AN0040
Application Note

AT32F403A/407 Security Library Application Note

Introduction

This application note mainly introduces the security library (sLib) application principle of AT32F403A/407 MCUs, operation methods and example projects.

Applicable products:

Part number	AT32F403A
	AT32F407

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1 Overview

As more and more MCU applications require complex algorithms and middleware solutions, it has become an important issue that how to protect IP-Codes (such as core algorithms) developed by software solution providers.

The AT32F403A/407 series MCUs are designed with a security library (sLib) to protect important IP-Codes against being changed or read by the end user's program.

This application note details the sLib application principle and operation methods of AT32F403A/407 MCUs.

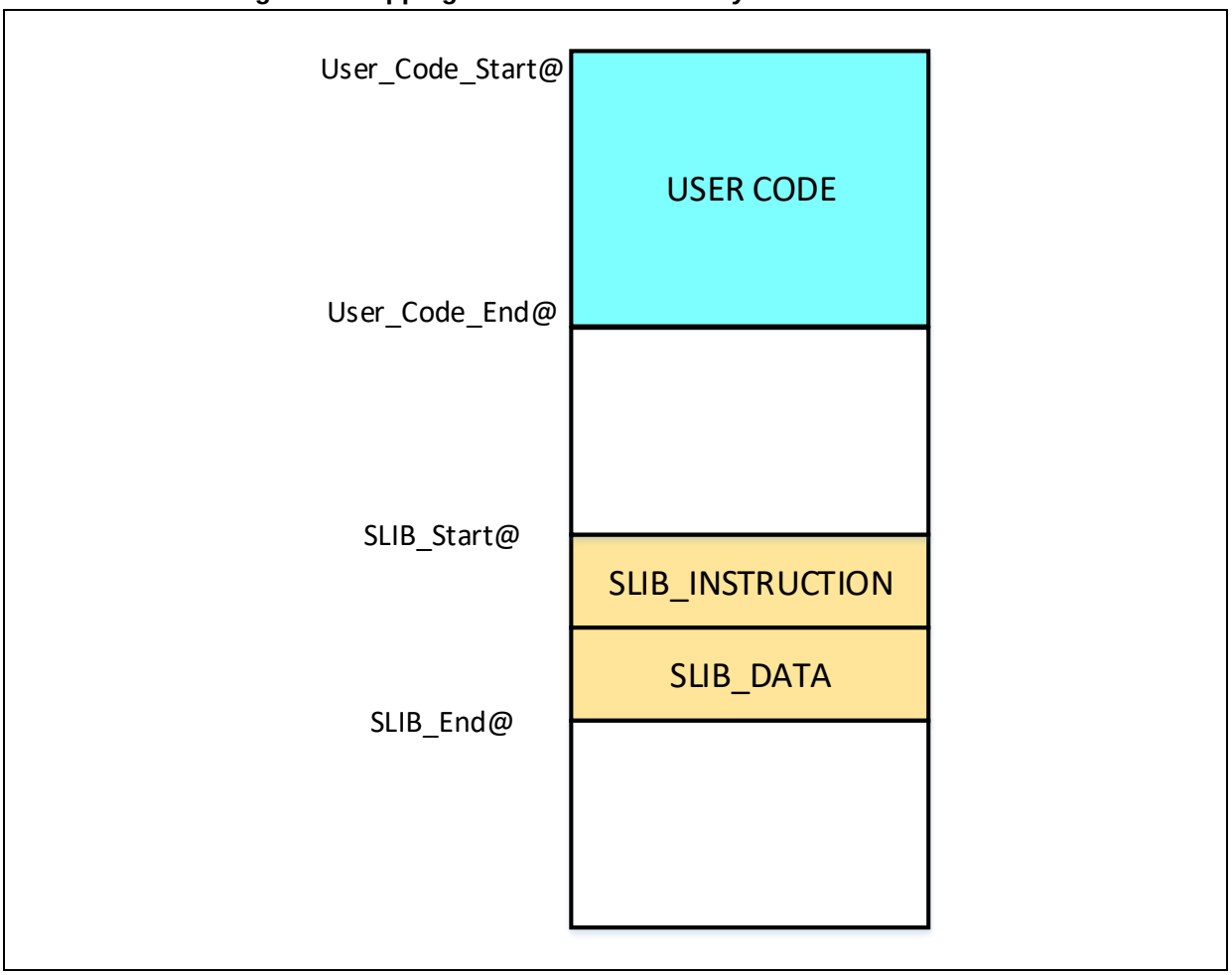
2 Application principles

2.1 Application principle of sLib

- Security library is a defined area protected by a code in the main memory, so that solution providers can program core algorithm into this area, and the rest of the area can be used for secondary development by end customers.
- Security library includes instruction security library (SLIB_INSTRUCTION) and data security library (SLIB_DATA), users can select part of or the whole security library for instruction storage, but using the whole security library for storing data is not supported.
- Program codes in the instruction security library (SLIB_INSTRUCTION) can only be fetched (can only be executed) by MCU through I-Code bus and cannot be read through D-Code (including ISP/ICP debug mode and programs that boot from internal RAM). When accessing the SLIB_INSTRUCTION in the manner of reading data, values are all read 0xFF.
- Data in the data security library (SLIB_DATA) can only be read through D-Code bus and cannot be programmed.
- The program code and data in security library cannot be erased unless the correct code is keyed in. If a wrong code is keyed in, in an attempt of writing or erasing the security library, a warning message will be issued by EPPERR=1 in the FLASH_STS register.
- The program code and data in security library are not erased when the end users perform a mass erase on the main Flash memory.
- Users can write the previously defined password in the SLIB_PWD_CLR register to disable security library protection. When the security library protection is disabled, the chip will perform a mass erase on the main Flash memory (including the contents of security library). Therefore, even if the code defined by the software solution provider is leaked, the program code will not be leaked.

The mapping of main Flash memory featured with sLib is shown in Figure 1. The program codes in security library can be easily called and executed by end users, but cannot be read directly.

Figure 1. Mapping of main Flash memory featured with sLib



The range of sLib is set by sector, and the size of each sector is subject to the specific MCUs. Table 1 lists the main Flash size, sector size and configurable range of AT32F403A/407 series MCUs.

Table 1. Flash size of AT32F403A/407

Part number	Internal Flash size(Byte)	Sector size (Byte)	Configurable range
AT32F403AxC AT32F407xC	256K	2K	Sector 2 ~ 63 (0x08001000 ~ 0x0801FFFF)
AT32F403AxE AT32F407xE	512K	2K	Sector 2 ~ 63 (0x08001000 ~ 0x0801FFFF)
AT32F403AxG AT32F407xG	1024K	2K	Sector 2 ~ 63 (0x08001000 ~ 0x0801FFFF)

2.2 How to enable sLib protection

By default, security library setting register is unreadable and write protected. To enable write access to this register, security library should be unlocked first. Write 0xA35F6D24 to the SLIB_UNLOCK register, and check the SLIB_ULKF bit in the SLIB_MISC_STS register to verify if it is unlocked successfully. Then, set values can be written into the security library setting register.

The steps to enable security library are as follows:

- Check the OBF bit in the FLASH_STS register to confirm that there is no other ongoing programming operation;
- Write 0xA35F6D24 to the SLIB_UNLOCK register to unlock security library;
- Check the SLIB_ULKF bit in the SLIB_MISC_STS register to verify that it is unlocked successfully;
- Set the sectors to be protected in the SLIB_SET_RANGE register, including the address of instruction and data areas;
- Wait until the OBF bit becomes “0”;
- Set a security library password in the SLIB_SET_PWD register;
- Wait until the OBF bit becomes “0”;
- Program the code to be saved in security library;
- Perform system reset, and then reload security library setting word;
- Read the SLIB_STS0/STS1 register to verify the security library settings.

Notes:

- It is allowed to set security library in the main Flash memory only, and refer to Table 1 for the configurable range;
- The security library code must be programmed by sectors, with its start address aligned with the main memory address;
- The interrupt vector table is in data type and usually placed in the first sector (sector0) of the main Flash memory, which should not be configured as security library;
- Codes to be protected by the security library should not be placed in the first 4 KB of main Flash memory.

For details of security library setting register, please refer to *AT32F403A/407 Series Reference Manual*.

The program to start security library can be found in the slib_enable() function in main.c file of project_l0. In addition, users can use Artery ICP/ISP tools for configuration.

2.3 How to disable sLib protection

The security library protection can be disabled by writing the previously defined password to the SLIB_PWD_CLR register. While disabling security library protection, MCU will perform mass erase operation to the main Flash memory (including the contents of security library).

The steps to disable main Flash security library are as follows:

- Check the OBF bit in the FLASH_STS register to ensure that there is no other ongoing programming operation;
- Write the previously defined password to the SLIB_PWD_CLR register;
- Perform system reset, and then reload security library setting word;
- Read the SLIB_STS0 register to check the security library settings.

2.4 Compile and execute program in sLib

As aforementioned, program codes in the instruction security library (SLIB_INSTRUCTION) can be fetched by MCU via I-Code bus but cannot be read via D-Code bus in the manner of reading data, which means that program codes in SLIB_INSTRUCTION cannot read the data saved in the same SLIB_INSTRUCTION. For example, literal pool, branch table or constant compiled from C program code in the SLIB_INSTRUCTION cannot be read via D-Code bus.

Only instructions rather than data can be placed in the instruction security library. Therefore, when compiling program codes to be placed in the instruction security library, the user must configure the compiler to generate execute-only codes to avoid generating the above mentioned data.

Figure 2 and Figure 3 show the examples of literal pool and branch table.

The “switch()” is a jump instruction in C program, and the “sclk_source” variable is used to read the CRM_CFG register. As shown in Figure 2, the compiled assembly code “LDR R7, [PC, #288]” obtains the address of CRM_CFG register in a PC (program counter) indirect addressing manner, and the address of CRM_CFG register is saved as a constant in the adjacent instruction area (within the instruction security library); therefore, the data is read when the switch() instruction is executed. An error will occur during execution if there is such program code in the instruction security library.

The example program in Section 3 introduces how to configure compiler settings to avoid error.

Figure 2. Literal pool example (1)

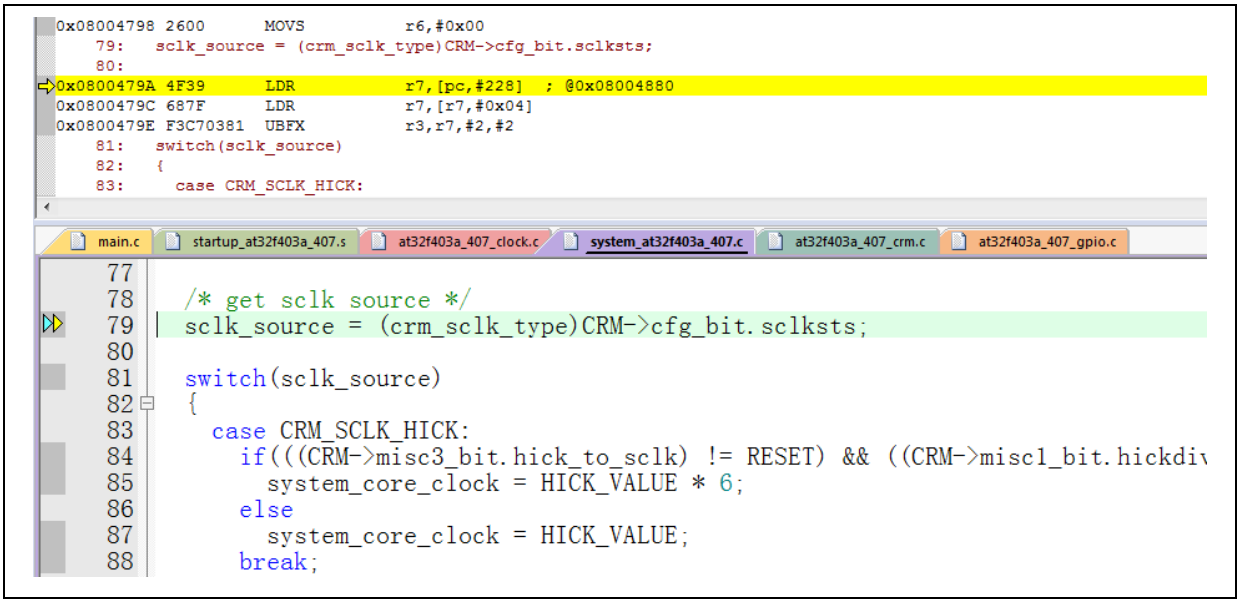
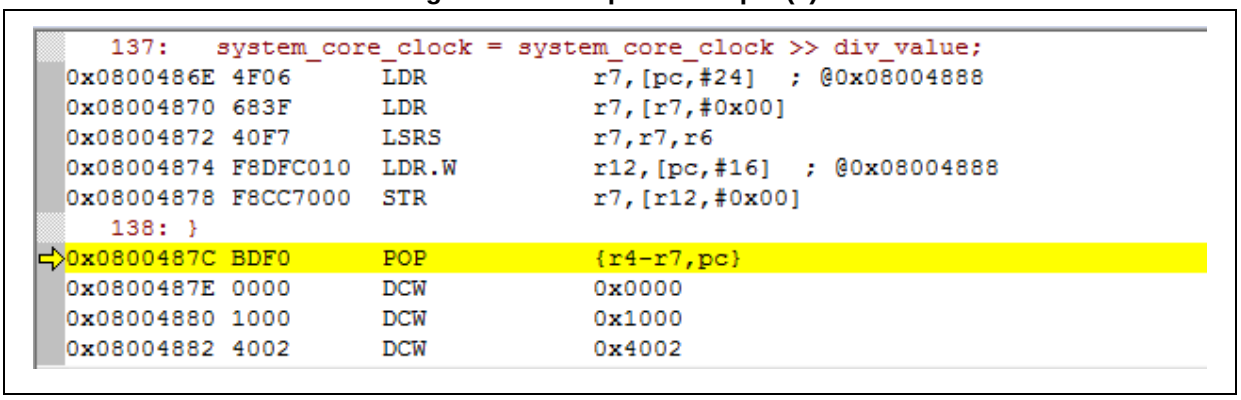


Figure 3. Literal pool example (2)



