AN13543

基于LPC553x/LPC55S3x对外部NOR FLASH烧写映像并以之启动

第1版—2022年5月25日 应用笔记

目录

1 介绍

1.1 概述

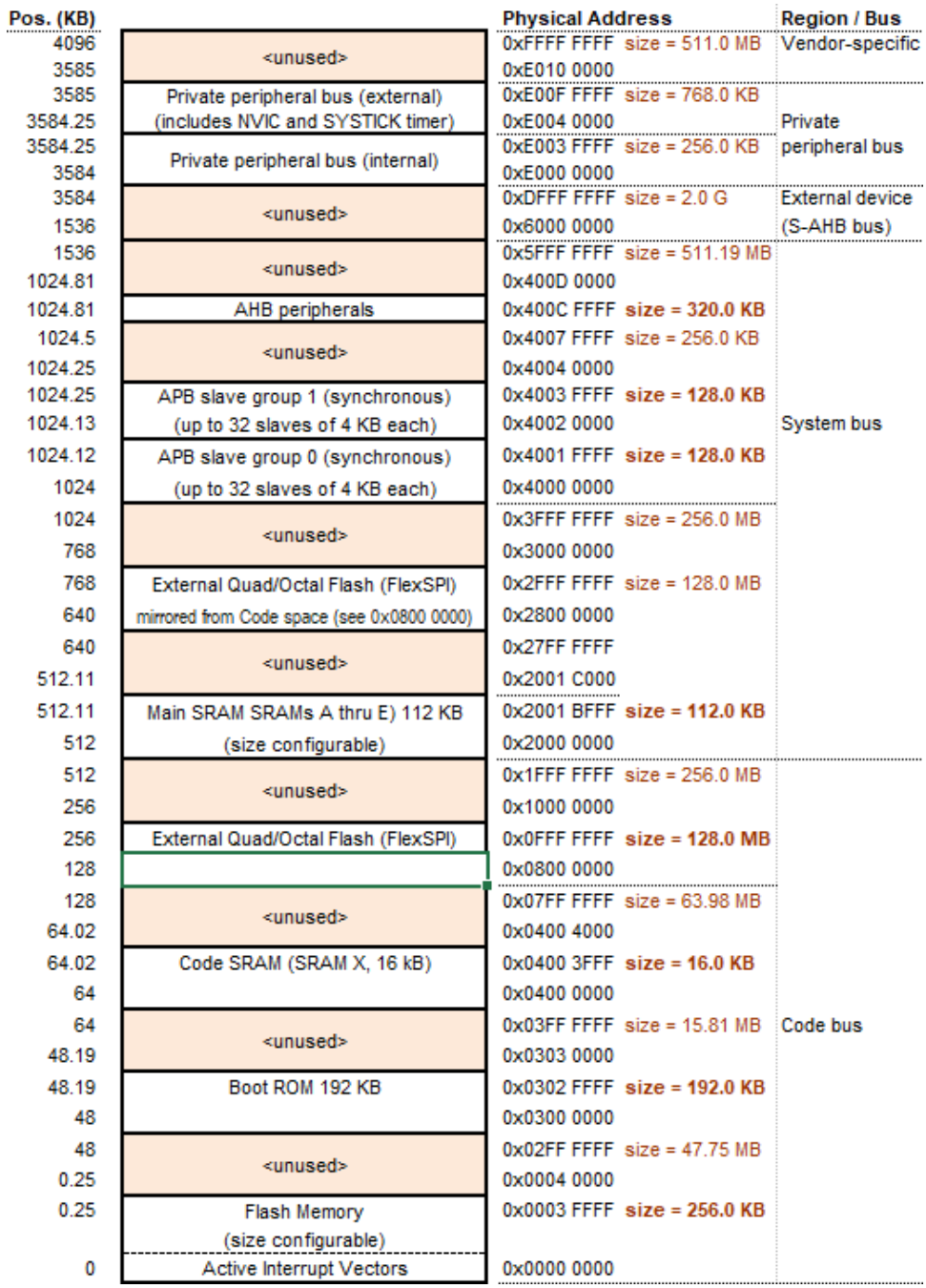
LPC553x/LPC55S3x是一个基于Arm Cortex-M33的微控制器，用于嵌入式应用。本文介绍了如何对外部NOR FLASH芯片烧写映像并从它来启动。

