

CAN Bus Bootloader for TMS470M MCU

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ABSTRACT

A bootloader enables field updates of application firmware. A controller area network (CAN) bootloader enables firmware updates over the CAN bus. The CAN bootloader described in this application report is based on the Hercules™ ARM® Cortex™-R4 microcontroller. This application report describes the CAN protocol used in the bootloader and details each supported command.

Project collateral and source code discussed in this application report can be downloaded from the following URL: <http://www.ti.com/lit/zip/spna200>.

Contents

1	Introduction	2
2	Hardware Requirements	3
3	CAN Settings	4
4	Software Coding and Compilation	6
5	On Reset	7
6	During Bootloader Execution	7
7	Bootloader Flow	8
8	CAN Bootloader Operation	11
9	CAN Bootloader Protocol	12
10	Create Application for Use With the Bootloader	14
11	Sample Code for PC-Side Application	15
12	References	15

List of Figures

1	Bootloader Process	2
2	Hardware Setup	3
3	Standard CAN Frame Format	4
4	CAN Bit Timing	5
5	CAN Bit Timing Calculation in HalCoGen	6
6	CAN Bootloader Flowchart	8
7	CAN Bootloader Initialization Flowchart	9
8	CAN Bootloader Update Check Flowchart	10
9	CAN Bootloader Data/EC Program Flowchart	11
10	The CAN Bootloader is Loaded Through the JTAG Port	11
11	User Application Code is Loaded Through the CAN Bootloader	12
12	CAN Bootloader Jumps to the Application Code	12
13	The Linker File for Application	14
14	Setup Project Property to Generate Binary File for Bootloader	15
15	VC++ Project for PC-Side Bootloader	15

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List of Tables

1	List of Source Code Files Used in CAN Bootloader	3
2	Commands Used in Bootloader.....	4
3	Vector Table in CAN Bootloader.....	7

1 Introduction

The CAN bootloader permanently resides in the first Flash block of target device. It enables programming of the Hercules microcontroller through its CAN interface. The bootloader also helps designers update the user application code for products already deployed in the field.

This document describes how to work with and customize the Hercules CAN bootloader application. The bootloader is provided as source code which allows any part of the bootloader to be completely customized.

The bootloader on the target device configures the CAN module in communication with PC host through the CAN bus. The bootloader polls the CAN port for messages. After a message is received, the bootloader attempts to decode the incoming commands for flash programming. After the internal flash has successfully downloaded the binary image, the bootloader jumps to the starting address of the new application image.

The target side bootloader has been built and validated using Code Composer Studio™ v5 on the TMS470M Hercules HDK. The bootloader host application that communicates with the target side bootloader is developed with Visual C++ 2010. [Figure 1](#) and show an overview of the source code provided with the bootloader.

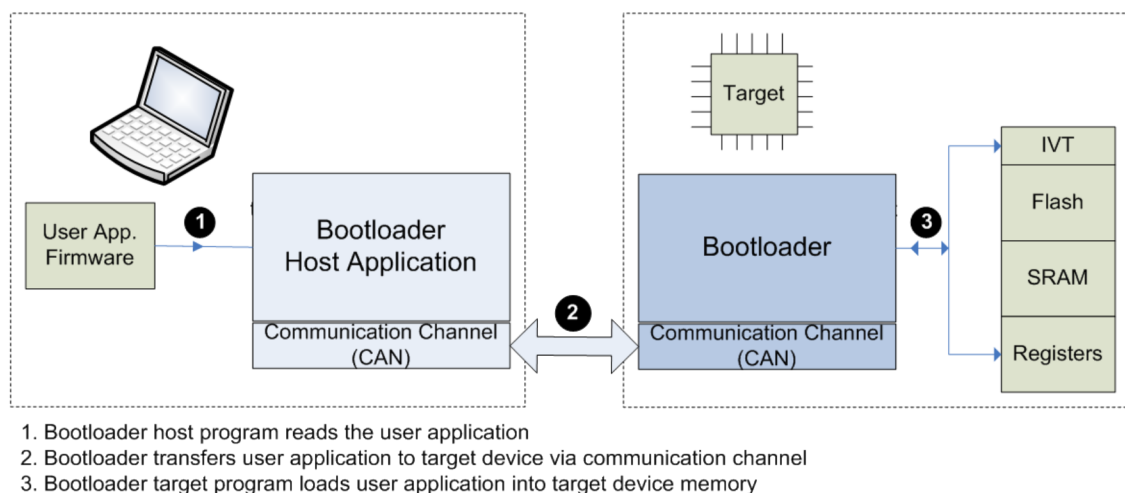


Figure 1. Bootloader Process

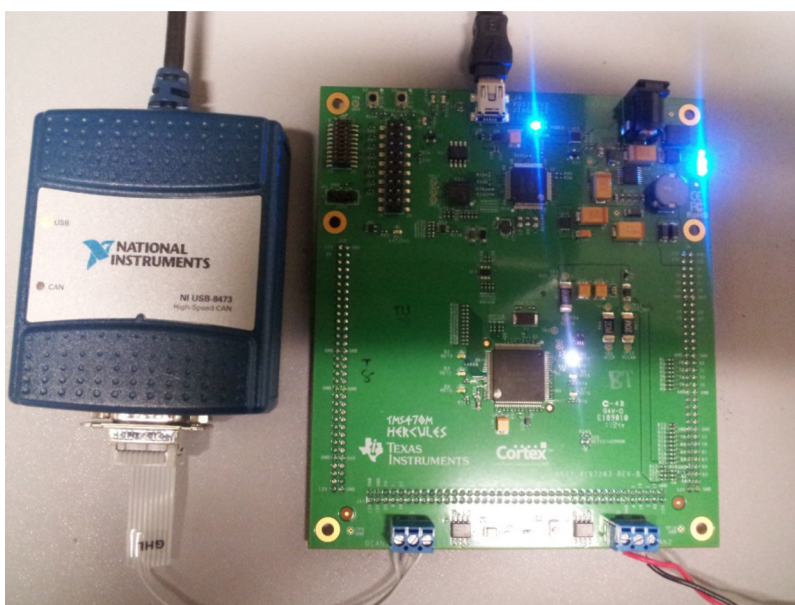
Table 1. List of Source Code Files Used in CAN Bootloader

