ACLE Extensions for ARM®v8-M

Version 1.0

ARM

ARM 100739_0100_0100_en

ACLE Extensions for ARM®v8-M

Release Information

Document History

Issue	Date	Confidentiality	Change
0100	01 September 2016	Non-Confidential	First release

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LES-PRE-20349

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Contents

ACLE Extensions for ARM®v8-M

Preface

This preface introduces the *ACLE Extensions for ARM® v8-M* .

It contains the following:

About this book

The ARM®v8-M C Language Extensions (ACLE) for ARMv8-M enable you to use the ARMv8-M Security Extension to build a Secure image, and to enable a Non-secure image to call a Secure image.

Product revision status

The r*m*p*n* identifier indicates the revision status of the product described in this book, for example, r*1*p*2*, where:

r*m* Identifies the major revision of the product, for example, r1.

p*n* Identifies the minor revision or modification status of the product, for example, p2.

Intended audience

Using this book

This book is organized into the following chapters:

Chapter 1 The ARM® C Language Extensions (ACLE) for ARM®v8-M

The *ARM C Language Extensions* (ACLE) for ARM®v8-M enables the ARMv8-M Security Extension to build a Secure image, and to enable a Non-secure image to call a Secure image. By default, the system starts up in Secure state if the Security Extension is implemented, otherwise the system is always in Non-secure state.

Glossary

The ARM Glossary is a list of terms used in ARM documentation, together with definitions for those terms. The ARM Glossary does not contain terms that are industry standard unless the ARM meaning differs from the generally accepted meaning.

See the *ARM Glossary* for more information.

Typographic conventions

italic
: Introduces special terminology, denotes cross-references, and citations.

bold
: Highlights interface elements, such as menu names. Denotes signal names. Also used for terms in descriptive lists, where appropriate.

`monospace`
: Denotes text that you can enter at the keyboard, such as commands, file and program names, and source code.

`mono`space
: Denotes a permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.

`monospace italic`
: Denotes arguments to monospace text where the argument is to be replaced by a specific value.

`monospace bold`
: Denotes language keywords when used outside example code.

`<and>`
: Encloses replaceable terms for assembler syntax where they appear in code or code fragments. For example:

```
MRC p15, 0, <Rd>, <CRn>, <CRm>, <Opcode_2>
```

SMALL CAPITALS
: Used in body text for a few terms that have specific technical meanings, that are defined in the *ARM glossary*. For example, IMPLEMENTATION DEFINED, IMPLEMENTATION SPECIFIC, UNKNOWN, and UNPREDICTABLE.

Timing diagrams

The following figure explains the components used in timing diagrams. Variations, when they occur, have clear labels. You must not assume any timing information that is not explicit in the diagrams.

Shaded bus and signal areas are undefined, so the bus or signal can assume any value within the shaded area at that time. The actual level is unimportant and does not affect normal operation.

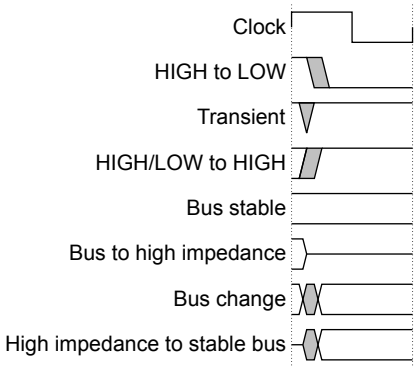

Figure 1 Key to timing diagram conventions

Signals

The signal conventions are:

Signal level

The level of an asserted signal depends on whether the signal is active-HIGH or active-LOW. Asserted means:

- HIGH for active-HIGH signals.
- LOW for active-LOW signals.

Lowercase n

At the start or end of a signal name denotes an active-LOW signal.

Feedback

Feedback on this product

If you have any comments or suggestions about this product, contact your supplier and give:

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- The product revision or version.
- An explanation with as much information as you can provide. Include symptoms and diagnostic procedures if appropriate.

Feedback on content

If you have comments on content then send an e-mail to *errata@arm.com*. Give:

- The title *ACLE Extensions for ARM®v8-M* .
- The number ARM 100739_0100_0100_en.
- If applicable, the page number(s) to which your comments refer.
- A concise explanation of your comments.

ARM also welcomes general suggestions for additions and improvements.

