Application Report
SWRA466A–February 2015–Revised May 2015

CC2538/CC26xx Serial Bootloader Interface

Aasmund Boe

ABSTRACT

This application report provides a brief overview on the serial bootloader that resides in ROM on the CC2538 and CC13xx/CC26xx devices. This document shows how the bootloader protocol can be used to perform basic operations like erasing and programming the flash of the devices. The device bootloaders support universal asynchronous receiver/transmitter (UART) and serial peripheral interface (SPI) as the protocol transportation layer. The example project is created in Visual Studio®, Visual Studio Express 2010 and utilizes a library called Serial Bootloader Library to demonstrate an implementation of the serial bootloader protocol on Windows®.

This application report covers UART and is intended to be used with associated example file, which can be downloaded from the following URL: http://www.ti.com/lit/zip/swra466.

Contents

Trademarks

1 Introduction

The main purpose of the CC2538 and CC26xx [(1)] ROM bootloader is to support functionality for programming a flash image into the device flash over either SPI or UART.

The scope of this document is to show how to use the bootloader to perform basic operations like erasing and programming flash. This document uses UART as the bootloader transportation layer.

[(1)] This document refers to the CC13xx/CC26xx device family as CC26xx for shortness.

2 ROM Bootloader

The built-in bootloader on the CC2538 and CC26xx devices start running after a power-on reset if there is no valid application image in flash, determined by an “image valid” field in the customer configuration area (CCA/CCFG).

Alternatively, the bootloader start if the so-called bootloader backdoor is enabled and the associated pin that opens the backdoor is set to the correct logic level. If the bootloader is activated, it is ready for communicating with an external host 10 ms after power-on-reset.

Since the CC2538 and CC26xx ROM bootloaders support commands that can read the flash, it is also possible to disable the bootloader entirely for security reasons. The bootloader and backdoor functionality is configured in the CCA/CCFG.

Figure 1 shows as simplified flow chart for the CC26xx boot code. The flow is similar for CC2538 devices.

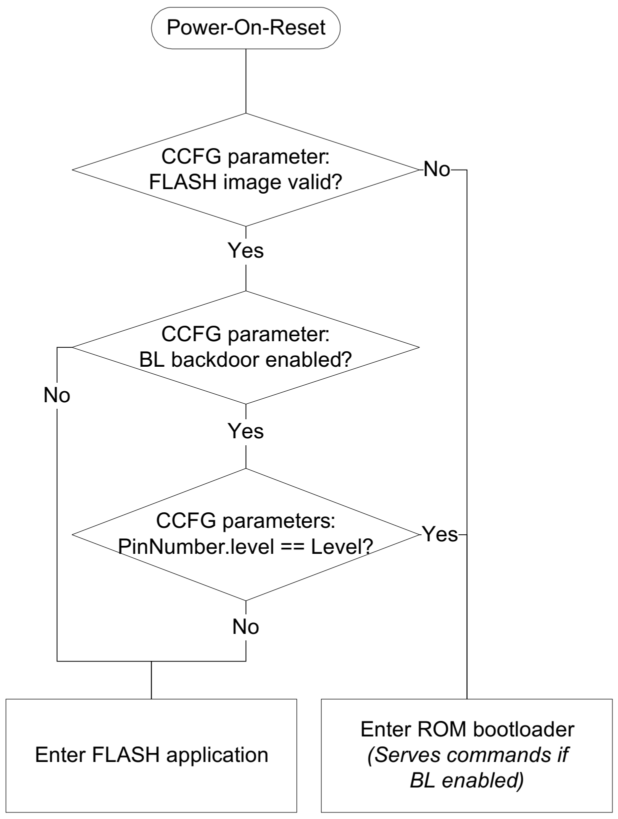

Power-On-Reset
CCFG parameter: FLASH image valid?
No
Yes
CCFG parameter: BL backdoor enabled?
No
Yes
CCFG parameters: PinNumber.level == Level?
Yes
No
Enter FLASH application
Enter ROM bootloader (Serves commands if BL enabled)

Figure 1. Simplified Flowchart for Entering Bootloader (CC26xx)

2.1 Configuring the Bootloader

2.1.1 CC2538

The customer configuration area for CC2538 is called CCA and is placed in the uppermost flash page, so the absolute address of the CCA depends on the device flash size. An 8-bit field in the CCA configures the bootloader backdoor functionality (byte offset 0x7D7). Table 1 lists the absolute address of this byte for different CC2538 variants.

Table 1. Address of 8-Bit Bootloader Configuration Field (CC2538 variants)

CC2538 Variant	Bootloader Configuration Address
Cx2538xF53 (512 KB flash)	0x0027.FFD7
Cx2538xF23 (256 KB flash)	0x0023.FFD7
Cx2538xF11 (128 KB flash)	0x0021.FFD7

The structure of the bootloader configuration byte is shown in Table 2. The pins that can open the bootloader backdoor are PA0 - PA7. Select which pin to use by writing a value from 0 to 7 in the three least significant bits of the backdoor configuration byte.