sys_intvecs.asm	Interrupt vectors
bl_config.h	Boot loader configuration file. This contains all of the possible configuration values.
bl_commands.h	The list of commands and return messages supported by the bootloader.
bl_can.c	The functions for transferring data via the CAN1 port.
bl_check.c	The code to check if a firmware update is required, or if a firmware update is being requested.
bl_flash.c	The functions for erasing, programming the Flash, and functions for erase and program check
sys_startup.c	The start-up code used when TI's Code Composer Studio compiler is being used to build the bootloader.
system.c	Configure PLL, enable peripherals, and so forth
sys_core.asm	Initialize the core registers, stack pointers , memory, and so forth
bl_main.c	The main control loop of the bootloader
bl_link.cmd	The linker script used when the Code Composer Studio compiler is being used to build the bootloader
bl_led_demo.c	Flashing LEDs when erasing and programming Flash, for bootloader demo

2 Hardware Requirements

The hardware required for configuration includes:

- Power supply: 12 V to HDK, or 5V USB power to HDK
- CAN bus: H, L and GND connecting to CAN1 header on HDK
- Hercules TMS470M HDK
- NI USB 8473 high-speed CAN adaptor
- PC with windows XP or Win7 for running VC++ project
- HyperTerminal for message display via RS232 connected to mini USB connector on HDK
 - Bits/sec: 115200
 - No parity: none
 - Stop bit: 1
 - Flow control: No


Figure 2. Hardware Setup

3 CAN Settings

The Hercules CAN is compliant with the 2.0A specification with a bitrate up to 1 Mbit/s. It can receive and transmit standard frames with 11-bit identifiers as well as extended frames with 29-bit identifiers. To change the CAN settings for the bootloader, knowledge of the CAN protocol, revision 2.0 is assumed. For details, see the CAN Protocol Revision 2.0 Specification. Figure 3 shows the essential fields of the standard frame that is used in this CAN bootloader.

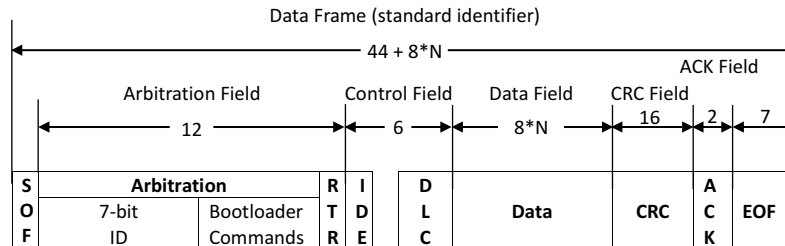


Figure 3. Standard CAN Frame Format

Table 2. Commands Used in Bootloader

COMMANDS	CMD	Description
PING	0x00	See Section 9
DOWNLOAD	0x01	See Section 9
RUN APPLICATION	0x02	See Section 9
GET REQUEST	0x03	See Section 9
SEND APP DATA	0x04	See Section 9
SW RESET	0x05	See Section 9
ACK	0x06	See Section 9

In this application, the CAN settings are:

- Standard identifier (not extended)
- Bitrate: at the default it is 125 kbps
- Functions used: *CANInit()*

The transmit settings (from MCU to the host) are:

- Tx mailbox2: On -- #define MSG_OBJ_BCAST_TX_ID 1 in *bl_can.c*
- Tx mailbox1: Off -- #define MSG_OBJ_BCAST_RX_ID 2 in *bl_can.c*
- Tx identifier: 0x5A (device ID) + CMDs (0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06)
- Functions used: *CANMessageSetTx()*, and *PacketWrite()*

The receive settings (from the host to the MCU) are:

- Synchronization (ACK), 0x06, is in the RX identifier and not in the data field.
- RX identifier depends on the commands (0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06).
- Error checking: Host re-transmits the frames which have lost arbitration or have been disturbed by errors during transmission.
- Incoming messages can contain from 1 to 8 data bytes.
- Functions used: *CANMessageGetRx()*, *CANMessageSetRx()*, and *PacketRead()*

CAN Bit timing setting:

Two clock domains are provided to the CAN module:

- VCLK: general module clock (*system.c*)
- VCLKA1: CAN core clock for generating the CAN Bit Timing (*system.c*)
- Functions used: *CANInit()*

Before configuring the CAN module, evaluate your system specifications such as system propagation delay (wire length and transceiver delay), crystal tolerance, and re-synchronization jump width. To initialize the CAN registers in CAN communication, you must define parameters such as baud rate, propagation segment (Prog_Seg), time segment 1 (Phase_Seg1) and time segment 2 (Phase_Seg2). Using HalCoGen is an easy way to get the correct BTR value. Figure 5 shows what CAN BTR calculations look like in HalCoGen.