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Chapter 1
The ARM® C Language Extensions (ACLE) for ARM®v8-M

The *ARM C Language Extensions* (ACLE) for ARM®v8-M enables the ARMv8-M Security Extension to build a Secure image, and to enable a Non-secure image to call a Secure image. By default, the system starts up in Secure state if the Security Extension is implemented, otherwise the system is always in Non-secure state.

ARMv8-M architecture with Security Extension implements TrustZone® technology for ARMv8-M. TrustZone technology enables the ARMv8-M processor to be aware of the security states that are available. In the ARMv8-M architecture with Security Extension implementation, TrustZone technology has been optimized for microcontrollers and low-power SoC applications.

It contains the following sections:

1.1 Building Secure and Non-secure images

ACLE provides tools that allow you to build images which run in the Secure state of the ARMv8-M Security Extension. You can also create an import library package that developers of Non-secure images must have for calling the Secure image, for example using `armclang`.

To build an image that runs in the Secure state you must include the `<arm_cmse.h>` header file in your code, and compile using the `-mcmse armclang` command-line option. Doing this makes the following available:

- The Test Target, `TT`, instruction.
- `TT` instruction intrinsics.
- Non-secure function pointer intrinsics.
- The `__attribute__((cmse_nonsecure_call))` and `__attribute__((cmse_nonsecure_entry))` function attributes.

On startup, your Secure code must set up the *Secure Attribution Unit* (SAU) and call the Non-secure startup code.

1.2 Calling a Secure image from a Non-secure image using veneers

Calling a Secure image from a Non-secure image requires a transition from Non-secure to Secure state. A transition is initiated through Secure gateway veneers. Secure gateway veneers decouple the addresses from the rest of the Secure code.

An entry point in the Secure image, `<entryname>`, is identified with:

```
__acle_se_<entryname>:
<entryname>:
```

The calling sequence is as follows:

1. The Non-secure image uses the branch `BL` instruction to call the Secure gateway veneer for the target entry function in the Secure image:

   ```
   bl    <entryname>
   ```

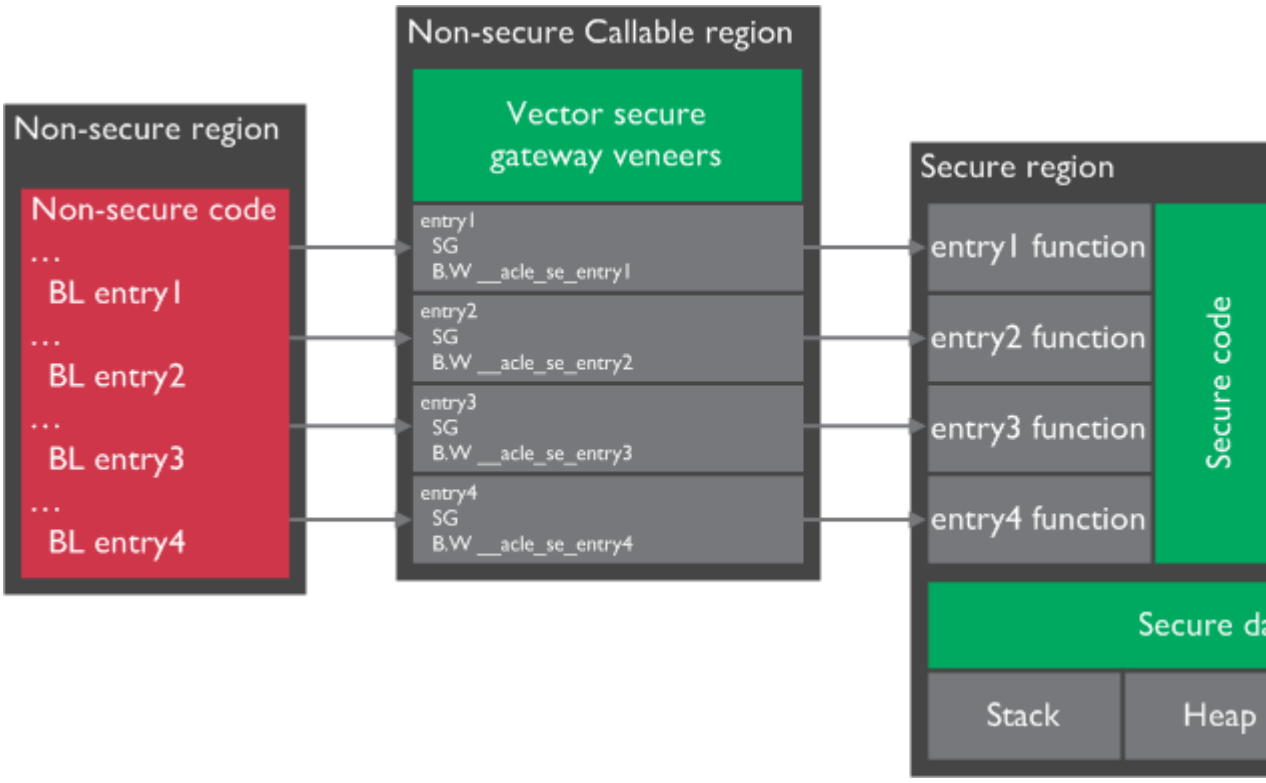
2. The Secure gateway veneer consists of the SG instruction and a call to the entry function in the Secure image using the B instruction:

   ```
   <entryname>
       SG
       B.W         __acle_se_<entryname>
   ```

3. The Secure image returns from the entry function using the BXNS instruction:

   ```
   bxns  lr
   ```

The following figure shows the calling sequence for a Non-secure image. For clarity, the return from the entry function is not shown:



1.3 Import library package

An import library package identifies the entry functions available in a Secure image.

The import library package contains:

- An interface header file, for example `myinterface_v1.h`. You manually create this file using any text editor.
- An import library, for example `importlib.o`. `armlink` generates this library during the link stage for a Secure image.

Note

- You must have separate compile and link stages to create an import library when building a Secure image. You must have separate compile and link stages to use an import library when building a Non-secure image.
- You must have separate projects for secure library and non-secure applications.

1.4 Building a Secure image using the ARM®v8-M Security Extension

When building a Secure image, you must also generate an import library that specifies the entry points to the Secure image. The import library is used when building a Non-secure image that calls the Secure image.

The following procedure is not a complete example. It assumes that your code sets up the *Security Attribution Unit* (SAU) and calls the Non-secure startup code.

Procedure

1. Create an interface header file, `myinterface_v1.h`, to be used by Non-secure code:

```
int entry1(int x);
int entry2(int x);
```

2. In the C program for your Secure code, `secure.c`, include the following:

```
#include <arm_cmse.h>
#include "myinterface_v1.h"

int func1(int x) { return x; }
int __attribute__((cmse_nonsecure_entry)) entry1(int x) { return func1(x) ; }
int __attribute__((cmse_nonsecure_entry)) entry2(int x) { return entry1(x); }

int main(void) { return 0; }
```

   In addition to the implementation of the two entry functions, the code defines the function `func1()` that can only be called by Secure code.

3. Create an object file using the `armclang -mcmse -mfpu=none` command-line options:

```
$ armclang -c --target arm-arm-none-eabi -march=armv8-m.main -mcmse -mfpu=none secure.c -
o secure.o
```

4. To see the disassembly of the machine code that is generated by `armclang`, enter:

```
$ armclang -c --target arm-arm-none-eabi -march=armv8-m.main -mcmse -mfpu=none -S secure.c
```

   The disassembly is stored in the file `secure.s`, for example:

```
        .text
        ...
        .code 16
        .thumb_func
        ...
    func1:
        .fnstart
        ...
        bx lr
        ...
    __acle_se_entry1:
    entry1:
        .fnstart
    @ BB#0:
        .save    {r7, lr}
        push    {r7, lr}
        ...
        bl func1
        ...
        pop.w {r7, lr}
        ...
        bxns lr
        ...
    __acle_se_entry2:
    entry2:
        .fnstart
    @ BB#0:
        .save    {r7, lr}
        push    {r7, lr}
        ...
        bl entry1
        ...
        pop.w {r7, lr}
        bxns lr
        ...
    main:
        .fnstart
```

```
    @ BB#0:
        ...
        movs r0, #0
        ...
        bx lr
        ...
```

The two symbols `__acle_se_entry_name` and `entry_name` indicate the start of an entry function to the linker. An entry function does not start with a Secure Gateway (SG) instruction.

