Application Note

Use the MMU to protect FLASH partitions in multi-user scenarios

Introduction

In the process of embedded product development, sometimes there are scenarios in which multiple users are required to develop application software in different stages within a single MCU. In this scenario, the codes and data of each user may not be shared with other users due to copyright or security considerations. So how can such problems be solved?

This document is mainly aimed at guiding users how to use the Nsing MCU series products in the above-mentioned application scenarios. By using the embedded memory management unit (Memory Management Unit, MMU), it achieves the multi-user areas division and manages access permissions of the FLASH main storage area, so as to solve the problem of code copyright protection and data security in the multi-user development process. Therefore, it can be widely used in various scenarios such as copyright protection, sensitive data and multi-user code protection.

This document is only applicable to Nsing MCU products with embedded MMU. Currently, the supported product series include N32G451 series, N32G452 series, N32G455 series, N32G457 series, N32G4FR series, N32WB452 series, N32L43x series, N32G43x series and N32L40x series products.

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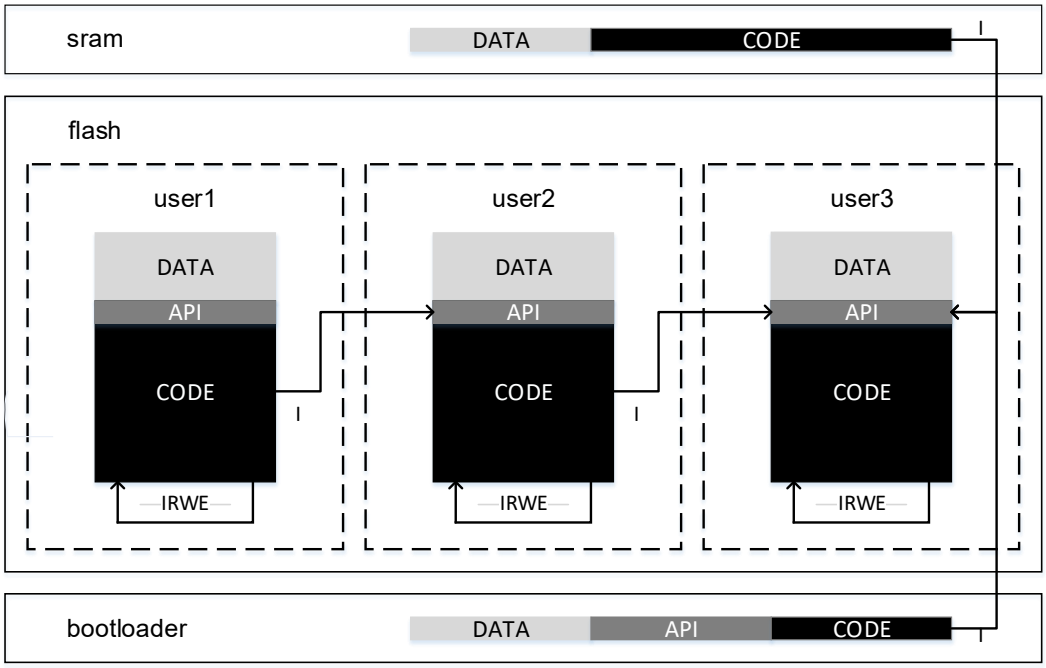
1 Implementation Mechanism Of Partition Protection

Generally, the FLASH memory (FLASH) in the MCU chip is connected to the memory bus, and the CPU can access any area in the FLASH without limit. The embedded FLASH should be divided into multiple user areas and protected in a single MCU to avoid different users from directly reading or modifying FLASH contents of other user areas by CPU instructions. We can use embedded MMU in the Nsing MCU, which can set the FLASH main memory partition and access permissions, at the same time can protect all the application code and data from illegal access and tampering. It also indicates illegal access errors to the memory and protected registers, all unauthorized operation will trigger the MMU abnormal alarm. Thereby it can achieve multi-user FLASH partition protection.

Figure 1-1 MMU Partition Protection Implementation Mechanism



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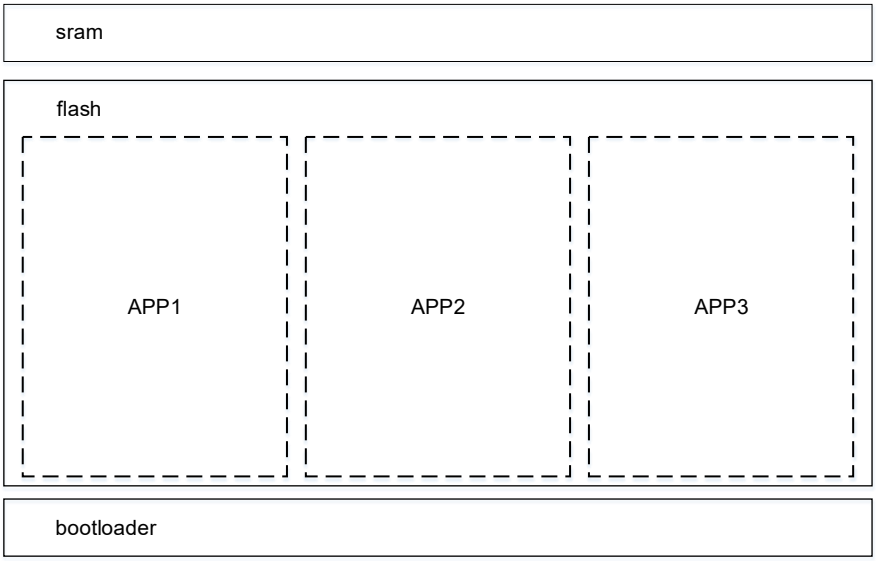
2 Function Description Of The MMU

MMU can realize partition and access permissions management of FLASH main memory, and can divide independent storage spaces for different applications of MCU (see Figure 2-1), and manage access permissions.

Figure 2-1 Memory Area Division



2.1 User Area Division

The FLASH main memory can be divided into USER1 (default), USER2, and USER3 at most. In practice, the user area can be divided into the following situations. For the settings of each situation, refer to Table 2-1

Table 2-1 User Partition Setting Instructions

Description	Partition setup sequence	FLASH space size involving authority management(3)			Instructions
		user1	user2	user3	
There are no partitions and the default is the user1 zone	-	-	-	-	The user1 area is flash_size and does not have the access permission management function.
Set one partition , do not keep the default user area(1)	user1	flash_size	-	-	
Set one partition, Keep the default user area (user1)(2)	user3	-	-	user3_size	The sum of the sizes of user1 and user3 is flash_size. User1 does not have the access permission management function.
Set two partitions, do not keep the default user area	user3→user1	user1_size	-	user3_size	The sum of the size of user1 and user3 is flash_size.
Set two partitions, do not keep the default user area	user3→user2	-	user2_size	user3_size	The sum of the size of user1, user2, and user3 is flash_size. User1 does not have the access permission management function.