2.4.1 Setting interrupt vector table as security library not allowed

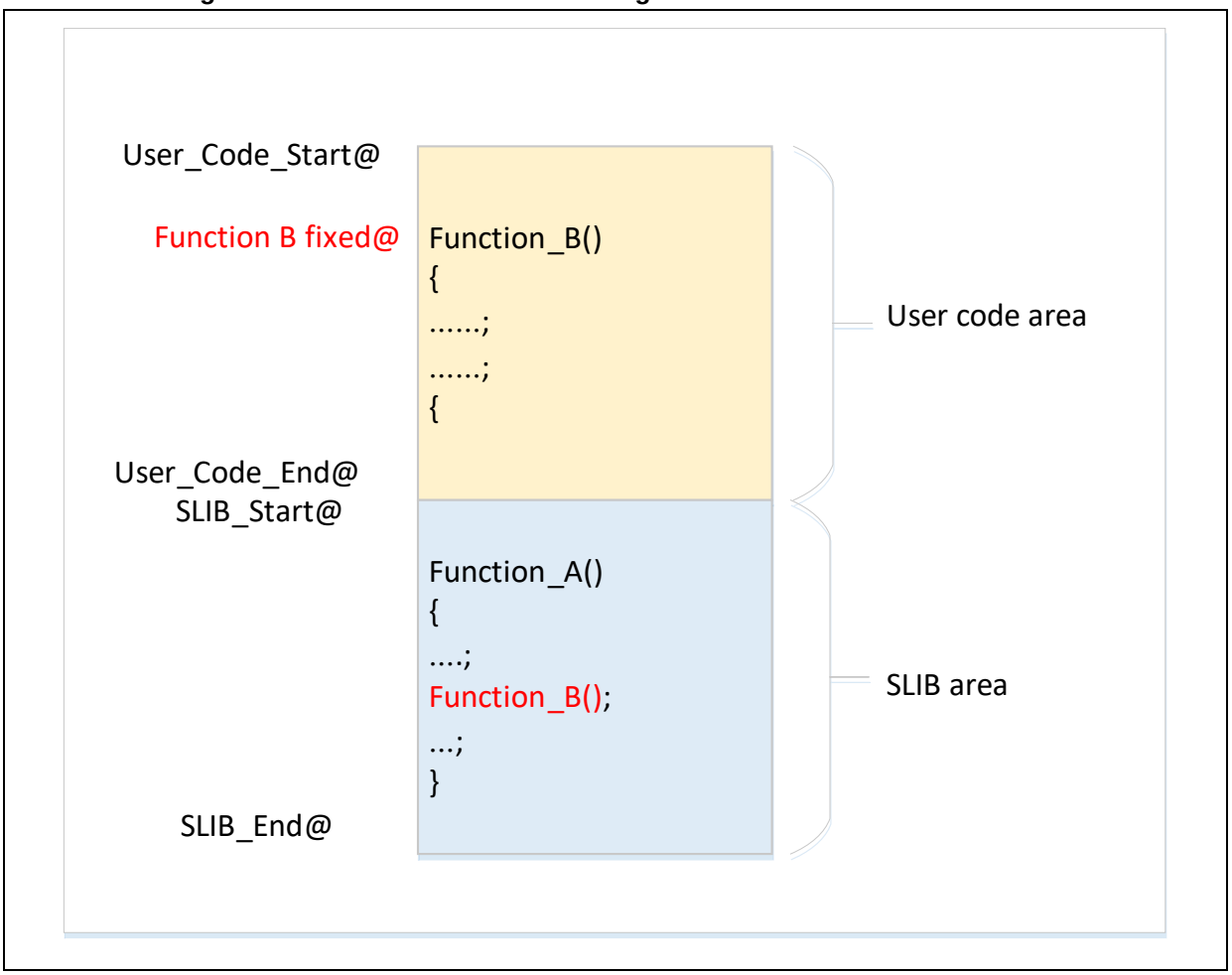
The interrupt vector table contains entry point address of each interrupt handler, which is read by MCU via D-Code bus. Generally, the interrupt vector table is located in the first sector (sector0, starting address: 0x08000000). Therefore, the following rules must be followed when setting the instruction security library:

- Do not configure the first sector of the main Flash as security library;
- Program codes to be protected by security library should not be placed in the first sector.

2.4.2 Correlation between sLib area and user code area

Program code (IP-code) protected by sLib area can call functions from the function library located in user code area (outside the sLib area). In this case, these function addresses are contained in the IP-Code, allowing PC (program counter) to jump to these functions when IP-Code is executed. Once the sLib area is enabled, function address cannot be changed. At this point, addresses of functions in the user code area must be fixed; otherwise, PC will jump to a wrong address and not work properly. Therefore, when configuring the sLib area, all functions related to IP-Code should be compiled into the sLib area. Figure 4 gives an example of the protected Function_A() being called to Function_B() in the user code area.

Figure 4. Function in sLib area calling the function in user code area



In addition, the standard function library of C programming language is commonly used, such as memset() and memcpy() functions. If both IP-Code and user area code call such functions, the above mentioned error may occur. The two solutions are recommended:

1) Compile into the sLib area (refer to Keil or IAR documents for details about implementation).
2) Do not use the standard function library of C programming language in IP-Code. If it is necessary to use in IP-Code, functions to be used must be renamed. Figure 5 shows an example of writing the my_memset() function to replace the original memset() in IP-Code.

Figure 5. Example of user-defined function

```
void* my_memset(void *s, int c, size_t n);

void arm_fir_init_f32(
  arm_fir_instance_f32 * S,
  uint16_t numTaps,
  float32_t * pCoeffs,
  float32_t * pState,
  uint32_t blockSize)
{
  /* Assign filter taps */
  S->numTaps = numTaps;

  /* Assign coefficient pointer */
  S->pCoeffs = pCoeffs;

  /* Clear state buffer and the size of state buffer is (blockSize + numTaps - 1) */
  my_memset(pState, 0, (numTaps + (blockSize - 1u)) * sizeof(float32_t));

  /* Assign state pointer */
  S->pState = pState;

}


void* my_memset(void *s, int c, size_t n)
{
  while (n>0)
      *( (char*)s + n-- -1 ) = (char)c;

  return (s);
}
```

3 Example applications of sLib

This section introduces example applications of sLib and how to complete these applications step by step.

The AT32F407 and AT32F403A series MCUs have the same SLIB feature. In this application note, the AT32F403A series is used for demonstration.

3.1 Example application requirements

3.1.1 Hardware requirements

- AT-START-F403A demo board with AT32F403AVGT7 chip
- AT-Link emulator for debugging example applications

3.1.2 Software requirements

- Keil® µvision IDE (µvision V5.18.0.0 is used in this example) or IAR Embedded workbench IDE (IAR V8.22.2 is used in this example)
- Artery ICP/ISP programming tools for enabling or disabling sLib

3.2 Overview

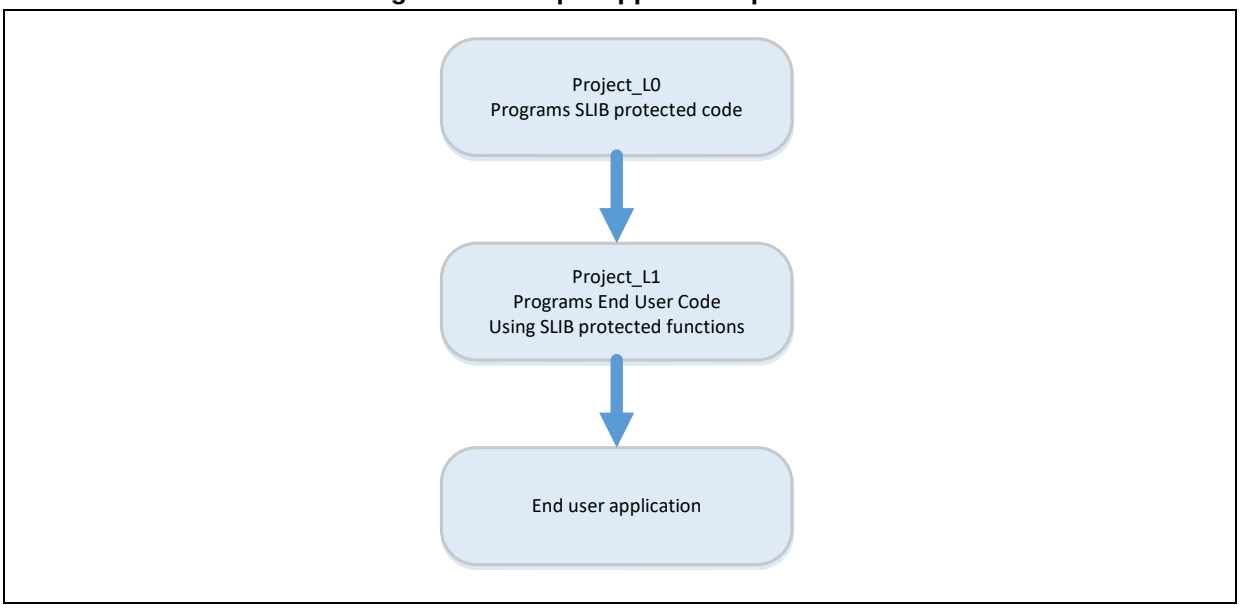
This application note provides two example projects to demonstrate that software developers develop IP-Code for end-user applications.

- Project_L0: Solution provider develops algorithm and compiles to sLib
- Project_L1: Apply algorithm for end users

The algorithm completed in Project_L0 will be pre-downloaded and pre-burned to AT32F403A chip and configured as sLib protected. In addition, the following settings are available for the end-user applications.

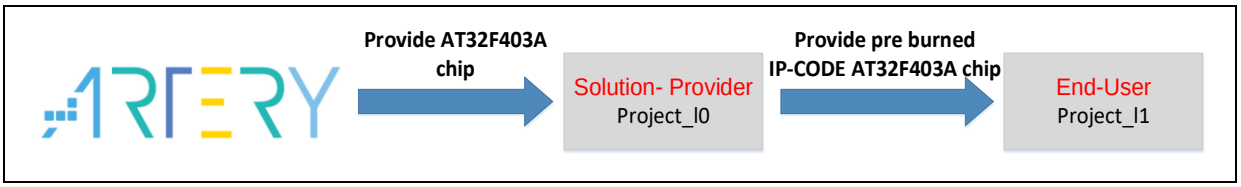
- Main Flash memory mapping, showing the area occupied by sLib and the area where users can develop programs
- Header file that contains algorithm function definitions, allowing end users to call relevant functions;
- Symbol definition file, which contains the actual address of each IP-Code function, so that functions can be called properly by the end-user application.

Figure 6. Example application process



Software solution providers can refer to the Project_L0 to develop algorithm code and refer to Project_L1 for end-user application.

Figure 7. Example application

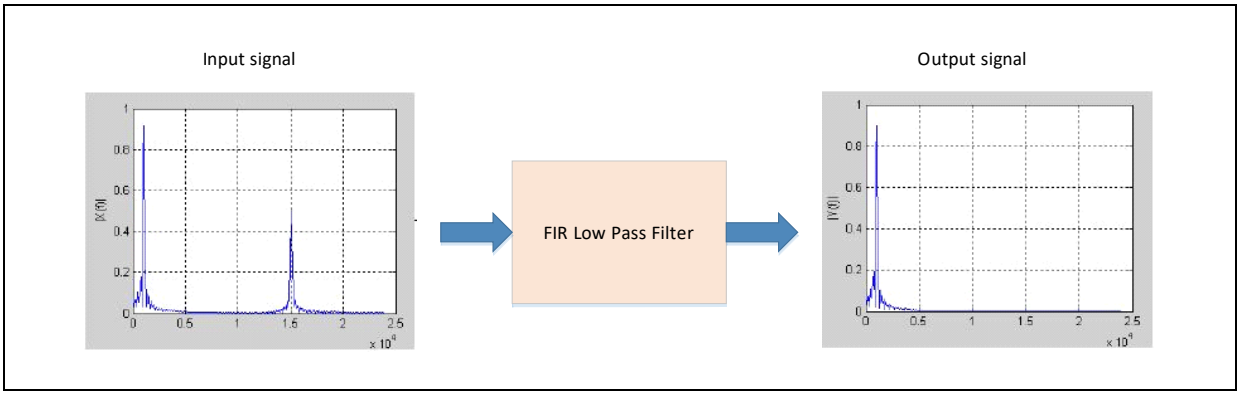


3.3 SLIB protected code: FIR low-pass filter

This example uses FIR low-pass filter algorithm provided by CMSIS-DSP library as the sLib protected IP-Code. For details about FIR low-pass filter algorithm, refer to CMSIS-DSP relevant documents. This application note mainly introduces how to configure sLib to protect this algorithm and how it is called by the end-user program code.

The low-pass filter input signal in this example is a combination of two sine waves with frequencies of 1 KHz and 15 KHz, while the low-pass filter cut-off frequency is about 6 KHz. A 15 KHz signal is filtered through the low-pass filter and outputs 1 KHz sine wave. Figure 8 shows the FIR low-pass filter functions.

Figure 8. FIR low-pass filter



CMSIS DSP library functions and files to be used are:

- arm_fir_init_f32()

It is used for initialization of filter function, which is included in “arm_fir_init_f32.c” file.

- arm_fir_f32()

It is the main part of filter algorithm, which is included in “arm_fir_f32.c” file.

- FIR_lowpass_filter()

It is a FIR low-pass filter global function written by using the above two functions for the end user to call, which is included in “fir_filter.c” file.

- fir_coefficient.c

This C file contains coefficients (read-only constants) used by FIR filter functions, and these coefficients are placed in data security library in the example.

In this example, FPU and DSP instructions in the MCU are used for signal processing and floating point arithmetic to realize accurate calculation and correct output signal.

3.4 Project_L0: example for solution providers

The following projects are completed in this example:

- Compile the algorithm-related functions to execute-only code;
- Place the algorithm program code to the main Flash memory sector 2;
- Place the coefficients of filter functions to the main Flash memory sector 4;
- Execute *FIR_lowpass_filter()* in the main program to verify its correctness;
- If correct, set sector 2/3 as the instruction security library and sector 4/5 as the data security library, which can be completed by calling the *slib_enable()* function in the main program or using Artery ICP Programmer (it is recommended to use ICP tools to complete configurations);
- Generate the header file and symbol definition files that are used by end-user program to call low-pass filter functions.

3.4.1 Generate execute-only code

Each toolchain has specific setting options to prevent the compiler generating literal pools and branch table that can read data while executing instructions, such as “LDR Rn, [PC, #offset]”. Section 2.4 lists examples of literal pools and branch table.