Table 2. CC2538 Bootloader Backdoor Encoding

Bit	Field	Value	Description	Default Value
7-5	Reserved	0	Reserved. Should be all ones.	111b
4	Enabled		Enable and disable backdoor function	1
		0	Backdoor and bootloader disable	
		1	Backdoor and bootloader enable	
3	Level		Sets active level for selected pin on pad A	1
		0	Active low	
		1	Active high	
2-0	Pin number		The number (0 - 7) of the pin on pad A that is used when backdoor is enable.	111b (7)

2.1.2 CC26xx

The customer configuration area for CC26xx is called CCFG and is located in the uppermost flash page, so the absolute address of the CCFG depends on the device flash size [(1)]. A 32-bit field in the CCFG configures the bootloader and backdoor functionality (byte offset 0xFD8). Table 3 lists the absolute address of this field for different CC26xx flash versions.

[(1)] The CC26xx CCFG is also memory mapped with read access to absolute address 0x5000.3000 for all flash variants.

Table 3. Address of 32-Bit Bootloader Configuration Field (CC26xx flash variants)

CC26xx Variant	Bootloader Configuration Address
128 KB	0x0001.FFD8
64 KB	0x0000.FFD8
32 KB	0x0000.7FD8

The structure of the bootloader configuration field is shown in Table 4. The configuration structure is little endian, meaning that the least significant byte is at the lowest address. Select which pin to use by writing the DIO number to the second byte of the configuration structure.

Table 4. CC26xx BL_BACKDOOR_CONFIG Parameter Encoding

Bit	Field	Value	Description	Byte Offset	Default Value
31-24	Enable bootloader		Enable and disable bootloader	0xFDB	0xC5
		0xC5	Bootloader enabled		
		Any other value	Bootloader disabled		
23-17	Reserved	0		0xFDA	0xFE
16	Level		Sets the active level of the selected pin.	0xFDA	
		0	Active low		
		1	Active high		
15-8	pinNumber		The number of the I/O pin that is level checked if the bootloader backdoor is enabled.	0xFD9	0xFF
7-0	Enable backdoor		Enables and disables the bootloader backdoor.	0xFD8	0xC5
		0xC5	Bootloader enabled		
		Any other value	Bootloader disabled		

2.2 *Communication Protocol*

The CC2538 and CC26xx bootloader uses the same format for receiving and sending packets. The actual signaling on SPI and UART transportation layers is different, but the packet format remains the same. The packet format is shown in Table 5 and each field is described in Table 6.

Table 5. ROM Bootloader Packet Format

Size (1 Byte)	Checksum (1 Byte)	Data byte 1	…	Data byte N

Table 6. Packet Format Field Description

Packet Field	Size (bytes)	Description
Size	1	The number of bytes in the packet, including the size byte.
Checksum	1	The checksum of the data. The checksum algorithm is the sum of the data bytes truncated to 8 bit. *Checksum = (∑data) mod 256*
Data	0-253	The actual data bytes. The first data byte is typically the bootloader's command byte.

Packet send and packet receive must adhere to the simple protocol shown in Figure 2. Both the host device and the CC2538/CC26xx bootloader can act as sender and receiver. The host device becomes the receiver when it waits for a data response from the bootloader.

For more details about the communication protocol, see the *CC2538 ROM User's Guide* (SWRU333) [1] and the *CC26xx Technical Reference Manual* (SWCU117) [2].

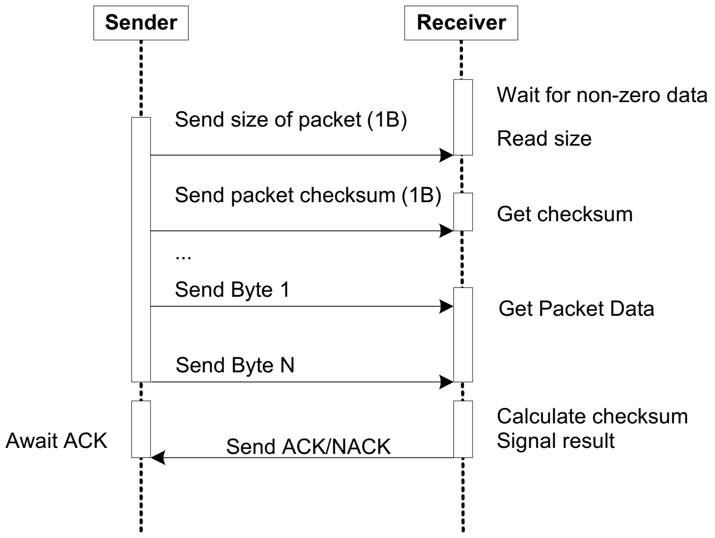


Figure 2. Sequence Chart for Send and Receive Protocol

2.2.1 ACK/NACK

The receiver should respond with an acknowledgment (ACK) or not-acknowledged (NACK) to indicate whether the command was received properly or not. The ACK and NACK signature is shown in Table 7.

