Renesas RA Family
Secure Bootloader for RA2 MCU Series

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 operating system and hardware independent and relies on hardware porting layers from the operating system it works with. Currently MCUboot is maintained by Linaro in the GitHub mcu-tools page [https://github.com/mcu-tools/mcuboot](https://github.com/mcu-tools/mcuboot). There is a /docs folder that holds the documentation for MCUboot in .md file format. This application note will refer to the above-mentioned documents wherever possible.

The Renesas Flexible Software Package (FSP) integrates an MCUboot port across the entire RA MCU Families starting from FSP v3.0.0. The Renesas RA2 MCU series is based on the Arm® Cortex®-M23 core and has limited flash and RAM memory. This application project is created to address the unique challenges and provide guidelines on the optimization of the RA2 MCU bootloader memory size. For the MCUboot cryptographic support for RA2 MCU groups, TinyCrypt ([https://github.com/intel/tinycrypt/](https://github.com/intel/tinycrypt/)) is integrated with the FSP MCUboot module to provide a smaller memory footprint compared with Mbed Crypto. Refer to the GitHub folder /tinycrypt/documentation/ for details on the TinyCrypt cryptographic algorithm usage guide.

This application note walks the user through secure bootloader creation using the MCUboot Module with TinyCrypt for enhanced security on the Renesas EK-RA2E1 kit. In addition, examples of how to configure the application project to use the bootloader are provided. Both Overwrite and Swap upgrade modes are discussed and example projects are provided which support these upgrade modes.

For the Renesas RA6 and RA4 MCU Series, Renesas provides an application project Using MCUboot with Renesas RA MCU Application Project which walks users through using MCUboot with RA6 and RA4 MCU groups with Mbed Crypto module. See the References section for information on this application project.

Required Resources

Development Tools and Software
- e² studio ISDE v2021-10 or greater
- Renesas Flexible Software Package (FSP) v3.4.0 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.

Hardware
- Workstation running Windows® 10 and Tera Term console, or similar application
- One USB device cable (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 development. Users are required to read the entire the MCUboot Port section in the FSP User’s Manual 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 use of a secure bootloader with the Renesas RA2 MCU family.
Using this Application Note

Section 1 covers the general overview of MCUboot and the application upgrade methods supported by MCUboot.

Section 2 covers the general flow of using the FSP MCUboot module to establish bootloader-based application systems.

Section 3 to Section 6 are the walk throughs of how to create bootloader project using overwrite and swap upgrade mode, how to configure the application projects to use the bootloader and boot the primary and secondary images.

Section 7 provides instructions on how to directly run the included example projects without going through Sections 3 to 6. For a quick evaluation of the included example projects, you can go to Section 7 directly.

Contents

1. Overview of MCUboot ................................ ................................ ................................ ................................. 4
   1.1.1 Overview of Application Booting Process ......................................................................................... 4
   1.1.2 Applications Update Strategies ......................................................................................................... 4

2. Architcting an Application with MCUboot Module using FSP for RA2 MCUs .............................. 6
   2.1 Secure Booting with TinyCrypt ........................................................................................................... 6
   2.2 Designing Bootloader and the Initial Primary Application Overview ..................................................... 6
   2.3 Guidelines for Using the MCUboot Module with RA2 Series MCUs ..................................................... 6
   2.3.1 Customize the RA2 Bootloader ........................................................................................................ 6
   2.4 Production Recommendations for RA2 MCU ...................................................................................... 7
   2.4.1 Make the Bootloader Immutable ....................................................................................................... 7
   2.4.2 Disable the Debug and Serial Programming Interface Prior to Deployment ....................................... 7

3. Creating the Bootloader Project ............................................................................................................. 7
   3.1 Include the MCUboot Module in the Bootloader Project ...................................................................... 7
   3.2 Further Optimization for the Bootloader Project Size ........................................................................... 16
   3.3 Compile the Bootloader Project ........................................................................................................... 18
   3.4 Configure the Python Signing Environment ...................................................................................... 19
   3.5 Signing Command............................................................................................................................ 20
   3.6 Usage Notes .................................................................................................................................... 21
   3.6.1 Migrating the Bootloader to other FSP versions .............................................................................. 21
   3.6.2 Migrating from One Upgrade Mode to Another Upgrade Mode ........................................................ 21
   3.6.3 Use the Memory Usage Window to Select Functions to Put in the Gap Area................................... 21

4. Using the Bootloader with a New Application or Existing Application ................................ .... 21
   4.1 Generate the Initial Application Project ............................................................................................. 21
   4.2 Configure the Existing Application to Use the Bootloader Project ...................................................... 22
   4.3 Signing the Application Image ........................................................................................................... 23

5. Booting the Initial Application Project .................................................................................................. 24
   5.1 Set Up the Hardware ........................................................................................................................ 24
   5.2 Configure the Debugger .................................................................................................................... 24
   5.3 Download the Primary Application .................................................................................................... 27
5.4 Booting the Primary Application

6. Mastering and Delivering a New Application
   6.1 Create a New Application
   6.2 Configure the Swap Test Mode
      6.2.1 Confirming the New Application at Compile Time
      6.2.2 Confirming the New Application at Run-time
   6.3 Downloading and Booting the New Application

7. Appendix: Compile and Exercise the Included Example Bootloader and Application Projects
   7.1 Running the Example Projects with Overwrite Upgrade Mode
      7.1.1 Without Signature Verification
      7.1.2 With Signature Verification
   7.2 Running the Example Projects with Swap Upgrade Mode
      7.2.1 Without Signature Verification
      7.2.2 With Signature Verification

8. References

9. Website and Support

Revision History
1. Overview of MCUboot

MCUboot is an open source project hosted at [mcu-tools github project](https://github.com/mcu-tools). It is currently managed by the [Linaro Community Project](https://github.com/mcu-tools). MCUBoot handles the firmware integrity and authenticity check after start-up and the firmware switch part of the firmware update process. The operation of switching of the firmware from the original image to a new image depends on the image upgrade methods. The image upgrade methods are described in section 1.1.2. 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.

1.1.1 Overview of Application Booting Process

For applications using MCUBoot, the MCU memory is separated into MCUboot, Primary App, Secondary App and the Scratch Area. Below is an example of the single image MCUboot memory map. For more information on the MCUboot memory layout, refer to the [Flash Map section](https://github.com/mcu-tools/mcuboot/blob/master/docs/design.md) of the reference MCUboot website.