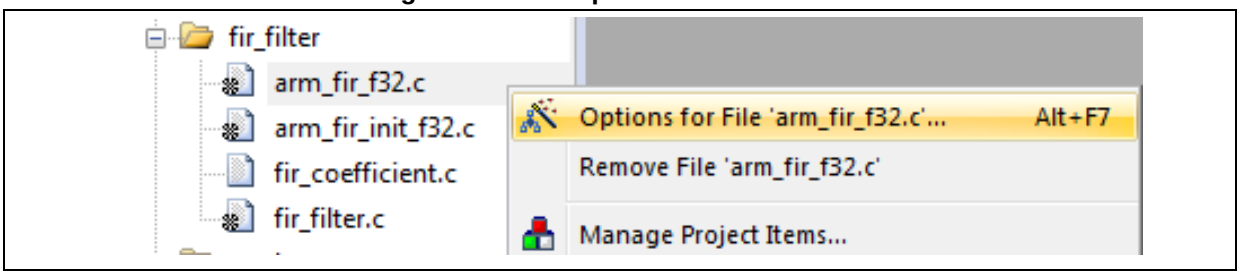
For Keil® µvision, it has the Execute-only Code option, which can be set as follows:

Keil® µvision: Set Execute-only Code option

Operate as follows:

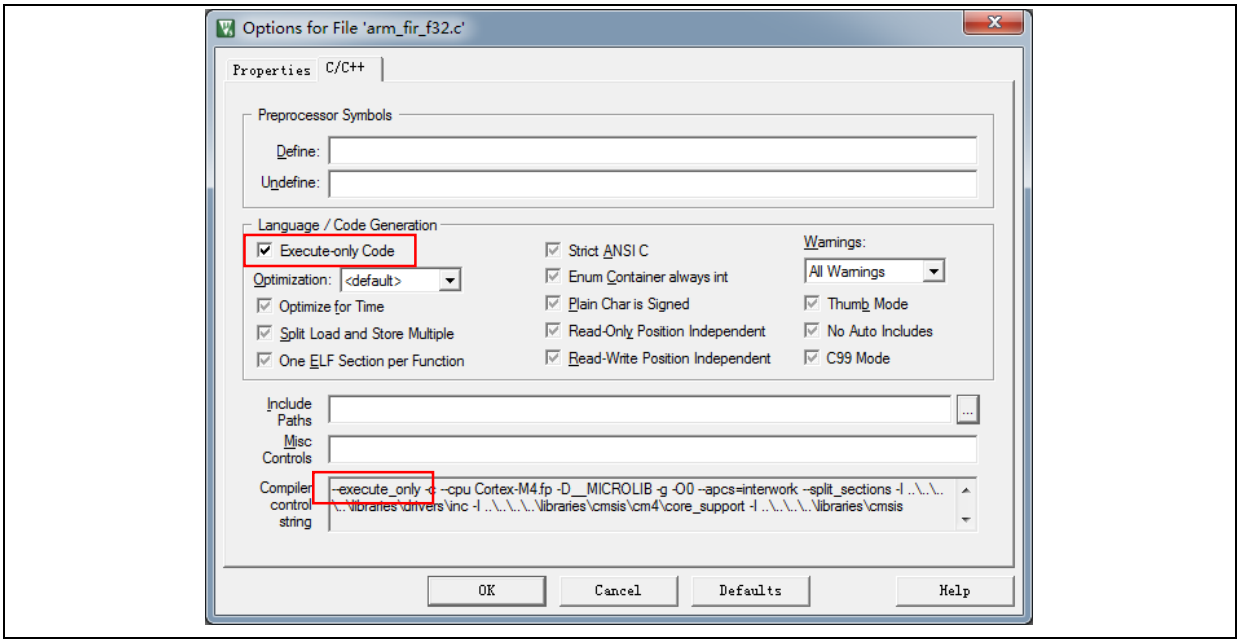
- Select C file group or individual C file (in this example, the C files to be protected are placed in “fir_filter”);
- Right click and select the corresponding files (for example, the *Option for File ‘arm_fir_f32.c’*), as shown in Figure 9;

Figure 9. Enter Option interface in Keil



- Tick “Execute-only Code” in the C/C++ interface, and the “--execute_only” instruction is added to the compiler control string, as shown in Figure 10;

Figure 10. Select Execute-only Code in Keil



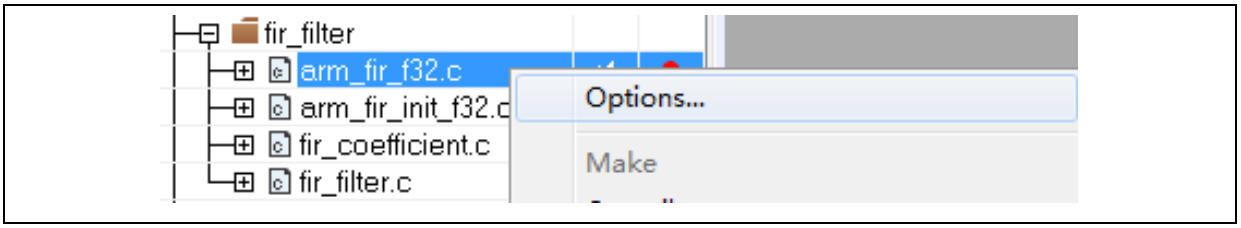
- The *arm_fir_f32.c*, *arm_fir_init_f32.c* and *fir_filter.c* files are in the SLIB_INSTRUCTION area, and these files need to be set as generating execute-only code.

IAR: Set No data read in code memory option

Operate as follows:

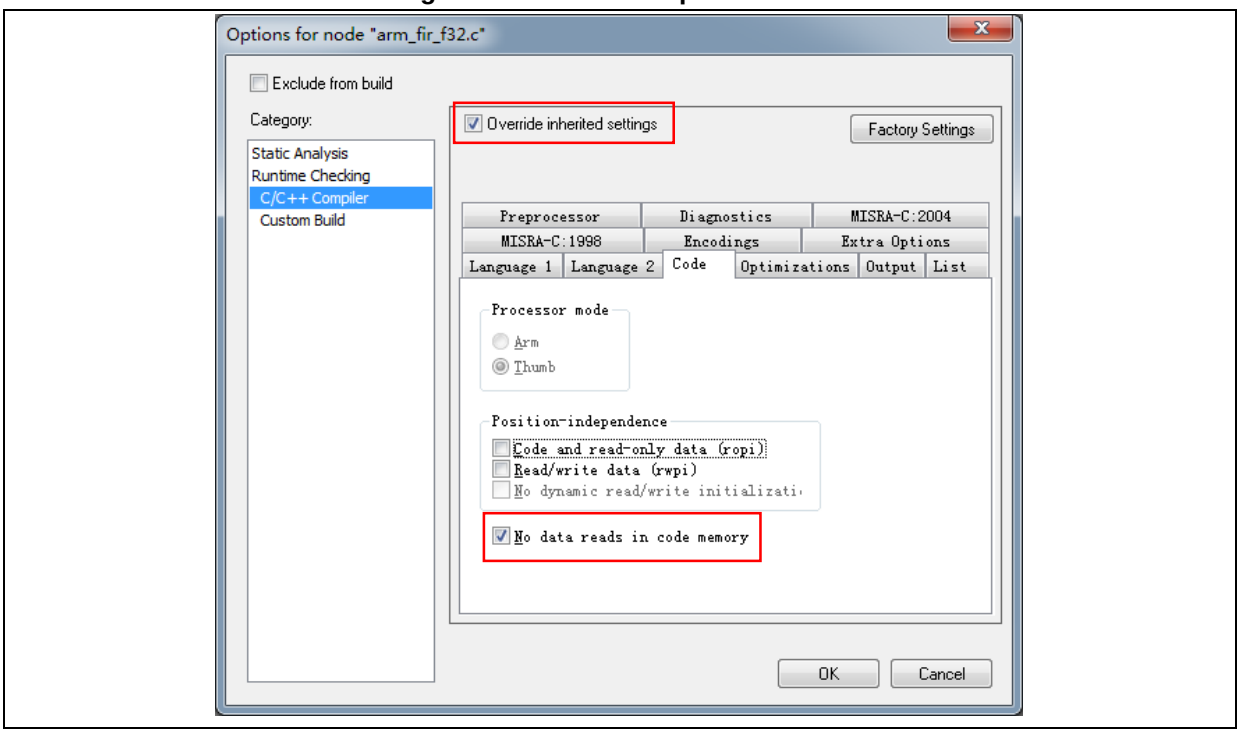
- Select the corresponding file in the fir_filter group; right click and select Option;

Figure 11. Enter Option interface in IAR



- Enter "C/C++" interface and tick “Override inherited settings” and “No data read in code memory”, as shown in Figure 12;

Figure 12. Set C/C++ options in IAR

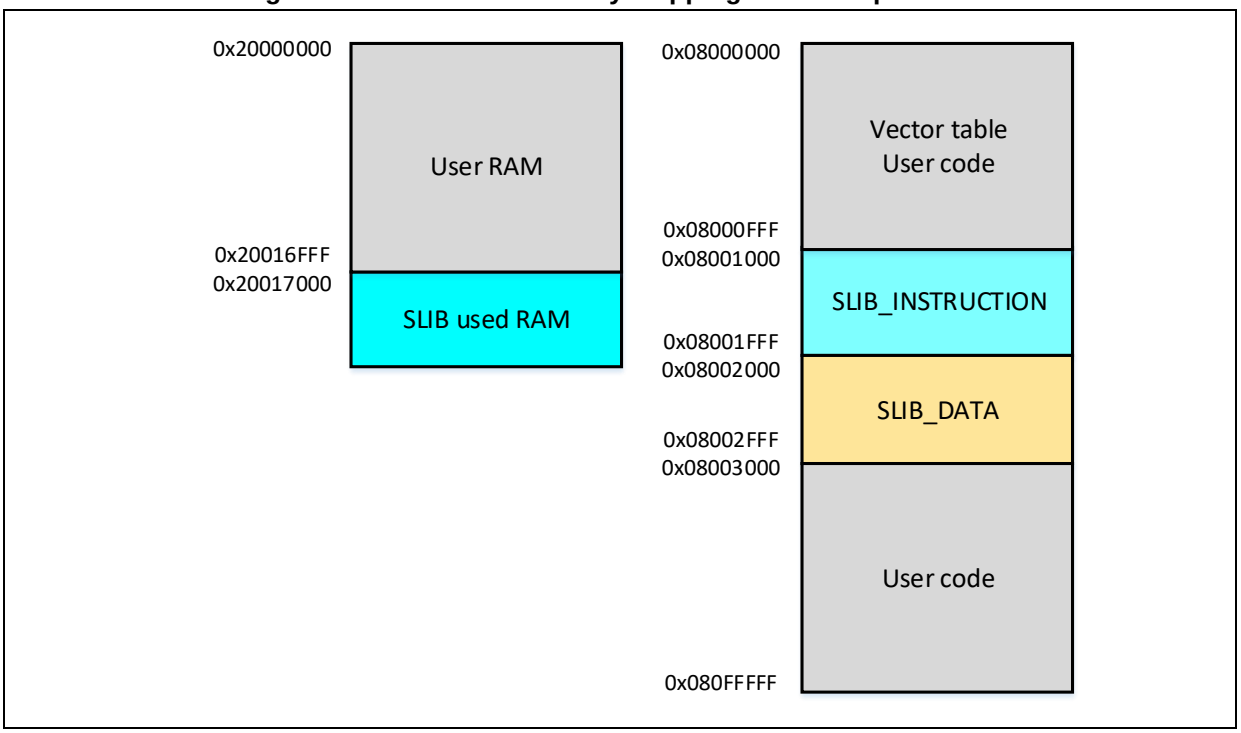


- The *arm_fir_f32.c*, *arm_fir_init_f32.c* and *fir_filter.c* files are in the SLIB_INSTRUCTION area, and these files need to be set as generating execute-only code.

3.4.2 Compile security library address

As aforementioned, the first sector (sector0) of the main Flash memory is used to store interrupt vector table. Therefore, the security library is set from sector 2 in this example, with sector 2 and sector 3 being set as instruction security library, and sector 4 and sector 5 being set as data security library. Figure 13 shows the main Flash memory mapping and RAM partition. The main purpose of RAM partitioning is to avoid the same RAM being used by sLib-protected code and end-user code.

Figure 13. Main Flash memory mapping and RAM partition

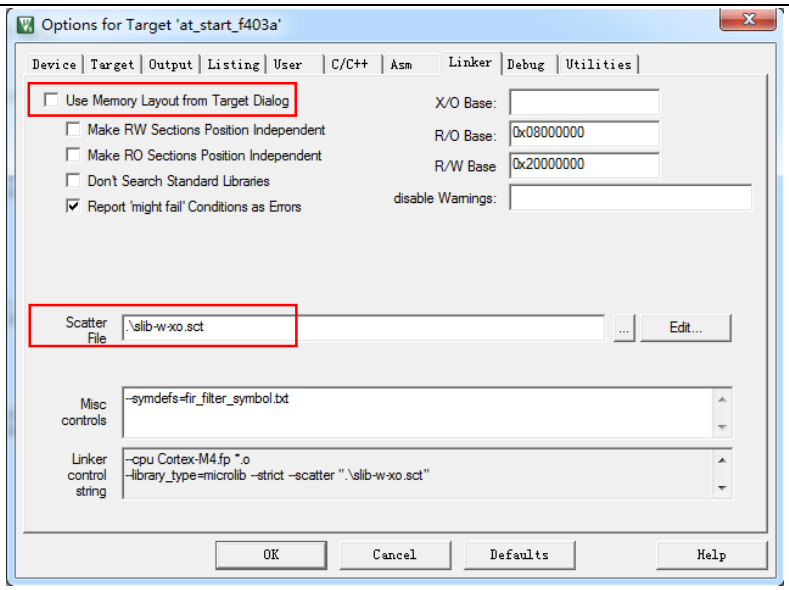


Keil® µvision: scatter file

Operate as follows:

- Click Project → Optios for Target→Linker, untick “Use memory layout from Target Dialog” and click “Edit” to open and modify *slib-w-xo.sct* file, as shown in Figure 14:

Figure 14. Set Linker option in Keil



- Open scatter file, load the object file of the code to be placed in SLIB_INSTRUCTION area to “LR_SLIB_INSTRUCTION” (a dedicated loading area that starts from sector 2 and occupies two sectors), and modify the label to “execute-only (+XO)”. In addition, place the area occupied by SLIB_Data to a dedicated loading area named “LR_SLIB_DATA” to avoid the compiler compiling other non-IP-code functions to the SLIB area. The RW_IRAM2 assigns the region from 0x20017000 to 0x20017FFF to the algorithm functions to avoid the same RAM region

being used by end-user project, causing fault or error in program execution.

Figure 15. Modify scatter in Keil

```
LR_IROM1 0x08000000 0x001000  {    ; load region size_region
  ER_IROM1 0x08000000 0x001000  {  ; load address = execution address
   *.o (RESET, +First)
   *(InRoot$$Sections)
   .ANY (+RO)
  }

  RW_IRAM1 0x20000000 0x00017000  {  ; user RW data
   .ANY (+RW +ZI)
  }

  RW_IRAM2 0x20017000 0x00001000  {  ; RAM used for slib code
   fir_filter.o (+RW +ZI)
  }
}

LR_SLIB_INSTRUCTION 0x08001000 0x00001000  {    ; slib instruction area
  ER_SLIBINSTRUCTION 0x08001000 0x00001000  {  ; load address = execution address
    arm_fir_init_f32.o (+XO)
    arm_fir_f32.o (+XO)
    fir_filter.o (+XO)
  }
}

LR_SLIB_DATA 0x08002000 0x00001000  {    ; sLib data area
  ER_SLIB_DATA 0x08002000 0x00001000  {
   fir_coefficient.o (+RO)
  }
}

LR_IROM2 0x08003000 0x000FD000  {    ; user code area
  ER_IROM2 0x08003000 0x000FD000  {  ; load address = execution address
   .ANY (+RO)
  }
}
```

- In addition to modifying the scatter file, for the RAM used by IP-Code, users can also use the Keil "__attribute__((at(address)))" descriptor to load variables to 0x20017000, as shown in Figure 16.