$$t_{prop} = 2(t_{bus} + t_{transmitter} + t_{receiver})$$

$$t_{bus} = \text{Bus Length (meter)} * 5 \text{ ns/meter}$$

$t_{transmitter}$ and $t_{receiver}$ can be found in the device-specific transceiver data sheet

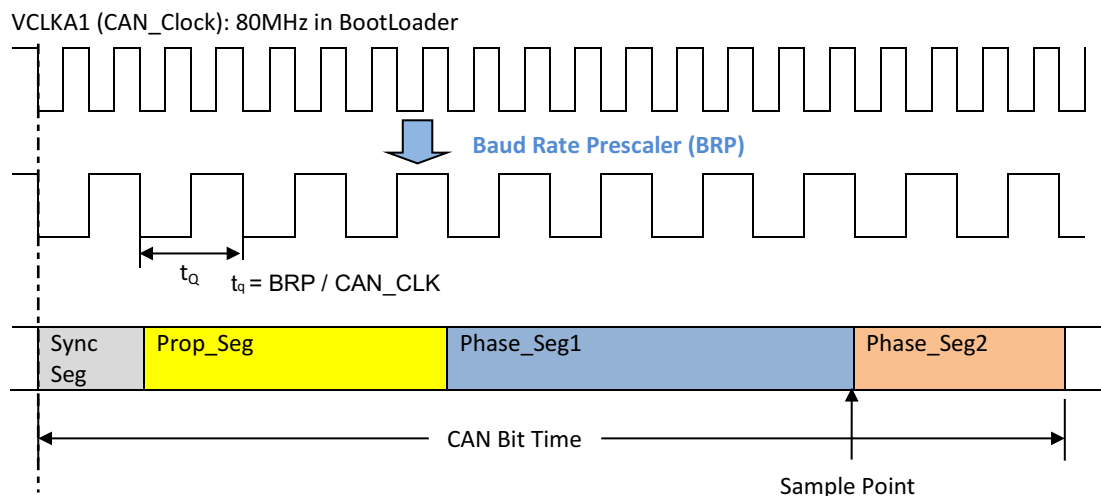


Figure 4. CAN Bit Timing

DCAN1 General
DCAN1 Msg1-8
DCAN1 Msg9-16

DCAN1 Timing Configuration

Bit Rate: 125
Propagation Delay: 700
SP Ref: 75
Calculated Bit Rate: 125.000

Calculated DCAN1 Timing

AVCLK1: 80.000
BRP: 15
fBp: 5.000
BRPE: 1
fCan: 1.000
tQ: 1000.000

Nominal Bit Time

SYNC_SEG
PROP_SEG
PH_SEG1
PH_SEG2

Sample Point

Nominal Bit Time: 8
Nominal Bit Rate: 125.000
Sample Point: 62.500
Synchronization Jump Width: 3

DCAN1 Auto Bus On Configuration

☐ Enable Auto Bus On
ABOTR: 0
tAbo: 0

VCLK1: 80.000
ABO Counter

tAbo Nominal: 0.000

DCAN1 General Configuration

☐ Disable Automatic Retransmission
☒ Enable Identifier Extension

Figure 5. CAN Bit Timing Calculation in HalCoGen

4 Software Coding and Compilation

- The bootloader code is implemented in C, ARM Cortex-M3, assembly coding is used only when absolutely necessary. The IDE is TI Code Composer Studio 5.4.
- The bootloader is compiled in the Thumb-2 mode.
- The bootloader is compiled and linked with the TI TMS470 code generation tools V 5.1.
- The maximum size of the bootloader executable is less than 16KB (size of the first sector Flash on TMS470M devices).

5 On Reset

On reset, the MCU enters in supervisor mode and starts executing the bootloader. The interrupt vectors are setup as shown in [Table 3](#).

Table 3. Vector Table in CAN Bootloader

.word	_STACK_TOP	; Address of the default stack on reset
.word	_c_int00	; Power-on or warm reset
.word	NmiSR	; Non maskable interrupt
.word	FaultISR	; Repeated or unhandled fault
.word	Dummy_ISR	; MPU related fault
.word	Dummy_ISR	; Memory address and data related fault
.word	Dummy_ISR	; Undef. instruction or similar fault
.word	Reserved	; Reserved
.word	Reserved	; Reserved
.word	Reserved	; Reserved
.word	Reserved	; Reserved
.word	UpdateHandler	; System call with SVC instruction
.word	Dummy_ISR	; Non-halting debug monitor
.word	Reserved	; Reserved
.word	Dummy_ISR	; Software pendable service request
.word	SysTicIntHandler	; System tick timer interrupt

6 During Bootloader Execution

During bootloader execution:

- MCU operates in supervisor mode
- MCU Clock is reconfigured and is maintained throughout the bootloader execution.
 - Clock Source: OSCIN = 16 MHz
 - System clock: HCLK = 80 MHz
 - Peripheral clock: VCLK = 80 MHz
- No interrupts are used
- CAN bit timing: the basic baud rates such as 125000, 250000, 500000, 750000, and 1000000 are supported. The default setting is 1250000. The baud rate is set in *bl_config.h*.
- SCI baudrate: The default setting is: 115200:8:N:1. The basic baud rates such as 9600, 19200, 38400, 57600, and 115200 are supported. The baud rate is set in *bl_config.h*. SCI is used for displaying the debug message. It is not required.
- F035 API V1.06 executes in RAM

For device configuration, see the *TMS470/570 Platform F035a Flash API Reference Guide v1.06* ([SPNU493](#)) and [HalCoGen](#).