![Figure 1. Single Image MCUboot Memory Flash Map](image)

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

The bootloader is started when the CPU is released from reset. If there are images in the Secondary App memory marked as to be updated, the bootloader performs the following actions:

1. The bootloader verifies the integrity and authenticity of the Secondary image.
2. Upon successful authentication, the bootloader will switch to the new image based on the update method selected. Available update methods are introduced in section 1.1.2.
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. The firmware image can be authenticated by hash (SHA-256) and digital signature validation.

1.1.2 Applications Update Strategies

The following are the update strategies supported by MCUboot. The Renesas FSP MCUboot Module in FSP v3.4.0 does not support all of the MCUboot update strategies. The analysis of pros and cons is based on the MCUboot functionality, but not the FSP v3.4.0 MCUboot Module functionality. In addition, this application note is not intended to provide all details on the MCUboot application update strategies. We recommend acquiring more details on these update strategies by referring to the MCUboot design page:

[https://github.com/mcu-tools/mcuboot/blob/master/docs/design.md](https://github.com/mcu-tools/mcuboot/blob/master/docs/design.md)
Overwrite
In the Overwrite update mode, the active firmware image is always executed from the Primary slot, and the Secondary slot is a staging area for new images. Before the new firmware image is executed, the entire contents of the primary slot are overwritten with the contents of the secondary slot (the new firmware image).

Pros
- Fail-safe and resistant to power-cut failures
- Less memory overhead, with a smaller MCUboot trailer and no scratch area
- Encrypted image support available when using external flash

Cons
- Does not support pre-testing of the new image prior to overwrite
- Does not support automatic application fallback mechanism

Overwrite upgrade mode is supported by Renesas RA FSP v3.0.0 or later. However, encrypted image support using external flash is not supported yet.

Swap
In the Swap image upgrade mode, the active image is also stored in the Primary slot and it will always be started by the bootloader. If the bootloader finds a valid image in the Secondary slot that is marked for upgrade, then contents of the primary slot and the secondary slot will be swapped. The new image will then start from the primary slot.

Pros
- The bootloader can revert the swapping as a fallback mechanism to recover the previous working firmware version after a faulty update
- The application can perform a self-test to mark itself permanent
- Fail-safe and resistant to power-cut failures
- Encrypted image support available when using external flash

Cons
- Need to allocate a scratch area
- Larger memory overhead, due to a larger image trailer and additional scratch area
- Larger number of write cycles in the scratch area, wearing the scratch sectors out faster

Swap upgrade mode is supported by Renesas RA FSP v3.0.0 or later. However, encrypted image using external flash is not supported. Runtime image testing is supported from FSP v3.4 or later.

Direct execute-in-place (XIP)
In the direct execute-in-place mode, the active image slot alternates with each firmware update. If this update method is used, then two firmware update images must be generated: one of them is linked to be executed from the primary slot memory region, and the other is linked to be executed from the secondary slot.

Pros
- Faster boot time, as there is no overwrite or swap of application images needed
- Fail-safe and resistant to power-cut failures

Cons
- Added application-level complexity to determine which firmware image needs to be downloaded
- Encrypted image support is not available

Direct execute-in-place is not currently supported by the Renesas RA FSP, but it is planned for a future release.

RAM loading firmware update
Like the direct execute-in-place mode, RAM loading firmware update mode selects the newest image by reading the image version numbers in the image headers. However, instead of executing it in place, the newest image is copied to RAM for execution. The load address (the location in RAM where the image is copied to) is stored in the image header. This upgrade method is not typically used in an MCU environment. Please refer to the RAM Loading section in the MCUboot page for more information on this update strategy. This image update mode does not support encrypted images (see MCUboot documentation on encrypted image operation).

RAM loading update mode is not supported by the Renesas RA FSP.
2. Architecting an Application with MCUboot Module using FSP for RA2 MCUs

This section provides an overview of the FSP MCUboot Module, the available application image upgrade modes, memory architecture design, and guidelines for mastering the new image. In addition, this section describes how the lightweight TinyCrypt is used in the RA2 bootloader design. We recommend reviewing the MCUboot Port section the FSP User's Manual to understand the build time configurations for MCUboot.

2.1 Secure Booting with TinyCrypt

TinyCrypt is a small-footprint cryptography library targeting constrained devices. Its minimal set of standard cryptographic primitives are designed to provide secure messages, basic encryption, and random number generation, which are all needed to secure the small footprint of IoT devices. FSP v3.4.0 release uses TinyCrypt v0.2.8. For the RA2 bootloader design, SHA256 and ECDSA from TinyCrypt are used to ensure the application image integrity and authenticity. TinyCrypt does not supported RSA.

The FSP TinyCrypt port module does not provide any interfaces to the user. Consult the documentation at https://github.com/intel/tinycrypt/blob/master/documentation/tinycrypt.rst for further information on use of the TinyCrypt port. The software only module is available in FSP on all RA devices. Hardware acceleration for AES-128 through FSP TinyCrypt port is provided for the RA2 family.

2.2 Designing Bootloader and the Initial Primary Application Overview

A bootloader is typically designed with the initial primary application. The following are the general guidelines for designing the bootloader and 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 as well as the cryptographic library used.
- Develop the initial primary application, perform the memory usage analysis, and compare with the bootloader memory allocation for consistency and adjust as needed.
- Determine the bootloader configurations in terms of image authentication and new image update mode. This may result in adjustment of the memory allocated definition in the bootloader project.
- Sign the application image. The signing command is output to the `<bootloader project>\Debug\<bootloader project >.bld` file. The application image can use a BuildVariable to access this .bld file. The IDE tools will use the signing command to sign the application and generate a binary file for downloading to the MCU.
- Test the bootloader and the initial primary application.

The above guidelines are demonstrated in the walk-through sections in this application note.

2.3 Guidelines for Using the MCUboot Module with RA2 Series MCUs

The MCUBoot Module is supported on all RA Family MCUs. For the Renesas RA2 Cortex-M23 MCU series, image hashing and image authentication are supported in FSP v3.4 or later.