Figure 16. Modify SLIB RAM address in KEIL

```
#if   defined ( __ICCARM__ )
static float32_t firStateF32[BLOCK_SIZE + NUM_TAPS - 1]  @ 0x20017000 ;
#elif defined ( __CC_ARM )
static float32_t firStateF32[BLOCK_SIZE + NUM_TAPS - 1] __attribute__((at(0x20017000)));
#endif
```

- The start address of data security library is sector 4 (0x08002000). To compile the constants used by FIR low-pass filter functions to this address, users can modify the scatter file as aforementioned, or use the Keil "__attribute__((at(address)))" descriptor to load the constants to a fixed address, as shown in Figure 17.

Figure 17. Modify SLIB constant address in KEIL

```
#if   defined ( __ICCARM__ )
const float32_t firCoeffs32[NUM_TAPS] @ 0x08002000 ={
#elif defined ( __CC_ARM )
const float32_t firCoeffs32[NUM_TAPS] __attribute__((at(0x08002000))) = {
#endif
  -0.0018225230f, -0.0015879294f, +0.0000000000f, +0.0036977508f, +0.0080754303f, +0.00
  -0.0341458607f, -0.0333591565f, +0.0000000000f, +0.0676308395f, +0.1522061835f, +0.22
  +0.1522061835f, +0.0676308395f, +0.0000000000f, -0.0333591565f, -0.0341458607f, -0.01
  +0.0080754303f, +0.0036977508f, +0.0000000000f, -0.0015879294f, -0.0018225230f
};
```

IAR: ICF file

Operate as follows:

- Open the icf file in \project_l0\IAR_V8.2\, and add three new SLIB loading areas as shown in Figure 18. The SLIB_RAM region reserves the RAM (0x20017000 ~ 0x20017FFF) for the algorithm functions.

Figure 18. SLIB address definition in icf

```
/* SLIB INSTRUCTION area */
define symbol __ICFEDIT_region_SLIB_INSTRUCTION_start__ = 0x08001000;
define symbol __ICFEDIT_region_SLIB_INSTRUCTION_end__   = 0x08001FFF;

/* SLIB DATA area */
define symbol __ICFEDIT_region_SLIB_DATA_start__ = 0x08002000;
define symbol __ICFEDIT_region_SLIB_DATA_end__   = 0x08002FFF;

define symbol __ICFEDIT_region_RAM_start__ = 0x20000000;
define symbol __ICFEDIT_region_RAM_end__   = 0x20017FFF;

/* SLIB RAM region */
define symbol __ICFEDIT_region_SLIB_RAM_start__ = 0x20017000;
define symbol __ICFEDIT_region_SLIB_RAM_end__   = 0x20017FFF;
```

- In the icf file, the area occupied by SLIB is reserved to avoid the compiler compiling other non-IP-code functions to the SLIB area, and the RAM region used by IP-Code is reserved.

Figure 19. Address assignment in icf file

```
/* Reserved 0x08001000 ~ 0x08002FFF as SLIB area */
define region ROM_region   = mem:[from __ICFEDIT_region_ROM_start__   to __ICFEDIT_region_ROM_end__]
                           -mem:[from __ICFEDIT_region_SLIB_INSTRUCTION_start__  to __ICFEDIT_region_SLIB_INSTRUCTION_end__]
                           -mem:[from __ICFEDIT_region_SLIB_DATA_start__  to __ICFEDIT_region_SLIB_DATA_end__] ;

define region SLIB_INSTRUCTION_region   = mem:[from __ICFEDIT_region_SLIB_INSTRUCTION_start__   to __ICFEDIT_region_SLIB_INSTRUCTION_end__];

define region SLIB_DATA_region   = mem:[from __ICFEDIT_region_SLIB_DATA_start__   to __ICFEDIT_region_SLIB_DATA_end__];

/* Reserved 0x20017000 ~ 0x20017FFF as RAM used for SLIB code */
define region RAM_region   = mem:[from __ICFEDIT_region_RAM_start__   to __ICFEDIT_region_RAM_end__]
                           - mem:[from __ICFEDIT_region_SLIB_RAM_start__   to __ICFEDIT_region_SLIB_RAM_end__];

define region SLIB_RAM_region = mem:[from __ICFEDIT_region_SLIB_RAM_start__   to __ICFEDIT_region_SLIB_RAM_end__];
```

- For the RAM used by IP-Code, users can use the IAR @ descriptor to load variables to a fixed address 0x20017000 or modify the icf file, as shown in Figure 20.

Figure 20. Modify IP-Code RAM in icf file

```
place in RAM_region   { readwrite,
                        block CSTACK, block HEAP };

/* Place slib used sram */
place in SLIB_RAM_region   { readwrite object fir_filter.o };
```

- The start address of data security library is sector 4 (0x08002000). To compile the constants used by FIR low-pass filter functions to this address, users can modify the icf file as aforementioned, or use the IAR @ descriptor to load the constants to a fixed address, as shown in Figure 21.

Figure 21. Modify SLIB constant address in IAR

```
#if   defined ( __ICCARM__ )
const float32_t firCoeffs32[NUM_TAPS] @ 0x08002000 ={
#elif defined ( __CC_ARM )
const float32_t firCoeffs32[NUM_TAPS] __attribute__((at(0x08002000))) = {
#endif
  -0.0018225230f, -0.0015879294f, +0.0000000000f, +0.0036977508f, +0.0080754303f,
  -0.0341458607f, -0.0333591565f, +0.0000000000f, +0.0676308395f, +0.1522061835f,
  +0.1522061835f, +0.0676308395f, +0.0000000000f, -0.0333591565f, -0.0341458607f,
  +0.0080754303f, +0.0036977508f, +0.0000000000f, -0.0015879294f, -0.0018225230f
};
```

3.4.3 Enable sLib protection

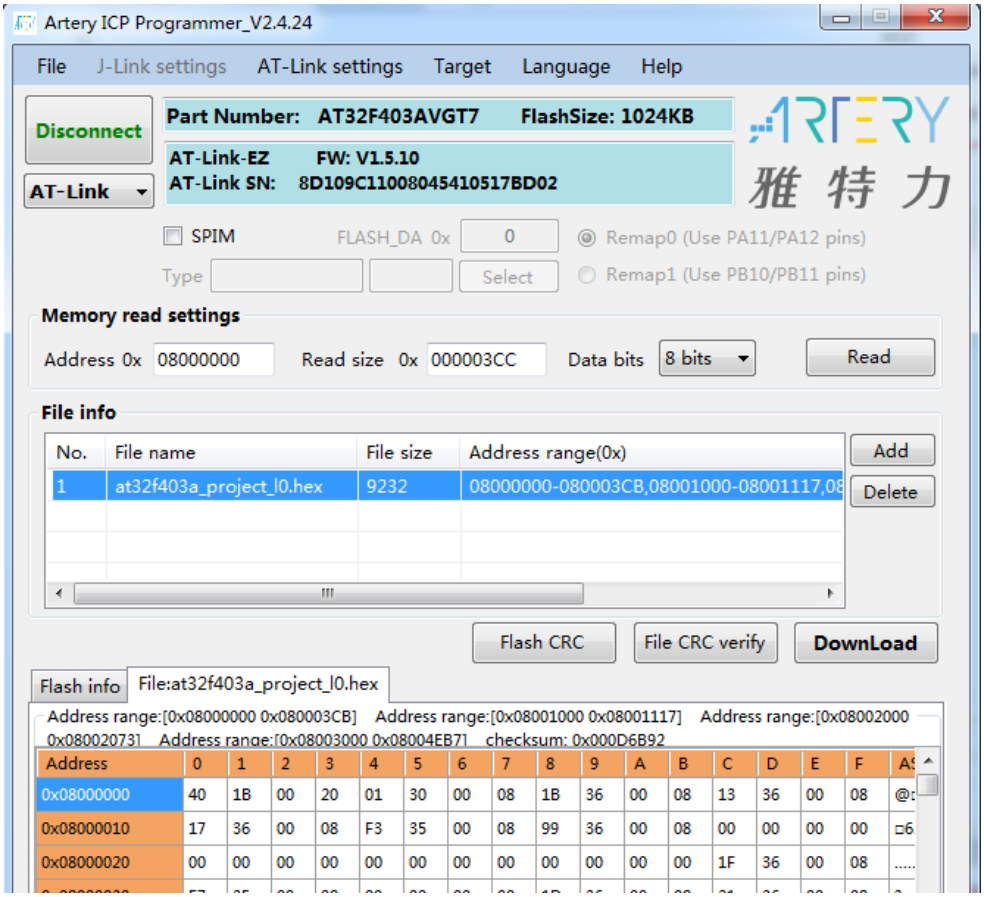
There are two methods to enable sLib protection:

(1) Use Artery ICP Programmer (recommended)

It is recommended to use the ICP Programmer as follows:

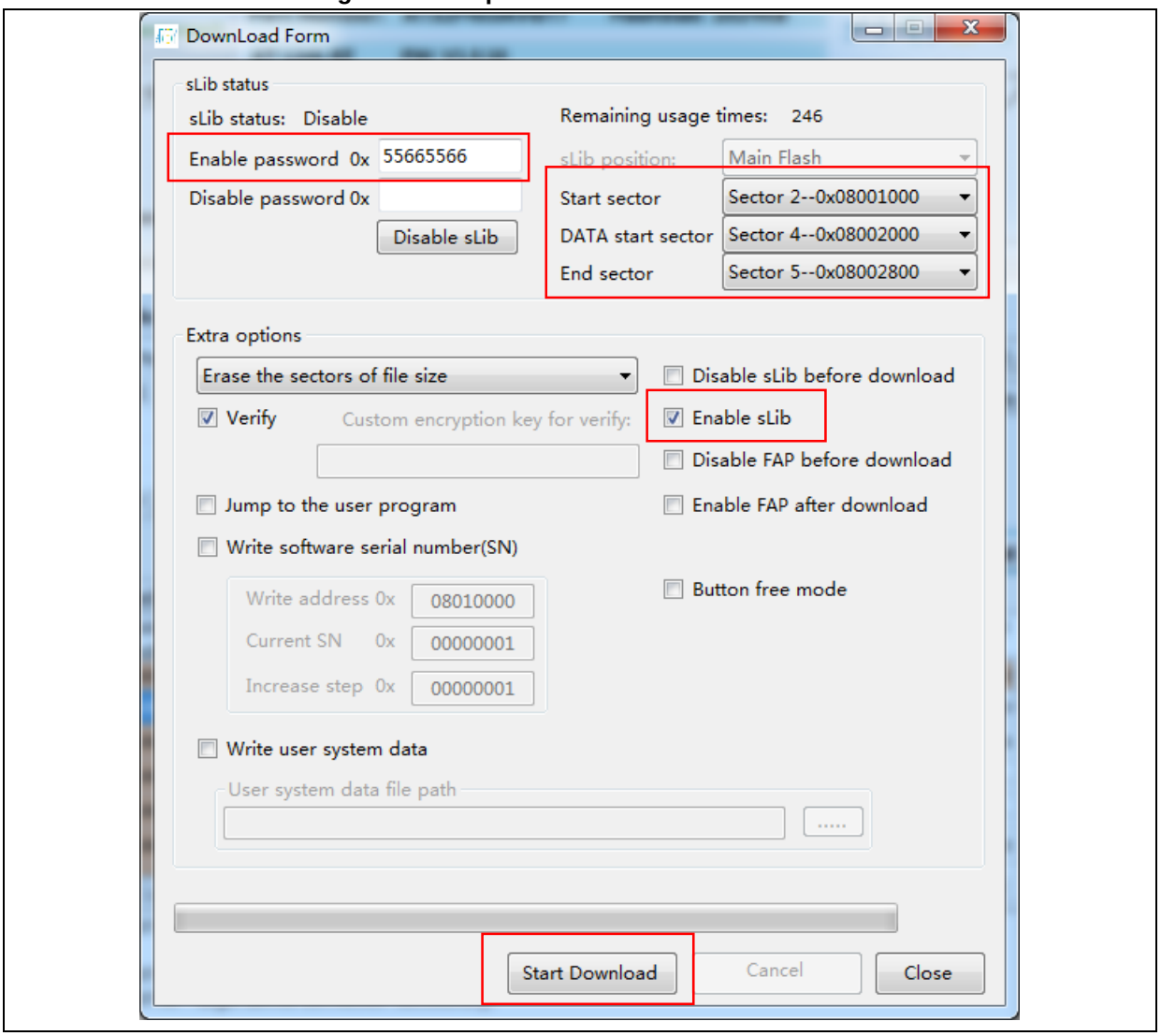
- Connect AT-Link emulator to AT-START-F403A board and power on;
- Open ICP Programmer, select AT-Link for connection, and add the HEX or BIN file generated by Project_L0, as shown in Figure 22.

Figure 22. Configure ICP Programmer



- Click “Download” and the “Download Form” pops up, which shows SLIB status and relevant parameters. Set sector 2 as the start sector, sector 4 as the data start sector and sector 5 as the end sector; set the enable password as “0x55665566” (user-defined), tick “Enable SLIB”, and then click “Start Download” to complete programming and enable SLIB, as shown in Figure 23.

Figure 23. Set parameters in Download Form



For details about ICP Programmer, refer to ICP Programmer User Manual.

