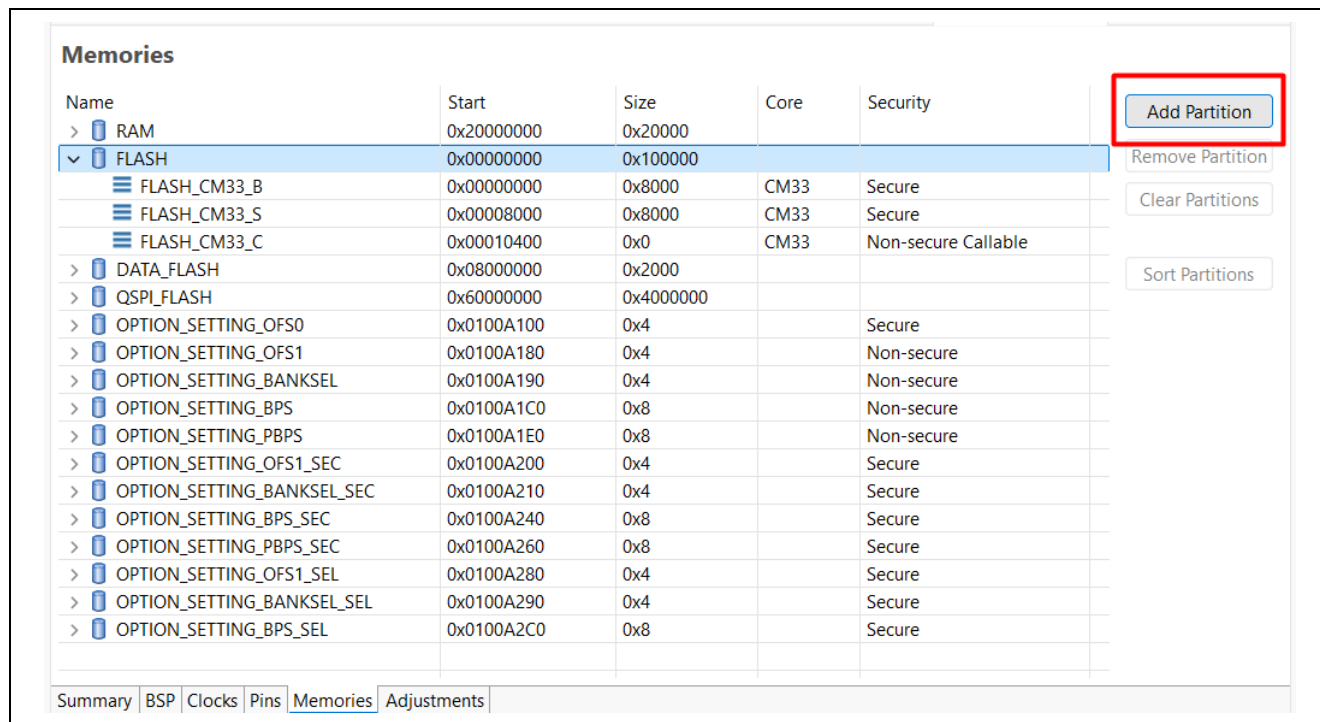


Figure 7. Example of Add Partition in Memories Tab

3. Enter the partition parameters according to the bootloader slot definitions in Table 3.

Example for Image 0 Primary Header:

Name: `__BL_0_P_H`

Start: `0x00010000`

Size: `0x200`

Core: `CM33`

Security: `Secure`.

4. Click **OK**. The Image 0 Primary Header (__BL_0_P_H) is added successfully, as shown in Figure 8.

Memories

Name	Start	Size	Core	Security
> RAM	0x20000000	0x20000		
▼ FLASH	0x00000000	0x100000		
FLASH_CM33_B	0x00000000	0x8000	CM33	Secure
FLASH_CM33_S	0x00008000	0x8000	CM33	Secure
__BL_0_P_H	0x00010000	0x200	CM33	Secure
FLASH_CM33_C	0x00010400	0x0	CM33	Non-secure Callable
> DATA_FLASH	0x08000000	0x2000		
> QSPI_FLASH	0x60000000	0x4000000		
> OPTION_SETTING_OFS0	0x0100A100	0x4		Secure
> OPTION_SETTING_OFS1	0x0100A180	0x4		Non-secure
> OPTION_SETTING_BANKSEL	0x0100A190	0x4		Non-secure
> OPTION_SETTING_BPS	0x0100A1C0	0x8		Non-secure
> OPTION_SETTING_PBPS	0x0100A1E0	0x8		Non-secure
> OPTION_SETTING_OFS1_SEC	0x0100A200	0x4		Secure
> OPTION_SETTING_BANKSEL_SEC	0x0100A210	0x4		Secure
> OPTION_SETTING_BPS_SEC	0x0100A240	0x8		Secure
> OPTION_SETTING_PBPS_SEC	0x0100A260	0x8		Secure
> OPTION_SETTING_OFS1_SEL	0x0100A280	0x4		Secure
> OPTION_SETTING_BANKSEL_SEL	0x0100A290	0x4		Secure
> OPTION_SETTING_BPS_SEL	0x0100A2C0	0x8		Secure

Buttons: Add Partition, Remove Partition, Clear Partitions, Sort Partitions

Summary | BSP | Clocks | Pins | **Memories** | Adjustments

Figure 8. Example of the __BL_0_P_H Partition Successfully Added to FLASH

5. Repeat Steps 1–3 for all remaining partitions until the **FLASH** layout is complete.

Figure 9 shows the complete layout as defined in Table 3.

Memories

Name	Start	Size	Core	Security
> RAM	0x20000000	0x20000		
▼ FLASH	0x00000000	0x100000		
FLASH_CM33_B	0x00000000	0x18000	CM33	Secure
__BL_0_P_H	0x00018000	0x200	CM33	Secure
FLASH_CM33_S	0x00018200	0x6FE0	CM33	Secure
__BL_0_S_H	0x00088000	0x200	CM33	Secure
__BL_0_S_I	0x00088200	0x6FE0	CM33	Secure
__BL_S	0x000F8000	0x8000	CM33	Secure
FLASH_CM33_C	0x00100000	0x0	CM33	Non-secure Callable
> DATA_FLASH	0x08000000	0x2000		
> QSPI_FLASH	0x60000000	0x4000000		
> OPTION_SETTING_OFS0	0x0100A100	0x4		Secure
> OPTION_SETTING_OFS1	0x0100A180	0x4		Non-secure
> OPTION_SETTING_BANKSEL	0x0100A190	0x4		Non-secure
> OPTION_SETTING_BPS	0x0100A1C0	0x8		Non-secure
> OPTION_SETTING_PBPS	0x0100A1E0	0x8		Non-secure
> OPTION_SETTING_OFS1_SEC	0x0100A200	0x4		Secure
> OPTION_SETTING_BANKSEL_SEC	0x0100A210	0x4		Secure
> OPTION_SETTING_BPS_SEC	0x0100A240	0x8		Secure
> OPTION_SETTING_PBPS_SEC	0x0100A260	0x8		Secure
> OPTION_SETTING_OFS1_SEL	0x0100A280	0x4		Secure
> OPTION_SETTING_BANKSEL_SEL	0x0100A290	0x4		Secure
> OPTION_SETTING_BPS_SEL	0x0100A2C0	0x8		Secure

Buttons: Add Partition, Remove Partition, Clear Partitions, Sort Partitions

Summary | BSP | Clocks | Pins | **Memories** | Adjustments

Figure 9. Example of a Completed MCUboot Internal Code Flash Layout

- After completing the **FLASH** layout, right-click the **Solution project** and select **Build Project** to apply the updated memory partitions.

Note: If an error related to RAM region overflow appears in the **Console** tab, adjust the RAM partition sizes in the **Memory Partition** settings of the **Solution Project** and rebuild.

- For the Bootloader Project, adjust the **RAM_CM33_B** size.
- For the Application Project, adjust the **RAM_CM33_S** size

Table 3. MCUBoot Memory Partition for Internal Code Flash

Start Address	Size	Memory Partition Labels	Flash Map	Definition of Memory Partition Labels
0x000F0000	0x8000	__BL_S	Scratch Area	Scratch area
0x00080200	0x6FE00	__BL_0_S_I	Trailer	Image 0 Secondary slot
			TLV	
			app_secondary.bin.signed	
0x00080000	0x200	__BL_0_S_H	Header	Image 0 Secondary Header
0x00010200	0x6FE00	FLASH_CM33_S	Trailer	Image 0 Primary slot
			TLV	
			app_primary.bin.signed	
0x00010000	0x200	__BL_0_P_H	Header	Image 0 Primary Header
0x00000000	0x10000	FLASH_CM33_B	MCUBoot	Bootloader area

In addition, refer to the [renesas.github.io: MCUBoot Port](https://github.com/renesas-github.io/MCUBoot-Port) for more details on creating an MCUboot project with the FSP Solution and for information on the MCUboot memory partition labels.

3.2 Set Up the Python Image Signing Environment

Download and Install Python v3.9 or later.

Python v3.9 or later- <https://www.python.org/downloads/>

Set up the Python development environment by following section 3.3, step 3.3.3. Note that this step only needs to be performed once.

3.3 Running the Initial Example Projects

Use the following steps to run the included initial example projects. The instructions on establishing the initial bootloader are provided in the application project R11AN0869 which is available for download on Renesas website.

3.3.1 Set Up the Hardware

- The default jumper setting of EK-RA4M3 is used for the example projects.
- Connect J10 (USB Debug) using a micro-USB device cable from EK-RA4M3 to the development PC to provide power and debug connection using the on-board debugger.
- Connect J11 (USB FS) using a micro-USB device cable from EK-RA4M3 to the development PC to provide USB Device connection.
- Placing the J12 jumper on pins 2-3 configures the EK-RA4M3 board's USB Full-Speed port for device mode.

Once the EK-RA4M3 is powered up, the user needs to initialize the MCU prior to exercising the bootloader project. This will create a clean environment to start the bootloader project verification.

Erase the entire MCU flash using J-Flash Lite.

J-Flash Lite is a free, simple graphical user interface which allows downloading into flash memory of target systems. J-Flash Lite is part of the J-Link Software and Documentation package that is installed when the

[J-Link software & documentation pack](#) is installed.

1. To use J-Flash Lite, connect the USB Debug port J10 to the PC and launch J-Flash Lite. Select the Device and debug Interface and communication speed.

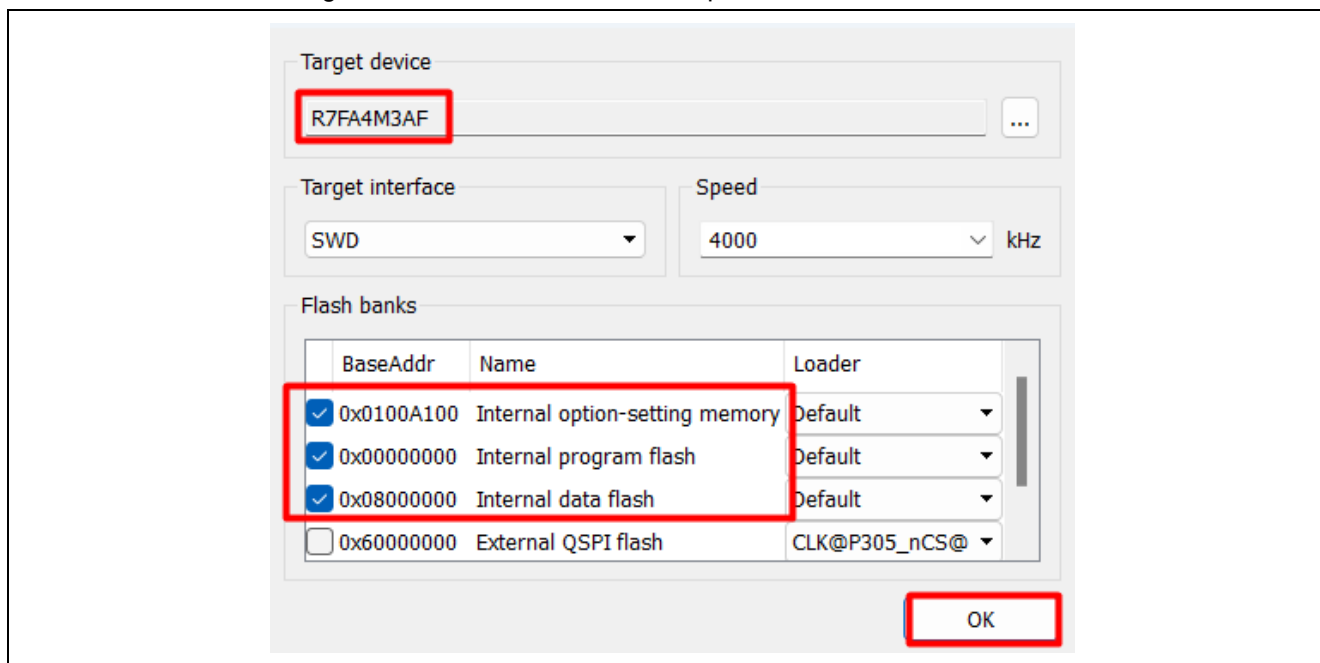


Figure 10. Launch the J-Flash Lite

2. Click OK. In the next screen, select Erase Chip.

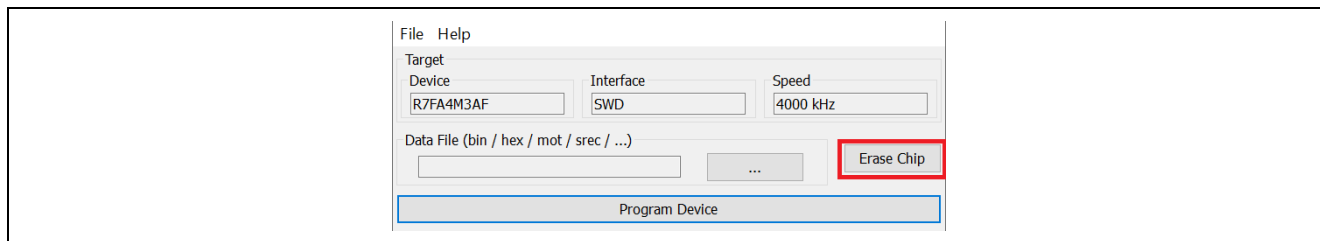


Figure 11. Select Erase Chip

3. Ensure the erase is successful.

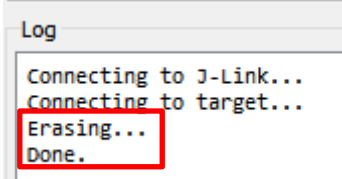


Figure 12. Erase Successful

3.3.2 Import the Projects

For new users, please refer to the FSP User's Manual section on Importing Projects into the IDE for guidelines.

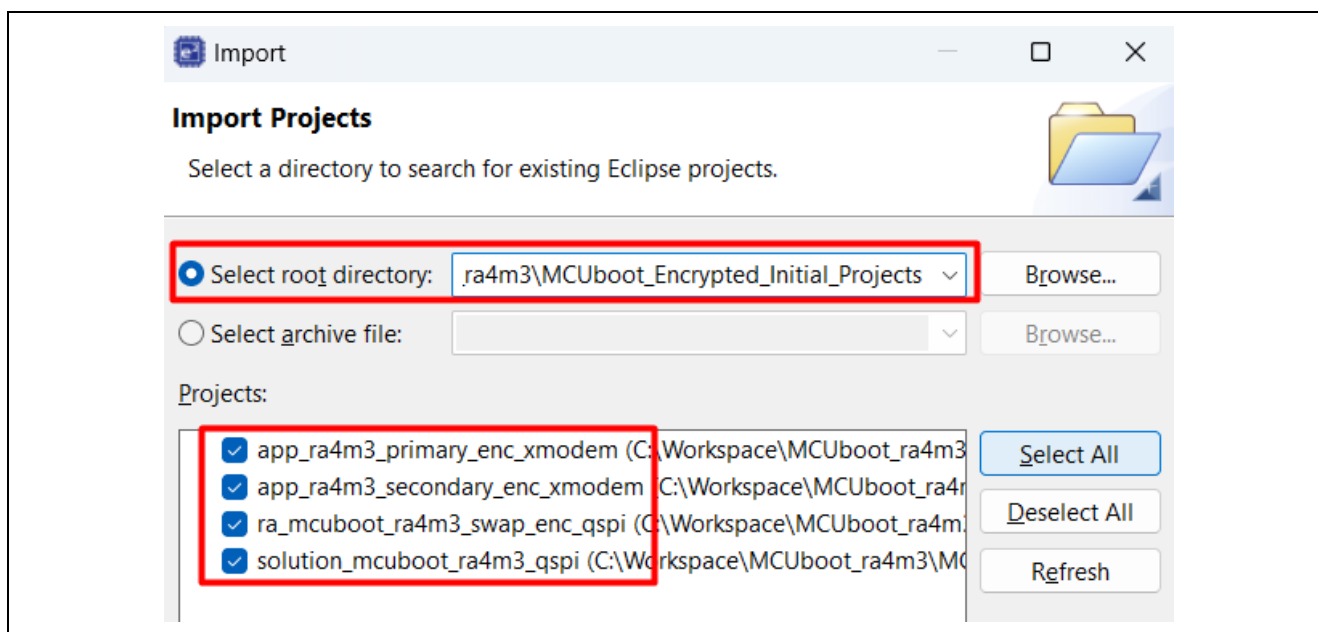


Figure 13. Initial Example Projects

3.3.3 Configure the Python Signing Environment

If this is **NOT** the first time you have used the python script signing tool on your computer, you can skip this section and proceed to section 3.3.4.