2.3.1 Customize the RA2 Bootloader

Customizing the Bootloader involves the following main aspects:

- Customized method to download the application. This is very application specific and is not discussed in this application project.
- Bootloader size optimization.
  Some of the bootloader size optimization actions that can be taken are summarized as follows. Details on the operational flow of these optimization are described in section 3.
  - Disable application image validation to reduce code size
  - Disable image signing to reduce code size
  - Update the linker script to optimize memory usage
  - Disable unused FSP components to reduce code size
  - Compile the bootloader with Optimization for Size (`-Os`)
  - Use pin configurations that initialize fewer peripheral and IO pins.
- Details on the RA2 bootloader memory optimization are introduced in later sections.
2.4 Production Recommendations for RA2 MCU

2.4.1 Make the Bootloader Immutable
Refer to the Renesas RA MCU Family Securing Data at Rest Utilizing the Renesas Security MPU application project section Permanent Locking of the FAW Region to understand how to make the bootloader immutable. The PC Application to Permanently Lock the FAW section in the same application note describes how to handle Flash locking in production mode.

2.4.2 Disable the Debug and Serial Programming Interface Prior to Deployment
Once the bootloader development is finished, you may want to set up ID Code protection on the Renesas RA2 MCU to lock down the debugger and the serial programming interface.

Refer to the Securing Data at Rest Utilizing the Renesas Security MPU Application Project section Setting up the Security Control for Debugging for the desired settings to control the device lifecycle management of the RA2 MCUs using the ID Code protection method.

3. Creating the Bootloader Project
This section walks the user through the creation process of the RA2 bootloader provided in this application note.

The example bootloader which user will create by following this section is provided in the RA2_secure_bootloader.zip. You can follow section 7 to exercise the example bootloader and application projects without going through the creation process in this section.

3.1 Include the MCUboot Module in the Bootloader Project
1. Launch e2 studio and start to establish a new C/C++ Project. Click File > New > C/C++ Project.

2. Choose Renesas RA > Renesas RA C/C++ Project. Click Next.

3. Provide a project name in the next screen. Note that, in this step, you should select different project names based on the upgrade mode and authentication method. These names will persist in the instructions used in this application note.

Table 1 is the name and intended application image update strategy of the bootloader project.
Table 1. Description of the Bootloader Projects

<table>
<thead>
<tr>
<th>Name of the project to be used</th>
<th>Intended application update strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ra_mcubootRa2e1</td>
<td>Overwrite update mode with no signature verification. Magic number and SHA256 integrity check are included.</td>
</tr>
<tr>
<td>ra_mcubootRa2e1_overwrite_with_signature</td>
<td>Overwrite update mode with signature verification, Magic number and SHA256 integrity check are also included.</td>
</tr>
<tr>
<td>ra_mcubootRa2e1_swap</td>
<td>Swap update mode with no signature verification. Magic number and SHA256 integrity check are included. Swap test prior to confirm is not supported.</td>
</tr>
<tr>
<td>ra_mcubootRa2e1_swap_with_signature</td>
<td>Swap update mode with signature verification, Magic number and SHA256 integrity check are also included. Swap test prior to confirm is supported.</td>
</tr>
</tbody>
</table>

Figure 4 is an example of setting the project name to **ra_mcubootRa2e1**.

**Figure 4. Name the Bootloader Project**

Click **Next**. If you can choose other names for the bootloader, please adapt the corresponding instructions in this application note to the project name used.

4. In the next screen, choose **EK-RA2E1** for **Board** and click **Next**.

**Figure 5. Select the Board**
5. Choose **Executable** for **Build Artifact Selection** and **No RTOS**. Click **Next**.

![Figure 6. Choose to Build Executable and No RTOS](image)

6. Choose **Bare Metal – Minimal** for the Project Template in the next screen and click **Finish** to establish the initial project.

![Figure 7. Choose the Project Template](image)

7. When following prompt opens, click **Open Perspective**.

![Figure 8. Choose Open the FSP Configuration perspective](image)

8. The project will now be created, and the bootloader project configuration will be displayed. Select the **Pins** tab and uncheck **Generate data** for **RA2E1 EK**.

![Figure 9. Uncheck Generate data for RA2E1 EK Pin Configuration](image)
Use the pull-down menu to switch from RA2E1 EK to R7FA2E1A92DFM.pincfg for the Select Pin Configuration option, then select the Generate data check box and enter g_bsp_pin_cfg. Note that here we choose to use this configuration which has fewer peripherals/pins configured since the bootloader does not use the extra peripheral or GPIO pins configured in the RA2E1 EK configuration. This change also reduces the bootloader memory usage and is highly recommended.

9. Once the project is created, click the Stacks tab on the RA configurator. Add New Stack > Bootloader > MCUboot.

10. Next, configure the General properties of MCUboot.
- For project ra_mcuboot_ra2e1 and ra_mcuboot_ra2e1_overwrite_with_signature, reference Figure 12
- For project ra_mcuboot_ra2e1_swap and ra_mcuboot_ra2e1_swap_with_signature, update below properties in Figure 12:
  - Change the Upgrade Mode to Swap
  - Set the Downgrade Prevention (Overwrite Only) to No.
Figure 13 is a more detailed application image format that can be referenced to understand the various MCUboot property definitions.

The following explains the various properties configured:

- **Custom mcuboot_config.h**: The default mcuboot_config.h file contains the MCUboot Module configuration that the user selected from the RA configurator. The user can create a custom version of this file to achieve additional bootloader functionalities available in MCUboot.

- **Upgrade Mode**: This property configures the application image upgrade method. The available options are Overwrite Only, Overwrite Only Fast, and Swap.

- **Validate Primary Image**: When Enabled, the bootloader will perform a hash or signature verification depending on the verification method chosen in addition to the MCUboot sanity check based on the image header and TLV area magic numbers. When Disabled, only sanity check is performed based on the MCUboot header and TLV area magic numbers. It is highly recommended to always enable this property. The additional code used when this property is enabled is less than 30 bytes while it adds critical security handling to the bootloader. Note that the image magic number is not part of the image validation, it is a reference value that can be used for sanity check during application upgrade debugging process. This image magic number is written to the flash after a successful image upgrade.

- **Number of Images Per Application**: This property allows user to choose one image for Non-TrustZone-based applications and two images for TrustZone-based applications. RA2 MCU groups do not support TrustZone, so this property is set to 1.

- **Downgrade Prevention (Overwrite Only)**: This property applies to Overwrite upgrade mode only. When this property is Enabled, a new firmware with a lower version number will not overwrite the existing application. For how to set the version number of an image, refer to Figure 39.