Table 7. Acknowledge/Not-Acknowledge Response

Protocol Byte	Value
ACK	0xCC
NACK	0x33

2.3 Interface Configuration

2.3.1 Hardware Pins

The hardware pins used by the ROM bootloader to communicate over UART and SPI are shown in Table 8.

Table 8. Serial Interface Configuration

Signal	CC2538	CC26xx			EM Pin
		QFN48/7x7	QFN32/5x5	QFN32/4x4	
UART_RX	PA0	DIO2	DIO1	DIO1	1.07
UART_TX	PA1	DIO3	DIO0	DIO2	1.09
SPI CLK	PA2	DIO10	DIO10	DIO8	1.16
SPI CSn	PA3	DIO11	DIO9	DIO7	1.14
SPI MOSI	PA4	DIO9	DIO11	DIO9	1.18
SPI MISO	PA5	DIO8	DIO12	DIO0	1.20

The bootloader selects the first interface accessed by the external device. The inactive interface (UART or SPI) will be disabled. To switch to the other interface, the device must be reset using, for example, pin reset.

2.3.2 UART Configuration

The UART data format is fixed at 8 data bits, no parity, and one stop-bit. The UART bootloader utilizes auto detection of the baud rate described in Section 2.3.3; therefore, any baud rate below the maximum can be used.

- Maximum UART baud rate for CC2538: 460800 baud (1)
- Maximum UART baud rate for CC26xx: 1.5 M baud

(1) This data rate number can be doubled if an external 32 MHz crystal oscillator is in use and selected using the COMMAND_SET_XOSC bootloader command. UART communication must be re-established after calling this command (see Section 2.3.3).

2.3.3 Establishing Communication

The bare minimum needed to establish communication with the bootloader over UART is shown in Figure 3, which includes sending two bytes with the value 0x55 to let the device detect the baud rate, followed by reading the device response, expecting an ACK if the auto baud rate routine was successful. If the device does not respond to the auto baud bytes, it may not be in bootloader mode, or the baud rate is not supported.

After a connection has been made, any command can be sent to the bootloader. The complete list of bootloader commands can be found in [1] and [2] for CC2538 and CC26xx, respectively.

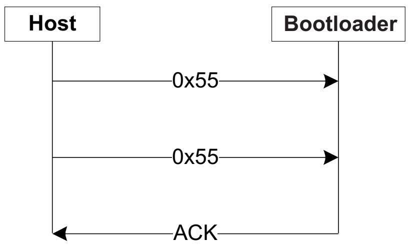


Figure 3. Sequence Chart for Connection Initialization

2.3.4 Status Command

To check the status of the bootloader, the CMD_GET_STATUS command can be used; this should be used after erasing or writing the flash memory to be sure that the erase and write were successful before proceeding. The possible status codes for the CMD_GET_STATUS command are shown in Table 9.

Table 9. Possible Status Return Values From Bootloader

Status Definition	Value	Description
COMMAND_RET_SUCCESS	0x40	Status for successful command
COMMAND_RET_UNKNOWN_CMD	0x41	Status for unknown command
COMMAND_RET_INVALID_CMD	0x42	Status for invalid command (incorrect packet size)
COMMAND_RET_INVALID_ADR	0x43	Status for invalid input address
COMMAND_RET_FLASH_FAIL	0x44	Status for failed attempt to program or erase the flash

3 Serial Bootloader Library (SBL)

The SBL is a PC library for Microsoft Windows that implements a host API for communicating with the CC2538 and CC26xx serial bootloaders. The SBL library project is created in Visual Studio C++ Express 2010. The serial bootloader library uses Windows API to communicate with the serial COM port and therefore is not cross-platform compatible.

All functions in SBL are synchronous; meaning that the function will not return until ACK or NACK have been received or an error has occurred. Figure 4 demonstrates a sequence chart of the SBL *ping()* function.

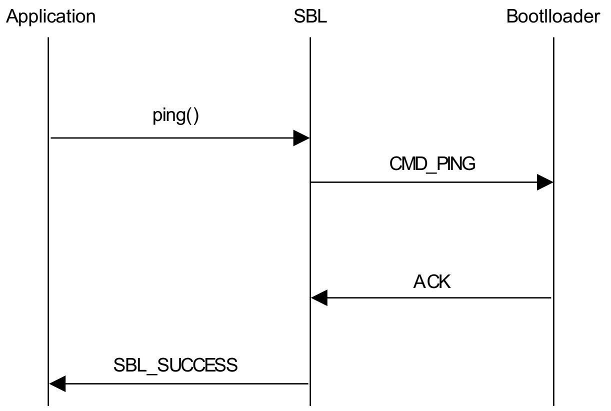


Figure 4. Sequence Chart for ping Function Call

All bootloader commands can be accessed through functions within SBL; which makes it easy to execute operations like erasing and writing to the flash memory directly through SBL.