7 Bootloader Flow

Figure 6 shows the execution flow of the CAN Bootloader.

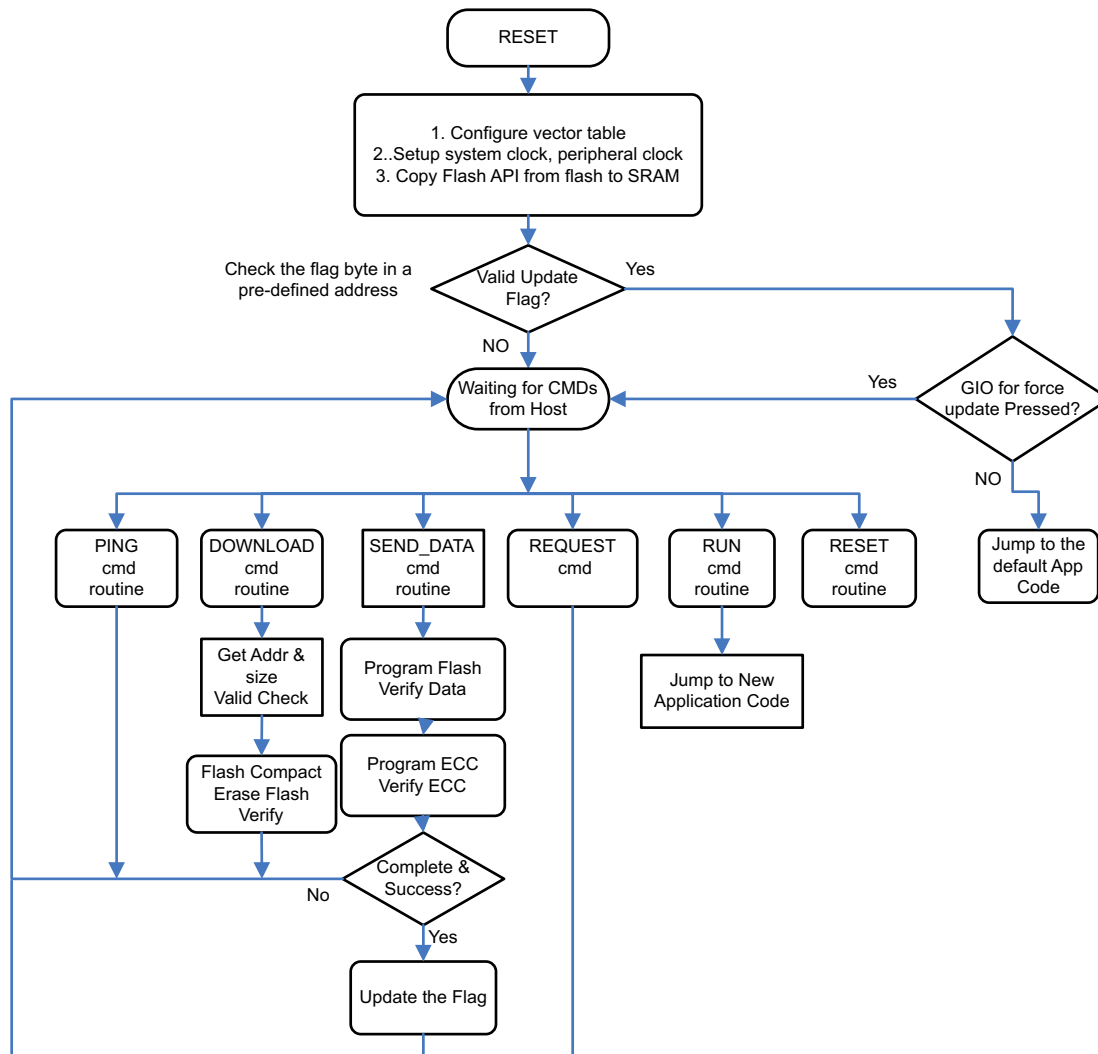


Figure 6. CAN Bootloader Flowchart

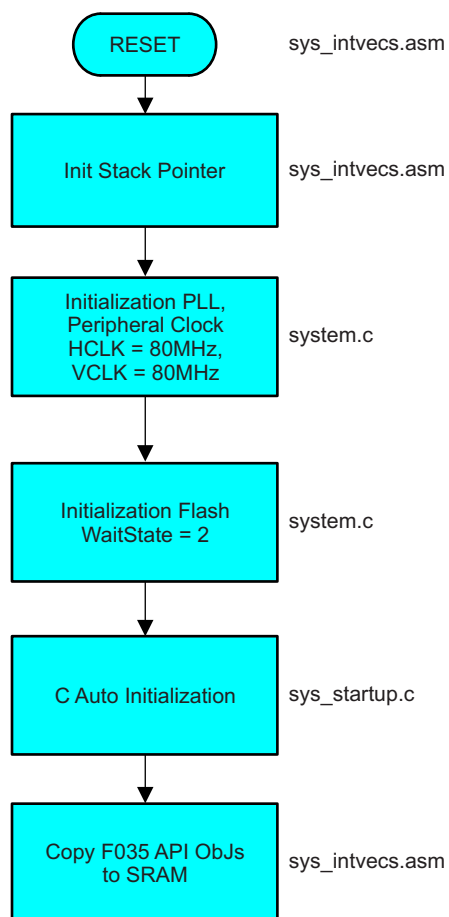


Figure 7. CAN Bootloader Initialization Flowchart

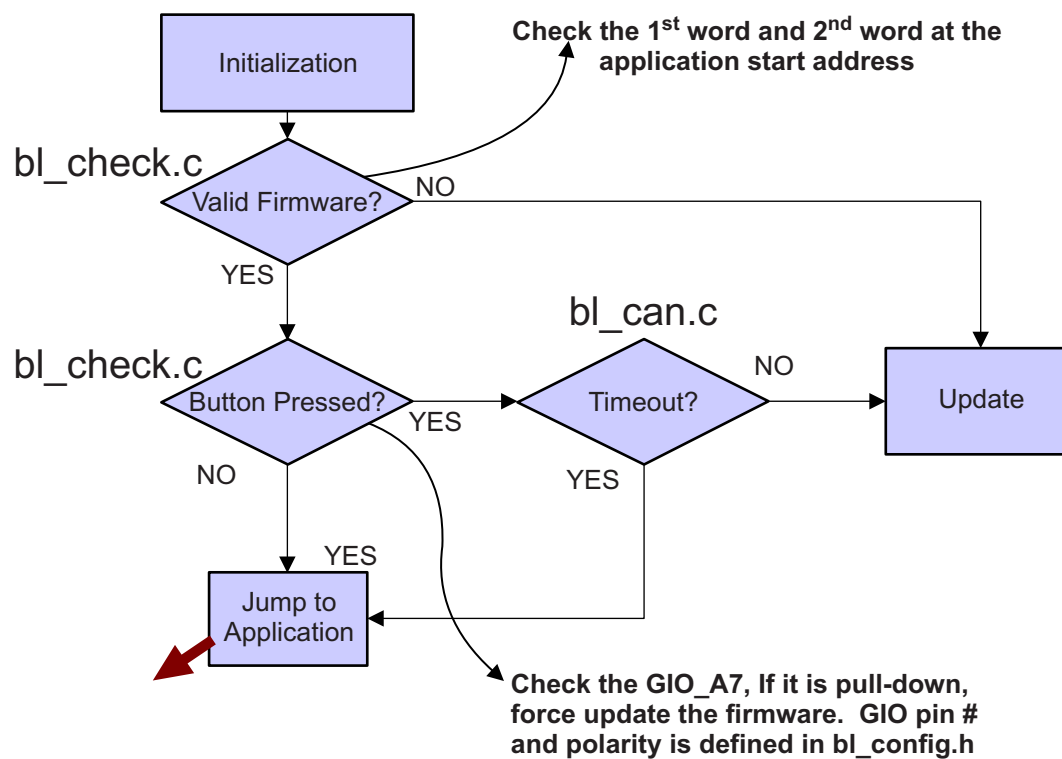


Figure 8. CAN Bootloader Update Check Flowchart