LPC553x/LPC55S3x既支持芯片内置FLASH映像启动，也支持外部NOR FLASH映像启动。为了擦除/烧写/读取芯片内置或外部FLASH，可使用ROM，通过ISP接口将启动映像下载到芯片内置和外部FLASH中。ROM也负责启动流程，它决定从片内FLASH、外部FLASH启动，或进入ISP模式。

CMPA/CFPA包含启动相关的参数。要更新设置，请在ISP模式下使用ROM，或在应用程序中使用ROM API。

1.2 存储区布局

图1显示了LPC553x的存储区布局。详情请见LPC553x用户手册（UM）中的附件。



Pos. (KB)		Physical Address	Region / Bus
4096	<unused>	0xFFFF FFFF size = 511.0 MB	Vendor-specific
3585		0xE010 0000	
3585	Private peripheral bus (external) (includes NVIC and SYSTICK timer)	0xE00F FFFF size = 768.0 KB	
3584.25		0xE004 0000	Private
3584.25	Private peripheral bus (internal)	0xE003 FFFF size = 256.0 KB	peripheral bus
3584		0xE000 0000	
3584	<unused>	0xDFFF FFFF size = 2.0 G	External device
1536		0x6000 0000	(S-AHB bus)
1536	<unused>	0x5FFF FFFF size = 511.19 MB	
1024.81		0x400D 0000	
1024.81	AHB peripherals	0x400C FFFF size = 320.0 KB	
1024.5	<unused>	0x4007 FFFF size = 256.0 KB	
1024.25		0x4004 0000	
1024.25	APB slave group 1 (synchronous) (up to 32 slaves of 4 KB each)	0x4003 FFFF size = 128.0 KB	
1024.13		0x4002 0000	System bus
1024.12	APB slave group 0 (synchronous) (up to 32 slaves of 4 KB each)	0x4001 FFFF size = 128.0 KB	
1024		0x4000 0000	
1024	<unused>	0x3FFF FFFF size = 256.0 MB	
768		0x3000 0000	
768	External Quad/Octal Flash (FlexSPI) mirrored from Code space (see 0x0800 0000)	0x2FFF FFFF size = 128.0 MB	
640		0x2800 0000	
640	<unused>	0x27FF FFFF	
512.11		0x2001 C000	
512.11	Main SRAM SRAMs A thru E) 112 KB (size configurable)	0x2001 BFFF size = 112.0 KB	
512		0x2000 0000	
512	<unused>	0x1FFF FFFF size = 256.0 MB	
256		0x1000 0000	
256	External Quad/Octal Flash (FlexSPI)	0x0FFF FFFF size = 128.0 MB	
128		0x0800 0000	
128	<unused>	0x07FF FFFF size = 63.98 MB	
64.02		0x0400 4000	
64.02	Code SRAM (SRAM X, 16 kB)	0x0400 3FFF size = 16.0 KB	
64		0x0400 0000	
64	<unused>	0x03FF FFFF size = 15.81 MB	Code bus
48.19		0x0303 0000	
48.19	Boot ROM 192 KB	0x0302 FFFF size = 192.0 KB	
48		0x0300 0000	
48	<unused>	0x02FF FFFF size = 47.75 MB	
0.25		0x0004 0000	
0.25	Flash Memory (size configurable)	0x0003 FFFF size = 256.0 KB	
0	Active Interrupt Vectors	0x0000 0000	

图1. LPC553x系列的FLASH存储区布局

1.3 启动选择

ROM有4种启动模式。ROM使用ISP引脚或CMPA配置来选择启动模式，即片内FLASH启动、FlexSPI启动、ISP启动或自动启动模式。更多详情，请参见启动模式和基于ISP引脚的ISP下载模式。