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Set up three partitions	user3→user2→user1	user1_size	user2_size	user3_size	The sum of the size of User1, user2, and user3 is flash_size

Notes:

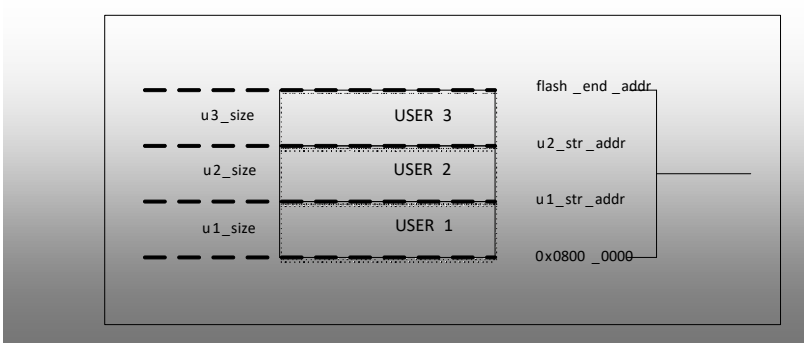
(1) "do not keep the default user area" means that all the space of FLASH main storage area is divided into user areas through partition Settings, and each partition involves access permission management function;

(2) " Keep the default user area " means that user1 will not be partitionized, that is, user1 area will be left open and access permission management is not involved;

(3) " FLASH space size involving authority management" refers to the FLASH main storage space with partition size set.

When the FLASH main memory is divided into three regions, USER1 (default), USER2, and USER3, as shown in Figure 2-2. The granularity of the partition is 16KB.

Figure 2-2 FLASH Main Storage Area Division Relationship



For details about how to set user partitions in the FLASH primary storage area, refer to Table 2-2. You can divide the FLASH main memory by setting the size of each user partition. Partition settings are static settings. Once set, the MCU will automatically load the configuration every time it is powered on. In particular, partition settings can only be operated once, and the operation is irreversible.

Table 2-2 FLASH Main Storage Area Partition Setting Instructions

Partition users(3)	The storage area	Partition size range
USER1	0x0800_0000 ~ (0x0800_0000 + u1_size - 1)	16KB(1) ~ (flash_size) KB
USER2	(0x0800_0000 + u1_size) ~ (flash_end_addr - u3_size)	0 KB ~ (flash_size - 32)KB
USER3	(flash_end_addr - u3_size + 1) ~ (flash_end_addr)(2)	0 KB ~ (flash_size - 16)KB

Notes:

(1) The granularity of the partition is 16KB;

*(2) Flash_end_addr varies according to model, and the corresponding flash_size is also different. Flash_size should be the sum of the size of the flash_area USER1, USER2, and USER3. The size is (flash_*end_addr - 0x0800_0000 + 1) KB.

(3) ***User partition settings cannot be reset***

2.2 Access Permission Management

The operation permissions of each user area of FLASH main memory are managed through user area division to realize memory access control. Table 2-3 provides the access permissions of each user area before and after FLASH main memory division.

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Table 2-3 User Permission Table

	Visited area					
	user1[4]		user2		user3	
Program ownership /	Whether the partitions		Whether the partitions		Whether the partitions	
Access method	N[1]	Y	N	Y	N	Y
user1 code	IRWE[2],[3]	IRWE	IRWE	I	IRWE	I
user2 code	IRWE	I	IRWE	IRWE	IRWE	I
user3 code	IRWE	I	IRWE	I	IRWE	IRWE
SRAM1/2 code	IRWE	I	IRWE	I	IRWE	I
DMA	RW	-	RW	-	RW	-
JTAG/SWD	IRWE	I	IRWE	I	IRWE	I

Notes:

[1] Before the partition, USER1, USER2, and USER3 are regarded as the same area, and all FLASH space is USER1 by default;

[2] I represents addressing, R represents reading, W represents writing, and E represents erasing;

[3] "Write Protection (WRP) Enable" is at the same level as "Access Rights Management for MMU Partitions".

[4] If the USER1 area size is not set (refer to Section 3.2.1 to Section 3.2.3 for "Operation steps"), the USER1 area does not have access permission management.

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3 Operation Instruction

You can partition the FLASH main memory area in MCU by using the Nations MCU Download Tool on the PC provided by Nsing. For details about how to use the Tool, refer to *Nations MCU Download Tool User Manual*.

3.1 The Operating Environment

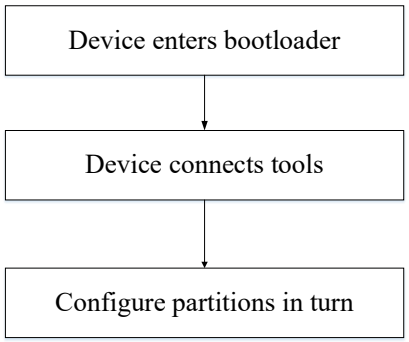
- Hardware environment: PC (Windows XP/7/10), development board N32G4XVL-STB V1.0 (including N32G457VEL7 chip)
- Target device: N32G457VEL7 chip
- Software environment: Download tool (Nations MCU Download tool. Exe), USB DFU driver or USB-to-serial driver (optional)

Note: Bootloader supports USB interface or USART interface download program, please confirm that the USB DFU driver or USB-to-serial port driver has been installed before using. At the same time, confirm that the target device has entered the Bootloader state, so that the device can be connected to the download tool normally. For details about how to make the target device enter the Bootloader state, please refer to the user manual of the target device chip. This document uses the N32G457VEL7 chip to download using the USART interface as an example for illustration.

3.2 Operation Steps

Figure 3-1 shows the process for dividing user areas in the FLASH main memory area. The following describes how to set partitions.

Figure 3-1 Partition Setup Steps



3.2.1 Device Enters The Bootloader

Connect the N32G457VEL7 BOOT0 pin to VDD, PB2 pin is connected to GND, then power on the chip and enters the Bootloader.

Note: For the development board N32G4XVL-STB V1.0, if using the USART interface, then connect the USB Debug Port interface for power supply, otherwise use the USB COMM interface for power supply.

3.2.2 Device Connection Tool

Double-click Nations MCU Download Tool.exe to open the download tool. The interface is shown in Figure 3-2. Here, please focus on the "Select Device" area. The interface defaults to "USART". Select the matching port number as the device. The "COM port number" can be viewed through the "Device Manager" of the PC. The serial port connected to the MCU in Figure 3-2 is identified as "COM3". At the same time, set the baud rate of USART (the default configuration "115200" can be used), click the "connect" button, the left display interface will prompt "The device is connected!". At this time, the device and the tool have been connected normally. Note: USART1 in the Bootloader of N32G457VEL7 uses PA9 and PA10 as TX and RX respectively. Please ensure that PA9 and PA10 are properly connected to TX and RX of the serial port.