For a more detailed description of the ROM bootloader and how to use all the serial commands, see the device-specific ROM user's guide [1] [2].

3.1 SBL Return Values

Each SBL function will return whether the desired operation was successful or not by interpreting the bootloader response. A list of the possible return values from SBL functions and possible causes for them are presented in Table 10.

Table 10. SBL Function Return Values

Constant Name	Value	Cause
SBL_SUCCESS	0	Command successfully executed by bootloader
SBL_ERROR	1	Error during execution of command
SBL_ARGUMENT_ERROR	2	SBL function arguments invalid
SBL_TIMEOUT_ERROR	3	Bootloader response not received within a given number of tries.
SBL_PORT_ERROR	4	Failed to send data to or receive data from bootloader
SBL_ENUM_ERROR	5	Failed to enumerate COM devices
SBL_UNSUPPORTED_FUNCTION	6	Function is not supported for the chosen hardware

3.2 SBL API

An overview of the SBL API is shown in Table 11. API functions that directly map to a bootloader command are marked with an X.

Table 11. SBL Functions

SBL Function Name	Bootloader CMD		Description
	CC2538	CC26xx	
Create	NA	NA	Static function for creating a SBL device object.
calculateCrc32	X	X	Calculate CRC32 over the specified range.
connect			Initialize connection with ROM bootloader
enumerate	NA	NA	Static function for enumerating COM ports on PC.
eraseFlashBank		X	Erases the entire flash. Not supported by CC2538.
eraseFlashRange	X	X	Erase the sectors in the specified range. Uses CMD_SECTOR_ERASE.
ping	X	X	Sends ping command.
readDeviceId			Uses CMD_MEMORY_READ to read device ID.
readFlashSize			Uses CMD_MEMORY_READ to read flash size.
readMemory32	X	X	Reads 32 bit word from device memory device memory.
readMemory8			Uses CMD_MEMORY_READ to read 8 bit from device memory.
readRamSize			Uses CMD_MEMORY_READ to read RAM size.
readStatus	X	X	Reads bootloader status.
reset	X	X	Resets device using CMD_RESET.
run	X		Runs the device CPU from the specified address. Not supported by CC26xx.
setCCFG		X	Set CC26xx CCFG. Not supported by CC2538.
setXosc	X		Switch to external oscillator. Not supported by CC26xx.
writeFlashRange	X	X	Writes FLASH using CMD_DOWNLOAD and CMD_DATA_SEND.
writeMemory32	X	X	Writes 32-bit word to device memory using CMD_MEMORY_WRITE.
writeMemory8			Implements 8-bit write to device memory using CMD_MEMORY_READ and CMD_MEMORY_WRITE.

3.2.1 Device-Specific Functions

There are a few commands in the ROM bootloader that differ between CC2538 and CC26xx, this means that there are also a few differences in SBL functions for these devices; these differences are presented in Table 12.

An SBL function that is not supported for the chosen hardware returns the constant SBL_UNSUPPORTED_FUNCTION without doing anything.

Table 12. Device-Specific SBL Functions

SBL Function Name	CC2538	CC26xx	Description
eraseFlashBank()	Not supported	Supported (COMMAND_BANK _ERASE)	This erases all the flash sectors for CC26xx; this can be achieved for CC2538 by using eraseFlashRange for the whole Flash memory size.
setCCFG	Not supported	Supported (COMMAND_SET_ CCFG)	Not implemented CC2538 bootloader.
setXosc	Supported (CMD_SET_XOSC	Not supported	Not implemented CC26xx bootloader.
run	Supported (CMD_RUN)	Not supported	Not implemented for CC26xx.