11. Configure the Signing Options and Flash Layout of the MCUboot module based on Table 2.

Table 2. Bootloader Configurations

<table>
<thead>
<tr>
<th>Bootloader Project Name</th>
<th>Screenshots for detailed configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>ra_mcuboot_ra2el</td>
<td>Figure 14</td>
</tr>
<tr>
<td>ra_mcuboot_ra2el_overwrite_with_signature</td>
<td>Figure 15</td>
</tr>
<tr>
<td>ra_mcuboot_ra2el_swap</td>
<td>Figure 16</td>
</tr>
<tr>
<td>ra_mcuboot_ra2el_swap_with_signature</td>
<td>Figure 17</td>
</tr>
</tbody>
</table>
Figure 14. Update Configurations for Project ra_mcuboot_ra2e1

Figure 15. Update Configurations for Project ra_mcuboot_ra2e1_overwrite_with_signature
### Figure 16. Update Configurations for `ra_mcuboot_ra2e1_swap`

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Signing Options</td>
<td></td>
</tr>
<tr>
<td>TrustZone</td>
<td></td>
</tr>
<tr>
<td>Signature Type</td>
<td>None</td>
</tr>
<tr>
<td>Boot Record</td>
<td></td>
</tr>
<tr>
<td>Custom</td>
<td><code>--confirm</code></td>
</tr>
<tr>
<td>Python</td>
<td>python</td>
</tr>
<tr>
<td>Debugging</td>
<td></td>
</tr>
<tr>
<td>Flash Layout</td>
<td></td>
</tr>
<tr>
<td>TrustZone</td>
<td></td>
</tr>
<tr>
<td>Bootloader Flash Area Size (Bytes)</td>
<td>0x3000</td>
</tr>
<tr>
<td>Image 1 Header Size (Bytes)</td>
<td>0x100</td>
</tr>
<tr>
<td>Image 1 Flash Area Size (Bytes)</td>
<td>0x2000</td>
</tr>
<tr>
<td>Scratch Flash Area Size (Bytes)</td>
<td>0x800</td>
</tr>
<tr>
<td>Data Sharing</td>
<td></td>
</tr>
</tbody>
</table>

### Figure 17. Update Configurations for `ra_mcuboot_ra2e1_swap_with_signature`

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td></td>
</tr>
<tr>
<td>Signing Options</td>
<td></td>
</tr>
<tr>
<td>TrustZone</td>
<td></td>
</tr>
<tr>
<td>Signature Type</td>
<td>ECDSA P-256</td>
</tr>
<tr>
<td>Boot Record</td>
<td></td>
</tr>
<tr>
<td>Custom</td>
<td><code>--pad</code></td>
</tr>
<tr>
<td>Python</td>
<td>python</td>
</tr>
<tr>
<td>Debugging</td>
<td></td>
</tr>
<tr>
<td>Flash Layout</td>
<td></td>
</tr>
<tr>
<td>TrustZone</td>
<td></td>
</tr>
<tr>
<td>Bootloader Flash Area Size (Bytes)</td>
<td>0x4000</td>
</tr>
<tr>
<td>Image 1 Header Size (Bytes)</td>
<td>0x100</td>
</tr>
<tr>
<td>Image 1 Flash Area Size (Bytes)</td>
<td>0x2000</td>
</tr>
<tr>
<td>Scratch Flash Area Size (Bytes)</td>
<td>0x800</td>
</tr>
</tbody>
</table>
Explanation of the Above Configurations
For both single-image and two-image configurations, the following five properties need to be defined:

- **Bootloader Flash Area**: Size of the flash area allocated for the bootloader with a boundary of 0x800 since 0x800 is the minimum erase size for code flash.
- **Image 1 Header Size**: Size of the flash area allocated for the application header for single image configuration. For Arm Cortex-M23 MCUs, this should be set to 0x100.
- **Image 1 Flash Area Size**: Size of the flash area allocated for the application image for single image configuration. This area needs to be equal or larger than the application image with a boundary of 0x800.
- **Scratch Flash Area Size**: This property is only needed for Swap mode. The scratch area must be large enough to store the largest sector that is going to be swapped. For both RA2 MCUs, the scratch area should be set up to 0x800 when Swap mode is used.
- **Signature Type**: is the signing algorithm selection. The choices are
  - **NONE**: this option is selected for the bootloaders which do not support signature verification as shown in Figure 14 and Figure 16.
  - **ECDSA P-256**: this option is selected for the example bootloaders which support signature verifications included in this application project as shown in Figure 15 and Figure 17.
  - **RSA 2048 and RSA 3072**: Application images using MCUboot must be signed to work with MCUboot. At a minimum, this involves adding a hash and an MCUboot-specific constant value in the image trailer. Note that when using TinyCrypt as the Cryptographic support for MCUboot, RSA signature verification is not supported.
  - **Custom**: This property allows a user to input any specific arguments for the signing command. By default **--confirm** is set for this property. The following explains the influence of this property to the secondary image when **--confirm** is set:
    - For overwrite upgrade mode: the new image will always overwrite the original application image upon successful verification.
    - For swap upgrade mode, the primary image slot will be marked as Confirmed after the swap update. No swap happens upon the next reset after the swap update.

If we set this property to **--pad**, the system behavior is:
- For overwrite upgrade mode, the system behavior is same as when **--confirm** is set.
- For swap upgrade mode, the system behavior depends on whether the application has routines to mark the primary image slot as Confirmed. The details about the system behavior is explained in section 6.2.2.

The primary image boot behavior is not influenced by the choice between **--confirm or --pad**.

Properties that vary based on the Upgrade Mode Selection
See Table 3 for the configuration used in the various bootloader projects introduced in this application project.
- Note that different authentication method uses different amount of flash memory. The user can select the most suitable configurations based on their specific application project requirement.
- The Image 1 Flash Area size is based on the simple blinky project. The user needs to adjust this memory configuration based on the specific application project they want to use with the bootloader.
- This swap upgrade based application project uses a larger flash area because the swap test mode is configured in the example project. For details on the swap test mode, please refer to 6.2.2.