5. You can control the placement of the section with the veneers using a scatter file and place it in your *Non-secure Callable* (`NSC`) region memory region. Create a scatter file containing the `Veneer$$CMSE` selector to place the entry function veneers, for example:

```
LOAD_REGION 0x0 0x3000
{
    EXEC_R 0x0
    {
        *(+RO,+RW,+ZI)
    }
    EXEC_NSCR 0x4000 0x1000
    {
        *(Veneer$$CMSE)
    }
    ARM_LIB_STACK 0x700000 EMPTY -0x10000
    {
    }
    ARM_LIB_HEAP  +0 EMPTY 0x10000
    {
    }
}
...
```

6. Using `armclang` you can link the object file using the `armlink --fpu softvfp` and `--import-cmse-lib-out` command-line options and the scatter file to create the Secure image:

```
$ armlink secure.o -o secure.axf --cpu 8-M.Main --fpu SoftVFP --import-cmse-lib-out
importlib_v1.o --scatter secure.scf
```

In addition to the final image, the link in this example also produces the import library, `importlib_v1.o`, for use when building a Non-secure image. Assuming that the section with veneers is placed at address `0x4000`, the import library consists of a relocatable file containing only a symbol table with the following entries:

Symbol type	Name	Address
STB_GLOBAL, SHN_ABS, STT_FUNC	entry1	`0x4001`
STB_GLOBAL, SHN_ABS, STT_FUNC	entry2	`0x4009`

Note

If you have an import library from a previous build of the Secure image, you can ensure that the addresses in the output import library do not change when producing a new version of the Secure image. To do this, specify the `--import-cmse-lib-in` command-line option together with the `--import-cmse-lib-out` option. However, make sure that the input and output libraries have different names.

7. When you link the relocatable file corresponding to this assembly code into an image, the linker creates veneers in a section containing only entry veneers. To see the entry veneers generated by the linker, enter:

```
$ fromelf --text -s -c secure.axf
```

The following entry veneers are generated in the EXEC_NSCR execute-only (XO) region for this example:

```
...

** Section #3 'EXEC_NSCR' (SHT_PROGBITS) [SHF_ALLOC + SHF_EXECINSTR + SHF_ARM_NOREAD]
    Size   : 32 bytes (alignment 32)
```

```
    Address: 0x00004000

    $t
    entry1
        0x00004000:    e97fe97f    ....    SG        ; [0x3e08]
        0x00004004:    f7fcb85e    ..^.    B         __acle_se_entry1 ; 0xc4
    entry2
        0x00004008:    e97fe97f    ....    SG        ; [0x3e10]
        0x0000400c:    f7fcb86c    ..l.    B         __acle_se_entry2 ; 0xe8

...
```

The section with the veneers is aligned on a 32-byte boundary and padded to a 32-byte boundary.

If you do not use a scatter file, the entry veneers are placed in an ER_XO section as the first execution region, for example:

```
...

** Section #1 'ER_XO' (SHT_PROGBITS) [SHF_ALLOC + SHF_EXECINSTR + SHF_ARM_NOREAD]
    Size   : 32 bytes (alignment 32)
    Address: 0x00008000

    $t
    entry1
        0x00008000:    e97fe97f    ....    SG        ; [0x7e08]
        0x00008004:    f000b85a    ..Z.    B.W       __acle_se_entry1 ; 0x80bc
    entry2
        0x00008008:    e97fe97f    ....    SG        ; [0x7e10]
        0x0000800c:    f000b868    ..h.    B.W       __acle_se_entry2 ; 0x80e0

...
```

Postrequisites

After you have built your Secure image:

1. Preload the Secure image onto your device.
2. Deliver your device with the preloaded image, together with the import library package, to a party who develops the Non-secure code for this device. The import library package contains:

- The interface header file, `myinterface_v1.h`
- The import library `importlib_v1.o`.

1.5 Building a Non-secure image that can call a Secure image

If you are building a Non-secure image that is to call a Secure image, you must obtain the import library package that was created for that Secure image.

The following procedure assumes that you have the import library package created using the ARMv8-M Security Extension. The import library package identifies the entry points for the Secure image.