默认的启动源是使用 ISP 引脚。参见表1中的CMPA -> BOOT_CFG -> DEFAULT_BOOT_SOURCE介绍。

表1. CMPA配置中的默认启动源

CMPA->BOOT_CFG->DEFAULT_BOOT_SOURCE	描述
0	ISP引脚源（默认）
1	FlexSPI闪存
2	串行ISP启动
3	内部FLASH
4	自动启动，类似于ISP的自动启动选项

当CMPA->BOOT_CFG->DEFAULT_BOOT_SOURCE=0（默认）时，ISP引脚决定启动选项，如表2中所示。

表2. 基于ISP引脚的启动模式和ISP下载模式

启动模式	ISP1 (PIO0_7)	ISP0 (PIO0_5)	说明
内部FLASH启动	低	低	从内部FLASH启动
ISP启动	低	高	从UART/SPI/I2C/USB等下载映像
FLEXSPI启动	高	低	从外部NOR FLASH启动。
自动启动	高	高	按如下优先级启动：内部启动 -> 外部NOR FLASH启动 -> 恢复启动 -> ISP模式。

CMPA中的3'位决定ISP下载模式接口。默认情况下，`ISP_MODE0-2`为`3'b0`，即自动ISP模式。在大多数情况下，不需要修改CMPA中的`ISP_MODE`位。

表3. 基于DEFAULT_ISP_MODE位的ISP下载模式（6:4，CMPA中的字0）

ISP启动模式	ISP_MODE_2	ISP_MODE_1	ISP_MODE_0	说明
Auto ISP	0	0	0	LPC553x/LPC55S3x从`UART0`、`I2C1`、`HS_SPI`、`USB0-FS`或`CAN`探测活跃的外设。 从被探测的外设上下载映像。
USB HID ISP	0	0	1	下载USB0端口的映像。
UART ISP	0	1	0	下载映像。
SPI slave ISP (HS-SPI)	0	1	1	下载映像。
I2C slave ISP	1	0	0	下载映像。
CAN slave ISP1	1	0	1	下载映像。
Disable ISP	1	1	1	禁用ISP模式。

对于每个ISP接口使用的引脚说明，请参见LPC553x 的用户手册（UM）。

1.4 启动映像偏移

引导加载程序从启动媒介上指定的偏移查找启动映像。具体请参见表4。

表4. 启动映像偏移

启动媒介	应用程序映像偏移
内部FLASH启动	0x0
FlexSPI NOR FLASH启动	0x1000
SPI 1位NOR恢复启动	0x0

注意

CPU时钟须设置为CMPA字段中指定的启动速度。映像直接从内部FLASH或外部NOR FLASH启动。如果映像从FlexSPI NOR FLASH启动，应用程序不要改变FlexSPI时钟。否则，FlexSPI停止工作，应用程序挂起。

1.5 启动映像头

一旦确定了启动模式（选择为FlexSPI启动），并且在NOR FLASH上有可用的启动映像，ROM引导加载程序就会尝试从NOR FLASH上启动映像。映像的开头应与Arm Cortex标准向量表格式兼容，但它使用了预留的用于特殊ROM定义的位置（0值）。

对于内部FLASH，空间地址基值是`0x0000_0000`。对于FlexSPI，空间地址基值是`0x0800_0000`。

表5. 映像头的布局

偏移	字节数	标记	说明
`0x00`	4	（初始SP）	栈指针。
`0x04`	4	（初始PC）	第1条执行指令。
`0x08`	24	（向量表）	Cortex-M33向量表入口。
`0x20`	4	（映像长度）	映像长度。
`0x24`	4	（映像类型）	映像类型： • `0x0000` — 明文映像 • `0x0002` — 带CRC的明文映像 • `0x0004` — 带签名的XIP明文映像 • `0x0005` — 带CRC的XIP明文映像 • `0x0006` — SB3 文件
`0x28`	4	`offsetToExtendedHeader`	验证区块偏移或CRC32校验和。
`0x2C`	8	（向量表）	
`0x34`	4	`imageExecutionAddress`	映像加载地址

续表接下一页...