Table 3 Configurations for Different Upgrade Modes

<table>
<thead>
<tr>
<th>Properties</th>
<th>ra_mcuboot_ra2e1</th>
<th>ra_mcuboot_overwrite_with_signature</th>
<th>ra_mcuboot_ra2e1_swap</th>
<th>ra_mcuboot_ra2e1_swap_with_signature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bootloader Flash Area Size</td>
<td>0x2000</td>
<td>0x3800</td>
<td>0x3000</td>
<td>0x4000</td>
</tr>
<tr>
<td>Image 1 Flash Area Size</td>
<td>0x2000</td>
<td>0x2000</td>
<td>0x2000</td>
<td>0x2800</td>
</tr>
<tr>
<td>Signature Type</td>
<td>NONE</td>
<td>ECDSA P256</td>
<td>NONE</td>
<td>ECDSA P256</td>
</tr>
<tr>
<td>Custom</td>
<td><strong>--confirm</strong></td>
<td><strong>--confirm</strong></td>
<td><strong>--confirm</strong></td>
<td><strong>--pad</strong></td>
</tr>
</tbody>
</table>

The properties under **TrustZone** are not used for RA2 MCUs since they do not have TrustZone.
For other properties shown in this step, please refer to the FSP User’s Manual on MCUboot port.
12. Next add the TinyCrypt module. The TinyCrypt (H/W Accelerated) includes hardware accelerated AES functionality which is not used in the bootloader, so TinyCrypt (S/W Only) is used. The MbedTLS (Crypto Only) module has a larger memory footprint compared with TinyCrypt and is not used in this bootloader design.

![TinyCrypt Module Select](image)

**Figure 18. Select TinyCrypt Module**

13. Now click on the Flash Driver block and set the Code Flash Programming to Enabled. As Data Flash Programming and Data Flash Background Operation are not used in the bootloader, select Disabled for these two properties to reduce the bootloader memory footprint.

![Flash Driver Enable](image)

**Figure 19. Enable Code Flash programming**

14. In this step, save Configuration.xml and click Generate Project Content. Next, expand the Developer Assistance > HAL/Common > MCUboot > Quick Setup and drag Call Quick Setup to the top of the hal_entry.c of the bootloader project.

Add the following function call to the top of the hal_entry() function:

```c
mcuboot_quick_setup();
```
15. Notice that by default the I/O Port Driver is brought into the project when the project is established. Because the I/O Port Driver is not used in the bootloader project, this stack can be removed to reduce the bootloader project size.

Figure 20. Remove the I/O Port Stack

After the I/O Port is deleted, remove all sections of code referencing the I/O Port API. For example, remove the two sections of the code in the red boxes in the function R_BSP_WarmStart in hal_entry.c as shown in Figure 21.

Figure 21. Remove Unused Code in hal_entry.c

3.2 Further Optimization for the Bootloader Project Size

To further optimize the bootloader project for size, you can put some application code in the gap area between the interrupt vector and the RA2E1 ROM registers. We can create a section (code_in_gap) in the linker script to store some application code in this section.

Note that the bootloader image size optimization methods introduced in this section applies to RA2 application project as well.
First, update the default linker script to include section `.code_in_gap` between the interrupt vector and the ROM register as shown in Figure 23. In addition, the application code after the ROM register can start at 0x43C instead of 0x500 as used in the default linker script.

Note that there is a section for `.mcuboot_sce9_key` which is not used for RA2 MCUs. We can safely comment this section out.

Next, you can choose some functions to put in the `.code_in_gap` section in order to reduce the flash usage. What functions to put in the `.code_in_gap` section is the user’s choice. This example, the bootloader has chosen some functions to put in the `.code_in_gap` section as explained in this section.

For all four bootloaders introduced in this application project, the following three functions are put in the gap area.

```
#include <hal_entry.c>

void R_BSP_WarmStart(bsp_warm_start_event_t event) BSP_PLACE_IN_SECTION(".code_in_gap*");
void mcuboot_quick_setup() BSP_PLACE_IN_SECTION(".code_in_gap*");

#include \ra\mcu-tools\MCUboot\boot\bootutil\include\bootutil\bootutil.h

fih_int context_boot_go(struct boot_loader_state *state, struct boot_rsp *rsp)
BSP_PLACE_IN_SECTION(".code_in_gap*");
```

Figure 24. Common Functions to Put in the .code_in_gap Section

Figure 25 shows the addition function in `image.h` that is put in the gap area for `ra_mcuboot_ra2e1` in addition to the common functions mentioned in Figure 24.
Figure 25. Functions to Put in the .code_in_gap Section for ra_mcuboot_ra2e1

Figure 26 shows the two additional functions in image.h that are put in the gap area for ra_mcuboot_ra2e1_overwrite_with_signature in addition to the common functions mentioned in Figure 24.

Figure 27 shows the addition function in image.h that is put in the gap area for ra_mcuboot_ra2e1_swap and ra_mcuboot_ra2e1_swap_with_signature in addition to the common functions mentioned in Figure 24.

3.3 Compile the Bootloader Project

Once all the above updates are done, change the compiling optimization to **Optimize size (-Os)** and compile the project.

Figure 28. Optimize Bootloader Size
After the above update, compile the project. Depending on which upgrade mode you have selected, Figure 29–Figure 32 show the compilation results. If you have migrated the projects to a later FSP version, the size may have some minor difference.

Figure 29. Compile the Bootloader ra_mcuboot_ra2e1

```bash
[Compilation output]
```

Figure 30. Compile the Bootloader ra_mcuboot_ra2e1_overwrite_with_signature

```bash
[Compilation output]
```

Figure 31. Compile the Bootloader ra_mcuboot_ra2e1_swap

```bash
[Compilation output]
```

Figure 32. Compile the Bootloader ra_mcuboot_ra2e1_swap_with_signature

```bash
[Compilation output]
```

3.4 Configure the Python Signing Environment

Signing the application image can be done using a post-build step in e² studio using the image signing tool Imgtool.py, which is included with MCUboot. This tool is integrated as a post-build tool in e² studio to sign the application image. If this is NOT the first time you have used the python script signing tool on your computer, you can skip to section 3.5.

If this is the first time you are using the Python script signing tool on your system, you will need to install the dependencies required for the script to work. Navigate to the `<boot_project > \ra\mcutools\MCUboot` folder in the Project Explorer, right click and select Command Prompt. This will open a command window with the path set to the `\mcu-tools\MCUboot` folder.
Figure 33. 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.

### 3.5 Signing Command

The signing command for the application image will be automatically generated when the bootloader is compiled. In the Project Explorer, navigate to the `<boot_project> debug > <boot_project>.bld` file. The signing command is under the section `<image>`. For RA2 MCU groups, the entry immediately after `<image>` is the signing command for the application image.