If this is the first time you are using the Python-based signing tool on your system, you must install the required dependencies before running the script.

1. **Generate Project Contents** for `ra_mcuboot_ra4m3_swap_enc_qspi` project by double click to `configuration.xml` file under `ra_mcuboot_ra4m3_swap_enc_qspi` folder and click **Generate Project Content**.
2. After `ra` folder is generated. In the **Project Explorer** navigate to:
`ra_mcuboot_ra4m3_swap_enc_qspi > ra > mcu-tools > MCUboot`
3. Right click to `MCUboot` folder and select **Command Prompt** as shown in Figure 14. This will open a command window with the path set to the `\mcu-tools\MCUboot` folder.

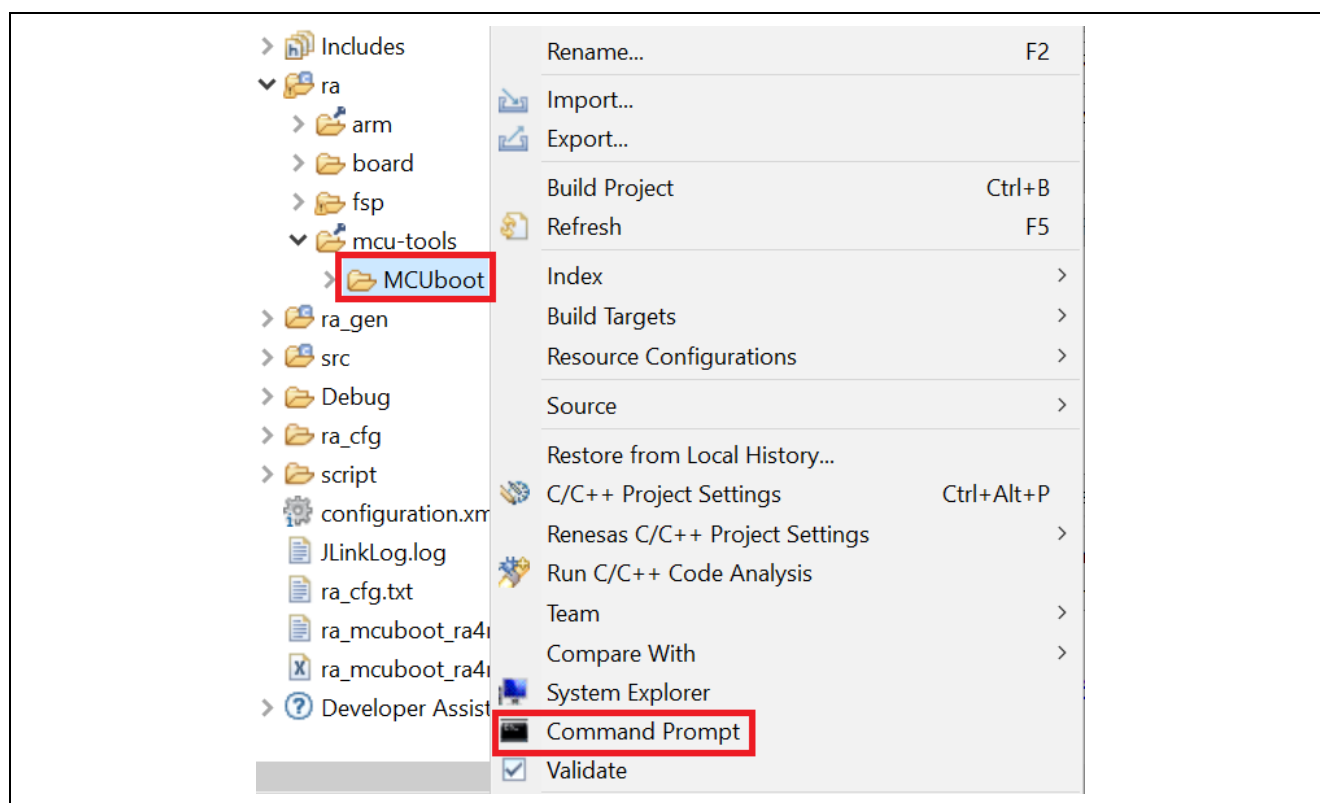


Figure 14. Open the Command Prompt

We recommend upgrading pip prior to installing the dependencies. Enter the following command to update pip:

```
python -m pip install --upgrade pip
```

Next, in the command window, enter the following command line to install all the MCUboot dependencies:

```
pip3 install --user -r scripts/requirements.txt
```

This will verify and install any dependencies that are required.


3.3.4 Compile all the projects

Use the following sequence to build the examples projects under folder \MCUboot_Encryption_Initial_Projects:

1. Build the **Solution Project**

- Right-click on the **Solution Project**: `solution_mcuboot_ra4m3_qspi`.
- Select **Build Project**. This action will build all projects that belong to the **Solution Project** chain, including:
 - `ra_mcuboot_ra4m3_swap_enc_qspi`
 - `app_ra4m3_primary_enc_xmodem`

2. Build the **Secondary Project**

- Select Build Project for the Secondary Application: `app_ra4m3_secondary_enc_xmodem`. Open the `configuration.xml` file, click Generate Project Contents and then click  to build the project.

The signed image for the application projects is located under the \Debug folder:

```
/app_ra4m3_primary_enc_xmodem/Debug/app_ra4m3_primary_enc_xmodem.bin.signed
```

and

```
/app_ra4m3_secondary_enc_xmodem/Debug/app_ra4m3_secondary_enc_xmodem.bin.signed
```


3.3.5 Debug the Applications

Choose to debug from primary application project `app_ra4m3_primary_enc_xmodem`.

Right click on project `app_ra4m3_primary_enc_xmodem` and select **Debug As > Debug Configurations**. Select **app_ra4m3_primary_enc_xmodem Debug_Flat > Startup** and confirm that the following configuration exists.

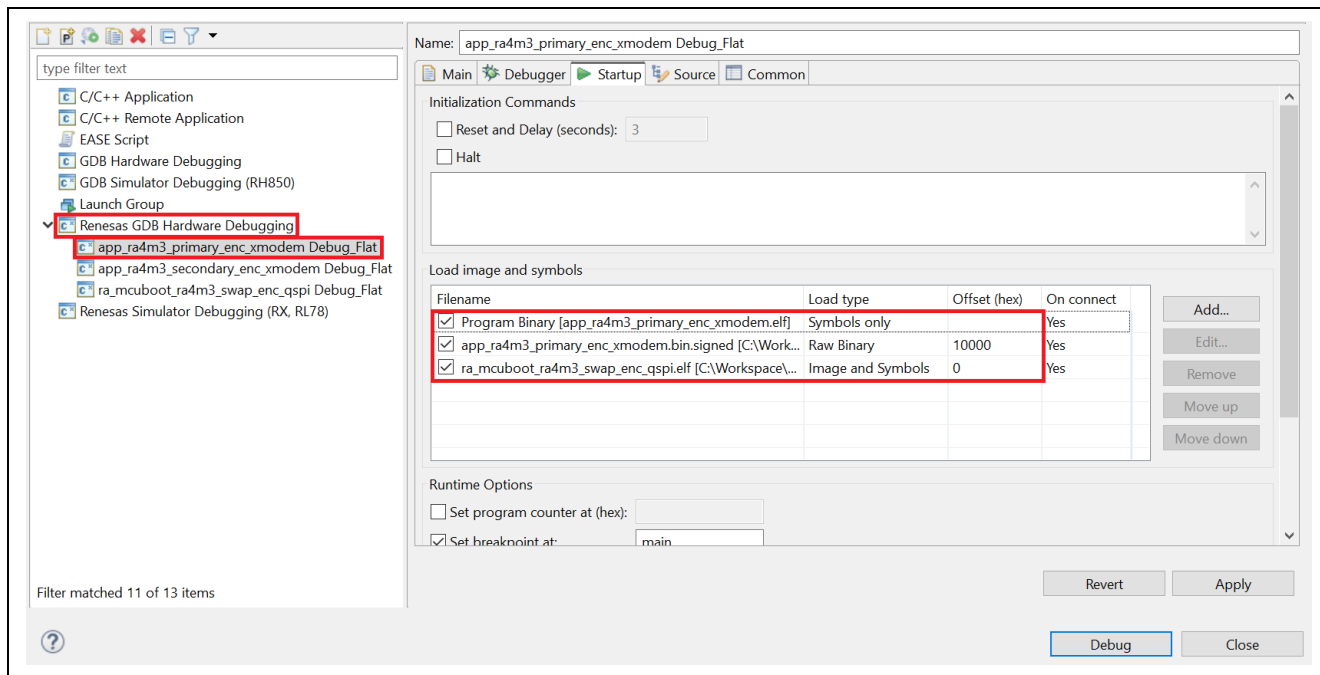



Figure 15. Debug Configurations

- Under the Startup configuration, verify the Load type of `app_ra4m3_primary_enc_xmodem.elf` is Symbols only rather than Image and Symbols.
- The `app_ra4m3_primary_enc_xmodem.bin.signed` entry exists with Load type as Raw Binary and the Offset is set to 0x10000 since that is the beginning of the primary application.
- The `ra_mcuboot_ra4m3_swap_enc_qspi.elf` is added with Load type as Image and Symbols with an Offset of 0 since the bootloader starts from 0x0.

Click **Debug**, then **Resume** the execution twice by clicking . The primary application is then booted, and the three LEDs are blinking.

3.3.6 Downloading and Running the Secondary Application

Use the following steps to download and run the secondary application.

1. Launch Tera Term and select the enumerated COM port "USB Serial Device". Your port number may be different from this. Click OK.

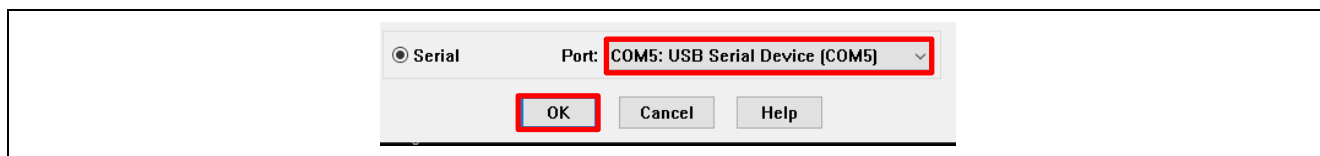


Figure 16. Launch Tera Term

2. Below message will be printed.

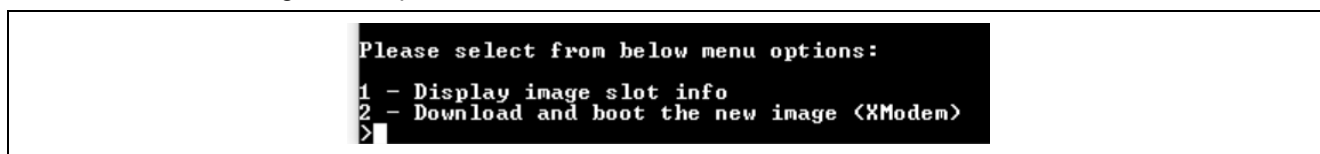


Figure 17. Menu item

3. View option 1 result. We can see Secondary Image Slot is empty.

```
>11
*****
* Primary Image Slot *
*****
Image version:      01.00 <Rev: 0, Build: 0>
Primary image start address: 0x00010000
Header size:        0x0200 <512 bytes>
Protected TLU size: 0x0000 <0 bytes>
Image size:         0x0000B008 <45064 bytes>

*****
* Secondary Image Slot *
*****
Image version:      255.255 <Rev: 65535, Build: -1>
Secondary image start address: 0x00080000
Header size:        0xFFFF <65535 bytes>
Protected TLU size: 0xFFFF <65535 bytes>
Image size:         0xFFFFFFFF <-1 bytes>
```

Figure 18. Primary and Secondary Slot Status

4. Now use the image downloader to load the new secondary application image. Choose option 2 to download the secondary image.

```
2
Blank checking the secondary slot...
NS Secondary slot blank
Start Xmodem transfer...
System will automatically reset after successful download...
```

Figure 19. Initiate Secondary Image Download

5. Choose **File > Transfer > XMODEM > Send**

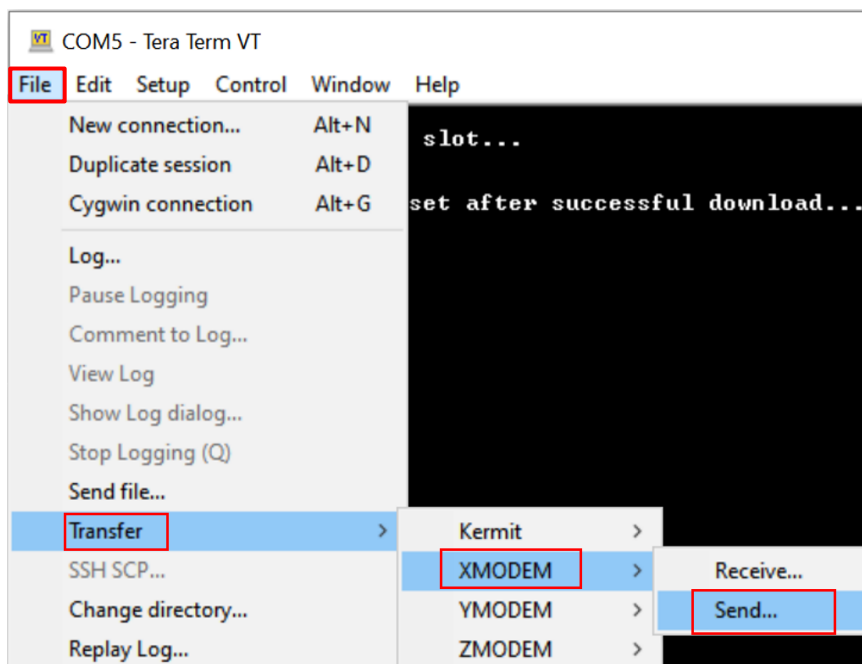


Figure 20. Choose to use XModem

6. Select the signed secondary image binary.

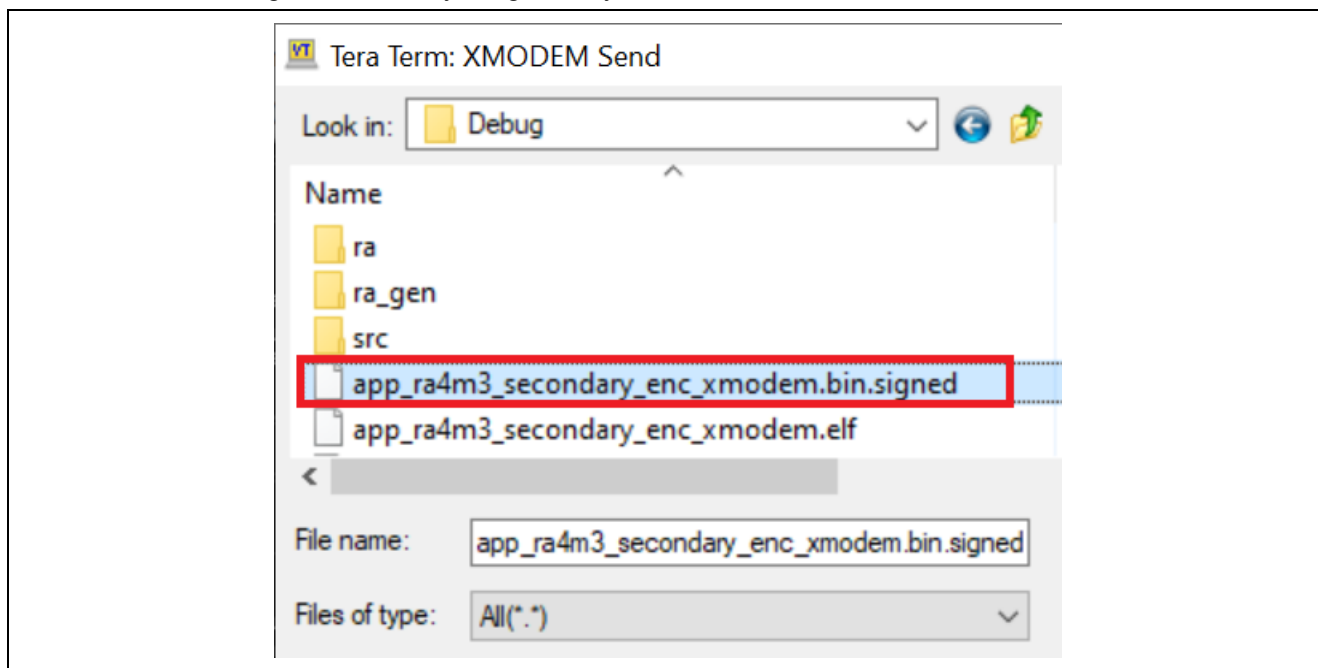


Figure 21. Select the Signed Secondary Image

7. It takes a few seconds to download a new image.

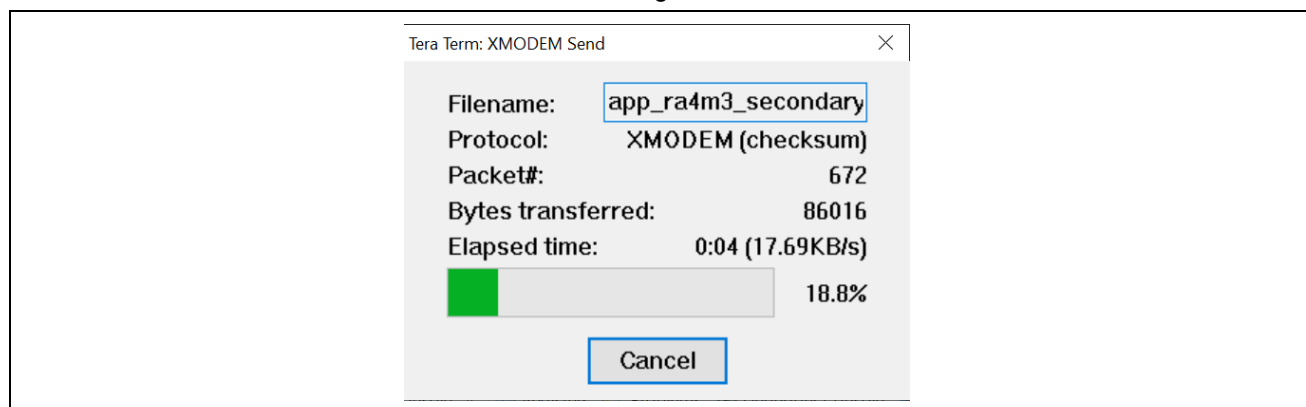


Figure 22. Download the Secondary Image using XModem

8. The primary application will reset the system once the entire secondary application is downloaded. The menu from the secondary application is printed. Wait about two seconds prior to the output of the new menu. The Blue LED should be blinking.