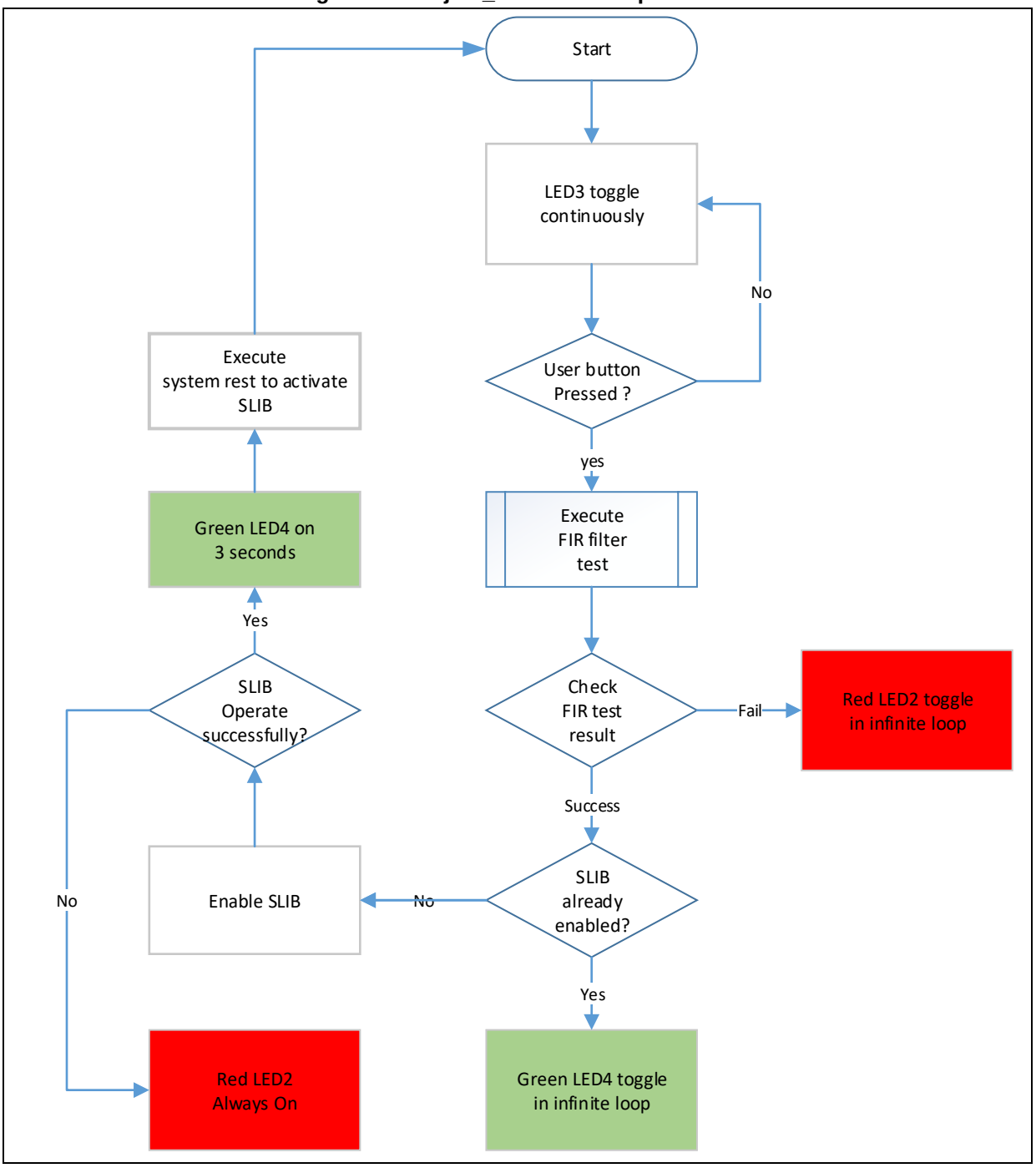
(2) Use slib_enable() function in main.c

After the slib_enable() function is verified correct by low-pass filter function and then executed, the sLib protection can be enabled. To execute this function, enable the “#define USE_SLIB_FUNCTION” in main.c.

3.4.4 Project_L0 execution process

In this example, FIR low-pass filter calculates the input signal (testInput_f32_1kHz_15kHz) mixed with 1 KHz and 15 KHz sine waves, and the output 1 KHz sine wave data is saved in testOutput, which will be compared with the data calculated by MATLAB and saved in refOutput. If the error value is smaller than expected (SNR larger than the preset threshold), the green LED on the board blinks; otherwise, the red LED blinks. Figure 24 shows the Project_L0 execution process.

Figure 24. Project_L0 execution process



Go through the following steps to execute this example program:

(1) Use Keil® µvision to open the Project_L0 under \utilities\at32f403a_407_slib_demo\project_l0\mdk_v5\, and then compile;

(2) Before downloading the code, check whether the chip on AT-START-F403A board is SLIB-protected or write/read-protected (FAP/EPP). If it is protected, use ICP programmer to disable protection and then download the code;

(3) After successful download, start to execute the code, and the on-board LED3 keeps blinking rapidly;

(4) Press the on-board USER button to perform operation of low-pass filter;

(5) Compare the computation result. If it is correct, the green LED4 keeps blinking; otherwise, the

red LED2 keeps blinking;

(6) After obtaining the correct result, if the USE_SLIB_FUNCTION in main.c is defined and the SLIB is not enabled, the slib_enable() function will be executed to set SLIB. If SLIB setting fails, the red LED2 will be always ON; if SLIB setting succeeds, the green LED4 will be ON for about three seconds and then perform system reset to enable SLIB; then, go to step (3).

3.4.5 Generate header file and symbol definition file

The header file and symbol definition file are used when the Project_L1 calls FIR low-pass filter functions, which is the *fir_filter.h* file in main.c in this example.

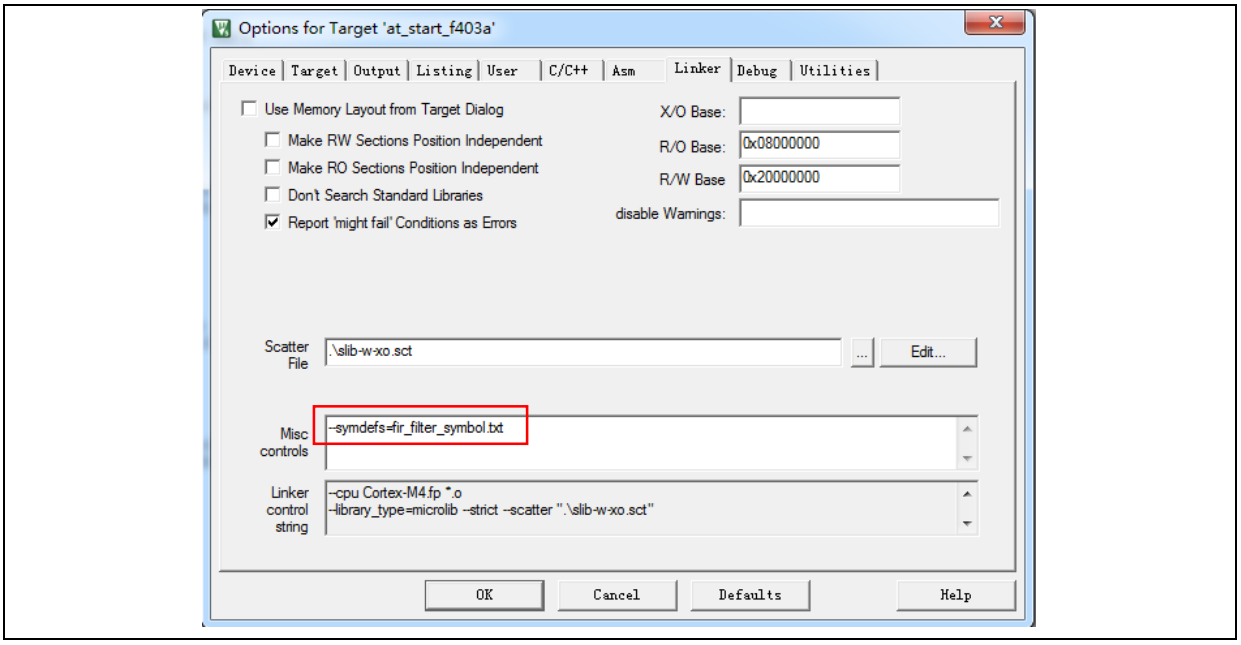
The generation of symbol definition file is related to the specific toolchain being used.

Use Keil® µvision to generate symbol definition file

Operate as follows:

- Enter Options for Target → Linker interface;
- Add "--symdefs=fir_filter_symbol.txt" command in the Misc controls, as shown in Figure 25;

Figure 25. Set Misc controls in Keil



- After compiling the project, a symbol definition file named "fir_filter_symbol.txt" is generated under project_l0\mdk_v5\Objects;
- This symbol definition file contains all symbol definitions of the project, and it needs to be modified to only remain the definitions of low-pass filter functions to be called by end users. The modified *fir_filter_symbol.txt* is shown in Figure 26;

Figure 26. Contents of modified fir_filter_symbol.txt

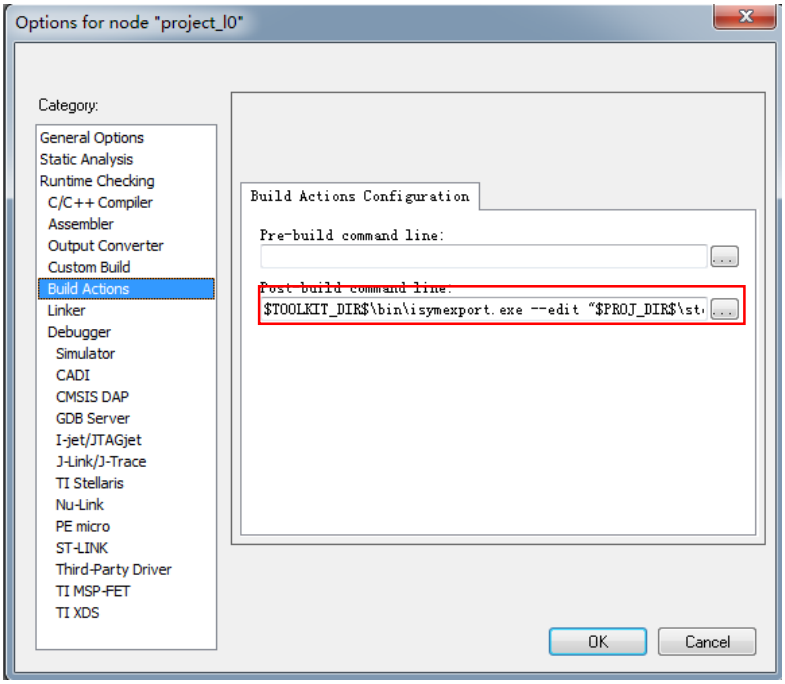
```
0x08001001 T FIR_lowpass_filter
```

Use IAR to generate symbol definition file

Operate as follows:

- Select Project→Option→Build Actions

Figure 27. Set Build Actions in IAR



- Input the following commands to the Post-build command line:

  $TOOLKIT_DIR$\bin\isymexport.exe --edit "$PROJ_DIR$\steering_file.txt" "$TARGET_PATH$" "$PROJ_DIR$\fir_filter_symbol.o"

- The *fir_filter_symbol.o* is the symbol definition file to be generated, and the *steering_file.txt* is saved under project_l0\iar_v8.2, which is used to select function symbols to be generated. Users can manually edit according to the contents called by sLib. As shown in Figure 28, the "show" is the command used to select functions.

Figure 28. Edit steering_file.txt content

```
show FIR_lowpass_filter
```

3.5 Project_L1: example for end users

Project_L1 uses the FIR low-pass filter function that is debugged in Project_L0, programmed to AT32F403A MCU main Flash memory and SLIB-protected According to the header file, symbol definition file and the main Flash memory mapping of Project_L0, end users can complete the followings for Project_L1:

- Create an application project;
- Add the header file and symbol definition file provided by Project_L0 to the project;
- Call the FIR low-pass filter function;

- Develop and debug user's program.

Notes:

Project_L1 must use the same toolchain and the same version of the compiler as that of Project_L0; otherwise, incompatibility problem may occur and the code provided by Project_L0 cannot be used properly. For example, Project_L0 uses Keil® µvision V5.18.0.0; therefore, Project_L1 need to use the same version.

3.5.1 Create user application project

The security library enabled in Project_L0 occupies some specific main Flash memory sectors; therefore, the address for Project_L1 code storage should be compiled according to the main Flash memory mapping of Project_L0, as shown in Figure 13. In the main Flash memory, sector 2~ sector 5 are occupied by the security library, and end users need to isolate this region by using linker control file to avoid code being compiled to this region.

Keil® µvision: scatter file

Refer to the *end_user_code.sct* file under project_l1\mdk_v5\ and divide the main Flash memory into two regions, and the middle part is the SLIB-protected area. In addition, the area after 0x20017000 needs to be reserved for the RAM area, as shown in Figure 29.

Figure 29. Modified scatter file

```
LR_IROM1 0x08000000 0x00001000  {    ; load region size_region
  ER_IROM1 0x08000000 0x00001000  {  ; load address = execution address
   *.o (RESET, +First)
   *(InRoot$$Sections)
   .ANY (+RO)
  }
  RW_IRAM1 0x20000000 0x00017000  {  ; RW data
   .ANY (+RW +ZI)
  }

 ; 0x20017000 ~ 0x20017FFF   RAM reserved for SLIB code

}

; 0x08001000 ~ 0x08002FFF is SLIB area

LR_IROM2 0x08003000 0x000FD000  {    ; load region size_region
  ER_IROM2 0x08003000 0x000FD000  {  ; load address = execution address
   .ANY (+RO)
  }
}
```

IAR: ICF file

Refer to the *enduser.icf* file under project_l1\iar_V8.2\, as shown in Figure 30.

Figure 30. Modified icf file

```
/* Reserved SLIB area */
define region ROM_region     = mem:[from __ICFEDIT_region_ROM_start__   to __ICFEDIT_region_ROM_end__]
                             -mem:[from __ICFEDIT_region_SLIB_start__ to __ICFEDIT_region_SLIB_end__];

define region RAM_region     = mem:[from __ICFEDIT_region_RAM_start__   to __ICFEDIT_region_RAM_end__]
                             - mem:[from __ICFEDIT_region_SLIB_RAM_start__   to __ICFEDIT_region_SLIB_RAM_end__];
```

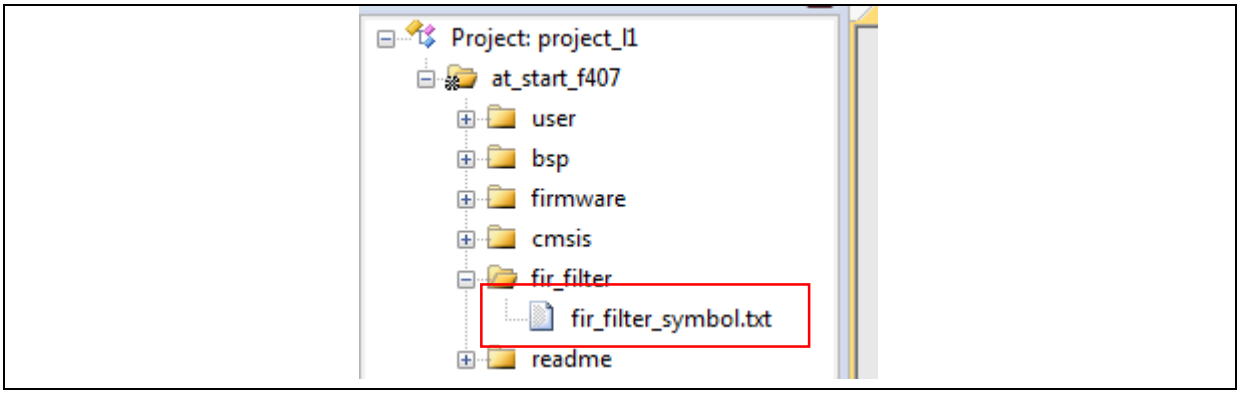
3.5.2 Add symbol definition file to project

The symbol definition *file fir_filter_symbol.txt* generated in Project_L0 must be added to Project_L1, so that it can be correctly compiled and linked to the SLIB-protected area code.