表5. 映像头布局（续）

偏移	字节大小	标记	说明
0x38	4	（向量表）	

本应用笔记着重介绍最简单的一种：明文映像。在这种模式下，映像类型为0x0000，映像长度为0。

2 通过blhost烧写NOR FLASH（非安全模式）

ROM支持通过FlexSPI接口访问来自不同供应商的各种四线/NOR SPI FLASH芯片。根据位于FLASH芯片上偏移0x400处的FLASH配置块（FCB），ROM可采用1位、2位（双线）、4位（四线）或8位（八线或HyperBus）模式。

为了正确地使用外部存储器件，请用相应的配置文件启动该器件。如果外部存储器件没有被启动，那么就不能用ROM ISP命令访问它。采用ROM中使用预先分配的存储器标识符（FCB），可以启动特定的，已支持的外部存储器件。

FCB位于FLASH芯片的偏移0x400处。它是一个由ROM预先分配的512字节的存储器标识符，描述了外部NOR FLASH的每个细节。Boot ROM利用FCB来获取NOR FLASH的所有信息，并通过FlexSPI配置NOR FLASH。有关FCB的详细信息，请参见LPC553x和LPC55S3x的参考手册中的第13.3.1.1.2章，FlexSPI NOR FLASH启动。

2.1 连接到NOR FLASH

本节介绍了如何使用blhost工具将映像烧写到外部NOR FLASH中，以用于启动。blhost工具使用UART、SPI、I2C和USB HID，通过ROM ISP模式与ROM代码通信。

表6. 用于NOR FLASH连接的FlexSPI引脚分配

FlexSPI引脚	GPIO
FLEXSPI_SSEL0	PIO0_21
FLEXSPI_SSEL1	PIO0_22
FLEXSPI_CLK	PIO0_19
FLEXSPI_D0	PIO0_6
FLEXSPI_D1	PIO0_4
FLEXSPI_D2	PIO0_3
FLEXSPI_D3	PIO0_2
FLEXSPI_D4	PIO1_16
FLEXSPI_D5	PIO1_15
FLEXSPI_D6	PIO1_27
FLEXSPI_D7	PIO1_29
FLEXSPI_DQS	PIO0_25

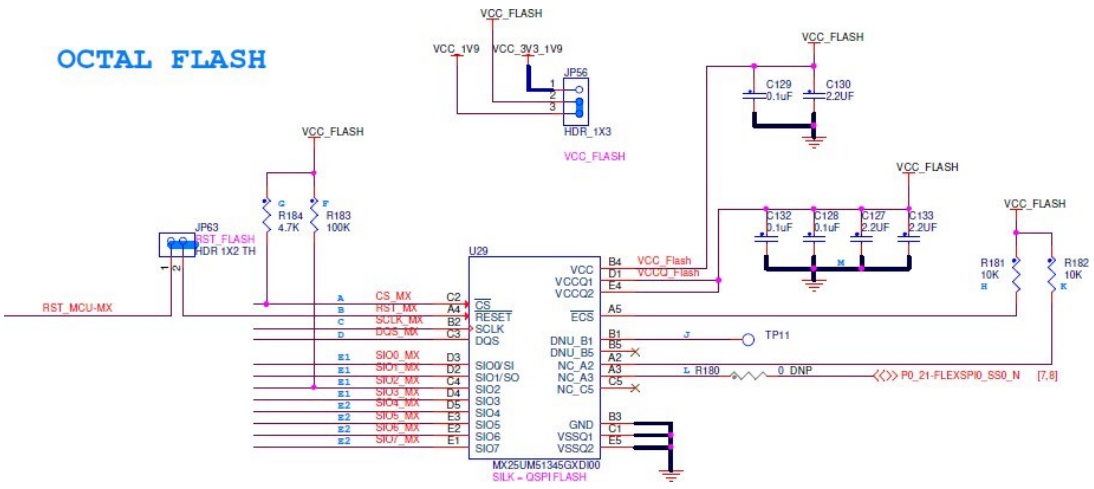


图2. LPCXpresso55S36上的NOR FLASH配置

2.2 配置FlexSPI NOR FLASH

FLEXSPI NOR FLASH配置参数的结构很复杂，但有一个简单的使用方法。为了对FCB进行编码，恩智浦定义了两个`uint32_t`变量，`option0`和`option1`。在大多数情况下，只需配置`option0`，而将`option1`留为`0x0000_0000`。