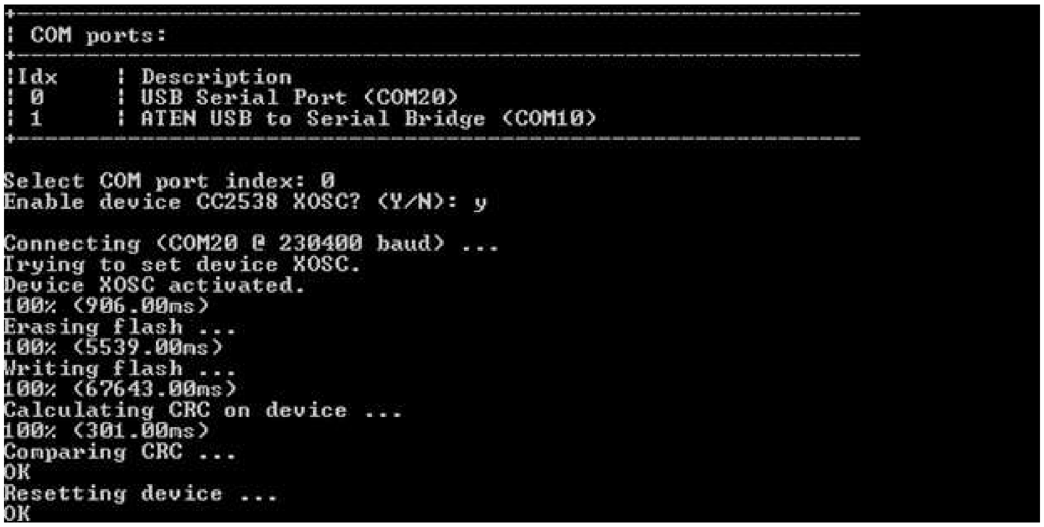
4 Example Project

The example application for SBL is created for Visual Studio C++ 2010 Express and is tested using the hardware included in the CC2538 and CC2650 development kits.

SblAppEx is a test application that performs the following actions using the CC2538 or CC26xx ROM bootloader:

- Erase flash
- Program flash
- Verify flash content
- Reset device

A successful execution of the test application should look similar to Figure 5.



```
+--------------------------------------------------------------
| COM ports:
+--------------------------------------------------------------
|Idx     | Description
| 0      | USB Serial Port (COM20)
| 1      | ATEN USB to Serial Bridge (COM10)
+--------------------------------------------------------------

Select COM port index: 0
Enable device CC2538 XOSC? (Y/N): y

Connecting (COM20 @ 230400 baud) ...
Trying to set device XOSC.
Device XOSC activated.
100% (906.00ms)
Erasing flash ...
100% (5539.00ms)
Writing flash ...
100% (67643.00ms)
Calculating CRC on device ...
100% (301.00ms)
Comparing CRC ...
OK
Resetting device ...
OK
```

Figure 5. Successful Execution of the CC2538 Example Application

4.1 Hardware Setup

The SBL communicates with the ROM bootloader over a serial COM port on the PC. If a built-in COM port is not available, a USB-to-serial interface can act as a virtual COM port.

Figure 6 demonstrates two different ways to connect the PC to the device: one is using a level shifter to convert UART signal from RS232 to TTL signals, and the other one is using a USB-to-UART bridge similar to what is used on the SmartRF06EB [3].

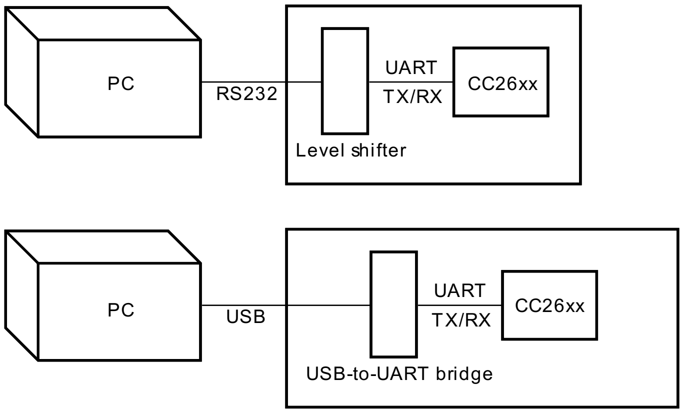


Figure 6. PC to UART Connection

4.1.1 SmartRF06EB Virtual COM Port

SmartRF06EB [3] comes with a built-in support for virtual COM port that can be used together with a CC2538EM [4] or a CC2650EM [5].

To enable the virtual COM port on SmartRF06EB, a jumper must be mounted on the "Enable UART over XDS100v3" header and all jumpers on the "XDS100V3 BYPASS" header should be mounted.

4.1.2 External Serial Interface

If a SmartRF06EB is being used and one wants to bypass the XDS100v3 Emulator to use an external serial interface, connect the external serial interface to the EM RX and EM TX pins on the "XDS100v3 BYPASS" header as shown in Figure 7.