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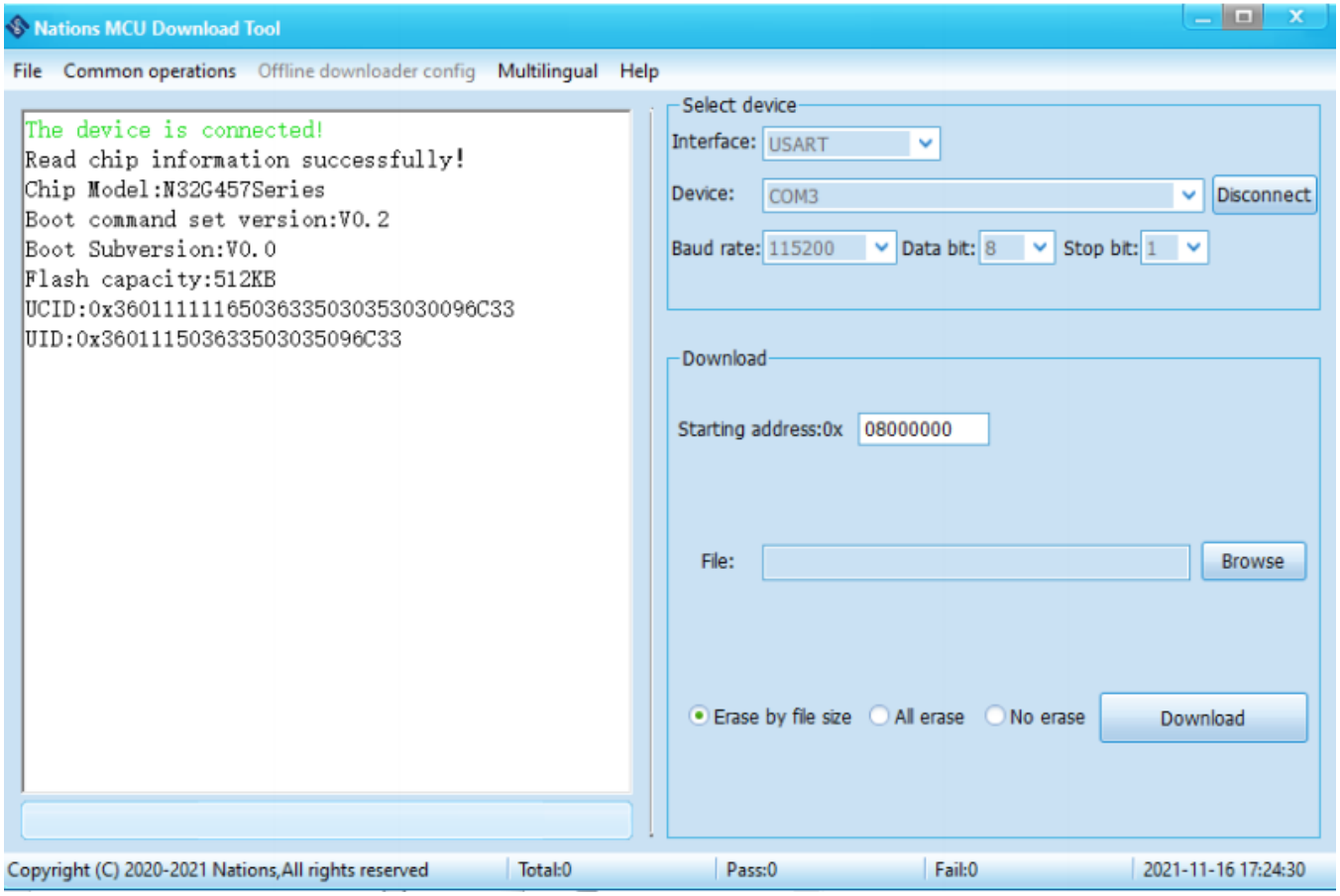
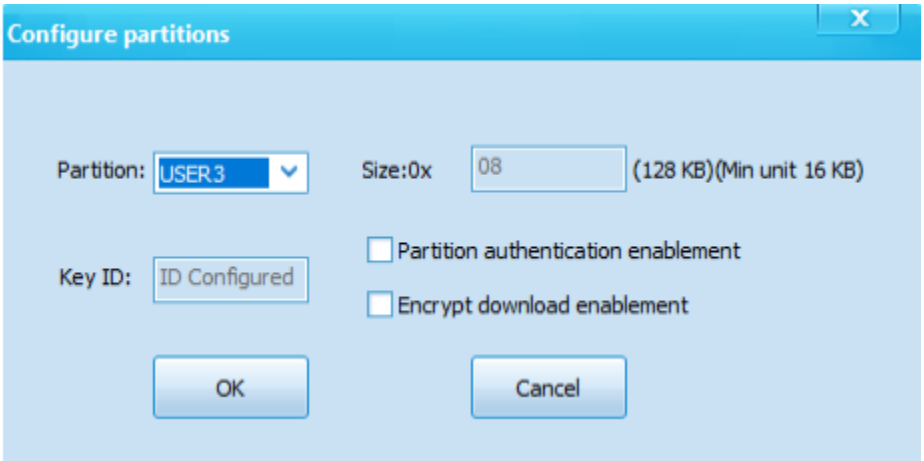
Figure 3-2 Download Tool Interface



3.2.3 Configuration Partition

Click the "Configure partition" button in the "Common operations" area to pop up the Configure Partition dialog box, select the partition user ID (USER1, USER2 or USER3) in turn, and enter the size of the partition (the value is set in the unit of partition granularity 16KB). As shown in Figure 3-3, suppose you need to partition a 32KB area for USER3, select "USER3" for the partition and enter 0x02 for the size. Click "Configure Partition" to confirm the configuration partition and complete the area division of the current user ID.

Figure 3-3 Interface For Configuring Partitions



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Notes:

(1) The partition configuration operation is irreversible, please operate with caution

(2) If multiple partitions need to be configured, each user can enter the Bootloader configuration respectively. For details about the configuration size and sequence, refer to Table 2-1 and Nations MCU Download Tool User Manual. Improper operations may lead to configuration failure.

3.2.4 Program Download

After the partition settings take effect, the user area cannot be accessed using the debugging interface. Therefore, there are two ways to download a user application:

(1) Before setting the partition, download the program through the debugging interface or Bootloader.

(2) After setting the partition, download the program through the built-in Bootloader (recommended);

3.2.4.1 Download Program Through The Debugging Interface

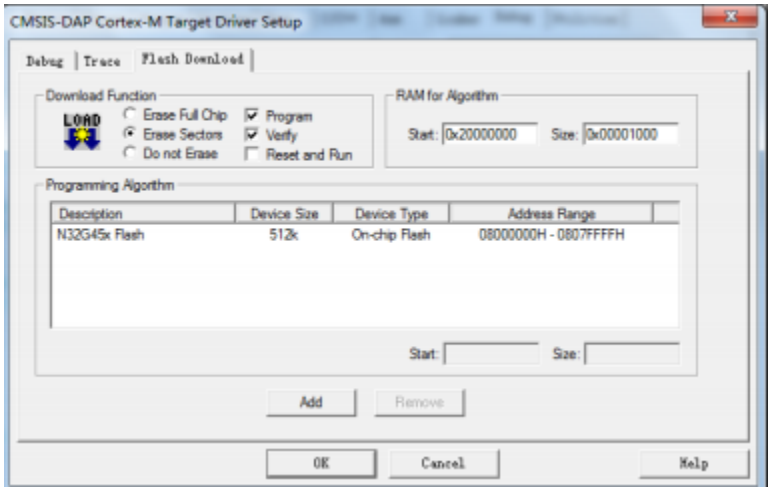
If the partition is not set, N32G457VEL7 can also use the debugging interface (JTAG or SWD) to download the program of each user. The specific operation steps are the same as the general situation and will not be described again.

The following highlights the precautions for downloading programs of each partition through debugging interfaces:

(1) Ensure that the start address position and size of FLASH and SRAM in the program are correct, and must match with the partition configuration (for setting the start address position and size of FLASH and SRAM, please refer to Section 4.1.1 " SCT distributed load file ");

(2) In order to ensure that the debug interface can download multiple programs in batches, in the MDK "Options for Target->Debug ->Use: xx Debugger->Settings->Flash Download" page, "Download Function" must not be selected "Erase Full Chip" "(see Figure 3-4).