更多信息，请参阅LPC553x用户手册（UM）中的第11.3.1.2.9.2章， FLEXSPI NOR FLASH配置参数。

表7列出了一些最常用的选项。

表7. 选项代码

Option0代码	说明
`0xc0000001`	QuadSPI NOR - Quad SDR Read
`0xc0233002`	HyperFLASH 1V8 (50 MHz)
`0xc0333002`	HyperFLASH 3V0 (50 MHz)
`0xc0433005`	MXIC OPI DDR (OPI DDR enabled by default) (50 MHz)
`0xc0600002`	Micron NOR DDR (50 MHz)
`0xc0603002`	Micron OPI DDR (50 MHz)
`0xc0633002`	Micron OPI DDR (DDR read enabled by default) (50 MHz)
`0xc0803002`	Adesto OPI DDR (50 MHz)

2.3 通过blhost烧写NOR FLASH

LPCXpresso55S36使用MX25UM513连接到FlexSPI接口。

1. 将配置参数存储在RAM中。这些参数用于在下一步配置FLEXSPI。如图4所示，FLEXSPI的配置参数为`0xC0403001`。
2. 根据FLASH类型选择配置参数。

2.3.1 进入ISP模式

1. 要将启动模式设置为ISP启动，请将ISP0设为高（HIGH），ISP1设为低（LOW）。
2. 将FLEXSPI信号系统与电路板上的引脚正确相连。
3. 关闭电路板的电源。
4. 打开电路板的电源。使用USB电缆（连接到J3），将ISP的USB接口连接到PC。

2.3.2 测试ISP连接

测试MCU是否进入ISP模式，硬件连接是否正常。要用ROM进行ping，请使用`get-property1`命令。

```
$ ./blhost.exe -u 0x1Fc9,0x0025 get-property 1
Inject command 'get-property'
Response status = 0 (0x0) Success.
Response word 1 = 1258488064 (0x4b030100)
Current Version = K3.1.0
```

图3. Ping ISP连接

2.3.3 生成FLASH配置块

用`option0`代码生成FLASH配置块，并将配置块存储在RAM中。

```
$ ./blhost.exe -u 0x1Fc9,0x0025 fill-memory 0x2000F000 4 0xC0000001
Inject command 'fill-memory'
Successful generic response to command 'fill-memory'
Response status = 0 (0x0) Success.
```

```
$ ./blhost.exe -u 0x1Fc9,0x0025 configure-memory 0x9 0x2000F000
Inject command 'configure-memory'
Successful generic response to command 'configure-memory'
Response status = 0 (0x0) Success.
```

图4. 生成FLASH配置块（FCB）并配置FLASH

2.3.4 用blhost擦除/烧写NOR FLASH

现在，外部NOR FLASH已经配置成功，你可以对其擦除/烧写。

```
$ ./blhost.exe -u 0x1Fc9,0x0025 flash-erase-region 0x08000000 0x20000
Inject command 'flash-erase-region'
Successful generic response to command 'flash-erase-region'
Response status = 0 (0x0) Success.
```

图5. 擦除NOR FLASH

```
$ ./blhost.exe -u 0x1Fc9,0x0025 read-memory 0x08000400 0x100
Inject command 'read-memory'
Successful response to command 'read-memory'
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff
(1/1)100% Completed!
Successful generic response to command 'read-memory'
Response status = 0 (0x0) Success.
Response word 1 = 256 (0x100)
Read 256 of 256 bytes.
```