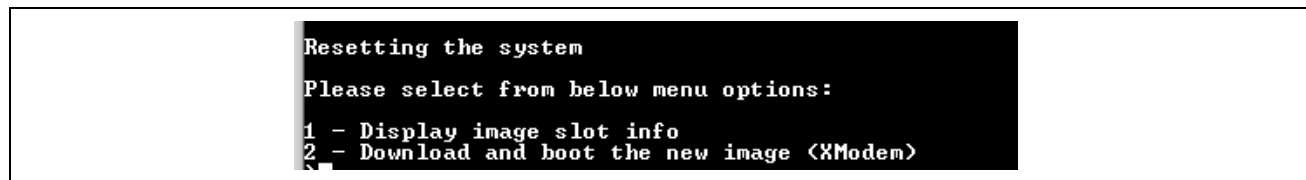


Figure 23. Secondary Image is booted

Reset the application from the debugger, the blue LED should still be blinking. There is no revert back to the original Primary application because the swap test mode is implemented with the secondary application.

4. Add Encryption to the Initial Example Project

In this section, we will add encryption to the application image. The bootloader is first updated and then the application projects are configured to use the new bootloader.

The system will go through the following stages. Note that when encryption is enabled, the bootloader image size increases to about 83 kB. With the code flash boundary at 32 kB, the bootloader image is allocated 96 kB.

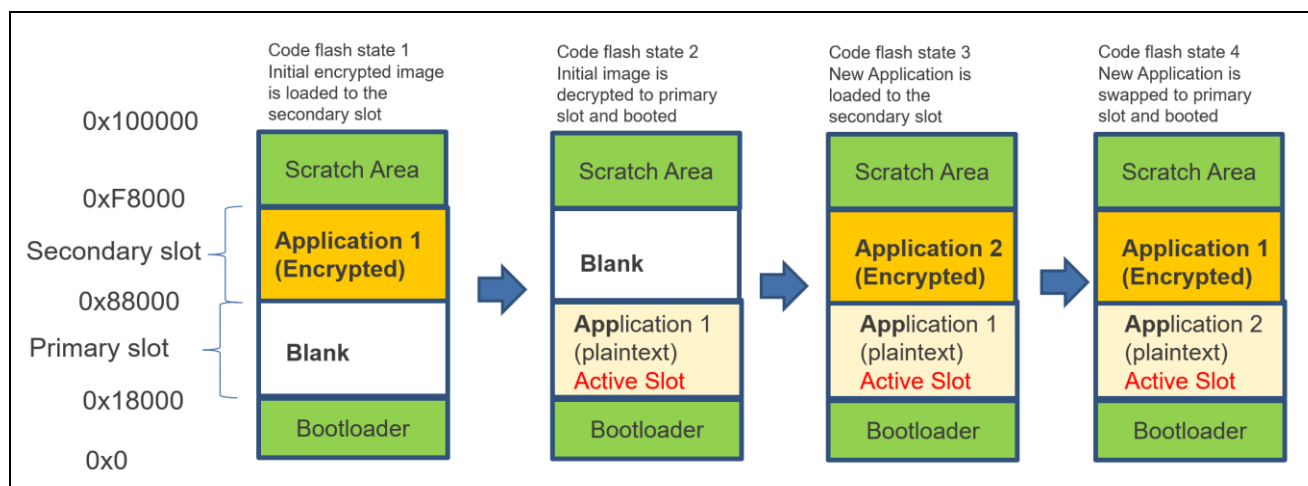


Figure 24. Booting Encrypted Image (Secondary Image Stored in Internal Flash)

Note that the initial application is downloaded to the secondary slot as encrypted rather than downloaded to the primary slot as plaintext image. This allows plaintext image being swapped to the secondary slot as encrypted.

4.1 Configure the Bootloader for Encryption Support

Stay in the same Workspace from the previous section and start to configure the bootloader using the following steps:

1. Double click and open the **configuration.xml** file from **ra_mcuboot_ra4m3_swap_enc_qspi** project.
2. Navigate to the **Stacks** tab, select **MCUboot** stack, and in the **Properties** panel set the **Encryption Scheme** to **ECIES-P256** as shown in Figure 25.

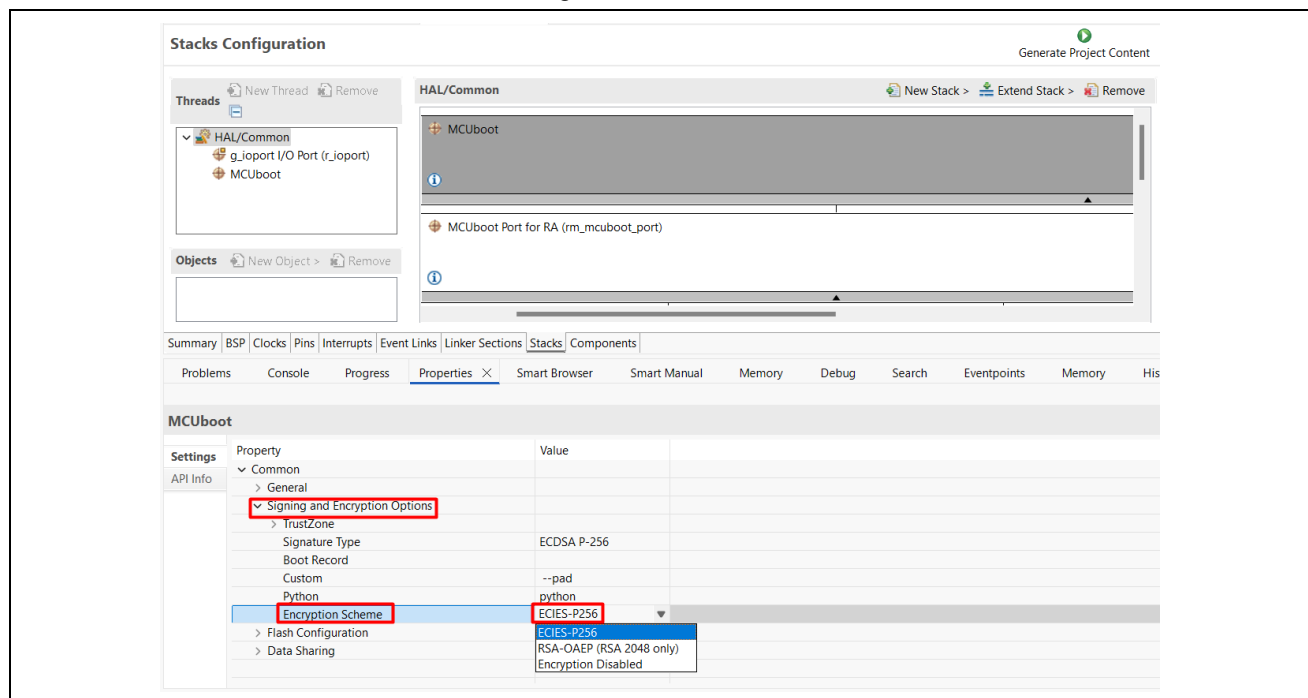


Figure 25. Choose ECIES-P256

3. Navigate to the BSP tab in `ra_mcuboot_ra4m3_swap_enc_qspi\configuration.xml` and update the BSP heap size from 0x600 to 0x1000 as illustrated in Figure 26 . When encryption is used, a minimum of 0x200 heap needs to be added. This increased heap usage came from the added AES algorithm usage.

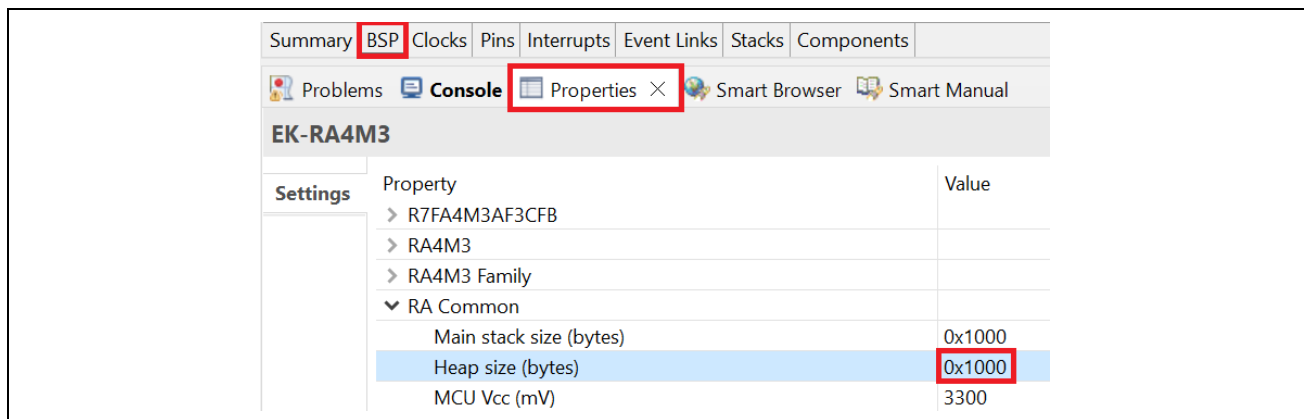


Figure 26. Update the Heap size to 0x1000

4. Right click on the bootloader project and select **Properties** (at the end of the menu tree).

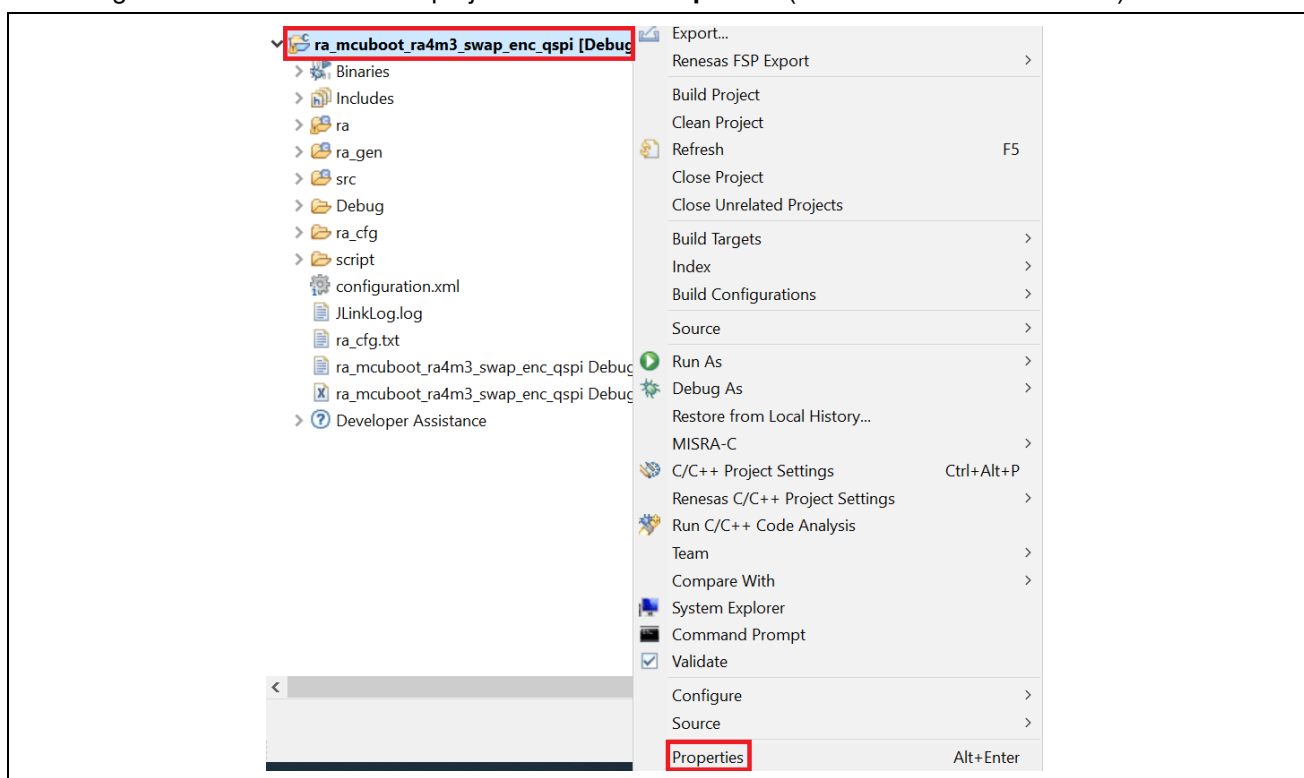


Figure 27. Open the Properties Window

5. Navigate to the **GNU Arm Cross C Compiler > Preprocessor**.

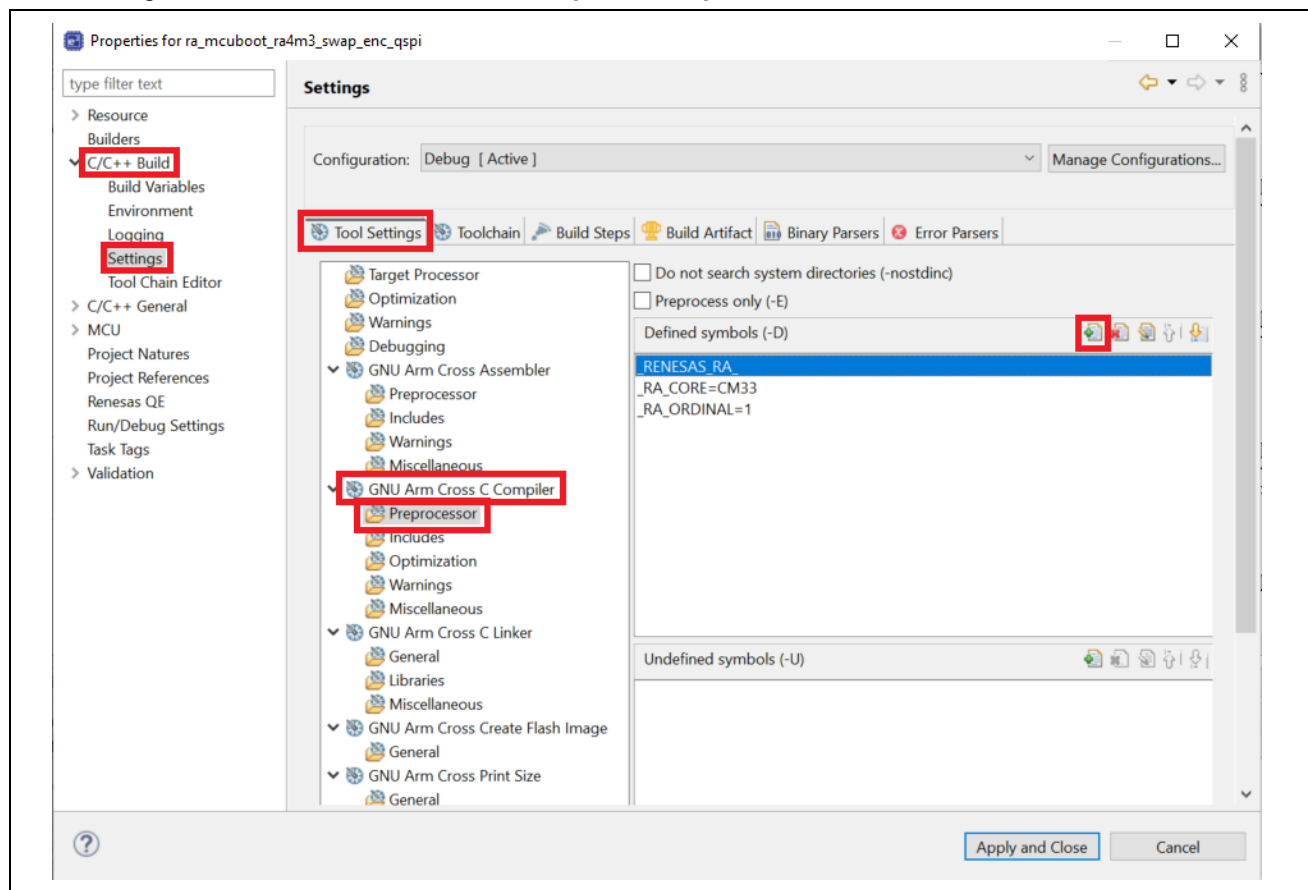


Figure 28. Add Preprocessor setting

6. Click the green '+' sign and add `MCUBOOT_BOOTSTRAP`. This preprocessor enables booting the first encrypted image from the secondary slot when having an empty image from the primary slot. Click **OK**.