Add symbol definition file in Keil® µvision

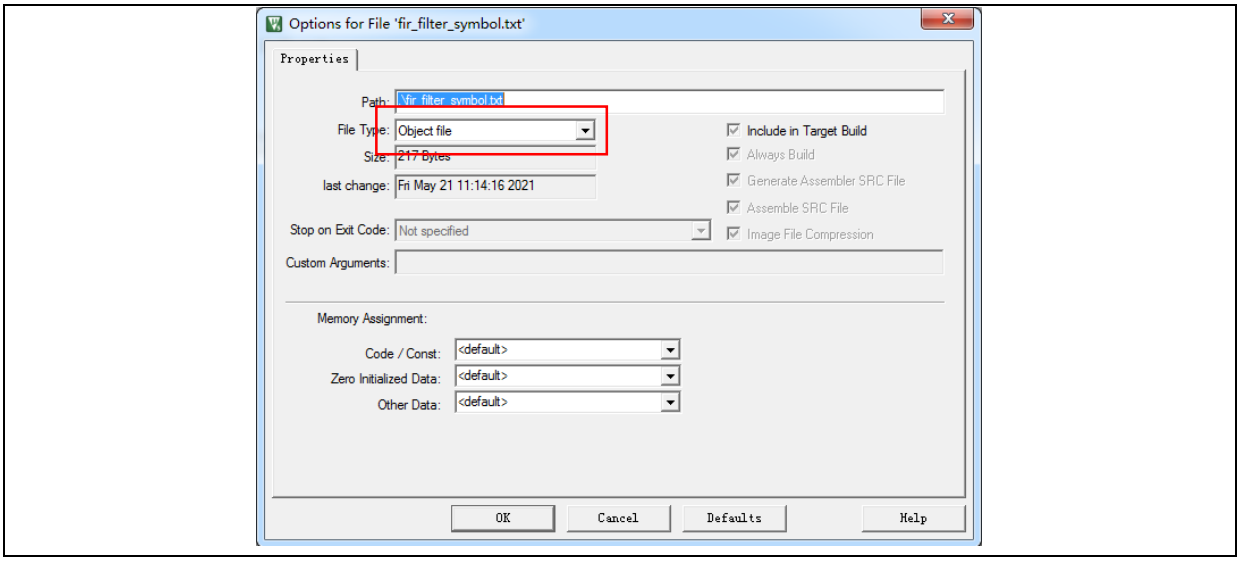
Add *fir_filter_symbol.txt* to the project, as shown in Figure 31.

Figure 31. Add symbol definition file in Keil



After adding this file to fir_filter, modify its file type from “text” to “Object”, as shown in Figure 32.

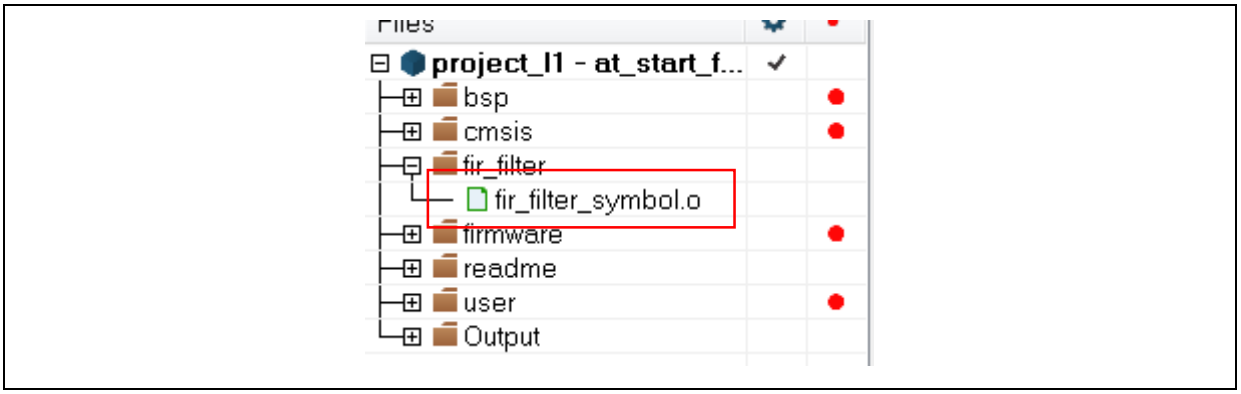
Figure 32. Modify symbol definition file type to “Object file”



Add symbol definition file in IAR

Add the *fir_filter_symbol.o* (Object) file to fir_filter, as shown in Figure 33.

Figure 33. Add symbol definition file in IAR



3.5.3 Call functions in SLIB-protected area

When the filter.h header file is referred in main.c and the symbol definition file is added to the project, the low-pass filter function in the protection area can be called, as shown below:

FIR_lowpass_filter(inputF32, outputF32, TEST_LENGTH_SAMPLES);

Where,

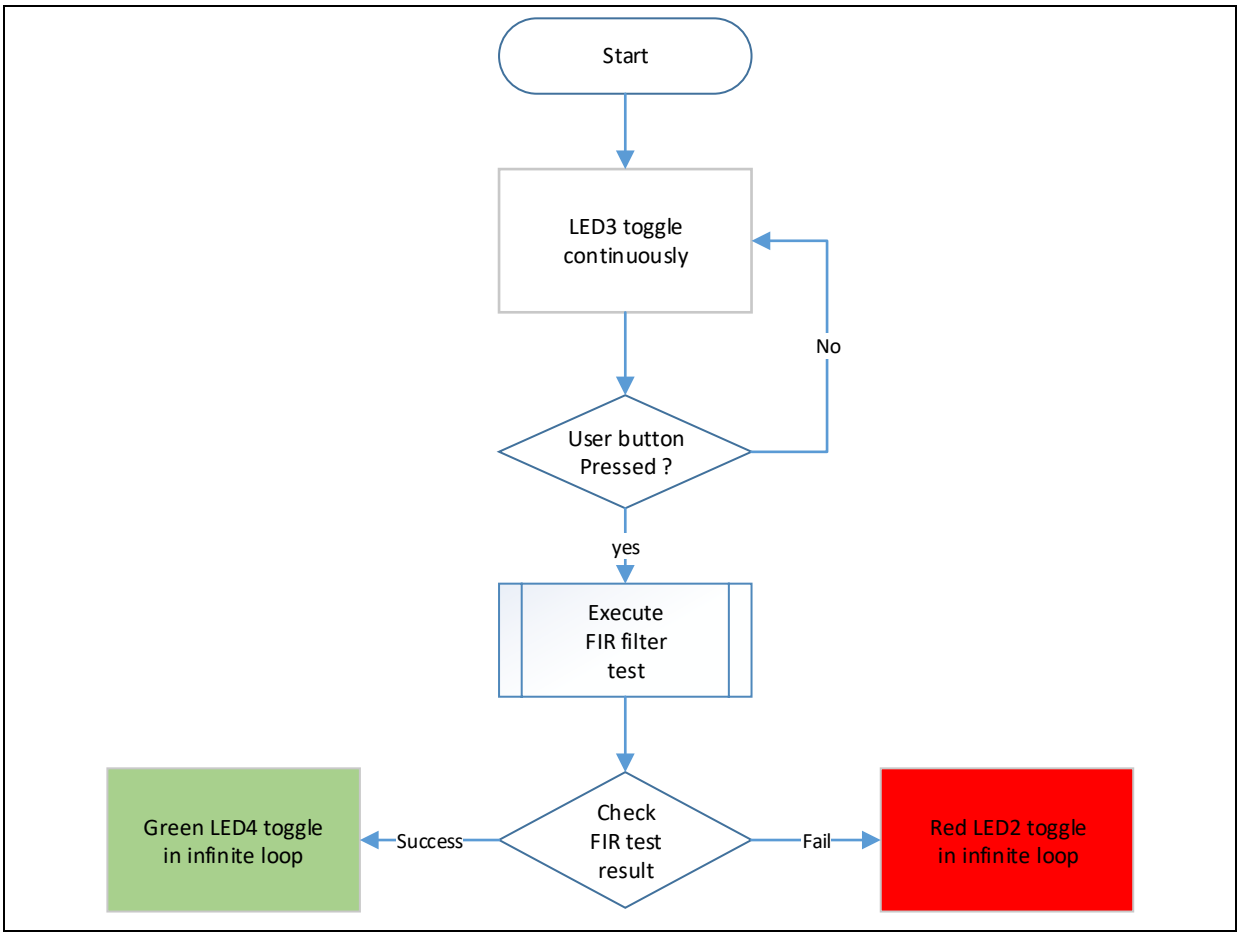
- *inputF32*: pointer containing input signal data table;
- *outputF32*: pointer storing output signal data table;
- *TEST_LENGTH_SAMPLES*: the number of signal samples to be processed.

3.5.4 Project_L1 execution process

Figure 34 shows the execution process of Project_L1:

- Start execution, and LED3 will keep blinking;
- Press the USER button on AT-START board, and the FIR_lowpass_filter() starts operation;
- If the result is correct, the green LED4 will keep blinking; otherwise, the red LED2 will keep blinking.

Figure 34. Project_L1 execution process



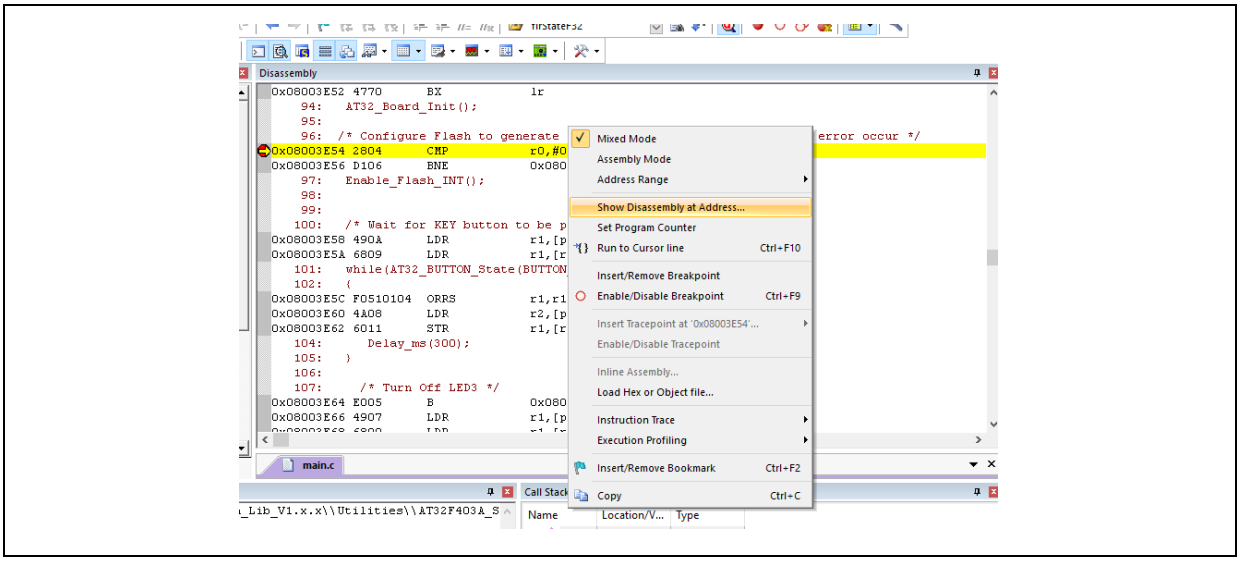
3.5.5 SLIB protection in debug mode

Development tools are used by end users to debug codes when developing applications. This section takes Keil® µvision as an example to introduce how to protect codes in the SLIB-protected

area from being read as data in debug mode.

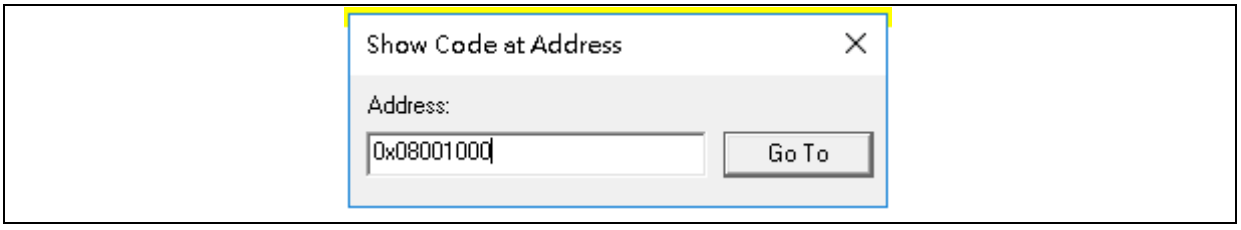
- Open Project_L1 and compile;
- Click “Start/Stop Debug Session” to enter debug mode;
- Right click in the “Disassembly” interface and select “Show Disassembly at Address”, as shown in Figure 35.

