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.
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.

1. Bootloader host program reads the user application
2. Bootloader transfers user application to target device via communication channel
3. Bootloader target program loads user application into target device memory

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

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

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](image)

<table>
<thead>
<tr>
<th>COMMANDS</th>
<th>CMD</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PING</td>
<td>0x00</td>
<td>See Section 9</td>
</tr>
<tr>
<td>DOWNLOAD</td>
<td>0x01</td>
<td>See Section 9</td>
</tr>
<tr>
<td>RUN APPLICATION</td>
<td>0x02</td>
<td>See Section 9</td>
</tr>
<tr>
<td>GET REQUEST</td>
<td>0x03</td>
<td>See Section 9</td>
</tr>
<tr>
<td>SEND APP DATA</td>
<td>0x04</td>
<td>See Section 9</td>
</tr>
<tr>
<td>SW RESET</td>
<td>0x05</td>
<td>See Section 9</td>
</tr>
<tr>
<td>ACK</td>
<td>0x06</td>
<td>See Section 9</td>
</tr>
</tbody>
</table>

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, v03, 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.

\[
t_{\text{prop}} = 2(t_{\text{bus}} + t_{\text{transmitter}} + t_{\text{receiver}})
\]

\[
t_{\text{bus}} = \text{Bus Length (meter)} \times 5 \text{ ns/meter}
\]

\[
t_{\text{transmitter}} \text{ and } t_{\text{receiver}} \text{ can be found in the device-specific transceiver data sheet}
\]

VCLKA1 (CAN_Clock): 80MHz in BootLoader

Figure 4. CAN Bit Timing
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

<table>
<thead>
<tr>
<th>.word</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>_STACK_TOP</td>
<td>Address of the default stack on reset</td>
</tr>
<tr>
<td>_c_into00</td>
<td>Power-on or warm reset</td>
</tr>
<tr>
<td>NmiISR</td>
<td>Non maskable interrupt</td>
</tr>
<tr>
<td>FaultISR</td>
<td>Repeated or unhandled fault</td>
</tr>
<tr>
<td>Dummy_ISR</td>
<td>MPU related fault</td>
</tr>
<tr>
<td>Dummy_ISR</td>
<td>Memory address and data related fault</td>
</tr>
<tr>
<td>Dummy_ISR</td>
<td>Undef. instruction or similar fault</td>
</tr>
<tr>
<td>Dummy_ISR</td>
<td>Reserved</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>UpdateHandler</td>
<td>System call with SVC instruction</td>
</tr>
<tr>
<td>Dummy_ISR</td>
<td>Non-halting debug monitor</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>Reserved</td>
<td>Reserved</td>
</tr>
<tr>
<td>SysTicIntHandler</td>
<td>System tick timer interrupt</td>
</tr>
</tbody>
</table>

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
Check the 1st word and 2nd word at the application start address.

Check the GIO_A7, if it is pull-down, force update the firmware. GIO pin # and polarity is defined in bl_config.h

Figure 8. CAN Bootloader Update Check 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 GPIO 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](image)

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

![Figure 12. CAN Bootloader Jumps to the Application Code](image)

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:

  ```c
  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:

  ```c
  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[8] = 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 */
-rtsv7m3_T_be_eabi.lib
--retain="*.intvecs"

/* Memory Map */
MEMORY
  VECTORS (X) : origin=0x00000400 length=0x000000E0
  FLASH0 (RX) : origin=0x00000400 length=0x001FF720
  RAM (RW) : origin=0x000000D00

/* Section Configuration */
SECTIONS
  .intvecs : {} > VECTORS
  .text : [] > FLASH0 /*FLASH0 | FLASH1 | FLASH2 | FLASH3*/
  .const : [] > FLASH0 /*FLASH0 | FLASH1 | FLASH2 | FLASH3*/
  .cinit : [] > FLASH0 /*FLASH0 | FLASH1 | FLASH2 | FLASH3*/
  .pininit : [] > 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} ${BuildArtifactFileBaseName}.bin"
"${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](image)

### 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 bootloader:
- 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](image)

### 12 References

- TMS470MF06607 16/32-Bit RISC Flash Microcontroller Data Manual (SPNS157)
- TMS470/570 Platform F035 Flash API Reference Guide v1.06 (SPNU493)
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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
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