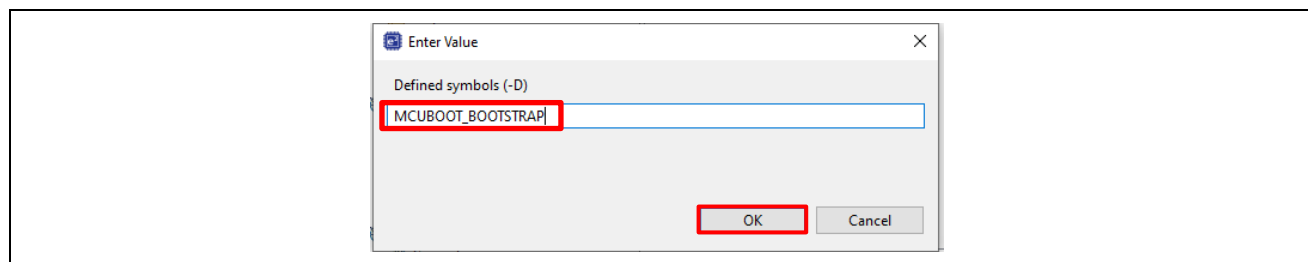


Figure 29. Enter Preprocessor `MCUBOOT_BOOTSTRAP`

7. Click **Apply and Close**.

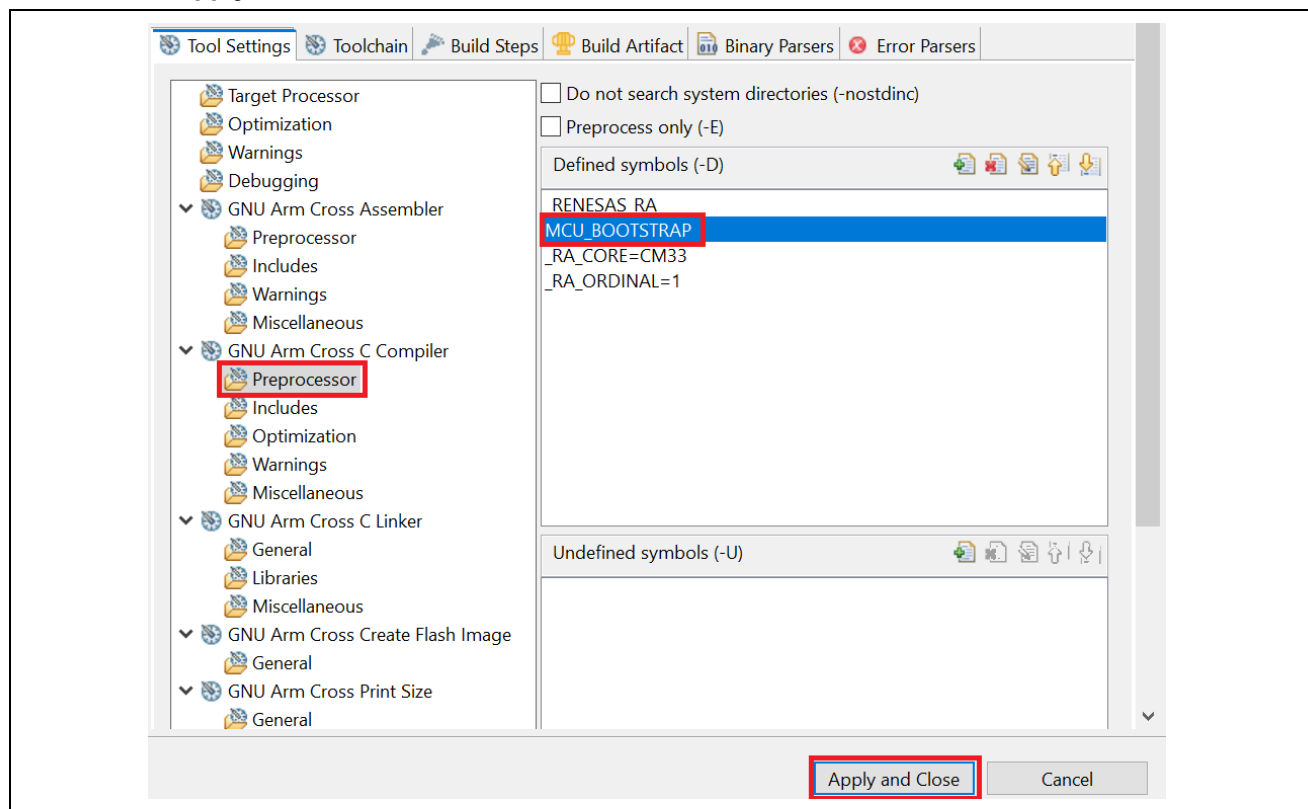


Figure 30. Add Preprocessor MCUBOOT_BOOTSTRAP

8. Check **Remember my decision** and click Yes if below window pops up.

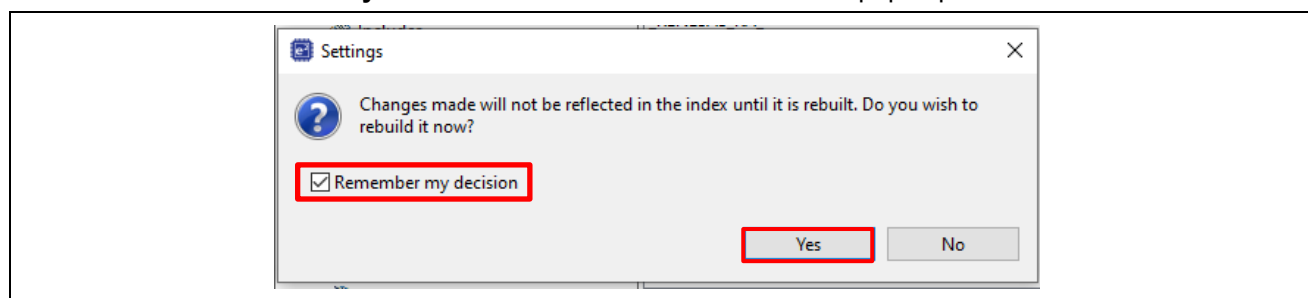


Figure 31. Setting option

9. Click **Generate Project Contents** to apply all configuration settings.
10. Update the Bootloader Flash Area Size and primary image in the `solution_mcuboot_ra4m3_qspi` project:
 Double click to `solution.xml` and navigate to `Memories` tab.
 Under **FLASH** map, change **FLASH_CM33_B** from 0x10000 to 0x18000 as shown in Figure 32.
 Note: After modifying the size of **FLASH_CM33_B**, the sizes of the remaining **FLASH** regions may adjust dynamically. Ensure that only the **FLASH_CM33_B** region is changed in this step.

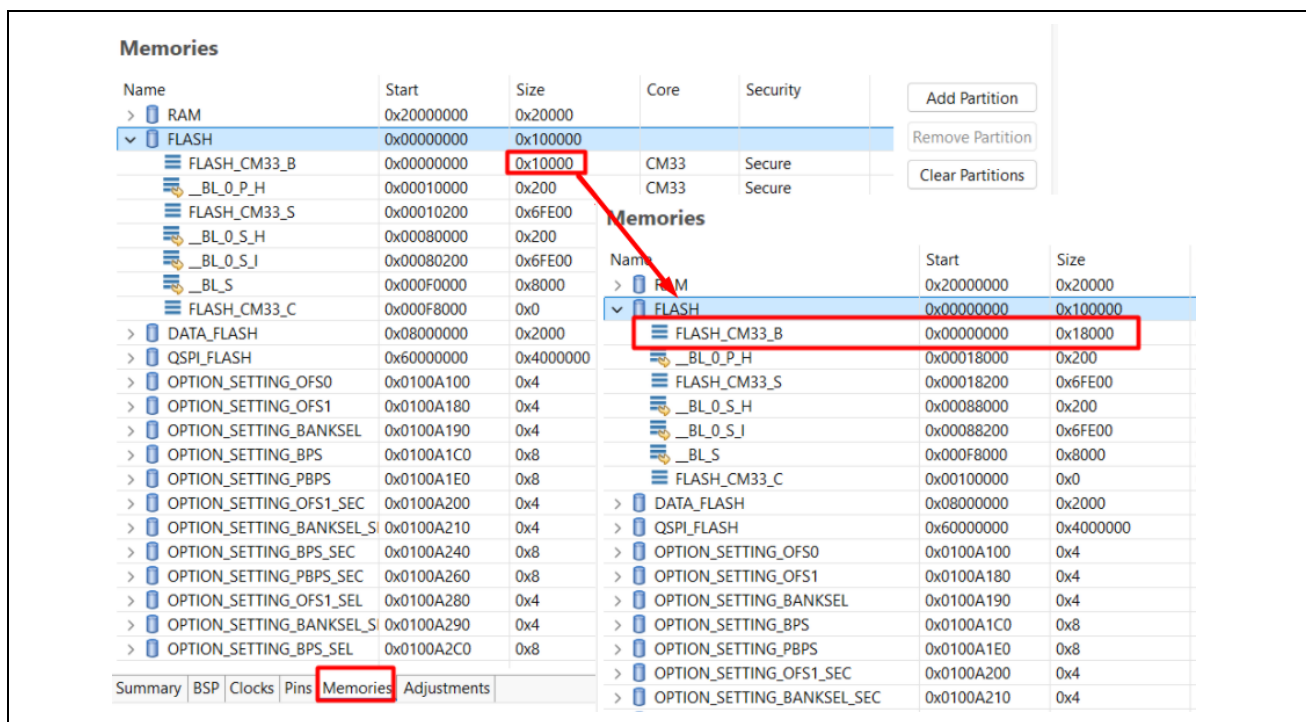


Figure 32. Update the Bootloader Flash Area Size

11. Rebuild the `solution_mcuboot_ra4m3_qspi` project to apply the changes. Note that any configuration change made in the Solution Project must be rebuilt for the updates to propagate to all projects in the solution chain.

4.2 Configure the Application Project for Encryption Support

Follow the steps below to configure the application project to support image encryption.

1. Right click on the Primary Application `app_ra4m3_primary_enc_xmodem`, select **Properties -> C/C++ Build -> Environment**.

Click **Add** and define the New variable **Name** as:

MCUBOOT_IMAGE_ENC_KEY

Define the **Value** as:

```
${workspace_loc:ra_mcuboot_ra4m3_swap_enc_qspi}/ra/mcu-tools/MCUboot/enc-ec256-pub.pem
```

Tick **Add to all configurations** after the value setting.

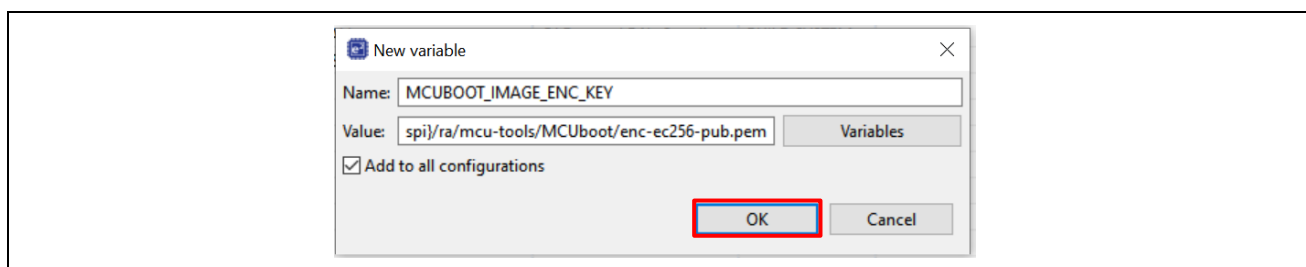


Figure 33. Configure the ECDSA Public Key to be Used in Image Encryption

2. Review the Build Variable Settings and click **Apply and Close**.

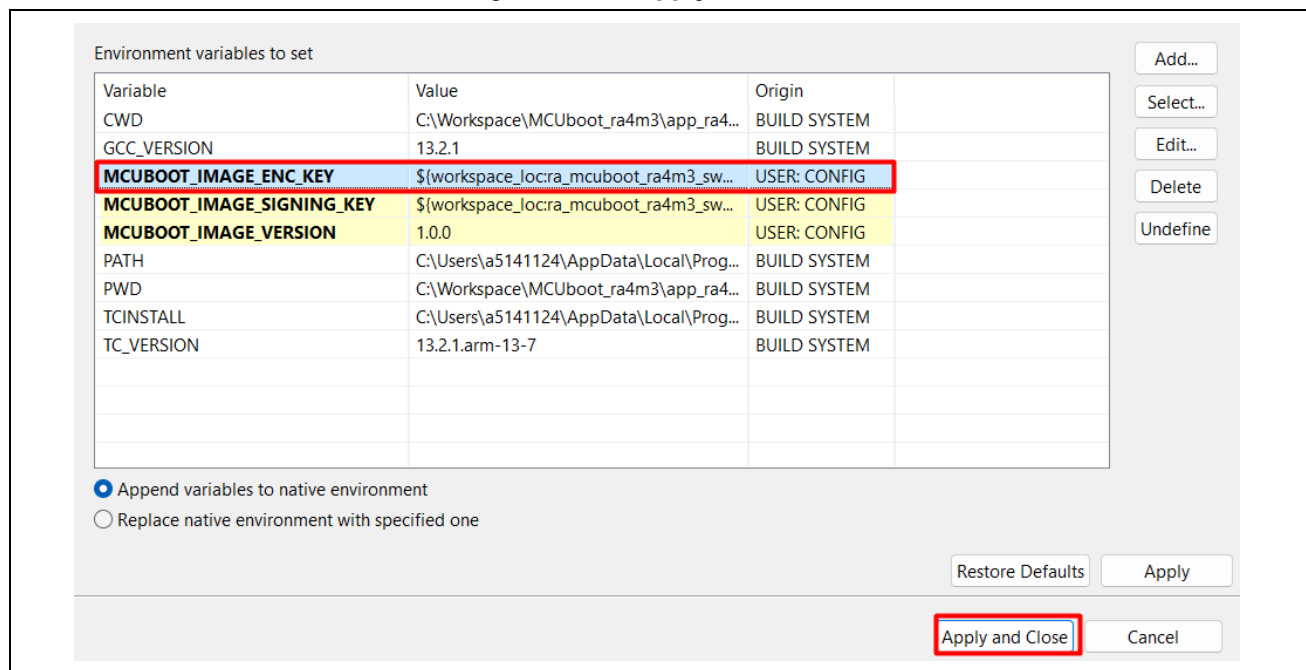


Figure 34. Review the Application Project Encryption Support Setting

3. Update the `\app_ra4m3_primary_enc_xmodem\src\header.h` file. This update takes care of the application image location change due to the change in the bootloader size.

Update below address configuration from:

```
#define PRIMARY_IMAGE_START_ADDRESS    0x00010000
#define PRIMARY_IMAGE_END_ADDRESS      0x0007FFFF
#define SECONDARY_IMAGE_START_ADDRESS  0x00080000
#define SECONDARY_IMAGE_END_ADDRESS    0x000EFFFF
```

To:

```
#define PRIMARY_IMAGE_START_ADDRESS    0x00018000
#define PRIMARY_IMAGE_END_ADDRESS      0x00087FFF
#define SECONDARY_IMAGE_START_ADDRESS  0x00088000
#define SECONDARY_IMAGE_END_ADDRESS    0x000F7FFF
```

4. Double click `configuration.xml` to open the smart configurator, click **Generate Project Content** and compile the Primary application `app_ra4m3_primary_enc_xmodem`.

Ensure `\Debug\app_ra4m3_primary_enc_xmodem.bin.signed.encrypted` is generated.