Figure 3-4 Interface For Flash Download



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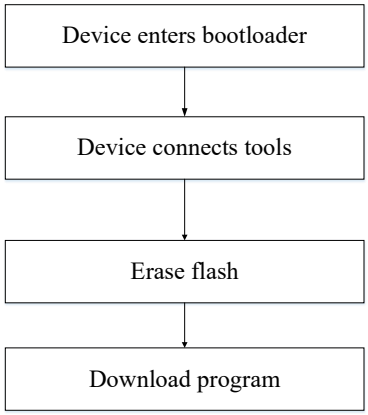
3.2.4.2 Download Program Through The Built-In Bootloader

Figure 3-5 Bootloader Download Operation Steps



In order to ensure the safety of the program update, the built-in Bootloader of the MCU also provides functions such as partition authentication and encrypted download (for the corresponding enabling and downloading procedures, please refer to the *Nations MCU Download Tool User Manual*). Here, the most basic program download process is introduced and described. As shown in Figure 3-5, the Bootloader download operation is roughly divided into 4 steps: the device enters the Bootloader, the device connects to tool, erases the FLASH and downloads the program.

- The specific process of program download is as follows:

1. Access the Bootloader and connect the tool

If the device is connected to a tool, skip this step and go to Step 3 to erase the FLASH. Otherwise, refer to Section 3.2.1 and Section 3.2.2 to perform Step 1 and Step 2 in sequence to ensure the normal connection between MCU and the download tool.

2. Erase FLASH

If the downloaded FLASH area is erased, go to Step 4. Otherwise, click “Erase sectors” in the “Common operations” area on the main window of the download tool. In the dialog box that is displayed, select the partition and enter the page address number (start page) and page number of the erased area. As shown in Figure 3-6, if the 128KB USER3 area is erased, the partition is selected as "USER3 ", the FLASH page size of N32G457VEL7 is 2KB, and the page number corresponding to the starting address 0x08060000 of USER3 partition is 0x00C0 and the page number is 0x0040. The erasing address ranges from 0x08060000 to 0x0807FFFF. After you confirm that the address range is correct, click "OK" and then confirm that the FLASH erasure operation is complete and the FLASH erasure is successful. Close the "Erase FLASH" dialog box and return to the main screen of the download tool.

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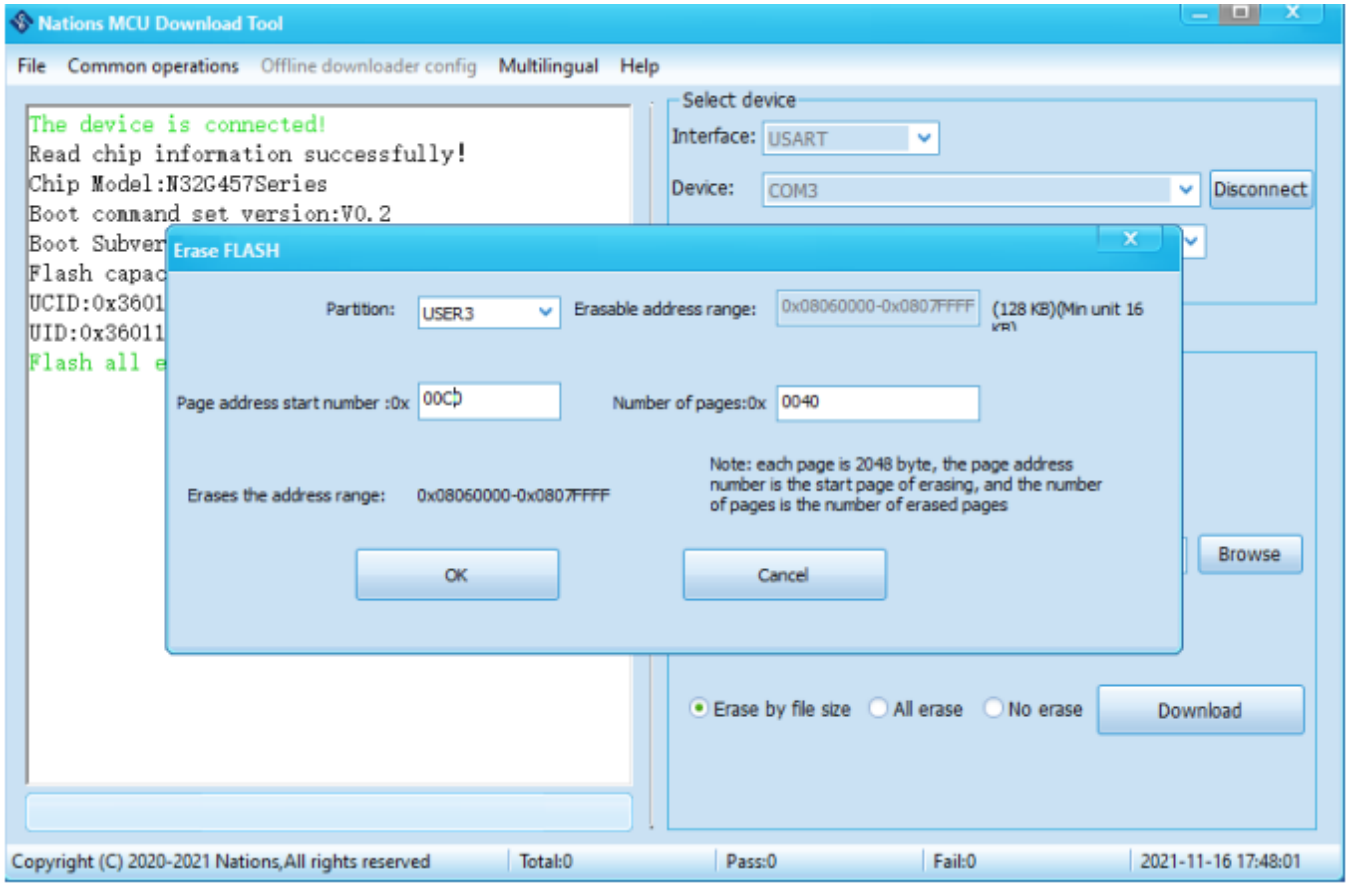
Figure 3-6 Erase FLASH Interface



3. Download the program

Click the "Partition download configuration" option in the "Common Operations" drop-down menu to open the "Partition download" dialog box. Sequentially check the partition download enable, select the file path (the path where the program BIN is located), and enter the starting address (the default is each partition) for USER1, USER2 and USER3. After checking that it is correct, click "OK" to automatically download and return to the main interface of the download tool. (See Figure 3-8).