Procedure

1. In the C program for your Non-secure code, `nonsecure.c`, include the interface header file and use the entry functions as required, for example:

```
#include <stdio.h>
#include "myinterface_v1.h"

int main(void) {
    int val1, val2, x;

    val1 = entry1(x);
    val2 = entry2(x);

    if (val1 == val2) {
        printf("val2 is equal to val1\n");
    } else {
        printf("val2 is different from val1\n");
    }

    return 0;
}
```

2. Create an object file, `nonsecure.o`:

```
$ armclang -c --target arm-arm-none-eabi -march=armv8-m.main nonsecure.c -o nonsecure.o
```

3. Create a scatter file for the Non-secure image, but without the *Non-secure Callable* (NSC) memory region, for example:

```
LOAD_REGION 0x8000 0x3000
{
    ER 0x8000
    {
        *(+RO,+RW,+ZI)
    }
    ARM_LIB_STACK 0x800000 EMPTY -0x10000
    {
    }
    ARM_LIB_HEAP  +0 EMPTY 0x10000
    {
    }
}
```

4. Link the object file using the import library, `importlib_v1.o`, and the scatter file to create the Non-secure image:

```
$ armlink nonsecure.o importlib_v1.o -o nonsecure.axf --cpu=8-M.Main --scatter
nonsecure.scf
```

1.6 Building a Secure image using a previously generated import library

You can build a new version of a Secure image and use the same addresses for the entry points that were present in the previous version. You specify the import library that is generated for the previous version of the Secure image and generate another import library for the new Secure image.

The following procedure is not a complete example, and assumes that your code sets up the *Secure Attribution Unit* (SAU) and calls the Non-secure startup code. It assumes you have the import library package created using the ARMv8-M Security Extension. The import library package identifies the entry points for the Secure image.

Procedure

1. Create an interface header file, `myinterface_v2.h`, to be used by Non-secure code:

```
int entry1(int x);
int entry2(int x);
int entry3(int x);
int entry4(int x);
```

2. In the C program for your Secure code, `secure.c`, include the following:

```
#include <arm_cmse.h>
#include "myinterface_v2.h"

int func1(int x) { return x; }
int __attribute__((cmse_nonsecure_entry)) entry1(int x) { return func1(x) ; }
int __attribute__((cmse_nonsecure_entry)) entry2(int x) { return entry1(x); }
int __attribute__((cmse_nonsecure_entry)) entry3(int x) { return func1(x) + entry1(x) ; }
int __attribute__((cmse_nonsecure_entry)) entry4(int x) { return entry1(x) * entry2(x); }

int main(void) { return 0; }
```

3. Create an object file using the `armclang -mcmse -mfpu=none` command-line options:

```
$ armclang -c --target arm-arm-none-eabi -march=armv8-m.main -mcmse -mfpu=none secure.c -
o secure.o
```

4. To see the disassembly of the machine code that is generated by armclang, enter:

```
$ armclang -c --target arm-arm-none-eabi -march=armv8-m.main -mcmse -mfpu=none -S secure.c
```

The disassembly is stored in the file `secure.s`, for example:

```
    .text
        ...
    code 16
    thumb_func

        ...

func1:
    fnstart
    ...
    bx lr

        ...

    __acle_se_entry1:
    entry1:
        fnstart
    @ BB#0:
        save    {r7, lr}
        push    {r7, lr}
        ...
        bl func1
        pop.w {r7, lr}
        ...
        bxns lr

        ...

    __acle_se_entry4:
    entry4:
        fnstart
    @ BB#0:
        save    {r7, lr}
```

```
        push    {r7, lr}
        ...
        bl entry1
        ...
        pop.w {r7, lr}
        bxns lr

        ...

    main:
        fnstart
    @ BB#0:
        ...
        movs r0, #0
        ...
        bx lr

        ...
```

An entry function does not start with a *Secure Gateway* (SG) instruction. The two symbols `__acle_se_entry_name` and `entry_name` indicate the start of an entry function to the linker.