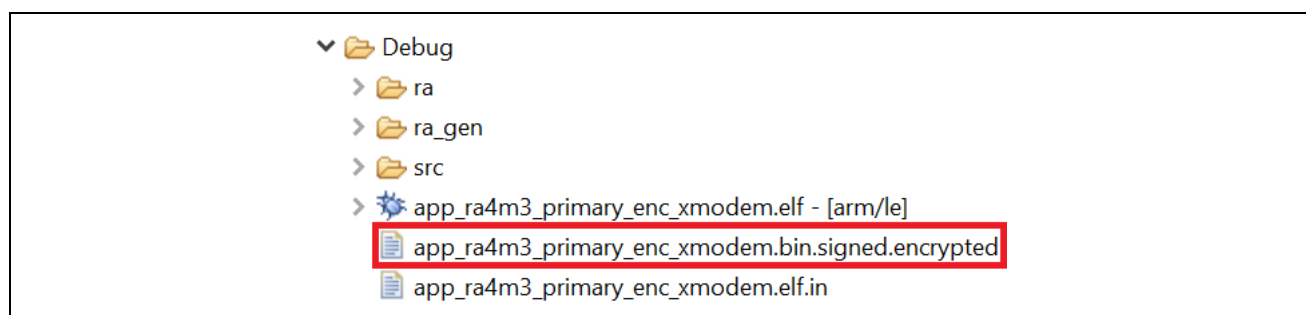


Figure 35. Ensure the Encrypted Binary is Generated

5. Repeat previous steps 1, 2, 3 and 4 in this section for the `app_ra4m3_secondary_enc_xmodem` project.
6. Follow step 2, 3 in section 3.3.1 to Erase the chip.

7. Update the Debug configuration.

Right click on the Primary application **app_ra4m3_primary_enc_xmodem** > **Debug As** > **Debug Configurations**, make sure the Primary application is selected and navigate to the Startup window. Update the Startup configuration Load image and symbols area as shown below.

- Remove the entry of `app_ra4m3_primary_enc_xmodem.bin.signed`.
- Click **Add** -> **Workspace** and browse to the file `app_ra4m3_primary_enc_xmodem.bin.signed.encrypted`.

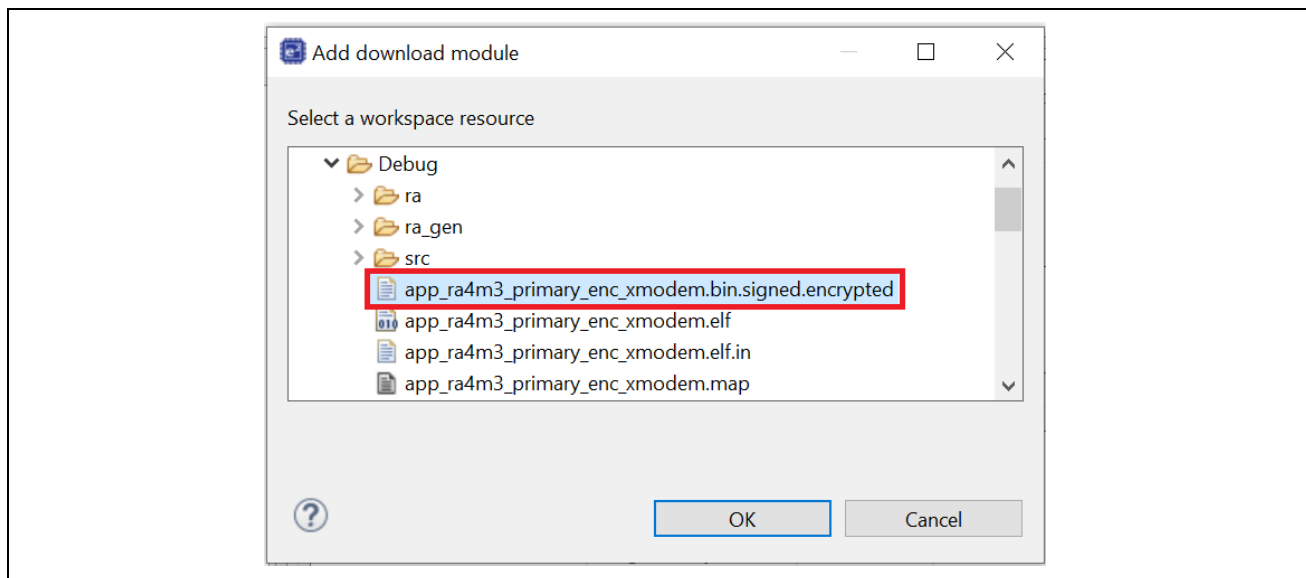


Figure 36. Startup of Debug Configuration

Click **OK**.

8. Update the Primary Image download address and Load type.

Change the Load type to of the `app_ra4m3_primary_enc_xmodem.bin.signed.encrypted` to **Raw Binary**. Update the **Offset** to the **secondary slot address** based on the new bootloader size.

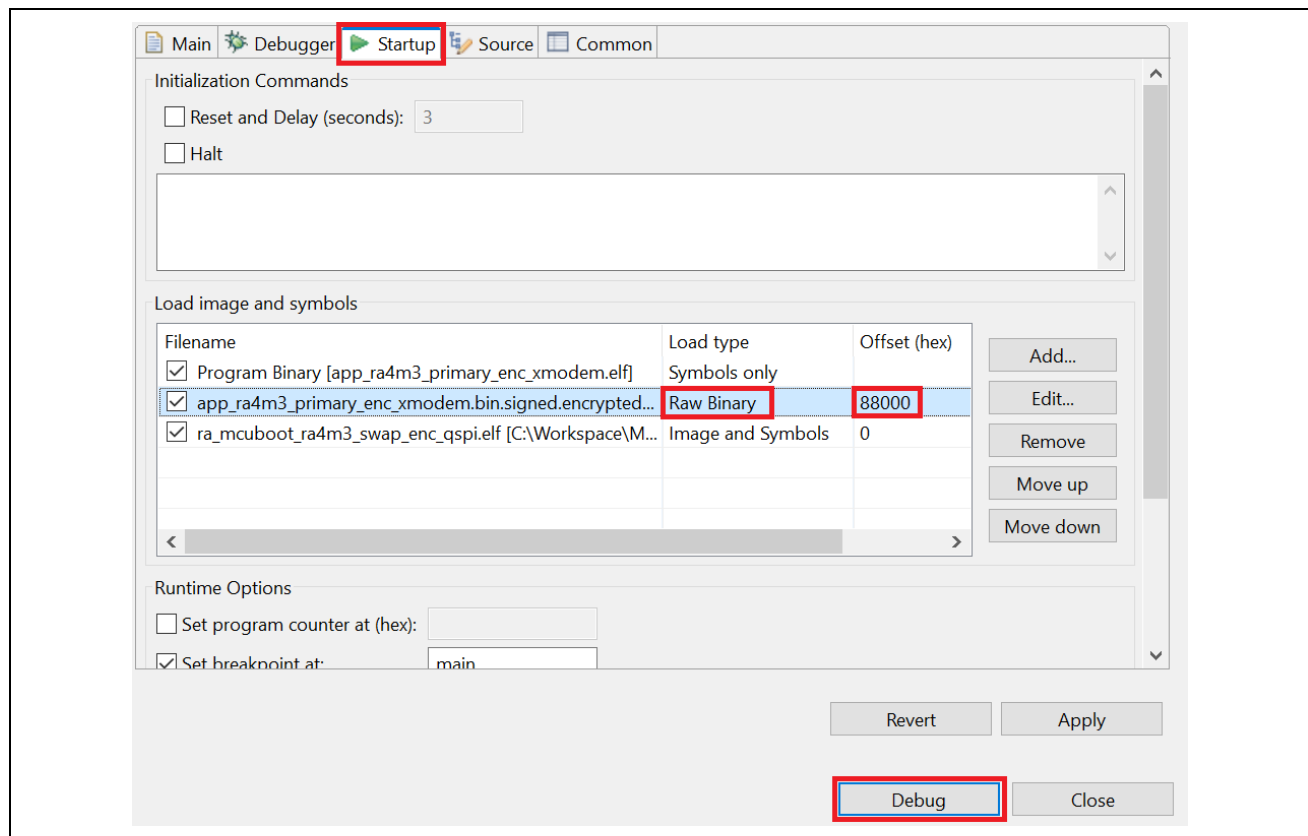



Figure 37. Update the Primary Application Load Address

9. Click **Debug** and resume  the execution twice; the Primary application will be booted, and three LEDs should be blinking.
10. Follow steps 3 to 8 in section 3.3.6 to use the XModem downloader to download the secondary application.
11. Make sure to select the encrypted secondary image.

When downloading the secondary image, make sure to select the encrypted image.

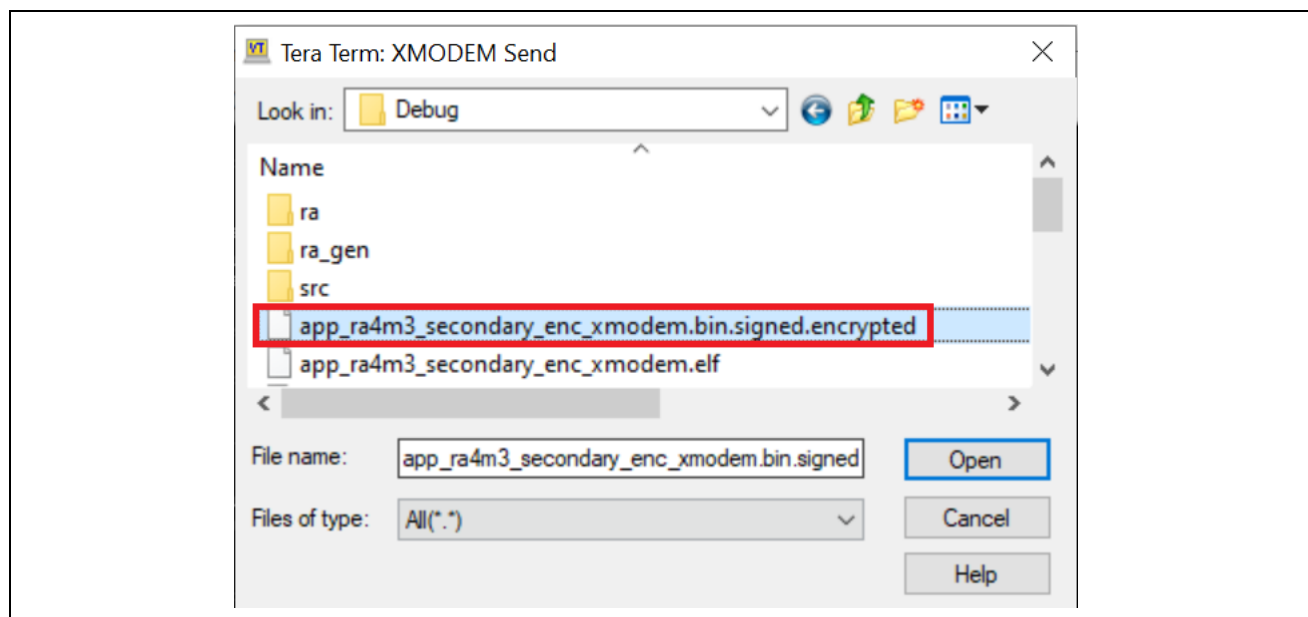


Figure 38. Select the Encrypted Secondary Image

12. After the secondary image is downloaded, it will be booted after the bootloader verified the image. The blue LED should be blinking.

5. Use QSPI as Secondary Storage Area

In this section, we will switch the secondary image storage area from internal flash to QSPI. User can also benefit from this section in terms of learning the key steps in the image downloader design when using XModem. Below is the memory layout of the resulting system.

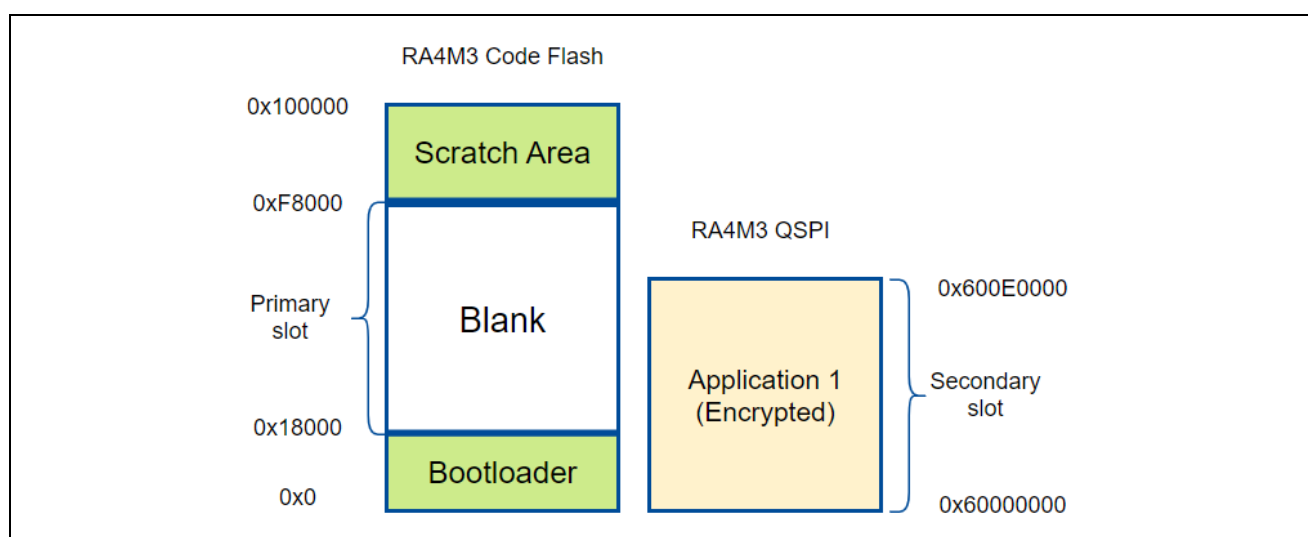


Figure 39. Using QSPI for Secondary Image Storage

Note that the primary and secondary application image sizes are increased to benefit from the usage of the QSPI.

There are four stages the system will go through by following the steps layout described in this section, which is generally similar to the case of using internal flash.

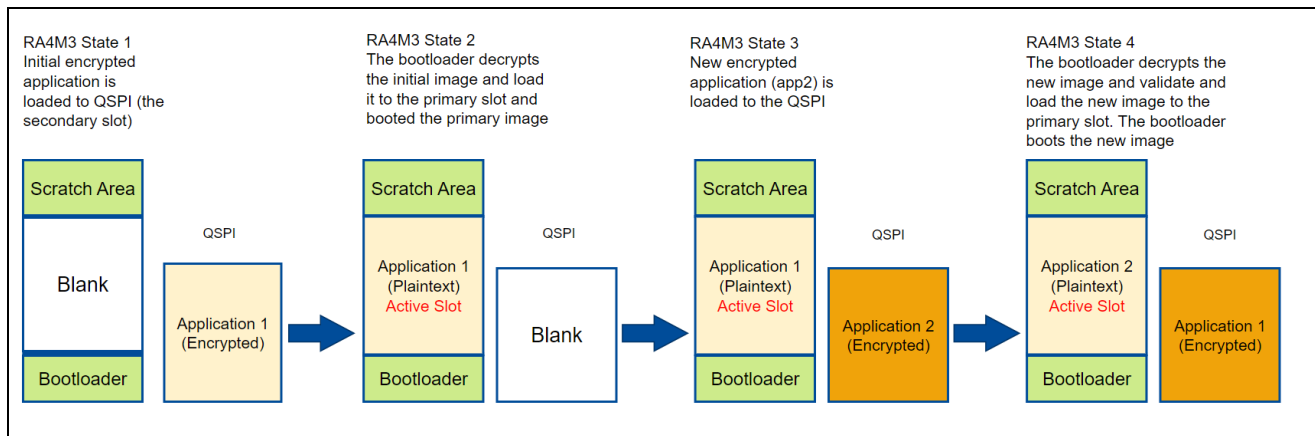


Figure 40. Functional Stages

5.1 Configure the Bootloader to Use QSPI for Secondary Application Storage

Use the following steps to update the secondary storage area to QSPI.

1. Open the `configuration.xml` file from the bootloader project `ra_mcuboot_ra4m3_swap_enc_qspi`.
2. Click on **Add External Memory Implementation**, select **New** to add the QSPI stack:

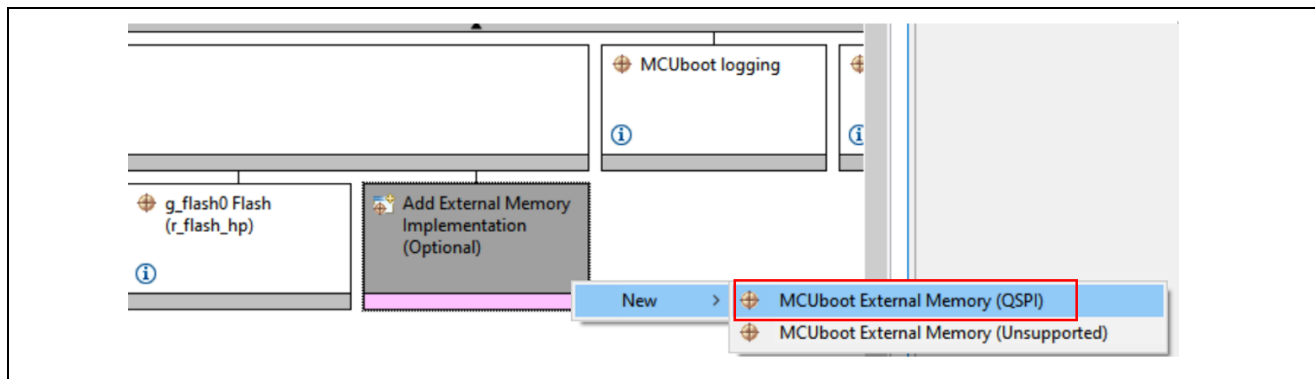


Figure 41. Choose QSPI from the Smart Configurator Stack Tab

3. Navigate to the **Pins** tab **Peripherals** group and select the **QSPI0**. First select **_B only** for the **Pin Group Selection**, then select **Quad** as the **Operation Mode**. The correct **Input/Output** pins will be automatically selected. We need to do this because the bootloader uses a minimal pin configuration rather than the pin configuration for EK-RA4M3.