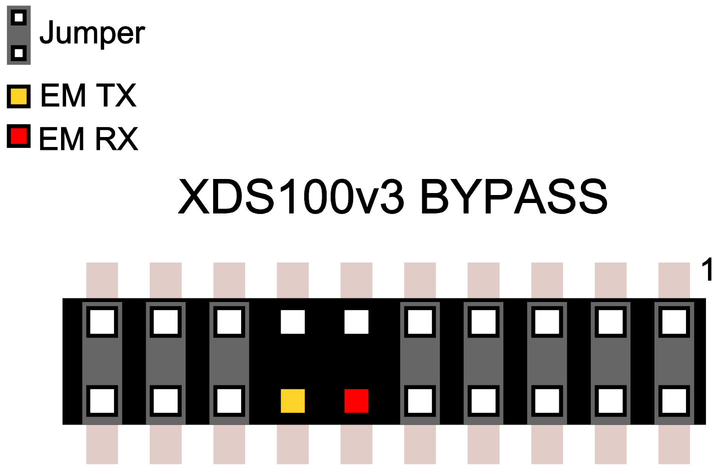


Figure 7. EM TX and RX Pins on XDS100v3 Emulator Bypass Header

4.1.3 Bootloader Backdoor

The application image programmed onto the CC2538 and CC26xx devices by the sblAppEx example is written for the CC2538 and CC2650 (7x7) Evaluation Modules (EMs) and blinks LEDs on the SmartRF06EB. The firmware image enables the bootloader backdoor, so that the bootloader can be triggered using an IO pin.

The IO pin used by the application image for opening the bootloader backdoor is shown in Table 13. This IO pin is connected to the SmartRF06EB SELECT button. To enter the bootloader backdoor, hold down the SELECT button (corresponds to logic ‘0’) while you press the EM reset button on the SmartRF06EB.

Table 13. Application Example IO Configuration

Signal	CC2538	CC26xx			EM Pin
		QFN48/7x7	QFN32/5x5	QFN32/4x4	
UART_RX	PA0	DIO2	DIO1	DIO1	1.07
UART_TX	PA1	DIO3	DIO0	DIO2	1.09
Bootloader backdoor enable	PA3	DIO11	DIO9	DIO7	1.14

4.2 Software Setup

The sblAppEx example has two configuration options: device type and baud rate.

4.2.1 Device Type

The device type is configured using the deviceType variable found in sblAppEx.cpp. It controls which bootloader commands the SBL is allowed to use, and which firmware image the SblAppEx programs onto the device. The deviceType variable is binary-coded decimal (BCD) of the device name. Table 14 lists the supported device types and corresponding deviceType value.

Table 14. Configuration: deviceType

Device	deviceType Value
CC2538	0x2538
CC13xx/CC26xx	0x2650

4.2.2 Baud Rate

The baud rate is configured by using the baudRate variable found in sblAppEx.cpp. The supported UART baud rates for CC2538 and CC26xx are covered in Section 2.3.2. The default baud rate is supported by all devices.

4.3 Program Flow

This section covers the SBL function calls discussed in the sblAppEx example project, which can be downloaded from: http://www.ti.com/lit/zip/swra466, and the underlying bootloader commands used.

4.3.1 Enumerate COM Ports

The enumerate function in SBL uses the Windows API to list the available COM ports. The first argument is a pointer to a *ComPortElement* array. The second argument specifies the maximum number of COM ports to enumerate. If the COM port to use is known, this function call can be skipped.

4.3.2 Create Device

The SBL must be told which device it’s working with. The Create function supports a single argument, the supported input values are given in Table 14. The Create function returns an instance of the SblDevice class that supports the specified hardware.

4.3.3 Connect

The connect function takes two parameters, the COM port number (see Section 4.3.1), and the baud rate (see Section 2.3.2).

The CC2538 ROM bootloader supports switching from the device's internal oscillator to an external oscillator (if available). Switching to an external oscillator increases the maximum baud rate supported by the CC2538 ROM bootloader. If an external oscillator is to be used, a third argument (boolean TRUE) can be passed to the connect function, this third parameter is optional and FALSE by default.

To check whether the connection already has been initialized, the SBL's initCommunication function sends a dummy command and waits for the bootloader to respond with an ACK. If no connection already exists, the initCommunication function sends the auto baud rate routine (described in Section 2.3.2), expecting an ACK from the ROM bootloader. An example of this sequence is shown in Figure 8.

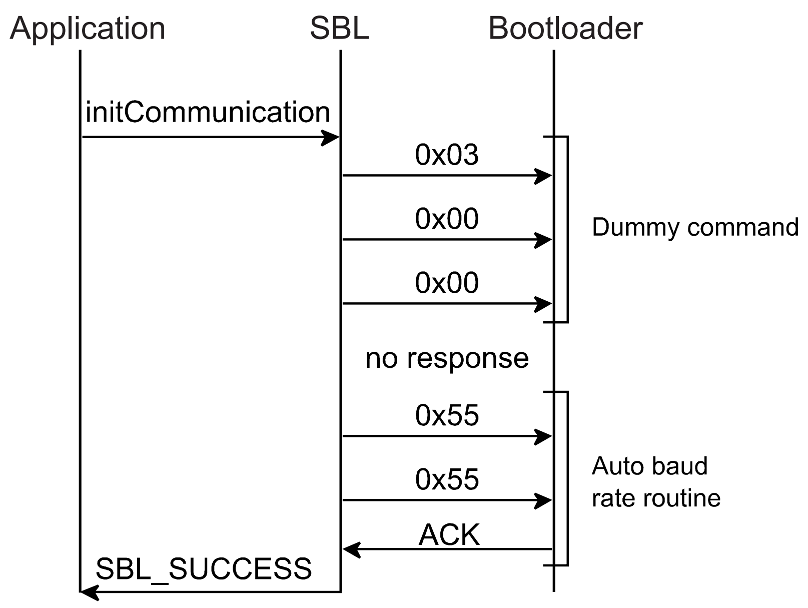


Figure 8. Sequence Chart for initCommunication Function With Uninitialized Bootloader

When the connection has been established, the connect function retrieves the device ID by using the serial bootloader command CMD_GET_CHIP_ID and FLASH size and RAM size by using the command CMD_MEMORY_READ to read from a location storing these values.