Figure 35. Enter Show Disassembly at Address



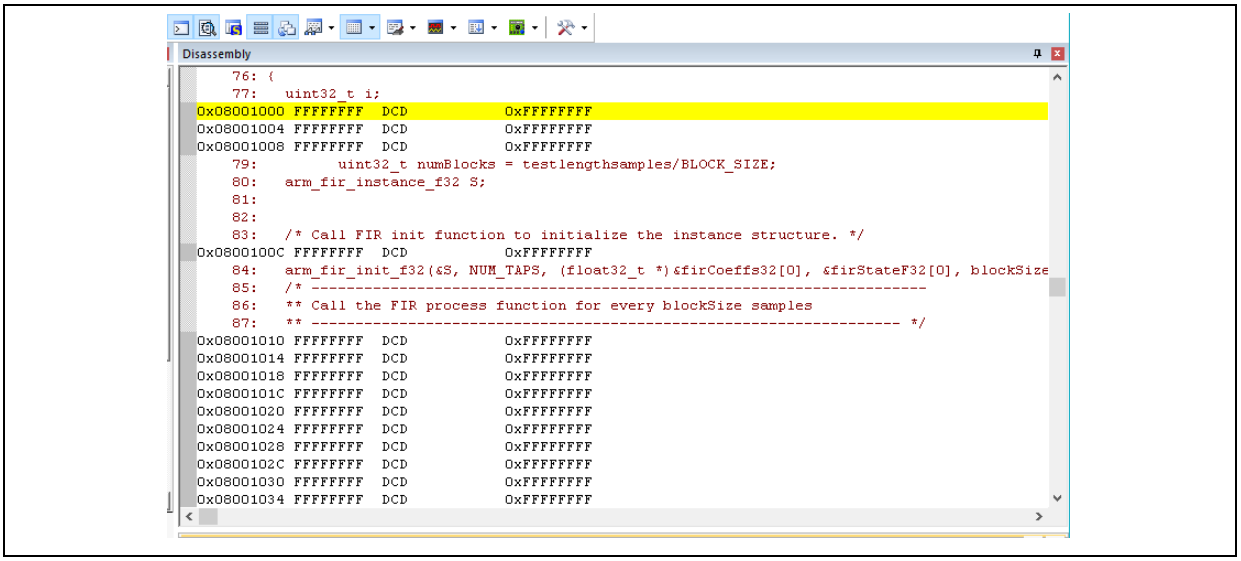
- Enter the address “0x08001000” of SLIB_INSTRUCTION start sector (sector 2);

Figure 36. Set Show Code at Address



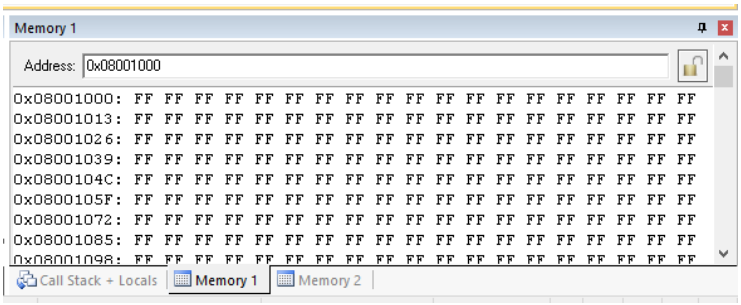
- As shown in Figure 37, codes from 0x08001000 are all 0xFFFFFFFF;

Figure 37. View codes



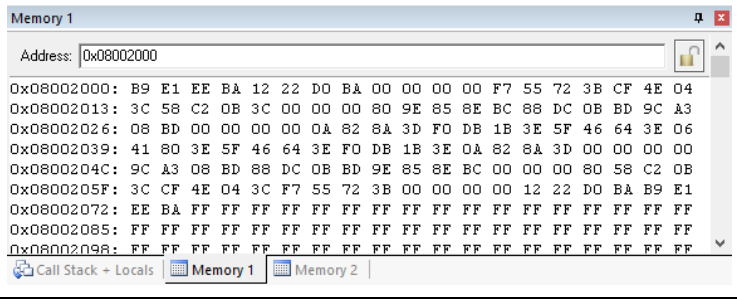
- Similarly, enter address 0x08001000 in “Memory” window, and codes are all 0xFF, as shown in Figure 38;

Figure 38. View codes in Memory



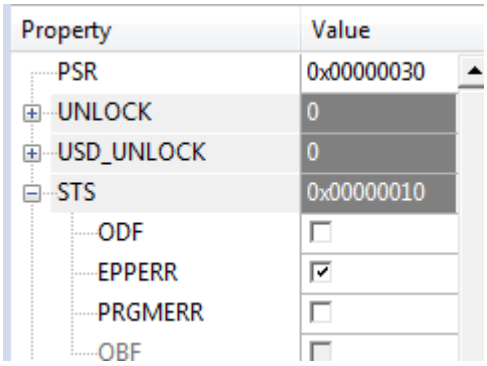
- In the “Memory” window, enter the address 0x08002000 of SLIB_DATA start sector (sector 4); this region is allowed to be read through D-Code bus, so original values can be found, as shown in Figure 39;

Figure 39. View SLIB_DATA start sector in Memory



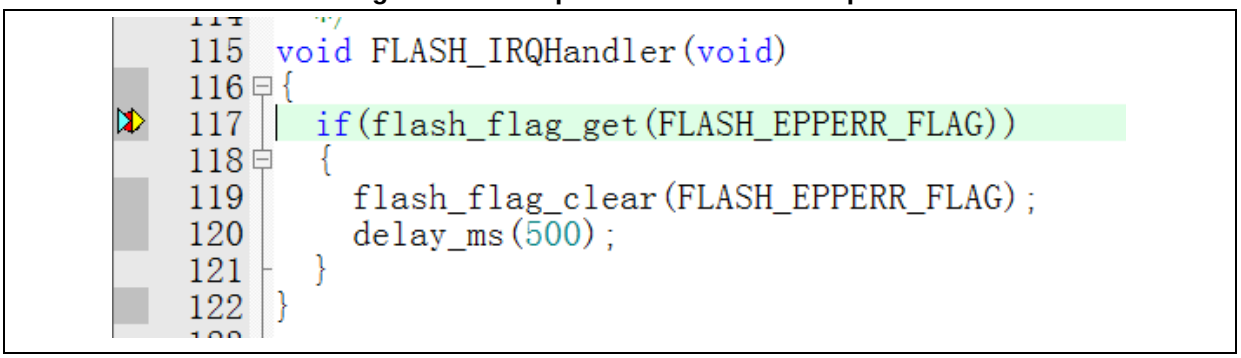
- In the “Memory” window, double click to modify the value of 0x08002000, and a warning pops up by setting EPPERR=1 in the FLASH_STS register, indicating the protection is enabled;

Figure 40. SLIB write test



- In case of enable erase/program protection error interrupt, continuing execution will enter the interrupt program;

Figure 41. Write protection error interrupt



4 Integrate codes and download

After codes of the solution provider and end user are well designed, download to the same MCU on the premise of guaranteeing code security. Project_L0 and Project_L1 are used to introduce two downloading methods for reference.

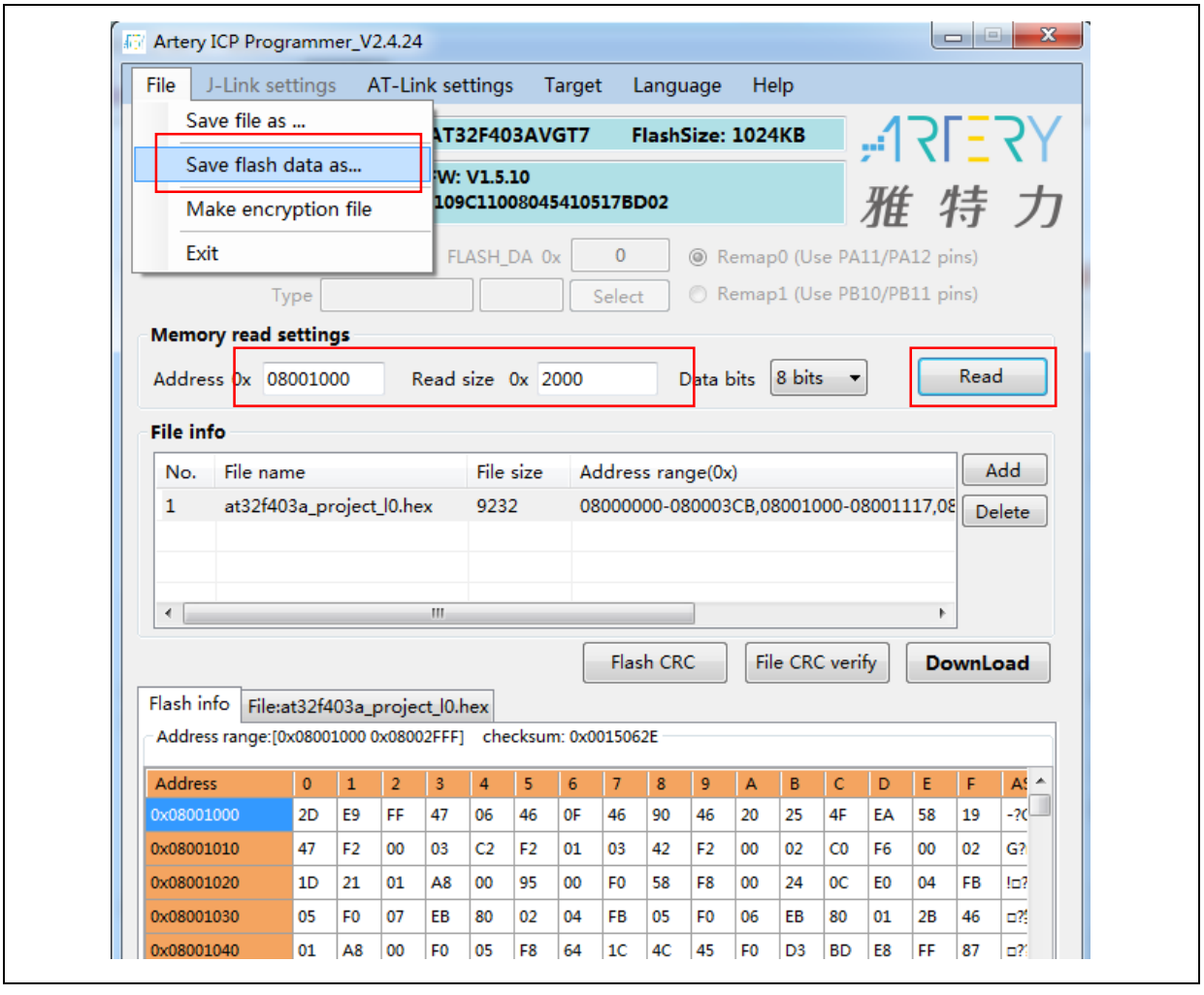
This operation involves offline downloading mode of AT-Link. For details, refer to operation manuals of ICP and AT-Link.

4.1 Program codes separately

Firstly, the solution provider programs SLIB codes to MCU; then, the end user programs application codes to MCU. The process is as follows:

(1) **Method A:** The solution provider uses ICP tool to save the SLIB code in the compiled project as BIN or HEX file: download the complete project to MCU (do not configure SLIB and FAP), read the corresponding SLIB codes (0x08001000~0x08002FFF) by using the memory access function, and then click “File-Save Flash data as” to save the codes as BIN or HEX file. In this example, it is named “slib.bin”, as shown in Figure 42.

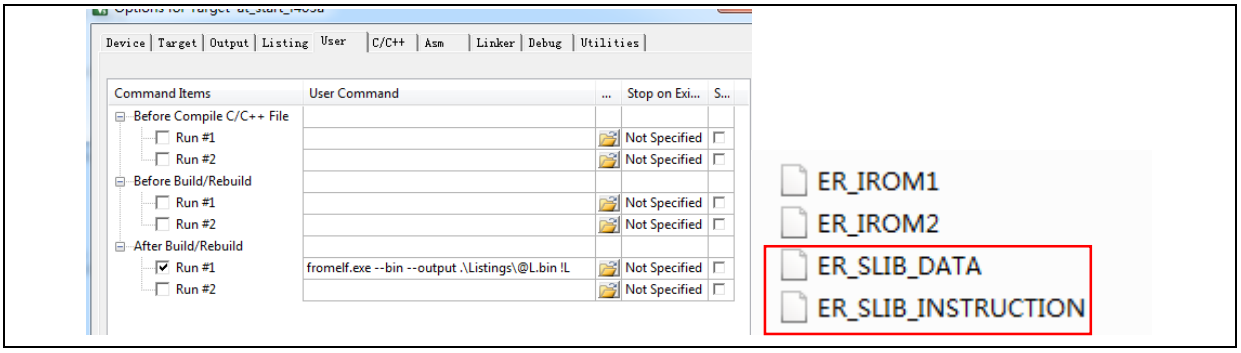
Figure 42. Save SLIB codes



Method B: The solution provider uses the compiled project to generate a bin file directly, and take the corresponding section in the SLIB area. For example, in the KEIL project, add “fromelf.exe

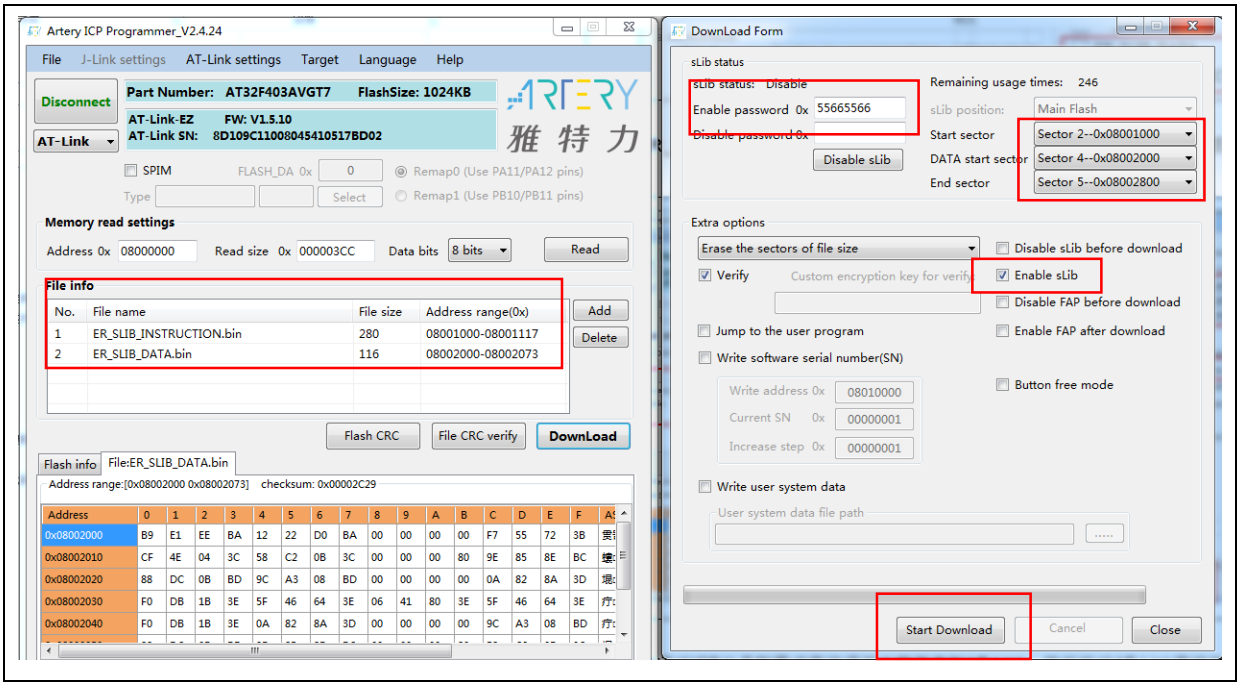
--bin --output .\Listings\@L.bin !L" in the "user" option to generate a bin file of the corresponding firmware, and add a suffix ".bin" to the SLIB area file. In this example, they are "ER_SLIB.bin" and "ER_SLIB_DATA.bin", corresponding to the SLIB-INSTRUCTION file (0x08001000) and SLIB-DATA file (0x08002000), respectively, as shown in Figure 43.