图6. 读取NOR FLASH

```
$ ./blhost.exe -u 0x1Fc9,0x0025 write-memory 0x08001000 boot_image.bin
Inject command 'write-memory'
Preparing to send 75464 (0x126c8) bytes to the target.
Successful generic response to command 'write-memory'
(1/1)100% Completed!
usbhid: received data phase abort
Response status = 10203 (0x27db) kStatusMemoryCumulativeWrite
Wrote 75464 of 75464 bytes.
```

图7. 烧写NOR FLASH

2.3.5 将FCB参数存储在NOR FLASH上

生成FLEXSPI NOR FCB并写入FLASH中，用于FLEXSPI启动。它需要一个位于偏移地址`0x08000400`处的FCB。当通过FLEXSPI接口从外部NOR FLASH启动映像时，该FCB用于配置FLEXSPI接口。每次当ROM试图从FLEXSPI FLASH启动映像时，都需要FCB。FCB是由之前的FLEXSPI配置参数（`0xc0000002`）生成的。将生成FCB和烧写参数都存储在RAM中。这些参数用于下一步生成FCB并烧写到FLASH中的`0x08000400`处。

注意

Boot ROM支持用一个特定的选项`0xF000000F`，将生成的FCB烧写到NOR FLASH存储器的起始位置（`0x08000400`）。

```
$ ./blhost.exe -u 0x1Fc9,0x0025 fill-memory 0x2000F000 4 0xF000000F
Inject command 'fill-memory'
Successful generic response to command 'fill-memory'
Response status = 0 (0x0) Success.
```

图8. 将FCB配置参数存储在RAM中

```
$ ./blhost.exe -u 0x1Fc9,0x0025 configure-memory 0x9 0x2000F000
Inject command 'configure-memory'
Successful generic response to command 'configure-memory'
Response status = 0 (0x0) Success.
```

图9. FCB生成并烧写到FLASH中，偏移地址为0x08000400

要检查FCB是否被写入，可读回0x08000400处的数据。

```
$ ./blhost.exe -u 0x1Fc9,0x0025 read-memory 0x08000400 0x200
Inject command 'read-memory'
Successful response to command 'read-memory'
46 43 46 42 00 04 01 56 00 00 00 00 03 03 03 00
00 00 01 00 00 00 00 00 00 00 00 00 01 00 02 00
01 07 00 00 01 0a 00 00 00 00 00 00 00 00 00 00
02 00 00 00 01 00 00 00 00 00 00 00 00 00 00 00
10 00 00 00 01 08 01 00 00 00 00 00 00 00 00 00
00 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
ec 07 13 07 20 0b 04 33 04 27 00 00 00 00 00 00
05 04 04 24 00 00 00 00 00 00 00 00 00 00 00 00
05 07 fa 07 20 0b 04 33 04 27 00 00 00 00 00 00
```