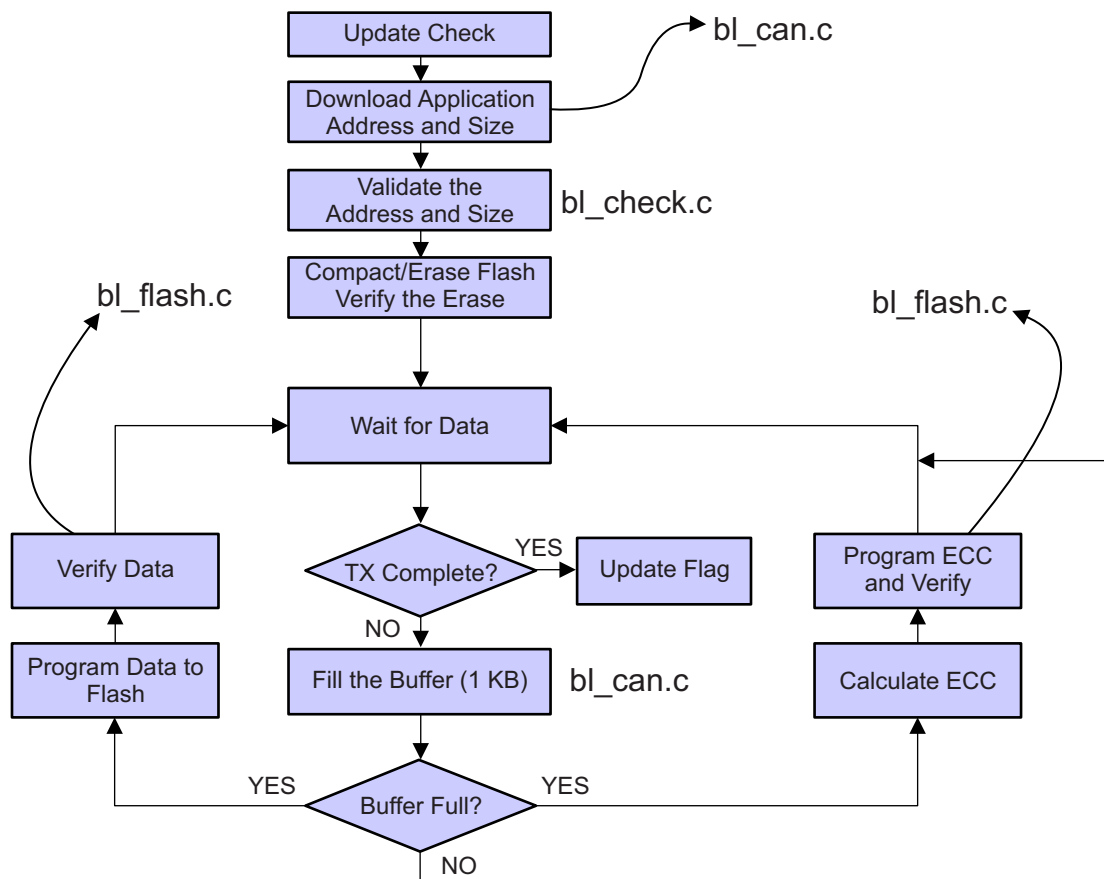


Figure 9. CAN Bootloader Data/EC Program Flowchart

8 CAN Bootloader Operation

1. Load the bootloader to Flash.

The CAN bootloader is built with Code Composer Studio 5.x and loaded through the JTAG port into the lower part of the program memory at 0x0000.