4.3.4 Erase Flash Range

The eraseFlashRange function uses bootloader command CMD_ERASE for CC2538 and CMD_SECTOR_ERASE for CC26xx.

The CC26xx CMD_SECTOR_ERASE takes an address parameter and erases the flash sector (4 KB) in which the address is located.

The CC2538 CMD_ERASE command requires a second argument for specifying the erase size. The CC2538 bootloader erases the flash sectors (2 KB) that are covered by the range [address, address + size].

After each bootloader erase command, eraseFlashRange checks the bootloader status using the CMD_GET_STATUS command.

Figure 9 shows the sequence chart for a flash erase using the serial bootloader protocol. The last four bytes in the command that defines the size that needs to be removed is specific for CC2538. For CC26xx, the CMD_SECTOR_ERASE command (and consequent CMD_GET_STATUS) must be repeated for each flash sector to erase.

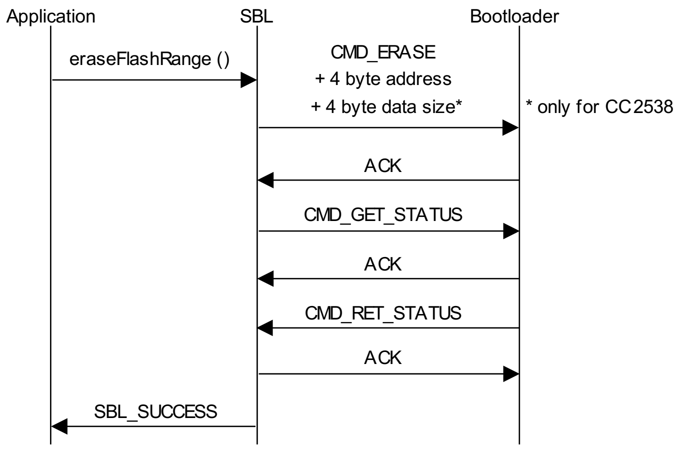


Figure 9. Sequence Chart for Flash Page Erase

If the whole Flash memory is to be erased on CC26xx, the CMD_BANK_ERASE command should be used. This erases the whole Flash memory in one operation, which is faster than deleting a single sector at a time.

4.3.5 Write Flash Range

To write data to the flash memory, the SBL function writeFlashRange can be used; this function sends the CMD_DOWNLOAD command to the bootloader together with the start address and the download size in bytes. The bootloader is now prepared to receive the specified amount of data and write it to flash, starting at the specified address.

To transfer the data, the CMD_SEND_DATA command is used. A maximum of 252 bytes of data can be transferred per CMD_SEND_DATA command. If the data to be downloaded is larger than 252 bytes, the CMD_SEND_DATA command must be repeated. The SBL writeFlashRange function handles splitting data transfer into multiple CMD_SEND_DATA commands.

The status of the bootloader should be read after both the CMD_DOWNLOAD command and after each CMD_SEND_DATA command by using the CMD_GET_STATUS command. This is to ensure that the start address and firmware size are valid, and that the data was successfully programmed into the flash. If the status indicates an error, the bootloader's internal address pointer is not incremented, allowing the data to be re-transferred.

Figure 10 demonstrates the flash write sequence using the SBL function writeFlashRange.