Figure 43. Generate bin file of SLIB code



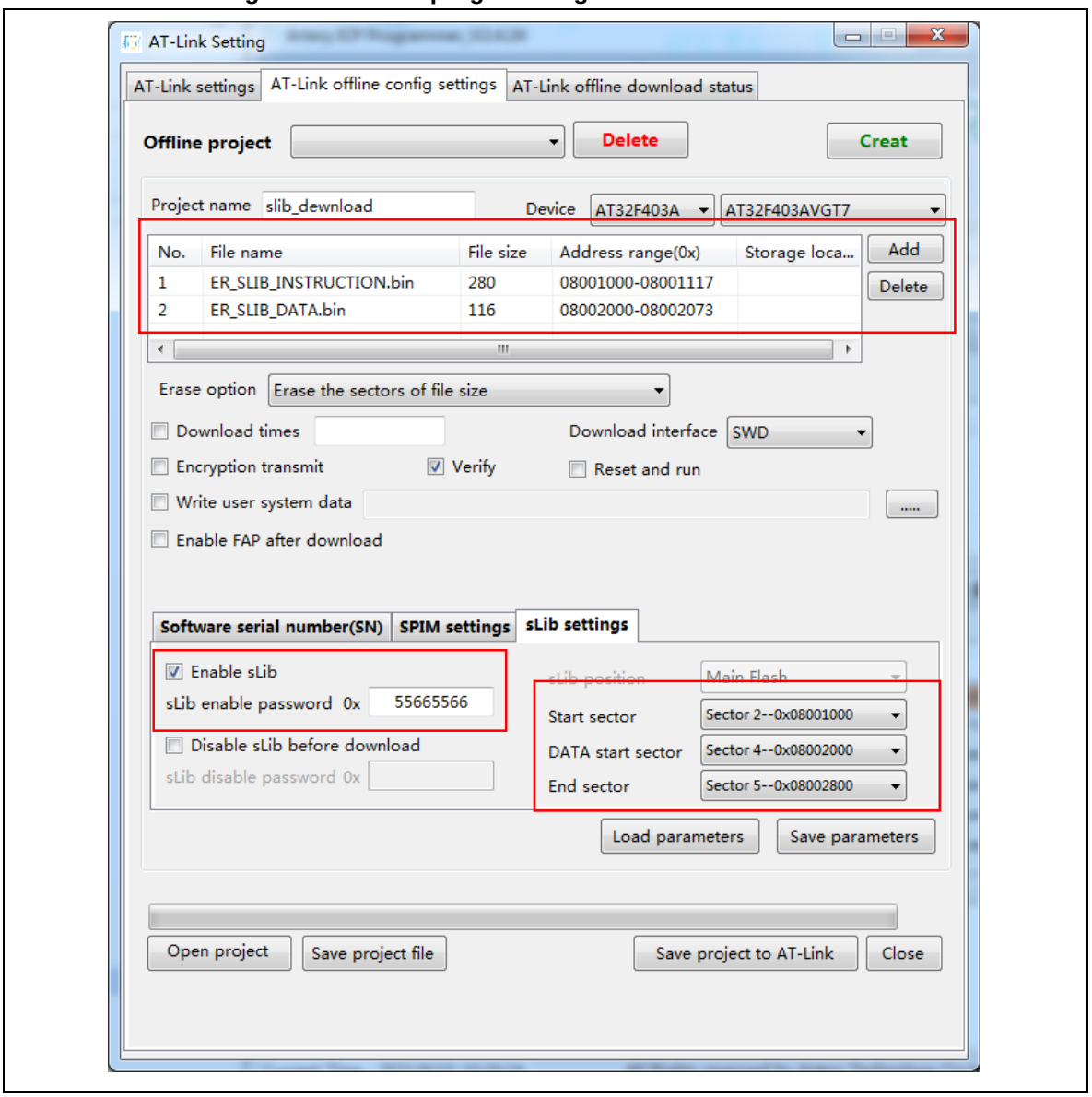
(2) Use ICP Programmer to program the ER_SLIB_INSTRUCTION.bin and ER_SLIB_DATA.bin to MCU, as shown in Figure 44.

Figure 44. Online programming to MCU in ICP



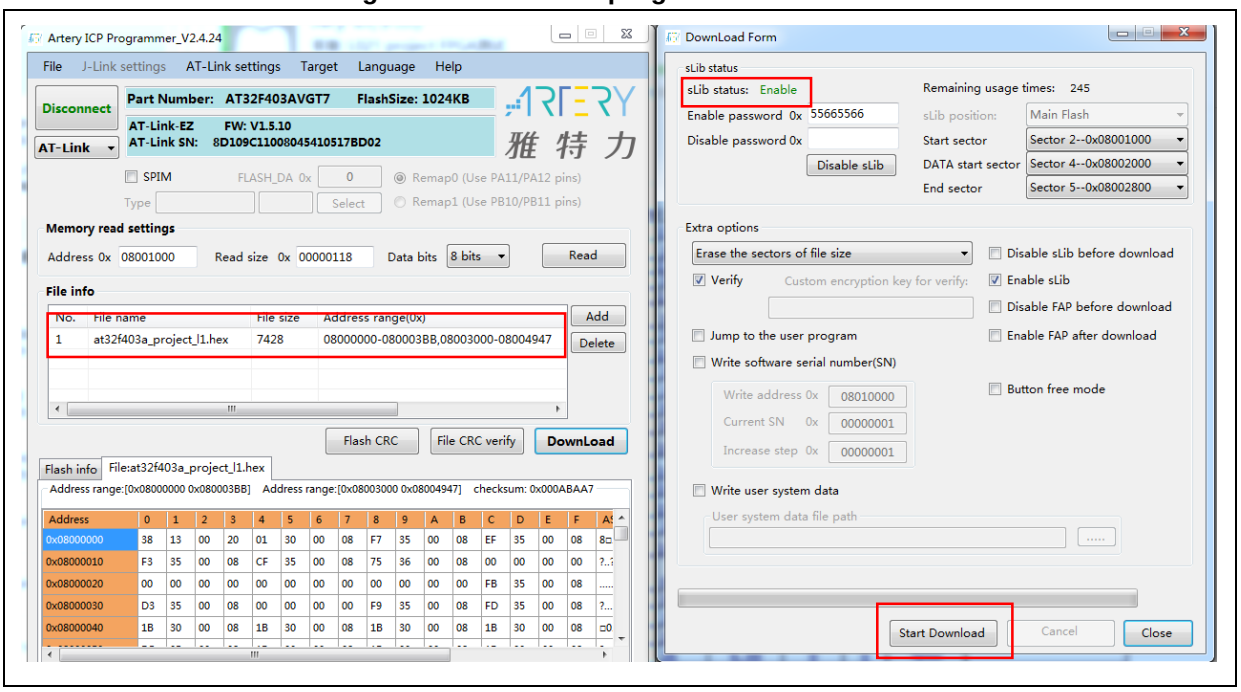
(3) End users also can use ICP Programmer to set an offline project and save to AT-Link, and then complete offline programming to MCU through AT-Link, as shown in Figure 45.

Figure 45. Offline programming to MCU via AT-Link



(4) After completing step 2/3, end users can get the MCU with programmed SLIB area (SLIB status: enabled), and program the application code to MCU through online or offline programming, as shown in Figure 46.

Figure 46. End users program codes to MCU



4.2 Integrate and program codes

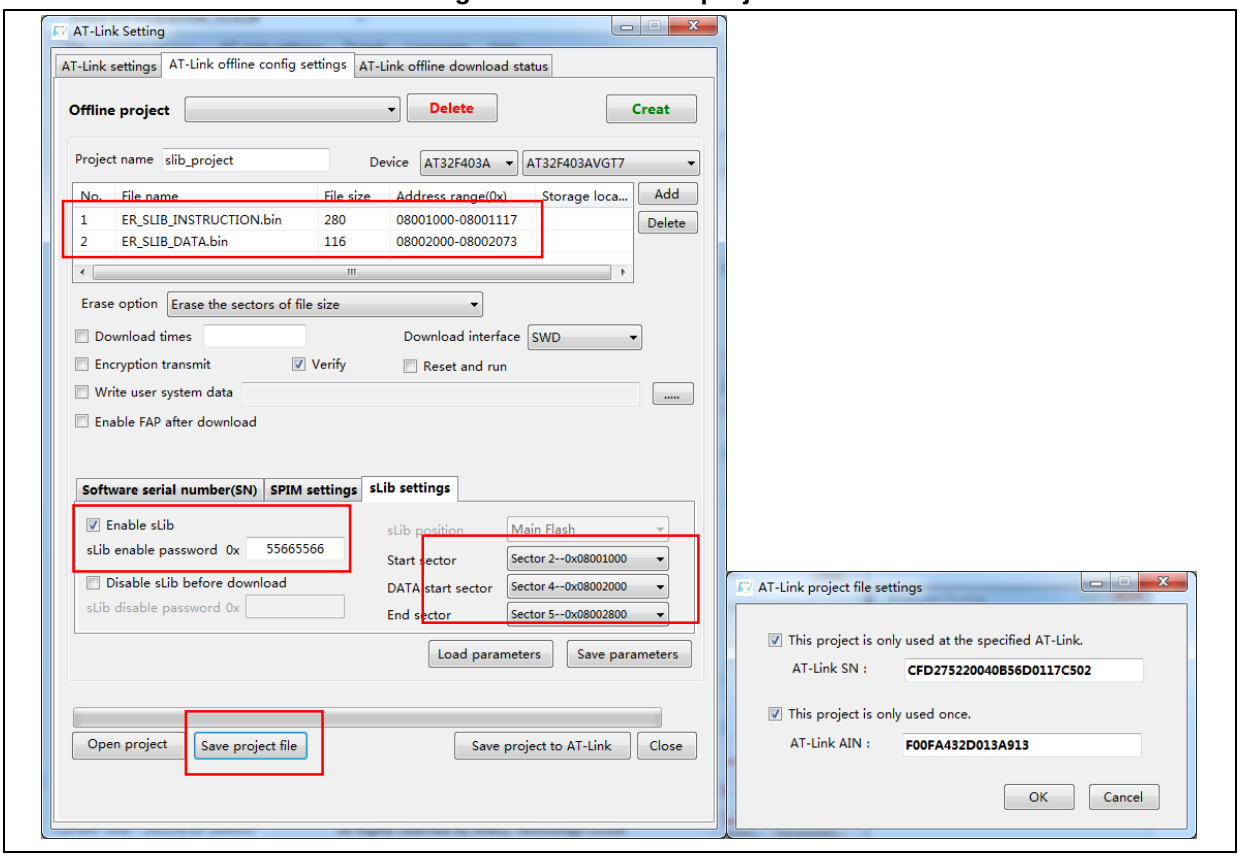
Integrate the SLIB code of solution provider and the end user application code to an offline project, and then download the integrated code to MCU through AT-Link offline programming. The process is as follows:

(1) The solution provider handles the compiled project as aforementioned to get a slib.bin file;

(2) The solution provider uses ICP Programmer to generate an offline project and save it to PC. Parameters (such as number of download, project files binding to AT-Link and enable FAP after download) can be configured as needed. Save the offline project as follows.

Note: The offline project is encrypted. To enhance security, the solution provider also can set the slib.bin file to an encrypted slib.benc and then add it to the offline project. In this case, the offline project can only be used on the AT-Link with the corresponding encryption key.

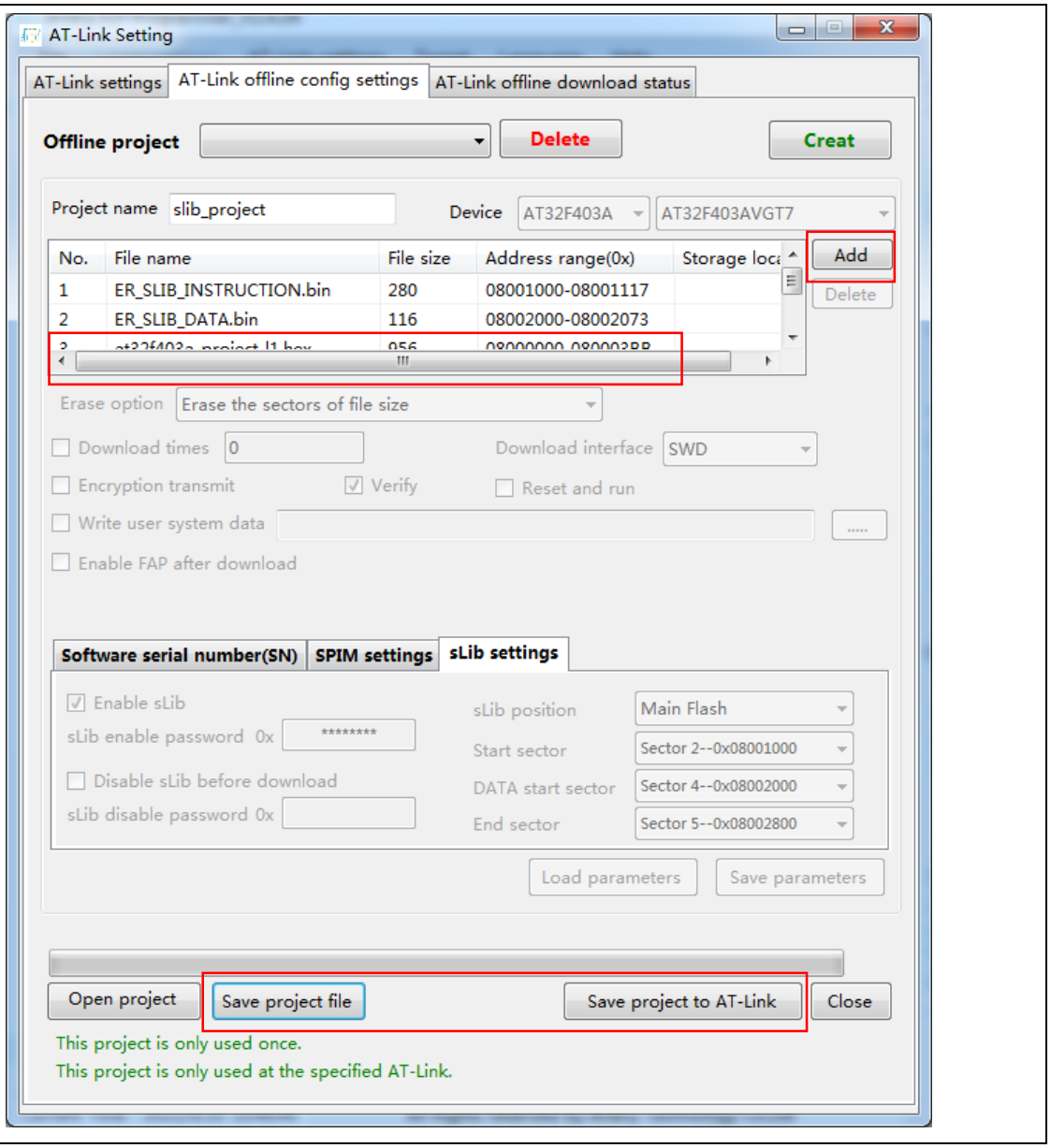
Figure 47. Set offline project



(3) After obtaining the offline project, the end user should use ICP Programmer to open the project file and add the application codes to the offline project; then save to PC or AT-Link, and perform offline download. Figure 48 shows how to add the project file.

Note: To protect codes from being leaked or decoded, do not other change settings when adding code file to the offline project, which requires the solution provider to configure the final settings in advance.

Figure 48. Add project file



5 Revision history

Table 2. Document revision history

Date	Version	Revision note
2021.05.21	2.0.0	Initial release.
2021.11.01	2.0.1	Optimized format.
2022.4.13	2.0.2	Modified the configurable range of sLib in the Flash.

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