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Figure 3-7 Partition Download Interface

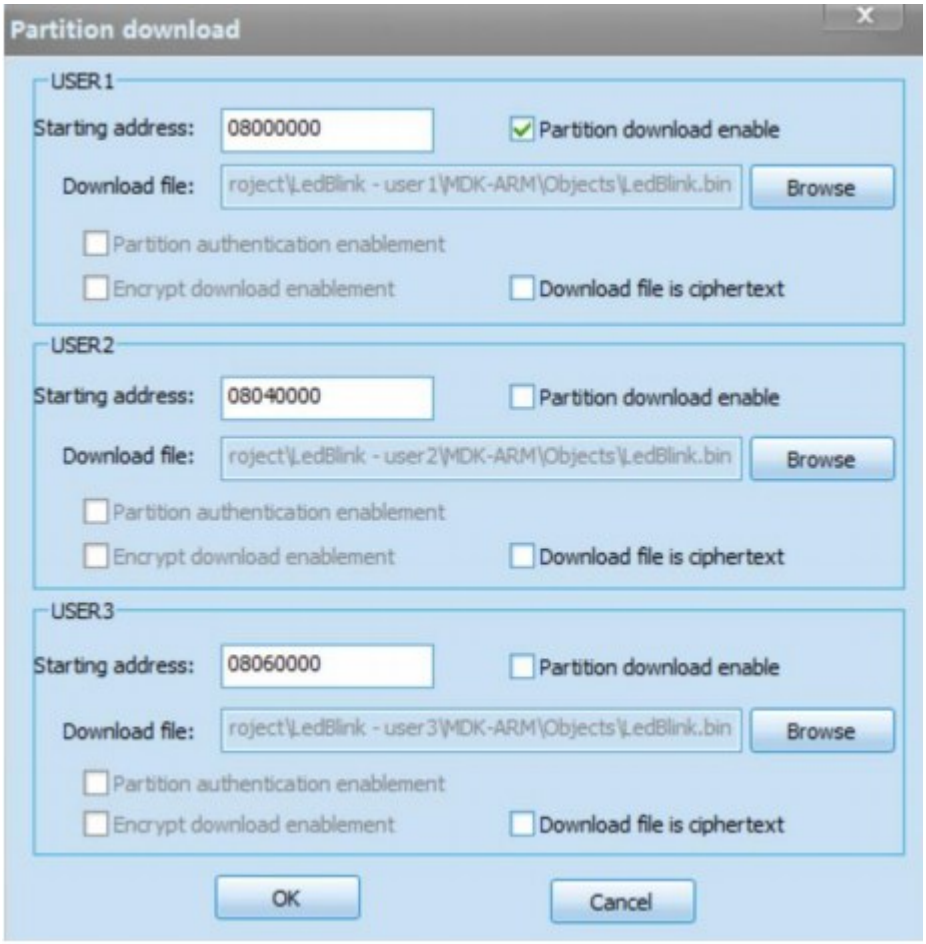

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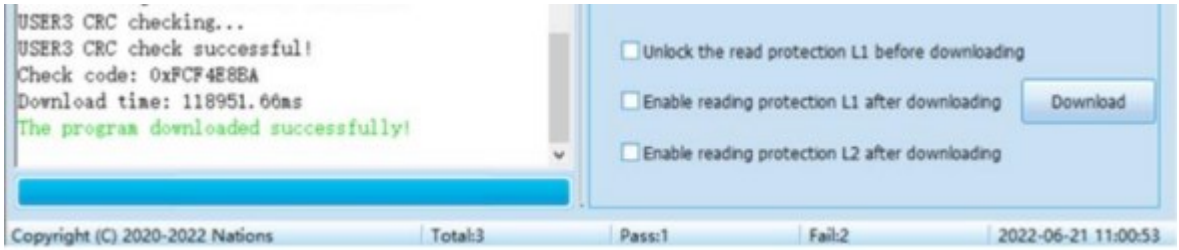
Figure 3-8 Download Interface



Notes:

(1) The sequence between "partition setup" and "Bootloader downloading program" is not mandatory. To ensure the security of the program, it is recommended to set the partition first, and then update the program;

(2) If no partition is set and the program is downloaded using the Bootloader, there is no need to operate "Partition download". In the "Download" area, select the file path (the path where the program BIN is located), enter the starting address, configure the erasing mode, and click "Download", wait for the download to complete. After setting the partitions, users can configure and download programs for USER1, USER2, or USER3 in "Partition download".

(3) The start address of download must match the start location of FLASH set by the program (refer to Section 4.1.1 "SCT Scattered Loading Files"), otherwise the program may run abnormally.

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4 Example Projects

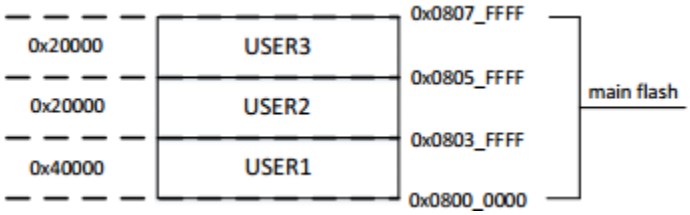
In order to show the execution mode of the program after the FLASH main memory area is partitioned, such as the function calling method between different partition areas, the different effects of reading data normally or abnormally, the interrupt processing method, etc., three example projects will be provided. Example projects are based on the LedBlink Demo extension implementation of GPIO module in N32G45x SDK (path:Nationstech.n32g45x_library\projects\n32g45x_EVAL\examples\GPIO).

The following subsections will focus on the section address configuration of the project, the generation of bin files, and the access operations between user partitions.

4.1 Section Address Configuration

Take the N42G457VEL7 chip as an example. Assume that the USER1, USER2, and USER3 user areas are 256KB, 128KB, and 128KB respectively. In this case, the partition relationship of the FLASH main memory area is shown in Figure 4-1. Each user can negotiate and divide the FLASH main memory area according to the actual code amount of the application.

Figure 4-1 Flash Main Memory Area Partition Relationship



In addition to partition the FLASH main memory area, to avoid global variable storage space conflicts among different partitioning programs, you can also partition the 144KB SRAM space of N42G457VEL7. Assume that the SRAM sizes of USER1, USER2, and USER3 are 72KB, 36KB, and 36KB respectively. The SRAM of each user can store the global variables in the corresponding program. Since chip program execution starts at address 0x08000000, USER1 serves as an end user and handles both stack and interrupt responses, so the SRAM of USER1 can also be used as stack space. The address specified by the global variable needs to avoid the stack (see the project's .map file for the stack top address).

SRAM partition is optional because the MMU of the N32G457VEL7 only manages partition access to the FLASH main memory area. SRAM is actually shared by USER1, USER2, and USER3. Dividing the SRAM into multiple regions is only for the stability of program execution (preventing overlapping of global variable spaces in different partitions) and does not provide the function of "protecting data security in user SRAM". According to the actual application, the space of global variables can be allocated by users through mutual negotiation without dividing SRAM.

After the user area is divided, the application programs of each user need to be downloaded to different address spaces. Therefore, the corresponding projects need to configure their respective section addresses to avoid program download failure or abnormal operation because the address space allocated by the program is inconsistent with the download address.

4.1.1 SCT Distributed Load File

The KEIL linker allocates each section address and generates the distributed load code according to the configuration of the SCT distributed load file, so the location of a section can be customized by modifying the SCT distributed load file.

- Select the SCT file generation method

SCT files can be automatically generated using MDK, or you can use user-defined SCT files. This selection can be configured through the MDK "Options for Target -> Linker->Use Memory Layout from Target Dialog" option, as shown in Figure 4-2.