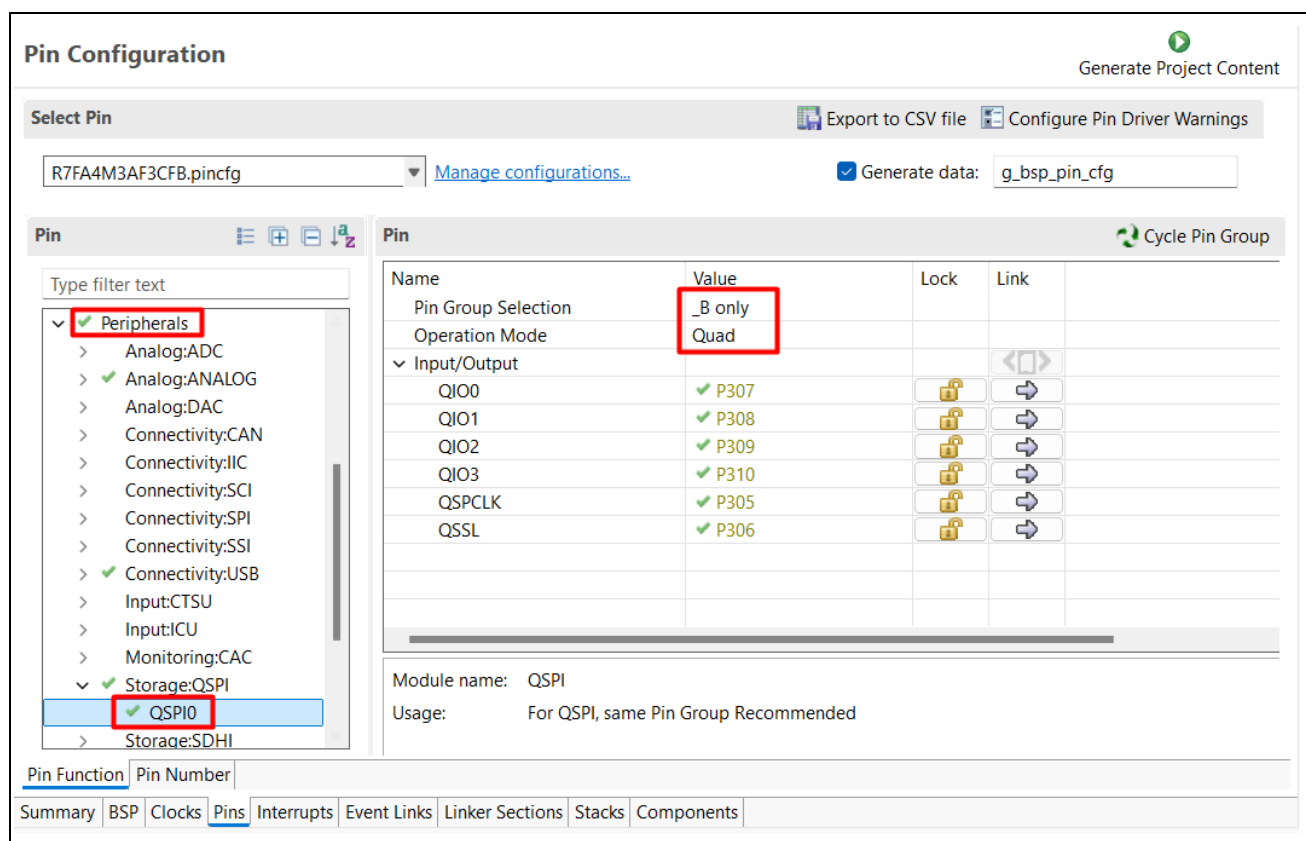


Figure 42. Configure the QSPI Pin and Operation Mode

4. Navigate to the **Stacks** tab, highlight the QSPI stack and update the Bus Timing Minimum QSSL Deselect Cycles to 8 QSPICLK.

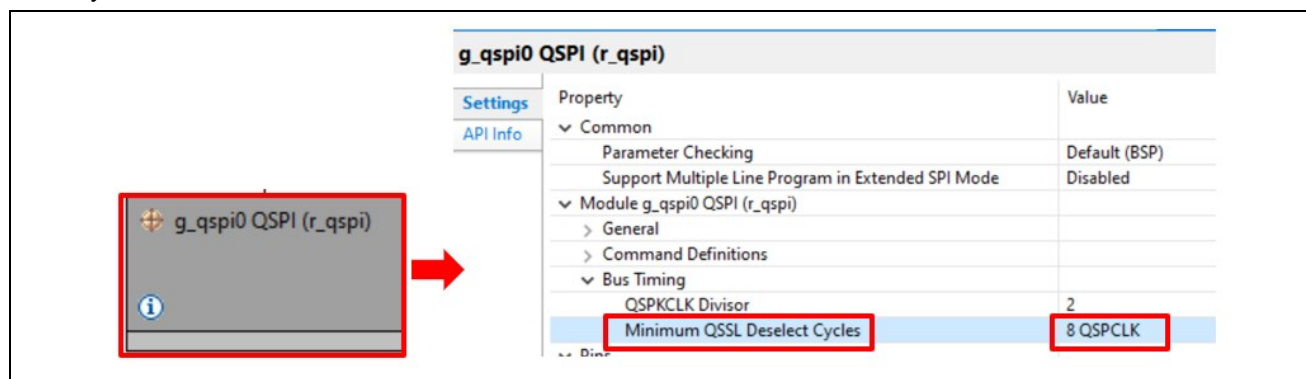


Figure 43. Update the QSPI Bus Timing Minimum QSSL Deselect Property

5. Click **Generate Project Contents** to apply the configuration changes.
6. When using QSPI, a much larger image is supported. Specifically, the image size can be up to twice as large as when using the internal code flash to store the image. Refer to Table 4 for the MCUboot flash map configuration when the secondary slot is allocated in external QSPI flash.

Table 4. Memory Partition Labels for MCUboot Internal and External Flash Maps

Memory Partition Labels	Internal Flash Map	Definition of Memory Partition Labels
__BL_S	Scratch Area	Scratch area
FLASH_CM33_S	Trailer	Image 0 Primary Image
	TLV	
	app_primary.encrypted	
__BL_0_P_H	Header	Image 0 Primary Header
FLASH_CM33_B	MCUBoot	Bootloader area
Memory Partition Labels	External Flash Map	Definition of Memory Partition Labels
__BL_0_S_I	Trailer	Image 0 Secondary Image
	TLV	
	app_secondary.encrypted	
__BL_0_S_H	Header	Image 0 Secondary Header

As mentioned in Section 3.1, the memory map is configured in the **Memories** tab of the **Solution project**, which in this application is the `solution_mcuboot_ra4m3_qspi` project.

Follow the procedure described in section 3.1 and the definitions in Table 4 to complete the bootloader slot configuration, with secondary slots located in external flash. The completed **Memories** configuration in `solution.xml` for the `solution_mcuboot_ra4m3_qspi` project is shown in Figure 44.

Note: Any modification made in the **Solution project** must be rebuilt to ensure that the changes are propagated to all dependent projects.

Memories				
Name	Start	Size	Core	Security
> RAM	0x20000000	0x20000		
▼ FLASH	0x00000000	0x100000		
FLASH_CM33_B	0x00000000	0x18000	CM33	Secure
BL_0_P_H	0x00018000	0x200	CM33	Secure
FLASH_CM33_S	0x00018200	0xDFE00	CM33	Secure
BL_S	0x000F8000	0x8000	CM33	Secure
FLASH_CM33_C	0x00100000	0x0	CM33	Non-secure Callable
> DATA_FLASH	0x08000000	0x2000		
▼ QSPI_FLASH	0x60000000	0x4000000		
BL_0_S_H	0x60000000	0x200	CM33	Secure
QSPI_FLASH_CM33_B	0x60000000	0x0	CM33	Secure
BL_0_S_J	0x60000200	0xDFE00	CM33	Secure
QSPI_FLASH_CM33_S	0x600E0200	0x0	CM33	Secure
> OPTION_SETTING_OFS0	0x0100A100	0x4		Secure
> OPTION_SETTING_OFS1	0x0100A180	0x4		Non-secure
> OPTION_SETTING_BANKSEL	0x0100A190	0x4		Non-secure
> OPTION_SETTING_BPS	0x0100A1C0	0x8		Non-secure
> OPTION_SETTING_PBPS	0x0100A1E0	0x8		Non-secure
> OPTION_SETTING_OFS1_SEC	0x0100A200	0x4		Secure
> OPTION_SETTING_BANKSEL_SEC	0x0100A210	0x4		Secure

Figure 44. Memory Partition for Primary and Secondary Image Storage with External Code Flash

7. Inside the `ra_mcuboot_ra4m3_swap_enc_qspi`, add these variable definitions to the beginning of `hal_entry.c`:

```
/* SREG pay-load size */
#define SREG_SIZE (0x03)
/* Status register pay-load */
#define STATUS_REG_PAYLOAD {0x01,0x40,0x00}
uint8_t data_sreg[SREG_SIZE] = STATUS_REG_PAYLOAD;
```

Figure 45. Add QSPI Variable Definition

8. Stay with `hal_entry.c`, add below code to the beginning of `hal_entry()` function and before the line `mcuboot_quick_setup()`;

```
fsp_err_t err = FSP_SUCCESS;
R_QSPI_Open(&qspi0_ctrl, &qspi0_cfg);
/* write enable for further operations */
err = R_QSPI_DirectWrite(&qspi0_ctrl, &(qspi0_cfg.write_enable_command), 1, false);
if(FSP_SUCCESS == err)
{
    err = R_QSPI_DirectWrite(&qspi0_ctrl, data_sreg, SREG_SIZE, false);
    if(FSP_SUCCESS != err)
    {
        while(1);
    }
}
```

Figure 46. Set up the QSPI

9. Within the bootloader smart configurator, click **Generate Project Content** and compile the bootloader project.

5.2 Update the Primary Application Project to Support QSPI

1. Within the `app_ra4m3_primary_enc_xmodem` project, in smart configurator, click **Downloader Thread -> New Stack -> Storage -> QSPI**, add the QSPI stack.

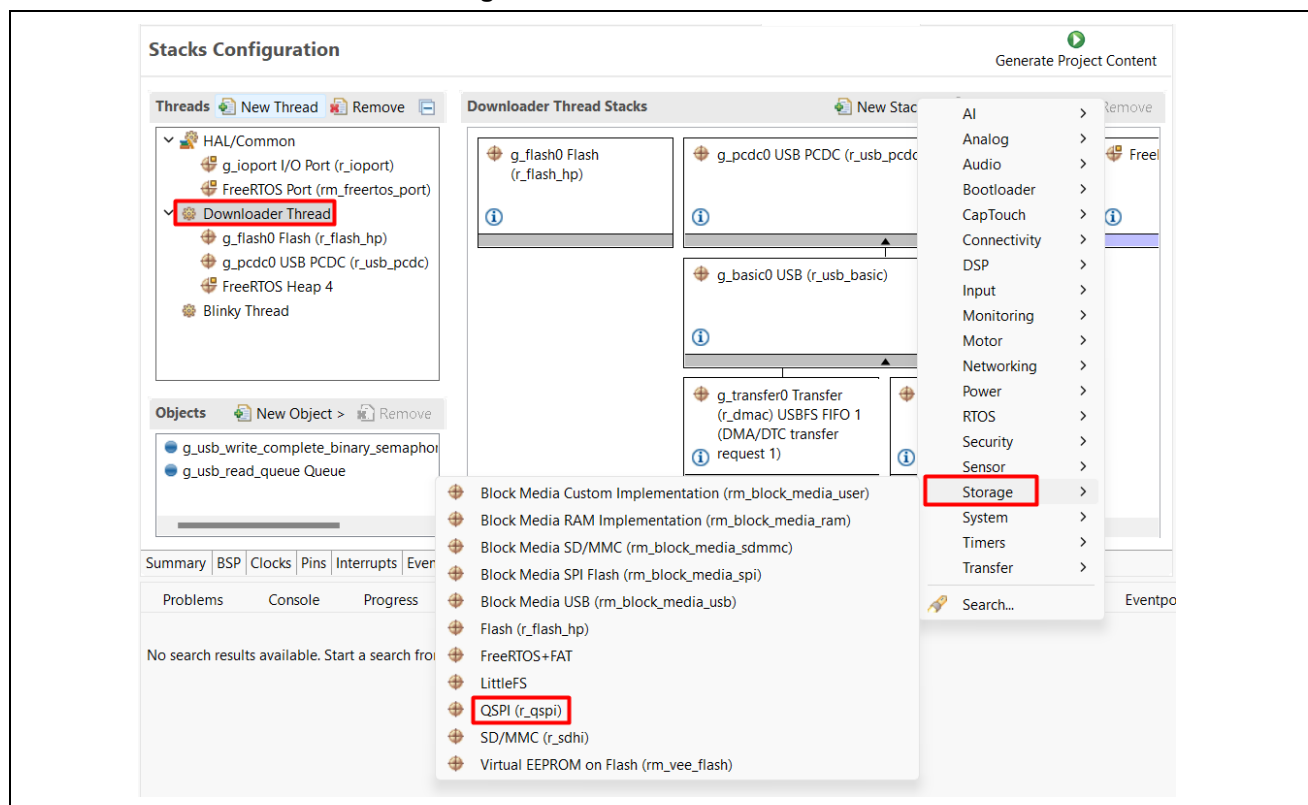


Figure 47. Add the QSPI Stack

2. Highlight the QSPI stack and update the **Bus Timing, Minimum QSSL Deselect Cycles** to **8 QSPCLK**.

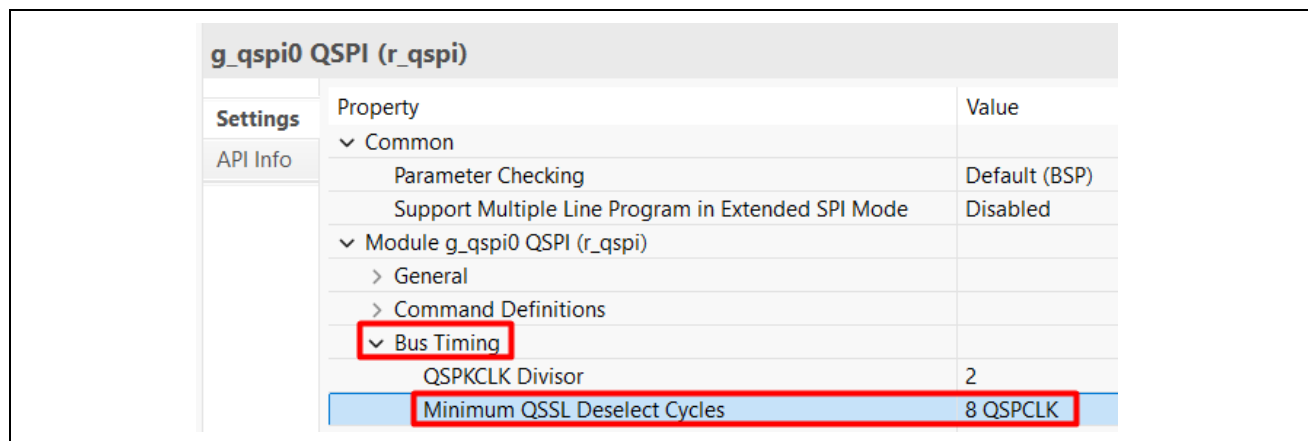


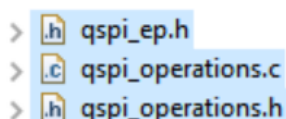
Figure 48. Add the QSPI Stack

3. Copy all the files listed in Table 5 below from `qspi_source.zip` and overwrite the existing files in the following directory of the primary application project `app_ra4m3_primary_enc_xmodem/src`. The updates related with supporting QSPI usage are explained in the **Updates Performed** column.

Table 5. Source File Updates Moving from Internal Flash to QSPI for Secondary Image Storage

Files to overwrite	Updates Performed
downloader_thread_entry.c	Remove code flash initialization and add QSPI initialization
menu.c	Prior to image download over USB PCDC, the flash area needs to be erased. The update performed is to switch from erasing the code flash to erasing the QSPI.
xmodem.c	xmodem.c handles downloading the new image and writing to the secondary application storage area. The updates to this file are to change from writing to internal flash to writing to QSPI.
header.h	The header.h file has definitions on the start and end location of the primary and secondary slot. The update to this file is to change the secondary application starting address as well as the size of the primary and secondary application based on the new bootloader image size configuration and the QSPI address.