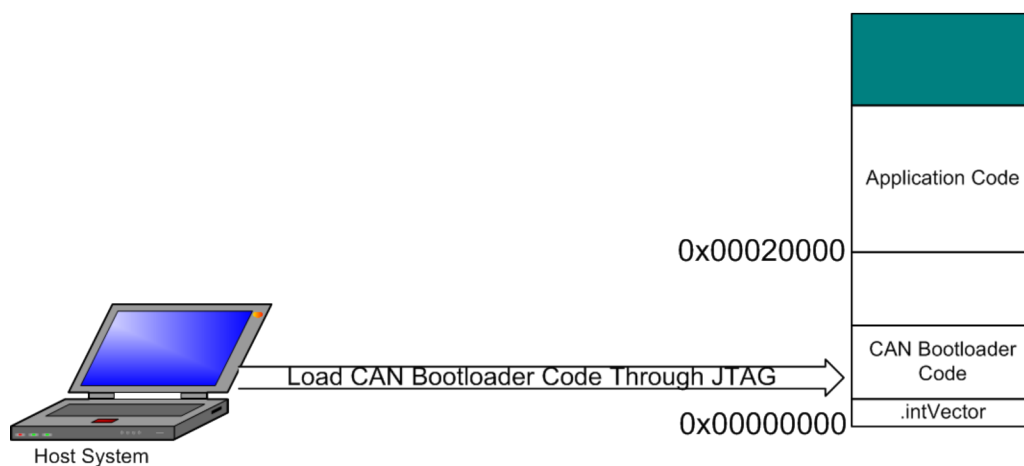


Figure 10. The CAN Bootloader is Loaded Through the JTAG Port

2. Load the user application code.

After HDK reset, the start-up code copies the Flash API of bootloader from Flash to SRAM, and executes the bootloader in Flash.

First, it checks the GPIO_A7 pin by calling *CheckGPIOForceUpdate()*. If GPIO-A7 is pulled LOW (S1 pushbutton on HDK), the bootloader is forced to update the application. The GPIO pin check can be enabled with *ENABLE_UPDATE_CHECK* in the *bl_config.h* header file, the *bl_config.h* also defines which GIO pin and what polarity are used for update check.

Then, it checks the value of the application address. Since the stack is located in SRAM, the first word of the interrupt vector table of the application should be 0x08xxxxxx. If the first word is 0xFFFFFFFF or is not 0x08xxxxxx, there is no application firmware in the Flash. The second word (reset) should be an odd number if there is an application in Flash. This check is at *CheckForceUpdate()*.

The CAN bootloader uses Message Box 2 to handle incoming messages; Message Box 1 is used for handling the outgoing messages.