图10. 通过blhost工具读回FCB的信息

如图10所示，46 43 46 42是FCFB的ASCII字符串。它标示了FCB块的开始。

3 从外部NOR FLASH启动（非安全模式）

本节演示如何从外部NOR FLASH启动映像。详情请参见LPC553X用户手册（UM）中的非安全启动ROM。

Boot ROM支持几种映像类型，包括明文映像、带CRC的明文映像、带签名的XIP明文映像和带CRC的XIP明文映像。本节只讨论最简单的一种：明文映像。

3.1 FlexSPI NOR FLASH启动映像布局（单个映像）

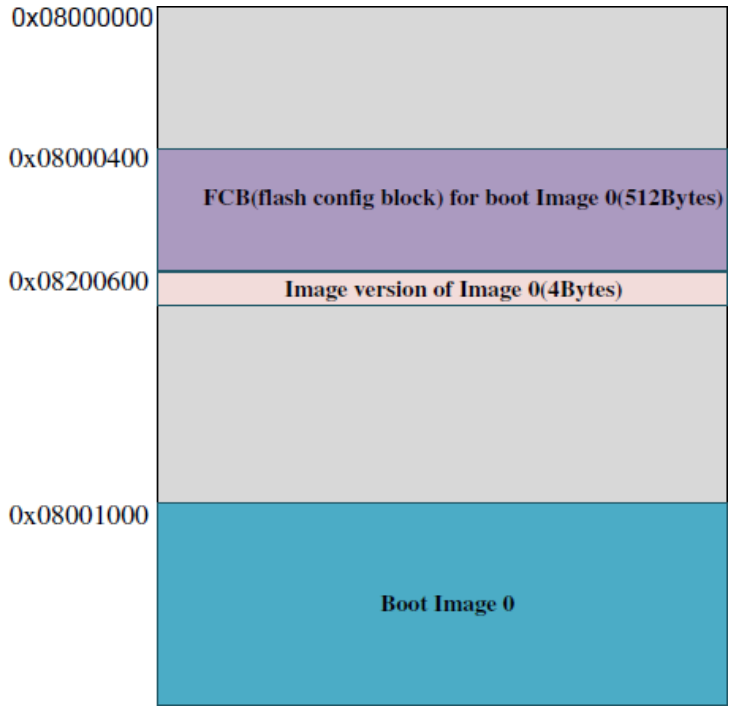


图11. FlexSPI启动映像布局（明文，单个印像）

FlexSPI启动映像地址必须是在`0x0800_1000`处（XIP、加载和执行地址相同）。须在`0x0800_0400`处写一个有效的FCB块。Boot ROM通过1位SPI模式获取FCB，用FCB信息配置NOR FLASH，并尝试启动NOR FLASH映像。

3.2 FlexSPI启动动手示例

3.2.1 准备FlexSPI启动映像

以SDK中的`led_blinky`演示程序为例，项目位置是：

```
\SDK_2_10_0_LPCXpresso55S36\boards\lpcxpresso55s36\demo_apps\led_blinky
```

1. 改变链接文件中的映像起始地址，开始地址必须是`0x0800_1000`。

led_blinky.c | LPC55S36_flash.scf | startup_LPC55S36.S | system_LPC55S36.c

```
43
44  #if (defined(__power_down__))
45    #define powerdownretention_RAMsize          0x00000604  /*
46  #else
47    #define powerdownretention_RAMsize          0x00000000
48  #endif
49
50  #if (defined(__powerquad__))
51    #define powerquad_RAMsize                   0x00004000  /*
52  #else
53    #define powerquad_RAMsize                   0x00000000
54  #endif
55
56
57
58  #define  m_interrupts_start                 0x08001000
59  #define  m_interrupts_size                  0x00000400
60
61  #define  m_text_start                       0x08001400
62  #define  m_text_size                        0x0003FC00
63
64  #define  m_data_start                       0x20000000 + powerdownret
65  #define  m_data_size                        0x0001C000 - powerdownret
66
67  ;#define  m_sramx_start                      0x04000000
```

图12. 更改链接器文件中的映像起始地址

2. 将BOARD_BootClockFROHF96M这一行注释掉，因为ROM使用PLL作为FlexSPI时钟源。当从外部存储器运行时，不可能改变PLL设置或时钟设置。当改变FlexSPI时钟设置时，设备必须从内部存储区（Flash或SRAM）运行。

```
47   */
48  int main(void)
49  {
50      /* Init output LED GPIO. */
51      GPIO_PortInit(GPIO, BOARD_LED_PORT
52      /* Board pin init */
53      BOARD_InitPins();
54
55      BOARD_BootClockFROHF96M();
56
57      /* Set systick reload value to ger
```

图13. 注释时钟配置

3. 为了编译和生成bin文件，要在用户选项中添加post build命令来生成二进制文件。编译该项目，led_blinky.bin就在*/mdk/debug* 文件夹中生成了。