5. You can control the placement of the section with the veneers using a scatter file and place it in your NSC memory region. Create a scatter file containing the `Veneer$$CMSE` selector to place the entry function veneers, for example:

```
LOAD_REGION 0x0 0x3000
{
    EXEC_R 0x0
    {
        *(+RO,+RW,+ZI)
    }
    EXEC_NSCR 0x4000 0x1000
    {
        *(Veneer$$CMSE)
    }
    ARM_LIB_STACK 0x700000 EMPTY -0x10000
    {
    }
    ARM_LIB_HEAP  +0 EMPTY 0x10000
    {
    }
}
...
```

6. Using armclang, link the object file using the `armlink --fpu softvfp`, `--import-cmse-lib-out`, and `--import-cmse-lib-in` command-line options, and the preprocessed scatter file to create the Secure image:

```
$ armlink secure.o -o secure.axf --cpu 8-M.Main --fpu SoftVFP --import-cmse-lib-out
importlib_v2.o --import-cmse-lib-in importlib_v1.o --scatter secure.scf
```

In addition to the final image, the link in this example also produces the import library, `importlib_v2.o`, for use when building a Non-secure image. Assuming that the section with veneers is at address `0x4000`, the import library consists of a relocatable file containing only a symbol table with the following entries:

Symbol type	Name	Address
STB_GLOBAL, SHN_ABS, STT_FUNC	entry1	0x4001
STB_GLOBAL, SHN_ABS, STT_FUNC	entry2	0x4009
STB_GLOBAL, SHN_ABS, STT_FUNC	entry3	0x4021
STB_GLOBAL, SHN_ABS, STT_FUNC	entry4	0x4029

7. When you link the relocatable file corresponding to this assembly code into an image, the linker creates veneers in a section containing only entry veneers. To see the entry veneers generated by the linker, enter:

```
$ fromelf --text -s -c secure.axf
```

The following entry veneers are generated in the EXEC_NSCR execute-only (XO) region for this example:

```
...

    ** Section #3 'EXEC_NSCR' (SHT_PROGBITS) [SHF_ALLOC + SHF_EXECINSTR + SHF_ARM_NOREAD]
        Size   : 64 bytes (alignment 32)
        Address: 0x00004000

        $t
        entry1
            0x00004000:    e97fe97f    ....    SG        ; [0x3e08]
            0x00004004:    f7fcb85e    ..^.    B         __acle_se_entry1 ; 0xc4
        entry2
            0x00004008:    e97fe97f    ....    SG        ; [0x3e10]
            0x0000400c:    f7fcb86c    ..l.    B         __acle_se_entry2 ; 0xe8

    ...

        entry3
            0x00004020:    e97fe97f    ....    SG        ; [0x3e28]
            0x00004024:    f7fcb872    ..r.    B         __acle_se_entry3 ; 0x10c
        entry4
            0x00004028:    e97fe97f    ....    SG        ; [0x3e30]
            0x0000402c:    f7fcb888    ....    B         __acle_se_entry4 ; 0x140

    ...
```

The section with the veneers is aligned on a 32-byte boundary and padded to a 32-byte boundary.

If you do not use a scatter file, the entry veneers are placed in an ER_XO section as the first execution region. The entry veneers for the existing entry points are placed in a CMSE veneer section. For example:

```
...

** Section #1 'ER_XO' (SHT_PROGBITS) [SHF_ALLOC + SHF_EXECINSTR + SHF_ARM_NOREAD]
    Size   : 32 bytes (alignment 32)
    Address: 0x00008000

    $t
    entry3
        0x00008000:    e97fe97f    ....    SG        ; [0x7e08]
        0x00008004:    f000b87e    ..~.    B.W       __acle_se_entry3 ; 0x8104
    entry4
       0x00008008:    e97fe97f    ....    SG        ; [0x7e10]
       0x0000800c:    f000b894    ....    B.W       __acle_se_entry4 ; 0x8138

    ...

** Section #4 'ER$$Veneer$$CMSE_AT_0x00004000' (SHT_PROGBITS) [SHF_ALLOC + SHF_EXECINSTR
+ SHF_ARM_NOREAD]
    Size   : 32 bytes (alignment 32)
    Address: 0x00004000

    $t
    entry1
        0x00004000:    e97fe97f    ....    SG        ; [0x3e08]
        0x00004004:    f004b85a    ..Z.    B.W       __acle_se_entry1 ; 0x80bc
    entry2
        0x00004008:    e97fe97f    ....    SG        ; [0x3e10]
        0x0000400c:    f004b868    ..h.    B.W       __acle_se_entry2 ; 0x80e0

...
```

Postrequisites

After you have built your updated Secure image:

1. Pre-load the updated Secure image onto your device.
2. Deliver your device with the pre-loaded image, together with the new import library package, to a party who develops the Non-secure code for this device. The import library package contains:
   - The interface header file, `myinterface_v2.h`.
   - The import library, `importlib_v2.o`.