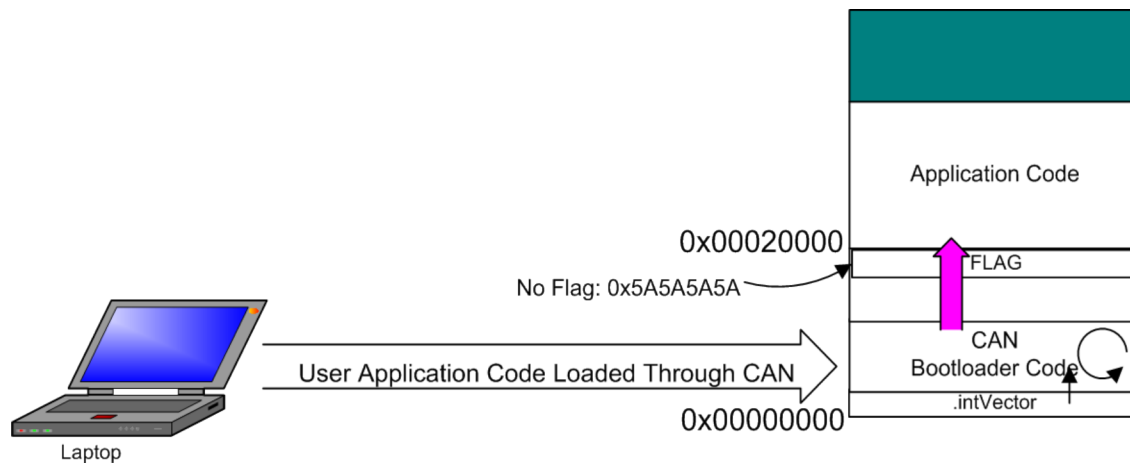


Figure 11. User Application Code is Loaded Through the CAN Bootloader

3. The user application code is loaded through the CAN bootloader.

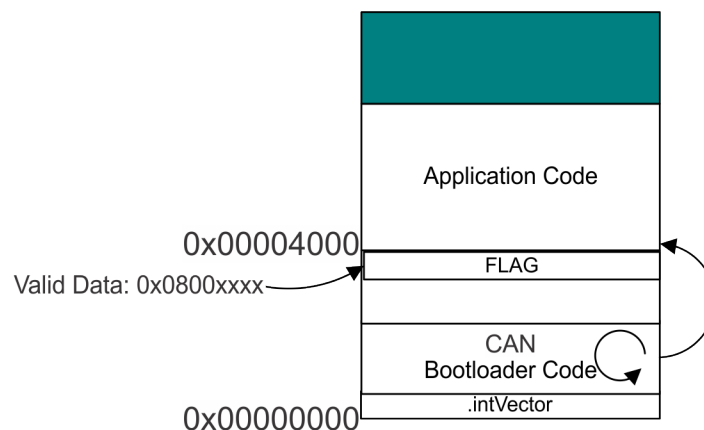


Figure 12. CAN Bootloader Jumps to the Application Code

9 CAN Bootloader Protocol

Messages between a CAN bootloader host and the target use a simple command and acknowledge (ACK) protocol. The host sends a command and within a timeout period the target responds with either an ACK or with a NACK. The command data is combined into message ID. The standard 11 bit message ID is used. Among the 11 bits, the bit 0 to bit 3 is for the bootloader commands, and bit 4 to bit 7 is used for device ID, and the bit 8 to bit 11 is used for manufacturer ID.

The CAN bootloader provides a short list of commands that are used during the firmware update operation. The definitions for these commands are provided in the file *bl_commands.h*. The description of each of these commands is covered in this section.

- **CAN_COMMAND_PING (0x00)**

This command is used to receive an acknowledge command from the bootloader indicating that communication has been established. This command has no data. If the device is present, it will respond with a CAN_COMMAND_PING back to the CAN update application.

- **CAN_COMMAND_DOWNLOAD (0x01)**

This command sets the base address for the download as well as the size of the data to write to the device. This command should be followed by a series of CAN_COMMAND_SEND_DATA that send the actual image to be programmed to the device. The command consists of two 32-bit values. The first 32-bit value is the address to start programming data into, while the second is the 32-bit size of the data that will be sent.

This command also triggers an erasure of the full application area in the Flash. This Flash erase operation causes the command to take longer to send the CAN_COMMAND_ACK in response to the command, which should be taken into account by the CAN update application.

The format of the command is as follows:

```
unsigned char ucData[8];
ucData[0] = Download Address [7:0];
ucData[1] = Download Address [15:8];
ucData[2] = Download Address [23:16];
ucData[3] = Download Address [31:24];
ucData[4] = Download Size [7:0];
ucData[5] = Download Size [15:8];
ucData[6] = Download Size [23:16];
ucData[7] = Download Size [31:24];
```

- **CAN_COMMAND_SEND_DATA (0x02)**

This command should only follow a CAN_COMMAND_DOWNLOAD command or another CAN_COMMAND_SEND_DATA command when more data is needed.

Consecutive send data commands automatically increment the address and continue programming from the previous location. The transfer size is limited to 8 bytes at a time based on the maximum size of an individual CAN transmission. The command terminates programming once the number of bytes indicated by the CAN_COMMAND_DOWNLOAD command have been received.

The CAN bootloader sends a CAN_COMMAND_ACK in response to each send data command to allow the CAN update application to throttle the data going to the device and not overrun the bootloader with data.

This command also triggers the programming of the application area into the Flash. This Flash programming operation causes the command to take longer to send the CAN_COMMAND_ACK in response to the command, which should be taken into account by the CAN update application.

The LED D5 is flashing until the application update is complete.

The format of the command is as follows:

```
unsigned char ucData[8];
ucData[0] = Data[0];
ucData[1] = Data[1];
ucData[2] = Data[2];
ucData[3] = Data[3];
ucData[4] = Data[4];
ucData[5] = Data[5];
ucData[6] = Data[6];
ucData[7] = Data[7];
```

- **CAN_COMMAND_RESET (0x05)**

This command is used to tell the CAN bootloader to reset the microcontroller. This is used after downloading a new image to the microcontroller to cause the new application or the new bootloader to start from a reset. The normal boot sequence occurs and the image runs as if from a hardware reset. It can also be used to reset the bootloader if a critical error occurs and the CAN update application needs to restart communication with the bootloader.

- **CAN_COMMAND_REQUEST (0x03)**
This command returns the status of the last command that was issued. This command has no data.
- **CAN_COMMAND_RUN (0x03)**
This command is used to tell the CAN boot loader to run the application located at APP_START_ADDRESS. This is used after downloading a new image to the microcontroller to cause the new application to start from a software reset. The normal boot sequence occurs and the image runs as if from a hardware reset