The application image uses a Build Variable to link with the `.bld` file. This process is explained in detail in the next section. The signing command will be automatically executed when the application image is compiled.

```plaintext
<image>

<image path="${BuildArtifactFileBaseName}.bin.signed">

python

${workspace_loc:ra_mcuboot_ra2e1}/ra/fsp/src/rm_mcuboot_port/rm_mcuboot_port_sign.py

sign --header-size 0x100 --align 8 --max-align 8 --slot-size 0x2000 --max-sectors 4

--overwrite-only --confirm --pad-header ${BuildArtifactFileName}

${BuildArtifactFileBaseName}.bin.signed</image>
```

Figure 34. Signing Command (in bold) in the `.bld` file
3.6 Usage Notes

3.6.1 Migrating the Bootloader to other FSP versions
When migrating the bootloader project to a new FSP version, the updated contents in the \ra folder will be overwritten by the extracted new FSP content. Hence, the functions that are put in the gap area need to be reconfigured.

3.6.2 Migrating from One Upgrade Mode to Another Upgrade Mode
As shown in section 3.2, a different set of functions need to be put in the gap area. The configurations selected in this application can be used as reference.

3.6.3 Use the Memory Usage Window to Select Functions to Put in the Gap Area
After compiling the bootloader project, a user can open the Memory Usage view to select the functions of suitable size to put in the Gap Area.

Open the Memory Usage view from the e² studio top menu Windows tab: Window > Show View > Other > C/C++ > Memory Usage > Symbol.

![Figure 35. Memory Usage View](image)

4. Using the Bootloader with a New Application or Existing Application

Developing an initial application to use a bootloader starts with developing and testing the application and the bootloader independently. Using the bootloader with an existing application or developing a new application to use the bootloader involves below common steps:

- Adjust the memory map of the bootloader to allow the application and bootloader to fit the available MCU memory area.
- Configure the application to use the bootloader.
- Sign the application image.
- Developing an application to use a bootloader typically requires the application to have the capability to download a new application. This aspect is not demonstrated in this application project. Customers typically have customized image download method which differs from one customer to another.

This section uses a simple blinky project to demonstrate how to use the bootloader with the blinky application. After the initial blinky project is established, we need to configure this blinky project to the use the bootloader project generated in the previous section. We also need to sign the blinky project using the signing command generated in the bootloader project. Detailed instructions are provided in this section.

Note: You can also follow section 7 to exercise the example bootloader and application projects without going through the application creation and configuration process to use with the bootloader. This section provides reference for users to understand how to customize for their specific application.

4.1 Generate the Initial Application Project

Follow the steps below to create a blinky application project as the Initial Application Project. The steps in section 4.1 are identical when generating a blinky project whether the application uses a bootloader or not.
Launch e² studio and open a Workspace, click File > New > C/C++ Project and select Renesas RA and Renesas RA C/C++ Project.

1. Assign the project name based on Table 4.

<table>
<thead>
<tr>
<th>Bootloader project name</th>
<th>Initial application project name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ra_mcuboot_ra2e1</td>
<td>blinky</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_overwrite_with_signature</td>
<td>blinky_with_signature</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_swap</td>
<td>blinky_swap</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_swap_with_signature</td>
<td>blinky_swap_with_signature</td>
</tr>
</tbody>
</table>

2. Click Next and choose EK-RA2E1 as the Board from the drop-down menu. Then click Next.
3. In the next screen, select Executable as the Build Artifact and No RTOS for the RTOS Selection. Then click Next.

4. Select the Bare Metal - Blinky as the Project Template for the board and click Finish. The initial application project is now created.

4.2 Configure the Existing Application to Use the Bootloader Project

Note that the steps described in this section can be applied to any other existing application projects to configure the application project to use the bootloader. Care should be taken in consideration of the size the application project. When using the bootloader with a different application project, the Image 1 Flash Area Size property should be adjusted accordingly.

Right-click on the application project folder in the Project Explorer and select Properties. Select the C/C++ Build > Build Variables, click Add and set the Variable name to BootloaderDataFile and check the Apply to all configurations box. Change the Type to File and enter the relative path to the .bld files for the bootloader project <boot_project_name>:

- Set $(workspace_loc:<boot_project_name>/Debug/<boot_project_name>.bld for the value.
- For example, for bootloader project ra_mcuboot_ra2e1 (see Figure 38), it will be: $(workspace_loc:ra_mcuboot_ra2e1)/Debug/ra_mcuboot_ra2e1.bld
4.3 Signing the Application Image

**Note:** If you do rebuild the bootloader project after changing any of the signing and signature Properties of the MCUboot module, you will need to select Generate Project Content again to bring in the updated .bld file.

Each application can have a defined version number. This version number can be used in the overwrite upgrade mode when Downgrade Prevention is Enabled. This is achieved by defining an Environment Variable: MCUBOOT_IMAGE_VERSION.

For applications that support signature verification, meaning for the applications that will work with bootloader `ra_mcuboot_ra2e1_overwrite_with_signature` and `ra_mcuboot_ra2e1_swap_with_signature`, the signing key can be configured using another Environment Variable: MCUBOOT_IMAGE_SIGNING_KEY.

Figure 39 is an example of setting the above two mentioned Environment Variables for the application project used with bootloader `ra_mcuboot_ra2e1_overwrite_with_signature` and `ra_mcuboot_ra2e1_swap_with_signature`.

If there is no signature verification, then it is not necessary to set the Environment Variable: MCUBOOT_IMAGE_SIGNING_KEY as are the cases for `ra_mcuboot_ra2e1` and `ra_mcuboot_ra21_swap`.

---

**Figure 38. Configure the Build Variable to Use the Bootloader**

Click **Apply** and then **Apply and Close**.
In order to be able to always recompile the project when the Environment Variables or the linker script are updated, it is recommended add a **Pre-build** step to always delete the `.elf` file as shown in Figure 40.

Next, a user can add the RTT Viewer usage related application code to the primary application project. Unzip RA2_secure_bootloader.zip, open the RA_secure_bootloader\<boot_project_name>\<Initial application project name > \src folder and copy all files under \src to the \src folder for the newly established project.

At this point, user can click **Generate Project Content** and compile the newly created application project and ensure \debug\< Initial application project name > .bin.signed is generated.

### 5. Booting the Initial Application Project

#### 5.1 Set Up the Hardware

Connect J10 using a USB micro to B cable from EK-RA2E1 to the development PC to provide power and debug connection using the on-board debugger.

#### 5.2 Configure the Debugger

Open the Debug Configurations: blinky > Debug As > Debug Configurations

Optional Step: Disable Flash content Caching from the Debugger setting

Otherwise, The debugging bootloader applications memory window information may show wrong information.
Figure 41. Disable Flash Content Caching

Make sure the `<initial_application_project_name > Debug Flat` is selected and select the Startup tab.
Click Add… and then Workspace and navigate to the `<boot_project_name>` and select the `<boot_project_name>.elf` file from the debug folder. Click OK.