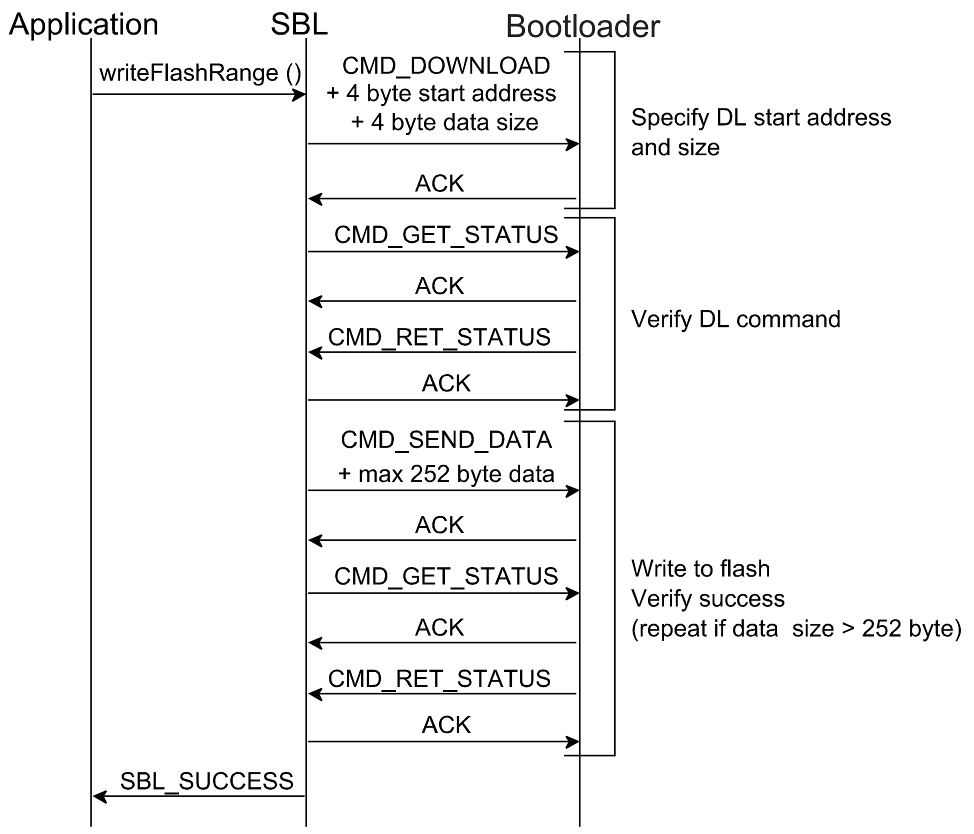


Figure 10. Sequence Chart for Flash Write

4.3.6 Calculate CRC32

To verify that the firmware was successfully programmed into the Flash memory, the SBL function calculateCrc32 can be used to get a CRC32 checksum of a specified part of the Flash memory from the bootloader. The calculateCrc32 function uses the command CMD_CRC32 together with a start address and the number of bytes to include in the CRC32 checksum.

For CC26xx, the bootloader also expects a read repeat count. Setting this to 0x00000000 ensures that the data locations are only read once.

The CC2538 and CC26xx bootloaders uses the CRC-32-IEEE 802.3 with the following polynomial to calculate CRC checksum.

$CRC32_{poly} = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{2} + x + 1$

An example of how to calculate the checksum using the CRC32$_{poly}$ is implemented in the SBL example project. The sequence chart for the calculateCrc32 function is shown in Figure 11.

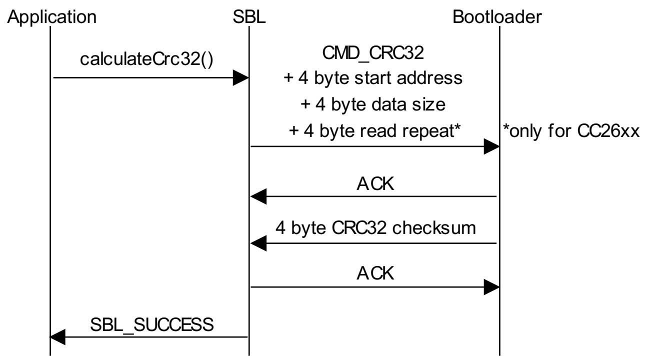


Figure 11. Sequence Chart for CRC32 Command

4.3.7 Reset

To run the firmware after it has been written and verified, the SBL function reset has to be used. The reset function sends the CMD_RESET command to the bootloader to invoke a reset. The connection between the host and the device will break after the CMD_RESET command has been sent and an ACK has been received from the bootloader. The sequence chart for the reset function can be observed in Figure 12.

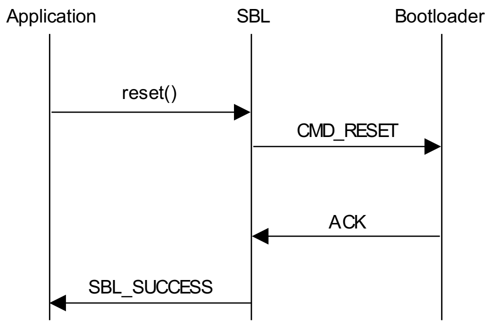


Figure 12. Sequence Chart for SBL Function Reset

5 References

1. *CC2538 ROM User's Guide* (SWRU333)
2. *CC26xx Technical Reference Manual* (SWCU117)
3. *SmartRF06 Evaluation Board User's Guide* (SWRU321)
4. CC2538DK: http://www.ti.com/tool/CC2538DK
5. CC2650DK: http://www.ti.com/tool/CC2650DK

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (February 2015) to A Revision	Page
• Update to Table 2 in Section 2.1.1	4