10. Copy the highlighted files shown in Figure 49 from `qspi_source.zip` to the `\src` folder for the primary project. These are files supporting QSPI operations.



```

> .h qspi_ep.h
> .c qspi_operations.c
> .h qspi_operations.h

```

Figure 49. QSPI related Source Files

4. Save all files. Navigate to the smart configurator in `app_ra4m3_primary_enc_xmodem` project, click **Generate Project Content** and compile the Primary application.
11. Perform the same update steps from step 1 to 5 for the secondary application project. Except for step 4, we need to copy over all the files from `\qspi_source` folder to `\src` folder of the secondary application.

- Update the Debug Configuration of the primary application. Right click on `app_ra4m3_primary_enc_xmodem`, select **Debug As > Debug Configurations**. Navigate to the Startup window and update the primary image download Offset to the address of the secondary slot `0x60000000`.

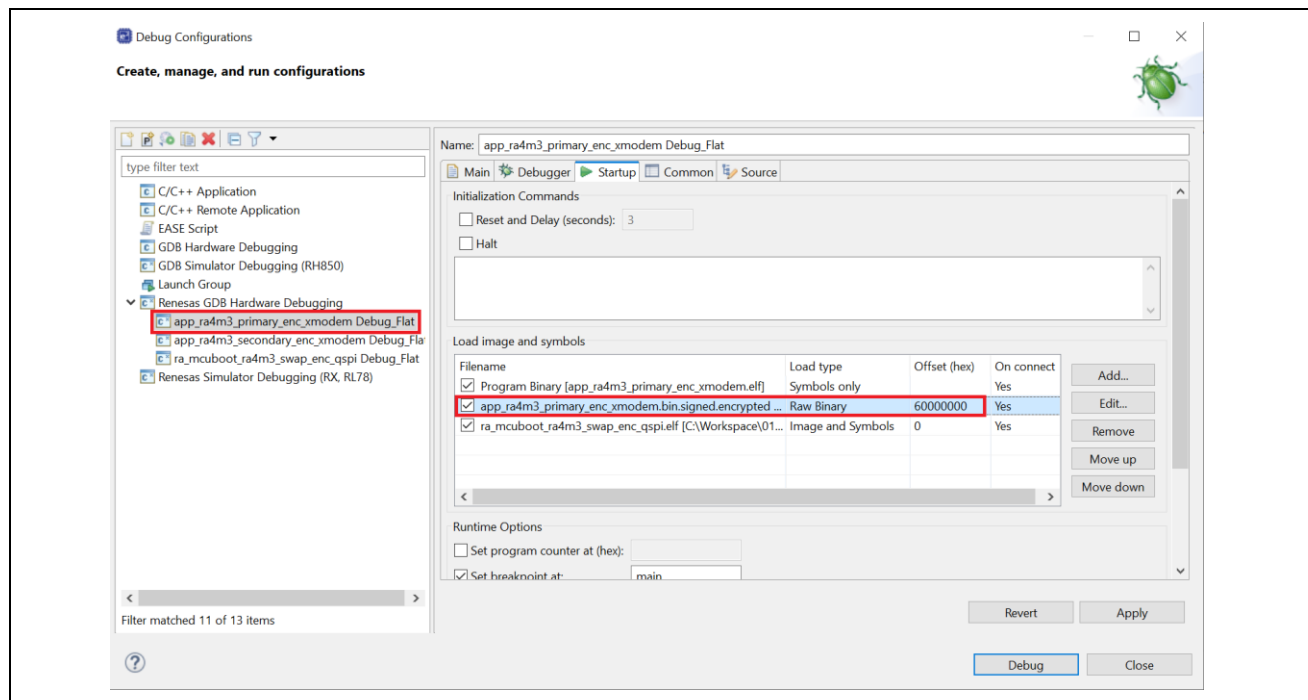


Figure 50. Configure the Debug Configuration

- Click **Debug** and resume the execution twice to boot the primary application. The three LEDs should be blinking.
- Follow section 3.3.6 to download the secondary signed encrypted image and exercise the secondary application.

Note that a solution to this section is provided with this application project as `MCUboot_Encryption_QSPI_Solution.zip` for user's reference.

6. Using Custom Signing Key and Encryption Key

In this section, you will generate two sets of ECDSA SECP256R1 keys using the `imgtool.py` tool included with MCUboot. One set will be used for image signing support, the other pair will be used for image encryption support.

Users can also use other key generation methods to generate the keys, for example OpenSSL. OpenSSL encodes its keys in SEC1 format, while MCUboot uses PKCS#8. So, if the customer uses OpenSSL, a conversion needs to take place.

The MCUboot Example Keys stack provides the example keys used in the image signing/verifying and image encryption/decryption process. The custom keys generated in this section replace these example keys.

These are the two example key structures in the bootloader project

```
\ra_mcuboot_ra4m3_swap_enc_qspi\ra\mcu-tools\MCUboot\sim\mcuboot-sys\csupport
\keys.c file.
```

The `root_pub_der` array is the public key for image verification.

```
const unsigned char root_pub_der[] = {
    0x30, 0x59, 0x30, 0x13, 0x06, 0x07, 0x2a, 0x86,
    0x48, 0xce, 0x3d, 0x02, 0x01, 0x06, 0x08, 0x2a,
    0x86, 0x48, 0xce, 0x3d, 0x03, 0x01, 0x07, 0x03,
    0x42, 0x00, 0x04, 0x2a, 0xcb, 0x40, 0x3c, 0xe8,
    0xfe, 0xed, 0x5b, 0xa4, 0x49, 0x95, 0xa1, 0xa9,
    0x1d, 0xae, 0xe8, 0xdb, 0xbe, 0x19, 0x37, 0xcd,
    0x14, 0xfb, 0x2f, 0x24, 0x57, 0x37, 0xe5, 0x95,
    0x39, 0x88, 0xd9, 0x94, 0xb9, 0xd6, 0x5a, 0xeb,
    0xd7, 0xcd, 0xd5, 0x30, 0x8a, 0xd6, 0xfe, 0x48,
    0xb2, 0x4a, 0x6a, 0x81, 0x0e, 0xe5, 0xf0, 0x7d,
    0x8b, 0x68, 0x34, 0xcc, 0x3a, 0x6a, 0xfc, 0x53,
    0x8e, 0xfa, 0xc1, };
const unsigned int root_pub_der_len = 91;
```

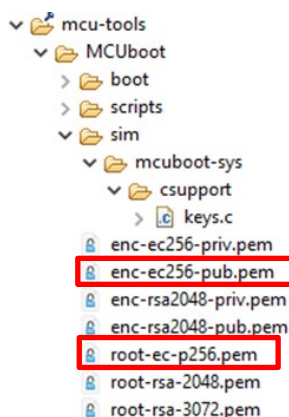
Figure 51. Public Key used for Image Verification

The `enc_key` array is the private key used in the image decryption process.

```
unsigned char enc_key[] = {
    0x30, 0x81, 0x43, 0x02, 0x01, 0x00, 0x30, 0x13, 0x06, 0x07, 0x2a, 0x86,
    0x48, 0xce, 0x3d, 0x02, 0x01, 0x06, 0x08, 0x2a, 0x86, 0x48, 0xce, 0x3d,
    0x03, 0x01, 0x07, 0x04, 0x29, 0x30, 0x27, 0x02, 0x01, 0x01, 0x04, 0x20,
    0xf6, 0x1e, 0x51, 0x9d, 0xf8, 0xfa, 0xdd, 0xa1, 0xb7, 0xd9, 0xa9, 0x64,
    0x64, 0x3b, 0x54, 0xd0, 0x3d, 0xd0, 0x1f, 0xe5, 0x78, 0xd9, 0x17, 0x98,
    0xa5, 0x28, 0xca, 0xcc, 0x6b, 0x67, 0x9e, 0x06, 0xa1, 0x44,
};
static unsigned int enc_key_len = 70;
```

Figure 52. Private Key used for Image Decryption

The matching private key for the public key `root_pub_der` is `root-ec-p256.pem`. We will generate a custom private key `ecc_sign_private.pem` to replace the usage of `root-ec-p256.pem` which is used in the image signing process. The matching public key for the private key `enc_key` is `enc-ec256-pub.pem`. For custom encryption support, we will generate a custom public key `ecc_enc_public.pem` to replace `enc-ec256-pub.pem` which is used in the image encryption process.



```
mcu-tools
├── MCUboot
│   ├── boot
│   ├── scripts
│   └── sim
│       ├── mcuboot-sys
│       │   └── csupport
│       │       ├── keys.c
│       │       ├── enc-ec256-priv.pem
│       │       ├── enc-ec256-pub.pem
│       │       ├── enc-rsa2048-priv.pem
│       │       ├── enc-rsa2048-pub.pem
│       │       ├── root-ec-p256.pem
│       │       ├── root-rsa-2048.pem
│       │       └── root-rsa-3072.pem
```

Figure 53. Image Signing Private Key and ECDSA SECP256R1 Public Key used in Image Encryption Process

Use the following steps to create and replace example keys generated by the MCUboot stack:

1. In the bootloader project, copy `keys.c` from the MCUboot folder to the `\src` folder of the bootloader project.

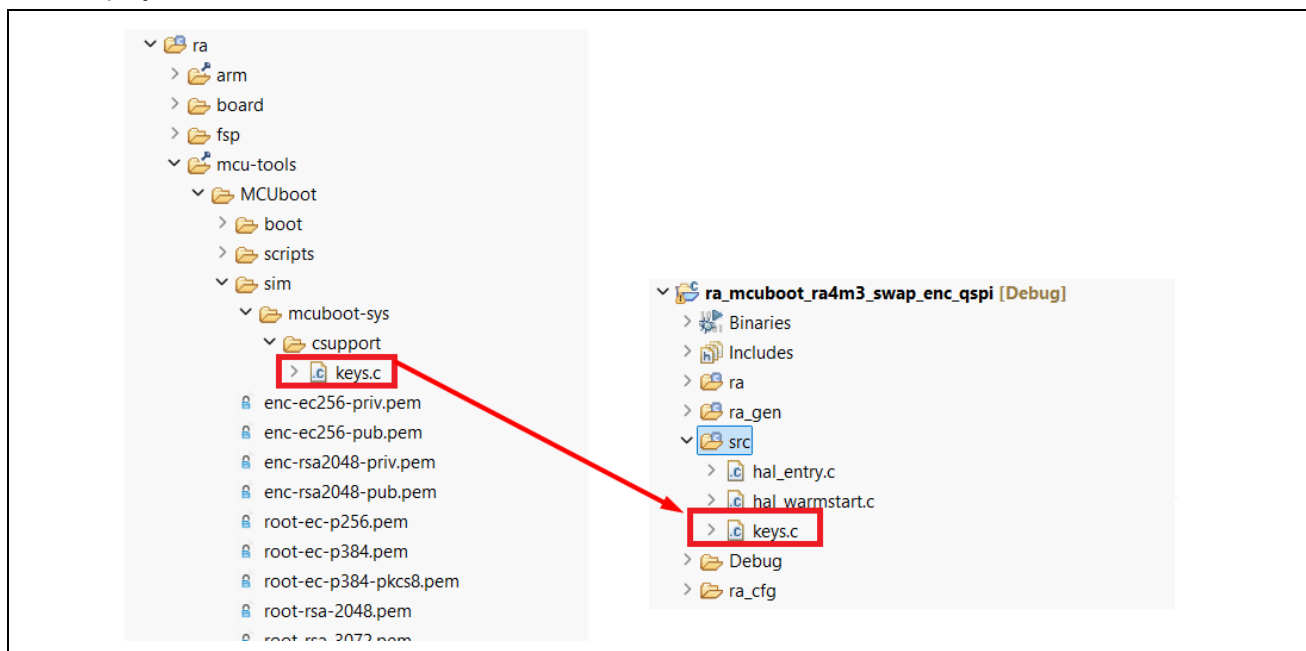


Figure 54. Copy the Example `keys.c`

2. Open the configurator for `ra_mcuboot_ra4m3_swap_enc_qspi`, right click on MCUboot Example Keys and select **Delete**.

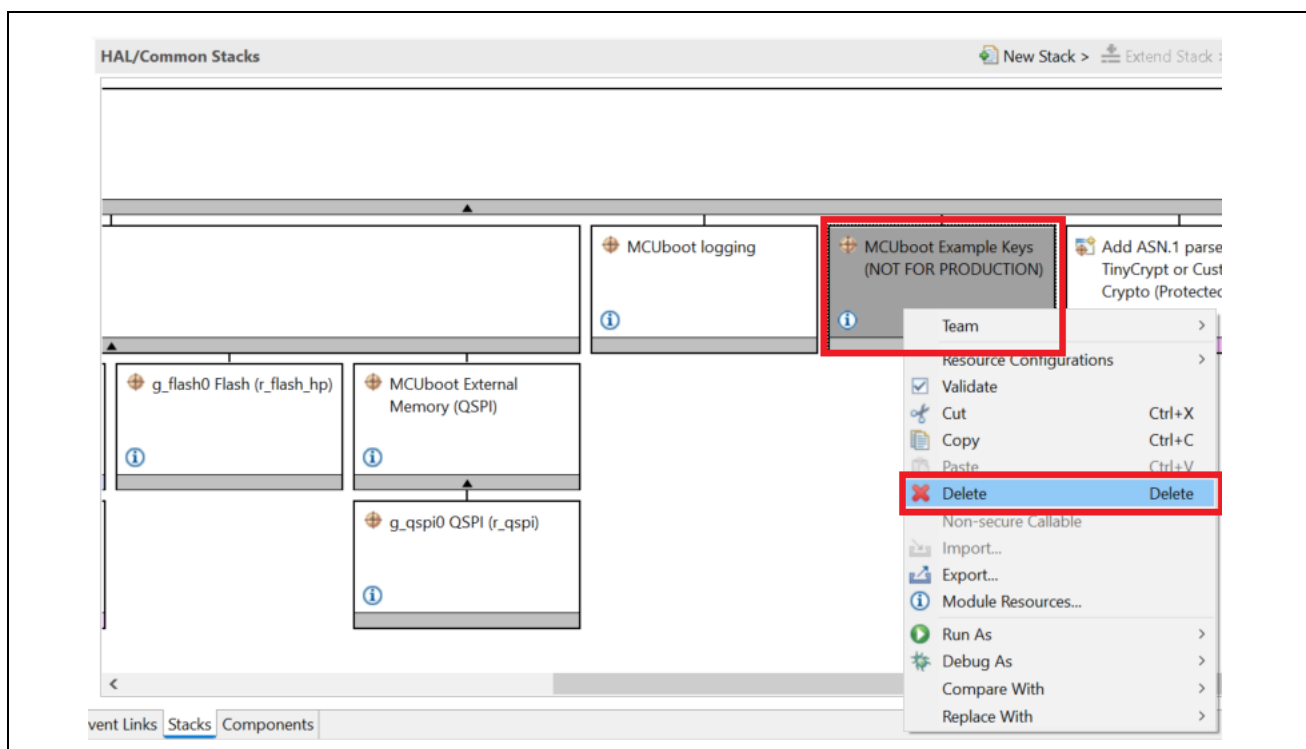


Figure 55. Delete the MCUboot Example Keys Stack

3. Extend `ra_mcuboot_ra4m3_swap_enc_qspi`, right click on folder `\scripts`. Select **Command Prompt** from this folder.