Change the load type of the Program Binaries for the `<initial_application_project_name>` project to Symbols only by clicking on the cell for load type and selecting Symbols only from the drop-down menu.
5.3 Download the Primary Application

At this point, only the bootloader image has been downloaded to flash. Now download the Application Image using the **Load Ancillary File** button. On the top of the e² studio toolbar, click the **Load** icon, then browse to the signed image `\Debug\<initial_application_project_name>.bin.signed` file.

Check the **Load as raw binary image** and set the address based on the Bootloader Flash Area Size and the bootloader project used from Table 3. For example, to use with `ra_mcuboot_ra2e1` bootloader, download the primary image to 0x2000 as shown in Figure 47. Press **OK** to download the image.
5.4 Booting the Primary Application

Click Resume to run the project.

The program should now be paused in main at the `hal_entry()` call in the bootloader.

Click to run again. The Red, Blue, and Green LEDs on the EK-RA2E1 should now be blinking while the blinking application is running.

Press to pause the program. Note that the program counter is in the application image. Click to run again.

Open the JLink RTT Viewer and set up the following configurations.
Click OK and observe the following output on the RTT Viewer. This output shows that the Primary application is being executed and all three LEDs are blinking. The message displayed indicates the upgrade mode and whether the primary or the secondary image is running.

Figure 50. RTT Viewer Output from the Primary Application

6. Mastering and Delivering a New Application

This section provides instructions on how to master and deliver a new application that will be loaded into the Secondary image slot.

Note that the example bootloader, the example Primary application as well the example Secondary applications are provided in the RA2_secure_bootloader.zip. The user can also follow section 7 to exercise these projects without going through the new application creation and mastering process described in this section if desired.

6.1 Create a New Application

The new application can be created by modifying the existing application. Import the initial project to the same workspace and rename the new project.

Right-click in the white space in the Project Explorer area and select Import.

Figure 51. Select Rename and Import the Primary Application

Once the Import window opens, name the project and click Browse for Select root directory as shown in Figure 52.
Name the new project based on Table 5.

Table 5. Project Naming

<table>
<thead>
<tr>
<th>Bootloader Project Name</th>
<th>Initial Application Project Name</th>
<th>New Application Project Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>ra_mcuboot_ra2e1</td>
<td>blinky</td>
<td>blinky_new</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_overwrite_with_signature</td>
<td>blinky_with_signature</td>
<td>Blinky_with_signature_new</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_swap</td>
<td>blinky_swap</td>
<td>Blinky_swap_new</td>
</tr>
<tr>
<td>ra_mcuboot_ra2e1_swap_with_with_signature</td>
<td>blinky_swap_with_signature</td>
<td>Blinky_swap_with_signature_new</td>
</tr>
</tbody>
</table>

Figure 53 is an example screenshot when importing the blinky project as **blinky_new**.
Click Finish, and the new application project will be created. When importing the primary application, the Build Variable and the Environment Variables are automatically imported.

Update Existing Application to a New Application

To demonstrate application update, portions of the code can be updated:

- Update the application to blinky one blue LED only
- Update the RTT Viewer message to show this is the update image

Unzip RA2_secure_bootloader.zip, open the `<boot_project_name>`\<new application project name>`\src folder and copy all files under \src to the newly established project \src folder.

To create a brand new application when using the overwrite and swap upgrade mode without importing the previous application, the user can follow section 4.2 to configure the application to use the bootloader and section 4.3 to sign the application image.

Click Generate Project Content and compile the new project.

6.2 Configure the Swap Test Mode

Prior to introducing the Swap test mode, it helps to introduce the image_ok byte as part of the application image trailer. The image_ok byte resides in the image trailer area. It is a flag byte that is used in swap and direct xip upgrade mode. This byte is used to determine whether the new image will be swapped or not after the next reset following an image update.
When using the Swap update mode, after the new image is loaded to the secondary slot and authenticated successfully, the old image and the new image are swapped. At the next system reset, the system behavior differs based on whether the image_ok byte which resides in the primary slot is 0x01 or 0xFF.

If the image_ok byte is 0x01, after the next reset, there will be no swapping and hence the new image still stays in the primary slot and will be booted. If the image_ok byte is 0xFF, after the next reset, the new image and the old image is again swapped and the old image is booted. This is the rollback feature of swap mode.

Setting the image in the primary slot as Confirmed can be achieved at the new image compile time or runtime. This is explained in section 6.2.1 and 6.2.2.

6.2.1 Confirming the New Application at Compile Time

FSP 3.4 or earlier only supports confirming the new image at compile time. FSP 3.4 or later supports runtime image confirmation of the flat projects.

Confirming the new image (which will be loaded to the primary slot) at compile time requires setting the Custom Signing Options to \texttt{--confirm} as shown in Figure 31. This usage is demonstrated in the example bootloader\texttt{blinky_swap_new}.

6.2.2 Confirming the New Application at Run-time

To confirming the new application at runtime requires the bootloader to use \texttt{--pad} for the Custom signing command as shown in Figure 17. In addition, confirming the new image at runtime requires the \texttt{MCUboot Image Utilities} module to be included in the new application image and configure the system to use several
files from the bootloader project. The example projects demonstrated this feature. This module is included in the example bootloader `blinky_swap_with_signagure_new`.

Open the secondary application project `blinky_swap_with_signature_new`, and navigate to the stack tab, click **New stack > Bootloader > MCBoot Image Utilities**. Then, configure the properties of **MCBoot Image Utilities** module as shown in Figure 57.

![Figure 56. Include the MCBoot Image Utilities Module](image)

Note that with FSP v3.4, absolute paths for the header files are needed.

![Figure 57. Include the Bootloader Header Files](image)

Next configure the `r_flash_lp` module in the same way as in Figure 19.

### 6.3 Downloading and Booting the New Application

Assume the Primary application `blinky` is now up and running and the three LEDs are blinking. Click **Pause** and use the **Ancillary Download** file button to load the compiled Secondary Application `blinky_new_signed.bin`. Select the new application image and set the download address to **0x4000**.
Figure 58. Download the Secondary Application Image

Note that for user-created customized applications, the download address needs to be adjusted by referencing the specific signing command generated in section 6.2.2.

Click Resume to allow the system to perform image overwrite and the new image will be booted. Only the blue LED should be blinking now, which indicates the new image is flashed to the Primary slot of the application area.