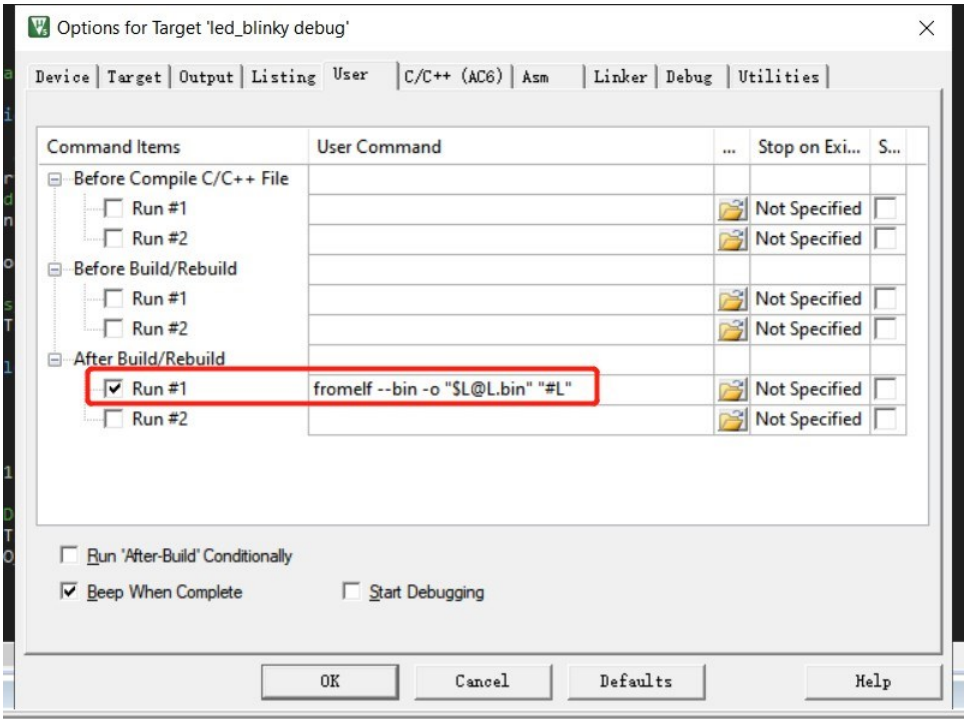


图14. 添加post build命令以生成.bin文件

3.2.2 将FlexSPI映像下载到NOR FLASH中

要把FCB写入`0x0800_0400`处，请按照“通过blhost烧写NOR FLASH”。要在`0x0800_1000`处下载led_blinky.bin，请使用`write-memory`命令。

图15显示了所有需要的`blhost`命令。

```
C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025  fill-memory 0x2000F000 4 0xC0000001
Inject command 'fill-memory'
Successful generic response to command 'fill-memory'
Response status = 0 (0x0) Success.

C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025  configure-memory 0x9 0x2000F000
Inject command 'configure-memory'
Successful generic response to command 'configure-memory'
Response status = 0 (0x0) Success.

C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025 flash-erase-region 0x08000000 0x20000
Inject command 'flash-erase-region'
Successful generic response to command 'flash-erase-region'
Response status = 0 (0x0) Success.

C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025  fill-memory 0x2000F000 4 0xF000000F
Inject command 'fill-memory'
Successful generic response to command 'fill-memory'
Response status = 0 (0x0) Success.

C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025  configure-memory 0x9 0x2000F000
Inject command 'configure-memory'
Successful generic response to command 'configure-memory'
Response status = 0 (0x0) Success.

C:\Users\YX\Desktop>blhost.exe -u 0x1Fc9,0x0025  write-memory 0x08001000 led_blinky.bin
Inject command 'write-memory'
Preparing to send 6284 (0x188c) bytes to the target.
Successful generic response to command 'write-memory'
(1/1)100% Completed!
Successful generic response to command 'write-memory'
Response status = 0 (0x0) Success.
Wrote 6284 of 6284 bytes.
```

图15. 烧写FCB并下载映像

3.2.3 执行NOR FLASH映像

将ISP启动引脚设置为外部NOR FLASH启动，按下电路板上的Reset（复位）引脚。板上的LED灯闪烁，意味着映像执行成功。

4 修订历史

版本号	日期	说明
0	2022年2月10日	初版发布
1	2022年5月25日	将LPC553x替换为LPC553x/LPC55S3x

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