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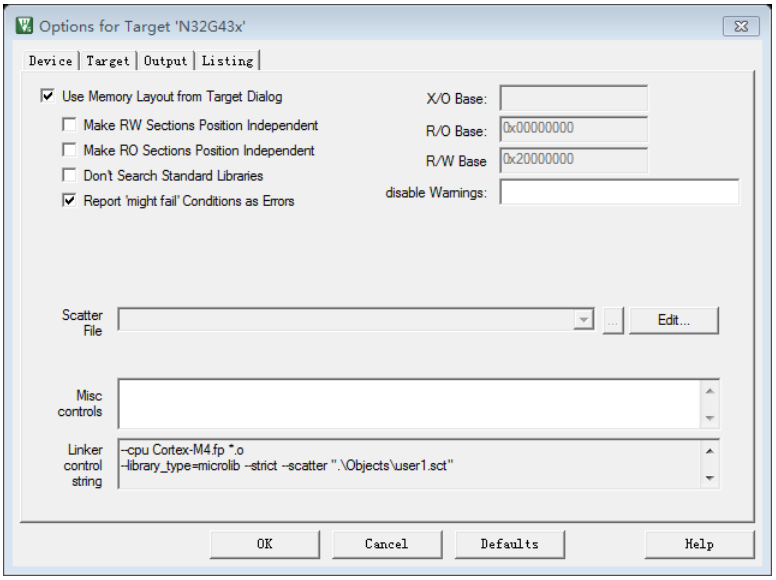
Figure 4-2 Choose How The SCT File Is Generated



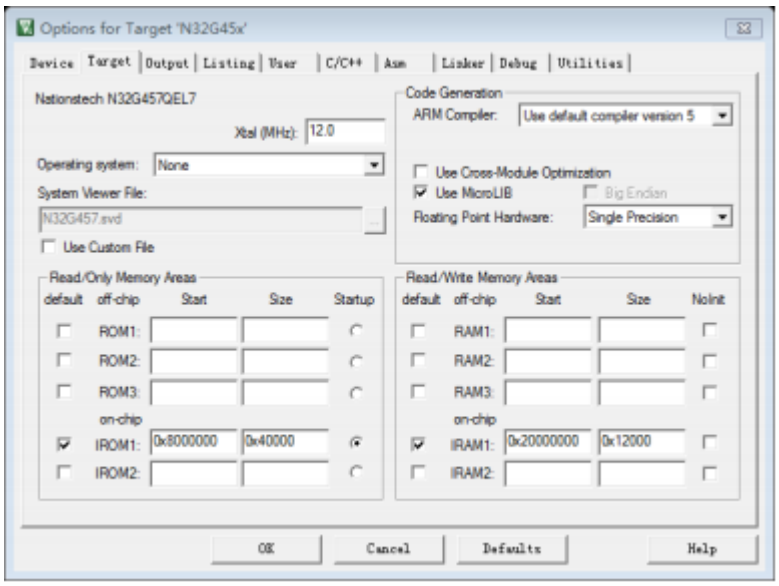
Select the "Use Memory Layout from Target Dialog" option (default for SDK) to generate the SCT file using the memory distribution configuration options of the "Options for Target -> Target" page. In this case, "Options for Target -> Linker-> Scatter File" is invalid. You cannot manually open the generated SCT File for editing. When the project construction is completed, MDK will generate a new SCT file to overwrite the old one.

If you need to manually edit the SCT file, uncheck the “Use Memory Layout from Target Dialog”, and specify the SCT file path in the options for “Options for Target -> Linker-> Scatter File” box. After that, clicking "Edit" will open the SCT file automatically, and users can edit the file manually.

- Configure storage distribution through Target control

After selecting "Options for Target -> Linker->Use Memory Layout from Target Dialog" in MDK, on the “Options for Target -> Target” page, the memory distribution configuration takes effect automatically. The default configuration in the SDK is automatically loaded after selecting the chip model on the “Options for Target -> Device” page. After setting the FLASH partition, reset the memory configuration is needed.

Figure 4-3 Target Storage Distribution Configuration



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In this example, USER1 is used as an example. Figure 4-4 shows the storage distribution configuration on the Options for Target -> Target page. In the on-chip part, IROM1 starts at 0x08000000 and its size is 0x40000, which are exactly the start address and size of USER1's FLASH. If IRAM1 has a start address of 0x20000000 and a size of 0x12000, they are the start address and size of USER1's SRAM region respectively. In the figure, IROM1 and IRAM1 are checked by default, indicating that the current configuration information will be used. If this parameter is unchecked, the storage configuration information will not be used.

The projects of USER2 and USER3 can reset the memory configuration in a similar way. For details, refer to the configuration of the corresponding example projects.

The path of the SCT file generated by MDK through the Target memory distribution configuration in Figure 4-3 is ".\Objects\ledblink.sct "(default setting of SDK), and the content of the SCT file is shown in Figure 4-4. You can manually edit the SCT file by referring to the file format.

Figure 4-4 SCT File Content

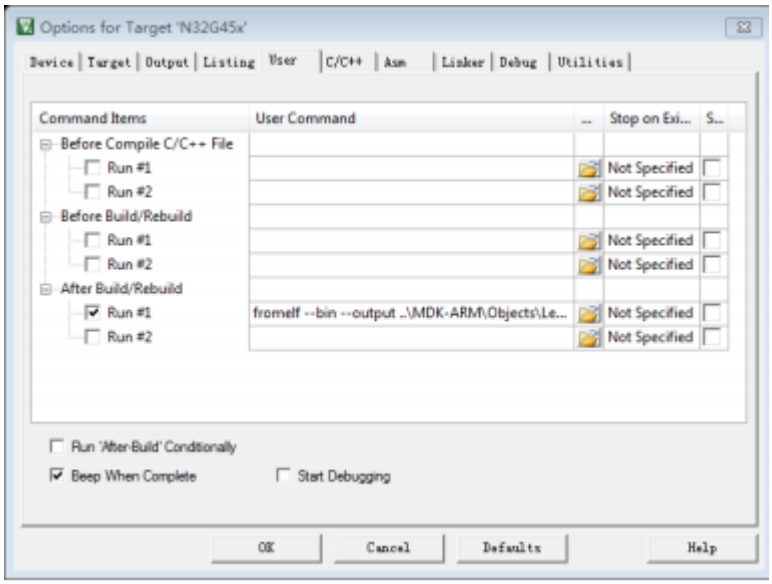
```
; *************************************************************
; *** Scatter-Loading Description File generated by uVision ***
; *************************************************************

LR_IROM1 0x08000000 0x00040000  {    ; load region size_region
  ER_IROM1 0x08000000 0x00040000  {  ; load address = execution address
   *.o (RESET, +First)
   *(InRoot$$Sections)
   .ANY (+RO)
   .ANY (+XO)
  }
  RW_IRAM1 0x20000000 0x00012000  {  ; RW data
   .ANY (+RW +ZI)
  }
}
```

4.2 Generating A Bin File

To download the program through *Nations MCU Download Tool*, you need to download the bin file of the program. Here, the fromelf instruction is used to generate a bin file. Users can also write their own Python scripts and enter user instructions to execute the scripts.

On the configuration page of "Options for Target->User" of MDK, the "After Build/Rebuild" column is added to call the fromelf tool to form the instruction to generate bin file (generate bin according to axf file), as shown in Figure 4-5

Figure 4-5 Interface For User Configuration



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The instruction to generate the bin file first calls the fromelf tool, followed by the tool's options, output file name, and input file name. If bin files and axf files are generated in the same folder "..\MDK-ARM\Objects", the user instruction of the sample project can be written as "fromelf --bin --output ..\MDK-ARM\Objects\LedBlink.bin ..\MDK-ARM\Objects\LedBlink.axf ".Therefore, in step 4 "Download program" of section 3.2.4.2 "Download program through the built-in bootloader ", select the bin file in this path.