On the RTT Viewer, information on the secondary application execution is displayed including the upgrade mode, whether signature authentication is supported as well as what LEDs are blinking. Below is an example when blinky_overwrite_with_signature_new is booted.

```
$> Running the Secondary (New) application with overwrite update mode without signature authentication.
$> Only the blue LED is blinking.
```

Figure 59. RTT Viewer Output from the New Application

7. Appendix: Compile and Exercise the Included Example Bootloader and Application Projects

Unzip RA2_secure_bootloader.zip to access the included bootloader and example application projects.

Figure 60. Example Projects included
7.1 Running the Example Projects with Overwrite Upgrade Mode

7.1.1 Without Signature Verification

Follow the steps below to run the example projects under folder `overwrite_no_signature`.

1. Import projects to a workspace
2. Open the `configuration.xml` file from project `ra_mcuboot_ra2e1`
3. Click Generate Project Content
4. Compile the project `ra_mcuboot_ra2e1`
5. Open the `configuration.xml` file from project `blinky`
6. Click Generate Project Content
7. Compile the blinky project
8. Open the `configuration.xml` file from project `blinky_new`
9. Click Generate Project Content
10. Compile the `blinky_new` project
11. Debug the application from project `blinky`
12. Pause the debugging session
13. Download the `blinky.bin.signed` to address 0x2000
14. Resume the program execution. All LEDs should be blinking
15. Pause the execution
16. Download the `blinky_new.bin.signed` to address 0x4000
17. Resume the program execution. All LEDs should be blinking
18. Update the Environment variable of `blinky_new`: `MCUBOOT_IMAGE_VERSION` from 0.90 to 1.0.0.
19. Recompile project `blinky_new`
20. Pause the debug session
21. Download the `blinky_new.bin.signed` to address 0x4000
22. Resume the program execution. The blue LED should be blinking

7.1.2 With Signature Verification

Follow the steps below to run the example projects under folder `overwrite_with_signature`.

1. Import projects to a workspace
2. Open the `configuration.xml` file from project `ra_mcuboot_ra2e1_overwrite_with_signature`
3. Click Generate Project Content
4. Compile the project `ra_mcuboot_ra2e1_overwrite_with_signature`
5. Open the `configuration.xml` file from project `blinky_with_signature`
6. Click Generate Project Content
7. Compile the `blinky_with_signature` project
8. Open the `configuration.xml` file from project `blinky_with_signature_new`
9. Click Generate Project Content
10. Compile the `blinky_with_signature_new` project
11. Debug the application from project `blinky_with_signature`
12. Pause the debugging session
13. Download `blinky_with_signature.bin.signed` to address 0x3800
14. Resume the program execution. All LEDs should be blinking
15. Pause the execution
16. Download the `blinky_with_signature_new.bin.signed` to address 0x5800
17. Resume the program execution, the blue LED should be blinking
7.2 Running the Example Projects with Swap Upgrade Mode

7.2.1 Without Signature Verification
Follow the steps below to run the example projects under folder \ swap_no_signature.

1. Import projects to a workspace
2. Open the configuration.xml file from project ra_mcuboot_ra2e1_swap
3. Click Generate Project Content
4. Compile the project ra_mcuboot_ra2e1_swap
5. Open the configuration.xml file from project blinky_swap
6. Click Generate Project Content
7. Compile the blinky_swap project
8. Open the configuration.xml file from project blinky_swap_new
9. Open the Properties view of the MCUboot Image Utilities stack, update the path to mcuboot_config.h, mcuboot_logging.h and sysflash.h.
10. Click Generate Project Content
11. Compile the blinky_swap_new project
12. Debug the application from project blinky_swap
13. Pause the debugging session
14. Download the blinky_swap.bin.signed to address 0x3000
15. Resume the program execution. All LEDs should be blinking
16. Pause the execution
17. Download the blinky_swap_new.bin.signed to address 0x5000
18. Resume the program execution. The blue LED should be blinking
19. Reset the program execution from e² studio
20. Run the application. The blue LED should be blinking

7.2.2 With Signature Verification
Follow the steps below to run the example projects under folder \ swap_with_signature.

1. Import projects to a workspace
2. Open the configuration.xml file from project ra_mcuboot_ra2e1_swap_with_signature
3. Click Generate Project Content
4. Compile the project ra_mcuboot_ra2e1_swap_with_signature
5. Open the configuration.xml file from project blinky_swap_with_signature
6. Click Generate Project Content
7. Compile the blinky_swap_with_signature project
8. Open the configuration.xml file from project blinky_swap_with_signature_new
9. Open the Properties view of the MCUboot Image Utilities stack, update the path to mcuboot_config.h, mcuboot_logging.h and sysflash.h.
10. Click Generate Project Content
11. Compile the blinky_swap_with_signature_new project
12. Debug the application from project blinky_swap_with_signature
13. Pause the debugging session
14. Download the blinky_swap_with_signature.bin.signed to address 0x4000
15. Resume the program execution. All LEDs should be blinking
16. Pause the execution
17. Download the blinky_swap_with_signature_new.bin.signed to address 0x6800
18. Resume the program execution. The blue LED should be blinking
19. Reset the program execution from e² studio
20. Run the application. The blue LED should be blinking
8. References

1. *Renesas RA Family MCU Securing Data at Rest using Security MPU Application Project* (R11AN0416)
2. *Using MCUboot with RA Family MCUs Application Project* (R11AN0497)

9. Website and Support

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

- **EK-RA2E1 Resources**: [renesas.com/ra/ek-ra2e1](renesas.com/ra/ek-ra2e1)
- **RA Product Information**: [renesas.com/ra](renesas.com/ra)
- **Flexible Software Package (FSP)**: [renesas.com/ra/fsp](renesas.com/ra/fsp)
- **RA Product Support Forum**: [renesas.com/ra/forum](renesas.com/ra/forum)
- **Renesas Support**: [renesas.com/support](renesas.com/support)
## Revision History

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<th>Rev.</th>
<th>Date</th>
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<th>Summary</th>
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<tr>
<td>1.00</td>
<td>Jul.26.2021</td>
<td>-</td>
<td>First release document</td>
</tr>
<tr>
<td>1.10</td>
<td>Dec.9. 2021</td>
<td>-</td>
<td>Update to add swap mode and signature verification support</td>
</tr>
<tr>
<td>1.11</td>
<td>Feb.4.2022</td>
<td>15</td>
<td>Corrected missing graphic Figure 18</td>
</tr>
</tbody>
</table>
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