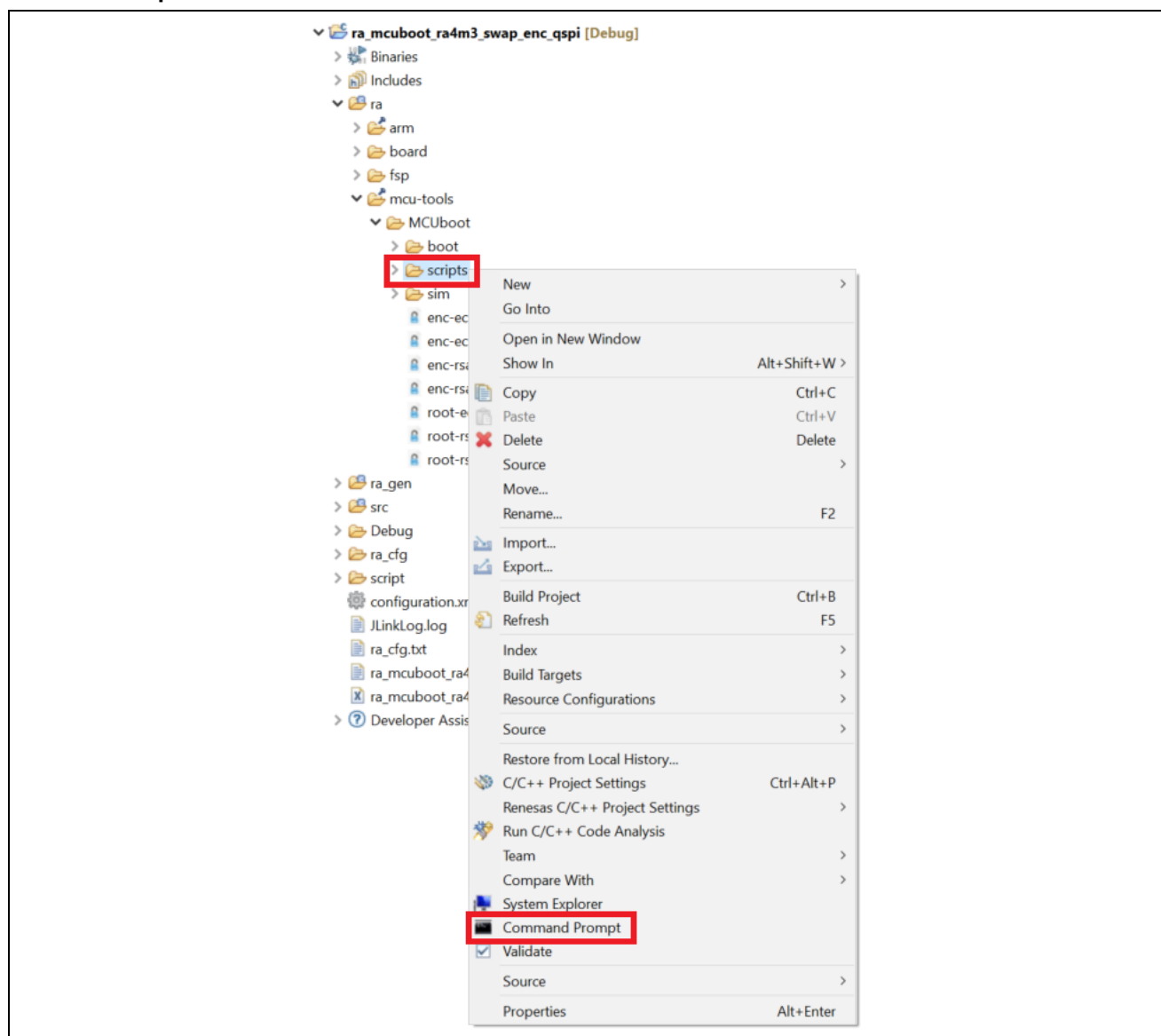


Figure 56. Start Command Prompt under the \MCUboot\scripts Folder

4. Under the command window, execute command:

```
python imgtool.py keygen -k ecc_sign_private.pem -t ecdsa-p256
```
5. Copy the generated `ecc_sign_private.pem` to folder `\ra_mcuboot_ra4m3_swap_enc_qspi\src`

6. Extract the public key from ecc_sign_private.pem to use in the bootloader project.

Execute command:

```
python imgtool.py getpub -k ecc_sign_private.pem
```

```
ot\scripts>python imgtool.py getpub -k ecc_sign_private.pem
/* Autogenerated by imgtool.py, do not edit. */
const unsigned char ecdsa_pub_key[] = {
    0x30, 0x59, 0x30, 0x13, 0x06, 0x07, 0x2a, 0x86,
    0x48, 0xce, 0x3d, 0x02, 0x01, 0x06, 0x08, 0x2a,
    0x86, 0x48, 0xce, 0x3d, 0x03, 0x01, 0x07, 0x03,
    0x42, 0x00, 0x04, 0xa9, 0x88, 0x60, 0xdb, 0x00,
    0xbd, 0xbd, 0xf8, 0x09, 0x37, 0x30, 0x2b, 0x10,
    0x43, 0x48, 0xd2, 0xc9, 0xaf, 0x62, 0x5a, 0xbf,
    0x8d, 0xa2, 0xa8, 0x5a, 0x56, 0xeb, 0x2c, 0x71,
    0xc7, 0x44, 0x4d, 0x8c, 0xee, 0x9a, 0xeb, 0xa5,
    0x48, 0x48, 0x8b, 0x6b, 0x7b, 0x4f, 0x23, 0xb7,
    0xdf, 0xcb, 0x53, 0x48, 0x1f, 0x53, 0xab, 0xde,
    0xe7, 0xe2, 0x7a, 0x91, 0x33, 0xa9, 0x8f, 0xa1,
    0x4f, 0xcf, 0x18,
};
const unsigned int ecdsa_pub_key_len = 91;
```

Figure 57. Generate ECDSA Public Key

7. Copy the generated content of ecdsa_pub_key from Figure 57 to array root_pub_der in \src\keys.c. Replace the original root_pub_der content.

```
#elif defined(MCUBOOT_SIGN_EC256)
#define HAVE_KEYS
const unsigned char root_pub_der[] = {
    0x30, 0x59, 0x30, 0x13, 0x06, 0x07, 0x2a, 0x86,
    0x48, 0xce, 0x3d, 0x02, 0x01, 0x06, 0x08, 0x2a,
    0x86, 0x48, 0xce, 0x3d, 0x03, 0x01, 0x07, 0x03,
    0x42, 0x00, 0x04, 0xa9, 0x88, 0x60, 0xdb, 0x00,
    0xbd, 0xbd, 0xf8, 0x09, 0x37, 0x30, 0x2b, 0x10,
    0x43, 0x48, 0xd2, 0xc9, 0xaf, 0x62, 0x5a, 0xbf,
    0x8d, 0xa2, 0xa8, 0x5a, 0x56, 0xeb, 0x2c, 0x71,
    0xc7, 0x44, 0x4d, 0x8c, 0xee, 0x9a, 0xeb, 0xa5,
    0x48, 0x48, 0x8b, 0x6b, 0x7b, 0x4f, 0x23, 0xb7,
    0xdf, 0xcb, 0x53, 0x48, 0x1f, 0x53, 0xab, 0xde,
    0xe7, 0xe2, 0x7a, 0x91, 0x33, 0xa9, 0x8f, 0xa1,
    0x4f, 0xcf, 0x18, };
const unsigned int root_pub_der_len = 91;
```

Figure 58. Replace ECDSA Public Key

8. Execute the following command to generate the ecc private key to be used in the application image encryption process:

```
python imgtool.py keygen -k ecc_enc_private.pem -t ecdsa-p256
```

9. Copy the generated ecc_enc_private.pem to folder

\ra_mcuboot_ra4m3_swap_enc_qspi\src.

10. Extract the private key to include in the bootloader.

Execute command: `python imgtool.py getpriv --minimal -k ecc_enc_private.pem`.

Remove superfluous fields from the ASN1 by passing it --minimal.

```
ot\scripts>python imgtool.py getpriv --minimal -k ecc_enc_private.pem
/* Autogenerated by imgtool.py, do not edit. */
const unsigned char enc_priv_key[] = {
    0x30, 0x41, 0x02, 0x01, 0x00, 0x30, 0x13, 0x06,
    0x07, 0x2a, 0x86, 0x48, 0xce, 0x3d, 0x02, 0x01,
    0x06, 0x08, 0x2a, 0x86, 0x48, 0xce, 0x3d, 0x03,
    0x01, 0x07, 0x04, 0x27, 0x30, 0x25, 0x02, 0x01,
    0x01, 0x04, 0x20, 0x1f, 0xf4, 0x0a, 0x3f, 0x71,
    0x3a, 0xf4, 0x59, 0x06, 0xed, 0x1e, 0xb2, 0xcc,
    0xb6, 0x52, 0xf2, 0x79, 0x81, 0xe8, 0x95, 0xe9,
    0x58, 0xd5, 0xa5, 0x85, 0xcb, 0x5c, 0xbd, 0x8f,
    0x79, 0x85, 0x97,
};
const unsigned int enc_priv_key_len = 67;
```

Figure 59. Generate the Private Key used for Image Encryption

11. Copy the content of `enc_priv_key` array generated in Figure 59 to the array `enc_key` in `\src\keys.c`. Replace the original `enc_key` array content.

```
#if defined(MCUBOOT_ENCRYPT_EC256)
unsigned char enc_key[] = {
    0x30, 0x41, 0x02, 0x01, 0x00, 0x30, 0x13, 0x06,
    0x07, 0x2a, 0x86, 0x48, 0xce, 0x3d, 0x02, 0x01,
    0x06, 0x08, 0x2a, 0x86, 0x48, 0xce, 0x3d, 0x03,
    0x01, 0x07, 0x04, 0x27, 0x30, 0x25, 0x02, 0x01,
    0x01, 0x04, 0x20, 0x1f, 0xf4, 0x0a, 0x3f, 0x71,
    0x3a, 0xf4, 0x59, 0x06, 0xed, 0x1e, 0xb2, 0xcc,
    0xb6, 0x52, 0xf2, 0x79, 0x81, 0xe8, 0x95, 0xe9,
    0x58, 0xd5, 0xa5, 0x85, 0xcb, 0x5c, 0xbd, 0x8f,
    0x79, 0x85, 0x97,
};
static unsigned int enc_key_len = 67;
```

Figure 60. Replace the Private Key used for Image Encryption

12. We will derive the encryption public key in PEM format from the encryption private key using `imgtool`. Execute the following command:

```
python imgtool.py getpub -k ecc_enc_private.pem -e pem > ecc_enc_public.pem
```

```
\ra\mcu-tools\MCUboot\scripts>python imgtool.py getpub -k ecc_enc_private.pem -e pem > ecc_enc_public.pem
\r\ra\mcu-tools\MCUboot\scripts>
```

Figure 61. Generate the Public Key using the Private Key

The `ecc_enc_public.pem` file created under `/ra_mcuboot_ra4m3_swap_enc_qspi/ra/mcu-tools/MCUboot/scripts`.

13. Copy the generated `ecc_enc_public.pem` to the folder `\ra_mcuboot_ra4m3_swap_enc_qspi\src`.
14. Click **Generate Project Content** and compile the bootloader project.
15. Update the signing key configuration of the primary application project.

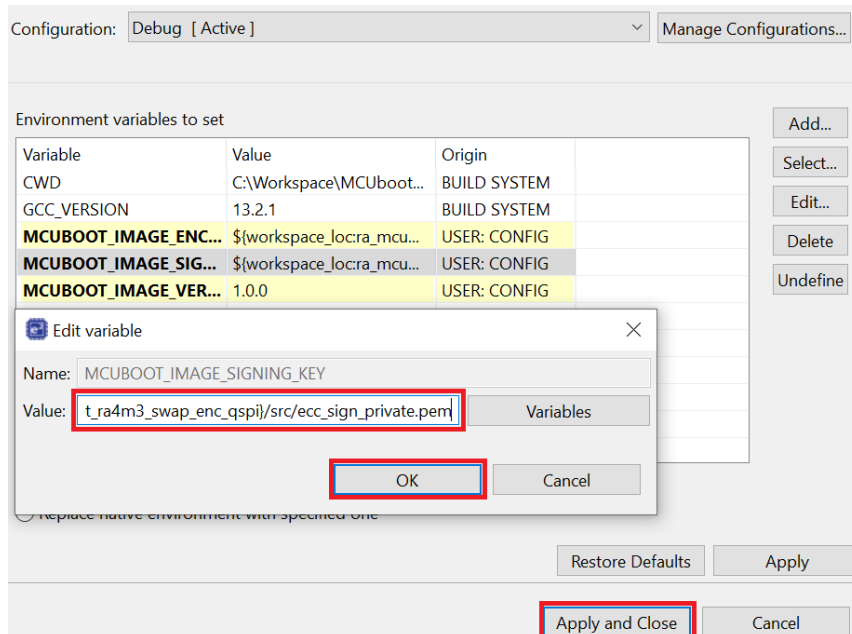


Figure 62. Configure the Application Project to use the Custom Image Signing

16. Update the encryption key configuration of the primary application project.

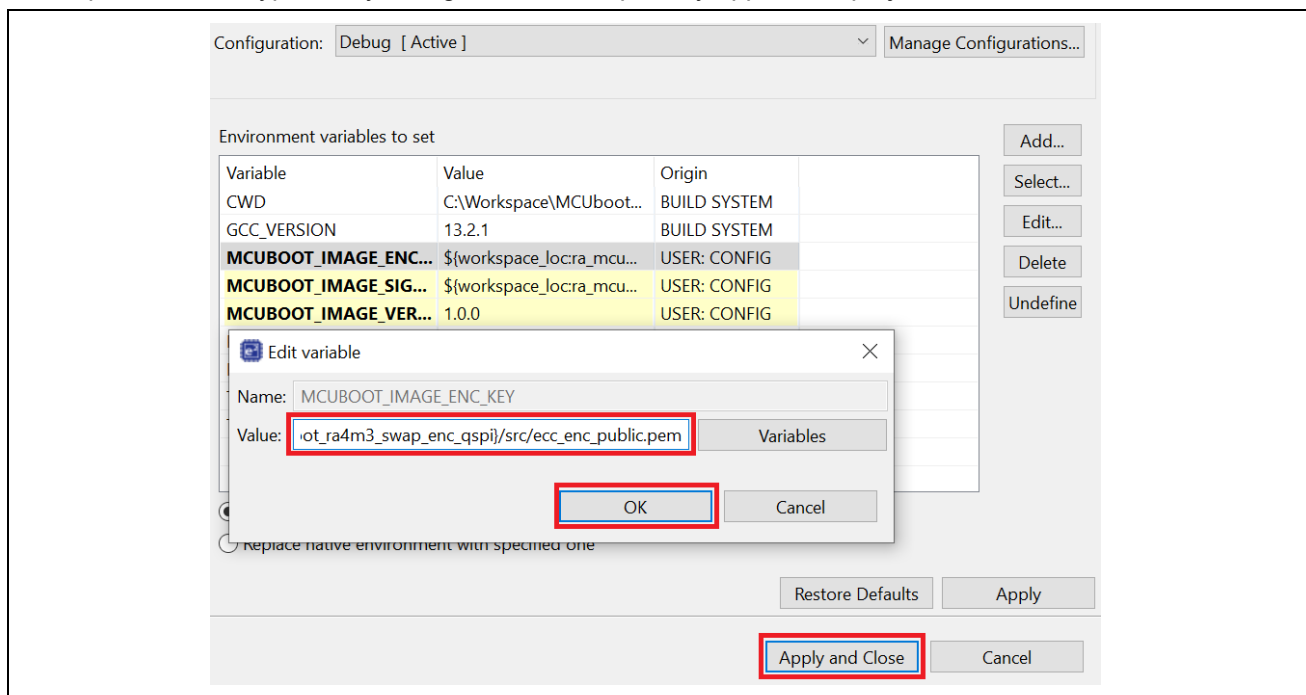


Figure 63. Configure the Application Project to use the Custom Key for the Image Encryption Process

17. For the primary application project, navigate to the smart configurator, click **Generate Project Content** and recompile the application.
18. Repeat steps 15, 16 and 17 for the `app_ra4m3_secondary_enc_xmodem` application project.
19. Follow steps in section 3.3.1 to erase the flash.
20. Start the Debug session from the primary application project, resume twice to boot the primary application. The three LEDs should be blinking.

User can now use the XModem to download and verify the operation for the secondary application image.

7. Appendix

7.1 Making the Bootloader for Cortex®-M33 Immutable

To make the bootloader immutable, the flash blocks containing the bootloader must be locked from being programmed and erased.

The RA4M3 features two sets of registers which facilitate flash block locking. Block Protect Setting (BPS) registers feature bits that map to individual flash blocks. When a bit is set to zero, the corresponding flash block cannot be erased or programmed. The Permanent Block Protect Setting (PBPS) Registers have a similar bit mapping to flash blocks. When a bit is set in one of these registers, the corresponding flash block is permanently locked from being erased and programmed so long as the same bit in the Block Protect Setting Register is also cleared to zero. This process is irreversible. **Once a flash block is permanently locked, it cannot be unlocked again.**

Based on the example bootloaders provided in this application project, the flash blocks used by the bootloader are:

- RA4M3 Overwrite Mode: block 0-7
- RA4M3 Swap Mode: block 0-8

Users can refer to the *RA Family MCU Securing Data at Rest using TrustZone Application Project* to understand the operational flow of setting up the Flash Block Protection.

Note that ticking the BPS0 and PBPS0 Flash Block settings will permanently lock the flash blocks. **This CANNOT be reversed.** Further details can be found in sections 6.2.5 and 6.2.6 of the RA4M3 Hardware User's Manual.

7.2 Device Lifecycle Management for Renesas RA Cortex®-M33 MCUs

Once the bootloader development is finished, the user may want to transition the Device Lifecycle State of the RA Cortex®-M33 MCU to lock down the debugger and the serial programming interface.

We recommend referring to the Device Lifecycle State Transitions in the Production Flow section in the *Renesas RA Family MCU Device Lifecycle Management Key Installation Application Note* to understand the device lifecycle management options during production.

The operational overview of how to use Renesas Flash Programmer to perform these transitions is explained in the *Overview of Device Lifecycle State Transitions using Renesas Flash Programmer* section.

8. References

1. [Renesas RA Family MCU Securing Data at Rest using Security MPU Application Project](#)
2. [Renesas RA Family MCU Securing Data at Rest using Arm TrustZone Application Project](#)
3. [Renesas RA Family MCU Device Lifecycle Management Key Installation Application Note](#)
4. [Renesas RA Family MCU Security Design with TrustZone – IP Protection](#)

9. Website and Support

Visit the following URLs to learn about the RA family of microcontrollers, download tools and documentation, and get support.

EK-RA4M3 Resources	renesas.com/ra/ek-ra4m3
RA Product Information	renesas.com/ra
Flexible Software Package (FSP)	renesas.com/ra/fsp
RA Product Support Forum	renesas.com/ra/forum
Renesas Support	renesas.com/support

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Apr.03.24	-	First release document
1.10	Jan.09.26	-	Update to FSPv6.2.0

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity.

Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on

The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state

Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins

Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals

After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin

Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).

7. Prohibition of access to reserved addresses

Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.

8. Differences between products

Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

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