4.3 Partition Access Operation

The sample projects for USER1, USER2, and USER3 work together to demonstrate mutual access between different partitions. Download the sample projects of USER1, USER2, and USER3 to the N32G457VEL7 chip respectively. After being powered on again, the chip with three partitions will execute the code according to the flow shown in Figure 4-6 (refer to the partition size configuration in section 4.1 "Section address configuration" for sample project). Chip program execution start address is 0x08000000, so USER1 as the end user is responsible for the control of the entire application process, including system initialization, stack processing, interrupt processing and other operations.

The MMU limits the read and write operations between different FLASH partitions. The access between partitions is realized by invoking API. For example, USER2 and USER3 have applications with certain functions (encapsulated in API form) respectively, and USER1 accesses the application functions of USER2 or USER3 by invoking the API. The MMU also restricts the partition user's relocation interrupt vector table operations (SCB->VTOR). Only the end user USER1 has the permission to set SCB->VTOR, and the address of the interrupt vector table must be in USER1's FLASH space. All unauthorized operations involving MMU (such as unauthorized reading or writing of debugging interface/program, unauthorized reading or writing of interrupt vector table address , etc.) will trigger the MMU abnormal alarm and inform the user in time in the way of reset or interruption.

The following highlights three partition access operations: calling API across partitions, reading and writing data across partitions, and interrupt handling.

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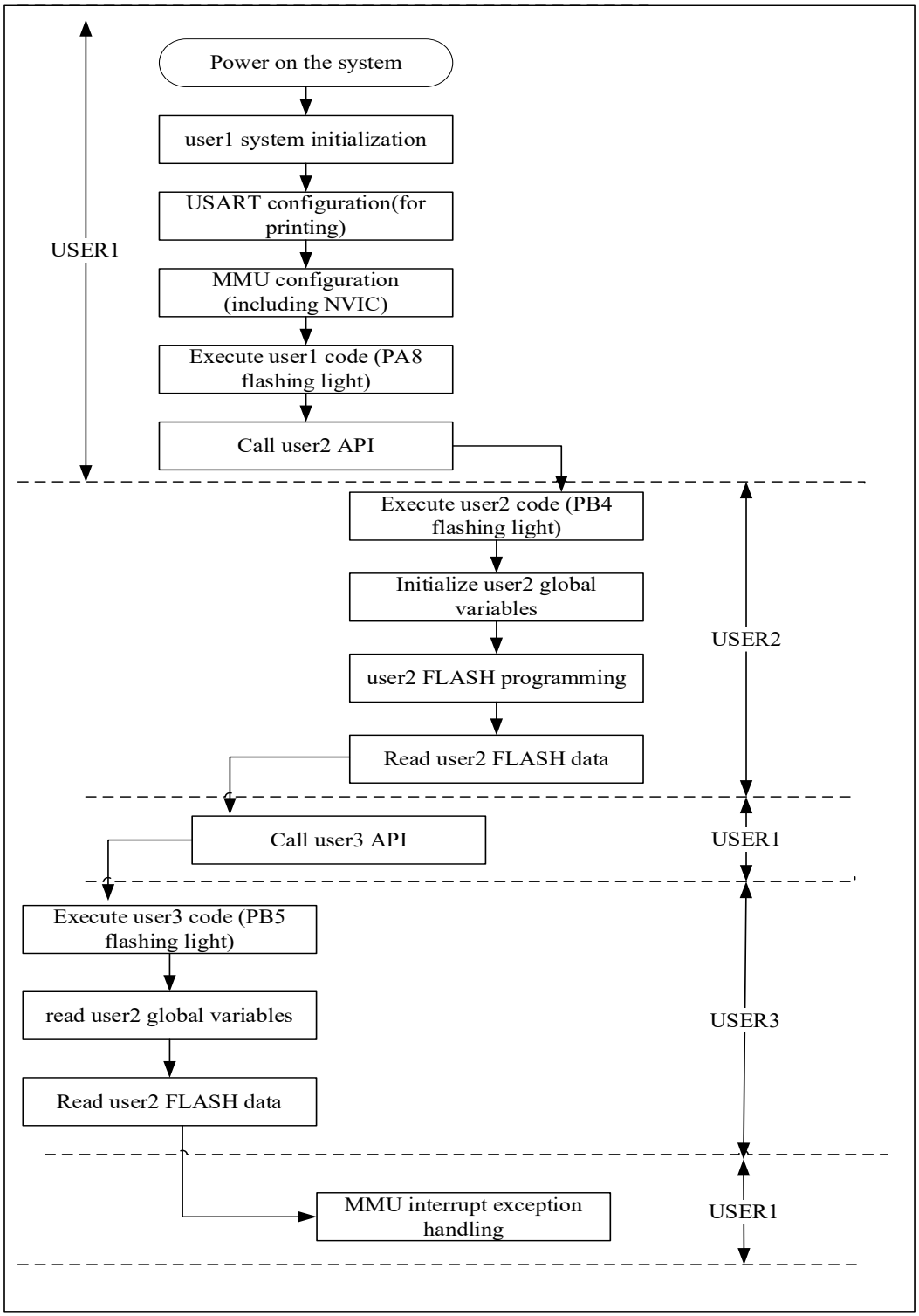
Figure 4-6 Example Project Execution Flow



4.3.1 Call API

The cross-partition call API is essentially the execution of a program by jumping to a function at a specified location. Functions can be assigned addresses automatically by the compiler (see the project's .map file), or they can be assigned addresses by users of each partition (recommended). In API scenarios that provide multiple cross-partition access,

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specifying fixed addresses for functions is clearly advantageous. The "__attribute__" keyword in MDK can specify the address.

In this case, USER1 calls the API of USER2 and USER3, respectively. This section describes how USER1 invokes USER2 API for reference.

The FLASH of USER2 ranges from 0x0804_0000 to 0x0805_FFFF, and the SRAM ranges from 0x2001_2000 to 0x2001_AFFF. In the user2_demo.c of sample project user2, place function "void Test_User2(void)") at address 0x08041000 (see Figure 4-7).

Figure 4-7 Specifies The Function Address

```
87  void Test_User2(void) __attribute__((section(".ARM.__at_0x08041000")));
88
89  /**
90   * @brief USER2_Demo
91   *
92   */
93  void Test_User2(void)
94  {
95      /* USART Configuration */
96      // USART_Configuration();
97      /* Output a message on Hyperterminal using printf function */
98      printf("\n\rHello! Here is USER2 Example!\n\r");
99
100     /* LED(PA9) Blinks */
101     Test_LedBlink(GPIOA, GPIO_PIN_9);
102
103     /* Initialize the global variable of USER2 */
104     Test_InitData();
105
106     /* Program USER2 FLASH */
107     Test_ProgramFlashWord(0x08042000, ~test_data);
108
109     /* Read USER2 FLASH */
110     printf("Get USER2 FLASH Data = 0x%X\r\n", *(__IO uint32_t*)(0x08042000));
111 }
```

USER2 provides the jump address of the function to other partition users so that they can jump to this address and call API functions. To facilitate co-development by multiple users, USER2 can use macros in the user2_demo.h file to define jump addresses and jump operations for functions (see Figure 4-8). After that, different users can get information about the jump to the application through the header file.