10 Create Application for Use With the Bootloader

In order to allow future upgrades using the bootloader, application images must be created with a starting address of 0x4000 (default). The reason for this is that the bootloader itself occupies the Flash area below this address. To achieve this, the default Flash start address defined in the linker command file must be changed as shown in [Figure 13](#).

```

/*-----*/
/* Linker Settings                                     */
/*-----*/

-l rtsv7M3_T_be_eabi.lib

--retain="*(.intvecs)"

/*-----*/
/* Memory Map                                         */
/*-----*/

MEMORY
{
    VECTORS (X) : origin=0x00004000 length=0x000000E0
    FLASH0 (RX) : origin=0x000040E0 length=0x001FF720
    RAM      (RW) : origin=0x08000000 length=0x00006D00
}

/*-----*/
/* Section Configuration                             */
/*-----*/

SECTIONS
{
    .intvecs : {} > VECTORS
    .text    : {} > FLASH0 /*FLASH0 | FLASH1 | FLASH2 | FLASH3*/
    .const   : {} > FLASH0 /*> FLASH0 /*| FLASH1 | FLASH2 | FLASH3*/
    .cinit   : {} > FLASH0 /*> FLASH0 /*| FLASH1 | FLASH2 | FLASH3*/
    .pinit   : {} > FLASH0 /*> FLASH0 /*| FLASH1 | FLASH2 | FLASH3*/
    .bss     : {} > RAM /*FLASH0 /*RAM*/
    .data    : {} > RAM /*FLASH0 /*RAM*/
}

```

Figure 13. The Linker File for Application

To create an application using TI Code Composer Studio 5.x, use the linker files included with this application report for your project. The included linker files set up the starting address of Vector Table and Memory Regions to 0x4000 for the binary. In the project properties window, type the following command in "Post-Built Steps Command":

```

"${CCE_INSTALL_ROOT}/utils/tiobj2bin/tiobj2bin.bat"
"${BuildArtifactFileName}" "${BuildArtifactFileName}.bin"
"${CG_TOOL_ROOT}/bin/ofd470.exe"
"${CG_TOOL_ROOT}/bin/hex470.exe"
"${CCE_INSTALL_ROOT}/utils/tiobj2bin/mkhex4bin.exe"

```

The resulting binary will be placed in your project folder, and binary file name is *projectName.bin* as default.

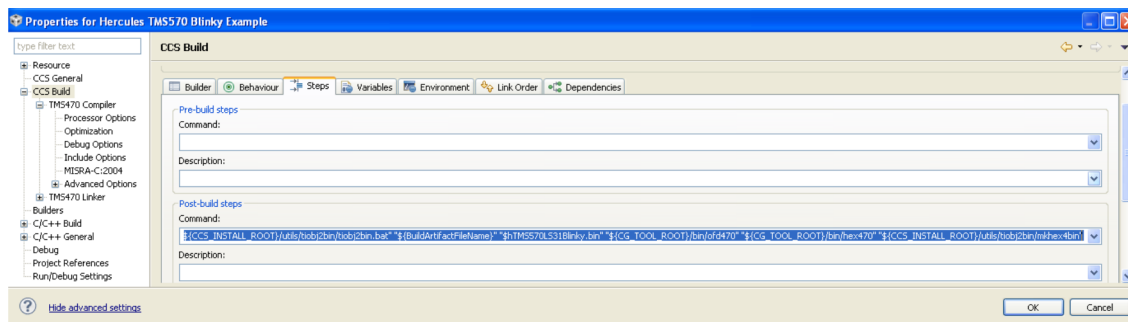


Figure 14. Setup Project Property to Generate Binary File for Bootloader

11 Sample Code for PC-Side Application

The PC-side application is developed using VC++ 2010. The *bl_command.h* defines the commands used for talking with the CAN bootloader on the MCU side. The library and header file for NI-CAN 8473 are included in the project.

The *can bltest.c* does all the tests for bootlader:

- Opens binary image (user application)
- Sends command to ping MCU bootloader
- Sends starting address and image size to the MCU bootloader
- Sends data of the image to the MCU bootloader
- Sends execution command to run the user application
- Sends Reset command to reset the MCU

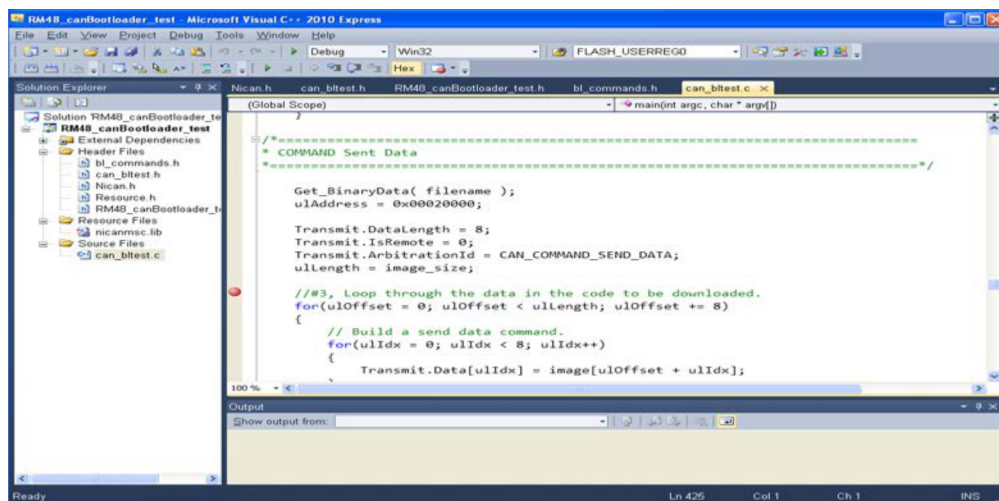


Figure 15. VC++ Project for PC-Side Bootloader

12 References

- *TMS470MF06607 16/32-Bit RISC Flash Microcontroller Data Manual* ([SPNS157](#))
- *TMS470/570 Platform F035 Flash API Reference Guide v1.06* ([SPNU493](#))
- Specification of NI USB-CAN 8473 Adaptor: <http://sine.ni.com/nips/cds/view/p/lang/en/nid/203384>

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