Figure 4-8 Jump Address And Function Pointer

```
44  typedef void (*pFunction)(void);
45
46  #define USER2_FUNC_ADDR (0x08016001)
47  #define API_FuncEntry2 ((pFunction)(USER2_FUNC_ADDR))
```

For USER1, you can choose to add user2_demo.h to the example project LedBlink - user1, or migrate the definition related to the USER2 jump (as shown in Figure 4-8, see user1_demo.h). After that, the program of USER1 can jump to the execution function of USER2 by calling the API "API_FuncEntry2()"; to realize operations such as PA9 flashing.

The example project demonstrates a jump to a no-argument function, allowing the user to further extend the API function definition (For example, a function with parameters, a function that returns a specified type, etc.).

Note: The nature of calling the API across partitions does not limit the functions to be jumped. But there is a special case that needs to be pointed out, it cannot jump to the reset function. The reason is that the Reset_Handler function processing in startup_n32g45x.s (as shown in Figure 4-9) involves cross-partition operations, which will trigger an MMU abnormal alarm.

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Figure 4-9 Reset_Handler Function Definition

```
170
171 ; Reset handler
172 Reset_Handler   PROC
173                EXPORT  Reset_Handler             [WEAK]
174                IMPORT  __main
175                IMPORT  SystemInit
176                LDR     R0, =SystemInit
177                BLX     R0
178                LDR     R0, =__main
179                BX      R0
180                ENDP
181
```

4.3.2 Read And Write Data MMU Abnormal Alarm

After the FLASH partition configuration takes effect, cross-partition data reading and FLASH programming, SRAM code accessing the user partition, DMA1/DMA2 or debugging interface accessing the user partition will trigger the MMU abnormal alarm (see Section 4.3.3 “Interrupt Handling” for the interrupt alarm mode and handling method). The example projects for USER2 and USER3 demonstrate normal and abnormal data reading and writing, respectively.

In the user2_demo.c file of the example project LedBlink - user2, the example demo demonstrates that USER2 reads and writes data in the owning partition area (SRAM or FLASH), as shown in Figure 4-7. Write the reserved value of the global variable test_data in USER2 SRAM to the position 0x0804_2000 specified by USER2 FLASH, and verify that the data written to address 0x0804_2000 is correct. The above operations are routine operations, and the specific operation methods will not be described. It is important to note that the initial value of the global variable of USER2 may not be 0 because the example project of USER2 did not execute the startup process. Please initialize the global variable before using it.

USER3 can read and write USER2 SRAM. However, USER3 cannot write to USER2 FLASH partition or read data from USER2 FLASH partition due to the partition permission management function of the MMU. In USER3's example project LedBlink - user3, the file user3_demo.c contains the sample demo code that lines 66 in Figure 4-10 will trigger an MMU abnormal reset alarm (the default).

Figure 4-10 USER3 Reading Data

```
48 /**
49  * @brief USER3_Demo
50  *
51  */
52 void Test_User3(void)
53 {
54     uint32_t i;
55
56     /* USART Configuration */
57     // USART_Configuration();
58     /* Output a message on Hyperterminal using printf function */
59     printf("\n\rHello! Here is USER3 Example\n\r");
60
61     /* LED(PA10) Blinks */
62     Test_LedBlink(GPIOA, GPIO_PIN_10);
63
64     /* Read USER2 SRAM */
65     printf("Get USER2 SRAM Data = 0x%x\r\n", *(__IO uint32_t*)(0x20012100));
66
67     /* Read USER2 FLASH (at address 0x08042000) */
68     for(i = 0; i < 20; i++)
69     {
70         data[i] = *(__IO uint32_t*)(0x08042000 + i);
71     }
72 }
```

4.3.3 Interrupt Handling

Since USER2 and USER3 cannot relocate the interrupt vector table (SCB->VTOR), all interrupt operations involving USER2 and USER3 are handled by the end user USER1.So the three users need to collaborate to complete the interrupt handling. USER2 and USER3 need to inform USER1 of their respective interrupt handling and add it to USER1's program for processing. If the operations involved in the interrupt service functions of USER2 and USER3 need to be kept secret, it is recommended that the interrupt handling content be encapsulated as an API assigned to a fixed location

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in the manner described in Section 4.3.1 "Call API", and that USER1 call the API to handle the corresponding interrupt.

There are two ways of MMU alarm: reset (default) or interrupt. In this example, we will demonstrate MMU interrupt handling. In the n32g45x_mmu.c file, “void MMU_Init(MMU_ALARM_MODE mode)” function is provided to configure the MMU alarm mode.

The example project LedBlink - user1 demonstrates how to use the MMU interrupt abnormalalarm. The user1_mmu_demo.c file provides the configuration method for the MMU interrupt abnormal alarm (sample code shown in Figure 4-11 MMU interruption alarm configuration), and the MMU interrupt handler function is defined in the user1_mmu_it.c file (see Figure 4-12). Any unauthorized operation by USER1, USER2, or USER3 triggers a call to the MMU interrupt handler function.

Figure 4-11 MMU Interruption Alarm Configuration

```
45  void NVIC_Configuration(void)
46  {
47      NVIC_InitType NVIC_InitStructure;
48
49      /* Enable MMU IRQChannel */
50      NVIC_InitStructure.NVIC_IRQChannel                   = MMU_IRQn;
51      NVIC_InitStructure.NVIC_IRQChannelPreemptionPriority = 0;
52      NVIC_InitStructure.NVIC_IRQChannelSubPriority        = 0;
53      NVIC_InitStructure.NVIC_IRQChannelCmd                = ENABLE;
54      NVIC_Init(&NVIC_InitStructure);
55  }
56
57 /**
58   * @brief  MMU_Config.
59   */
60  void MMU_Configuration(void)
61  {
62      /* NVIC Configuration */
63      NVIC_Configuration();
64
65      /* Configure mode of MMU alarm */
66      MMU_Init(MMU_INT_EN);
67  }
```

Figure 4-12 MMU Interrupt Processing Example

```
136 /**
137   * @brief  This function handles MMU interrupt request.
138   */
139  void MMU_IRQHandler(void)
140  {
141      NVIC->ICPR[2] |= (uint32_t)(1UL << ((uint32_t)16));;
142      *((volatile unsigned long  *)(MMU_BASE + 0x04)) = 0;
143      while(*((volatile unsigned long  *)(MMU_BASE + 0x04)))
144      {
145
146      }
147
148      printf("MMU Alarms~~~\r\n");
149  }
150
```


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5 Conclusion

The FLASH can be divided into three regions (USER1, USER2 or USER3) by using the embedded MMU in the Nsing MCU chip, and the access control function is provided for each user region. It can not only protect internal memory attacks (such as mutual access between different user areas, SRAM1/2 access, etc.), but also resist some external attacks (such as debugging interface access, DMA access, etc.).

Users can set partitions and download programs through the Bootloader. Once the partition is successfully set, the user area division and permission management functions take effect immediately. In addition, the partition configuration can only be set once and cannot be reset. The operation is irreversible. These features enable the MMU to prevent unauthorized access to the FLASH and effectively protect data and code stored in the FLASH. Thus, it plays a security role in application scenarios such as copyright protection and sensitive data protection.

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6 Version History

Version	Date	Changes
V1.0	2020.2.20	Initial release
V1.1	2020.5.15	Update some diagram and description
V1.2	2022.6.21	Update diagram and description according to download tool
V1.3	2023.6.20	Add N32G451 series

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