IIC Boot Loader Design on the Kinetis E Series

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1 Overview

Many applications or products need to upgrade firmware in the field to fix some bugs found, or sometimes to improve performance. Most of them do not use the dedicated debug interface, but only use the communication interfaces, such as UART, USB, IIC, and so on. In this case, a serial boot loader is required to upgrade firmware via one of the communication interfaces without debugger or dedicated program tools.

This application note guides how to design boot loader on Kinetis E series MCUs with IIC interface.

2 Introduction

Boot loader is a built-in firmware which is implemented to program the application code to flash memory via the communication interface.

This application note introduces how to use KE02Z Freedom Development (FRDM-KE02Z) board to convert UART data from PC terminal to the IIC bus, and communicate with the target board (KE02Z board) to implement update of the target application code. See the following figure.
The boot loader takes advantage of AN2295SW software tools, available on freescale.com, which is widely used in all Kinetis products to implement boot loader to update the application code through the UART interface.

The convert board uses the freedom board FRDM-KE02Z to convert UART bus to IIC bus, and repackage data transfer to the target board.

The target board has built-in boot loader code, which acts as IIC slave device to communicate with the convert board, after receiving command and data, and program the application code to flash memory on the target board.

The software attached with this application note, AN4775SW.zip, contains the following:
- a sample code, which can directly run on the FRDM-KE02Z board
- “I2C_boot loader” which shall be downloaded to the target board
- “Bridge_UartToIIC” which shall be downloaded to the convert board
- the project “RTC_demo” is for generating S19 file, which can be downloaded using PC software.

## 3 Software architecture

The software tool attached with this application note, AN4775SW.zip (containing win_hc08sprg.exe) available on freescale.com, decodes S19 file and communicates with the convert board through FC protocol.

### 3.1 Convert board

The convert board communicates with PC terminal through the FC protocol. For detail information regarding the FC protocol, see AN2295: Developer's Serial Bootloader for M68HC08 and HCS08 MCUs, available on freescale.com.

Convert board will be initialized to IIC master and communicates with the target board, in order to receive or transmit data package with the target board using IIC bus; it repackages data frame with data length and checksum. Below is the format of the data package.

<table>
<thead>
<tr>
<th>Data length</th>
<th>Original data frame</th>
<th>Checksum</th>
</tr>
</thead>
</table>

The following steps explain the flow chart given in the following figure.
1. The convert board sends FC_CMD_HOOK(0x02) to the target board.
2. Then, it reads status from the target board to check if it works in boot loader mode or user code mode.
3. If the received state is FC_CMD_HOOK0x80, then it will send 0xFC to start hook up with PC terminal, otherwise, it will always check state of the target board till it receives FC_CMD_HOOK0x80.
4. After this, it receives data frame from the target board, repackages it with data length and checksum and sends it through the IIC bus.
5. After that, it reads data from slave; the first data received is to determine whether the slave is ready. If it is, (command | 0x80), then it indicates to the receiver that the correct acknowledge is received.

For example, when the command sent to slave is 0x03, the received acknowledge must be 0x03|0x80.

**Figure 2. Convert board software flow chart**

Convert board functions as a bridge between PC terminal and target board, with which a S19 file can be downloaded to the target board from PC.

### 3.2 Target board

The target board contains built-in boot loader code. After power up, it first checks the work mode to know whether it is in boot mode or user code mode. One of the methods to identify the work mode is by checking the level of an external GPIO.

- If the GPIO pin is low, then it will enter into boot mode to run the boot loader.
- If the GPIO pin is high, then it will enter user code mode to run the application code.

But for some applications, there are limited pin/wires available and no extra GPIO for such purpose. For such cases, the hook up command is used to determine the work mode.

- If overtime occurs and hook up fails, then the board enters the user mode.
- If hook up succeeds, the board enters the boot loader mode.

This figure presents the flow chart to check the work mode.
3.2.1 IIC slave driver

The target board configures IIC as a slave. It receives and transmits data to the master in IIC interrupt service routine. For detailed interrupt flow, see KE02Z64P20SF0RM, available on freescale.com. Below is a sample code snippet:

```c
void I2C_SlaveCallback( void )
{
    I2C_ClearStatus(I2C0,I2C_S_IICIF_MASK);
    if( I2C_GetStatus(I2C0) & I2C_S_ARBL_MASK )
    {
        I2C_ClearStatus(I2C0,I2C_S_ARBL_MASK);
        if( !(I2C_GetStatus(I2C0) & I2C_S_IAAS_MASK) )
        {
            // IIAAS is 0
            return;
        }
    }
    if( I2C_GetStatus(I2C0) & I2C_S_IAAS_MASK )
    {
        I2C_SendAck(I2C0);
        gbI2CRecFrameFlag = 0;
        if( I2C_GetStatus(I2C0)& I2C_S_SRW_MASK )
        {
            // slave send data
            I2C_TxEnable(I2C0);
            u8SendIndex = 0;
            I2C_WriteDataReg(I2C0,u8SendBuff[u8SendIndex++]);
        }
        else
        {
```
I2C_RxEnable(I2C0);
I2C_ReadDataReg(I2C0);
    u8RecIndex = 0;
}
else
{
    if( I2C0->S & I2C_S_SRW_MASK )
    {
        // if require ACK from master
        if( I2C0->S & I2C_S_RXAK_MASK )
        {
            // no receive the ACK, switch to RX
            I2C_RxEnable(I2C0);
            I2C_ReadDataReg(I2C0);
        }
    }
    else
    {
        if( u8SendIndex < I2C_TX_BUFF_LENGTH )
        {
            I2C_WriteDataReg(I2C0,u8SendBuff[u8SendIndex++]);
        }
    }
}
else
{
    if( u8RecIndex < I2C_RX_BUFF_LENGTH )
    {
        u8RecBuff[u8RecIndex++] = I2C_ReadDataReg(I2C0);
        if( u8RecIndex > sizeof(uint32_t) )
        {
            pRxFrameLength = (uint32_t *)&u8RecBuff[0];
            if( u8RecIndex >= (*pRxFrameLength) )
            {
                // receive a frame data from master
                gbI2CRecFrameFlag = 1;
                Memcpy_Byte((uint8_t *)&gu8I2CrxFrameBuff[0],
                            (uint8_t *)&u8RecBuff[0], u8RecIndex);
                // reset index counter
                u8RecIndex = 0;
                // change MCU state to BUSY
                u8SendBuff[0] = SLAVE_MCU_STATE_BUSY;
            }
        }
    }
}

After IIC receives a data frame, it will set the flag (g_bIICRecFrameFlag) so that the application code can further process data frame.

### 3.2.2 Command description

In boot loader loop, always check the flag (g_bIICRecFrameFlag). When the flag (g_bIICRecFrameFlag) is 1, it will start to handle the received frame. Initially, use checksum to verify if frame received is correct and after the verification, unpack the frame and handle the appropriate command. Below is the format of the received frame.

<table>
<thead>
<tr>
<th>Total data length(4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>Data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
</table>

**IIC Boot Loader Design on the Kinetis E Series, Rev 0, 07/2013**

Freescale Semiconductor, Inc.
A brief summary of commands is given in the following table.

<table>
<thead>
<tr>
<th>Command function</th>
<th>Command</th>
<th>Loader positive acknowledge</th>
<th>Loader negative acknowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook up</td>
<td>0x02</td>
<td>0x82, 0xFC</td>
<td>0x82, 0x03</td>
</tr>
<tr>
<td>Ident</td>
<td>0x49</td>
<td>0xC9, ident information</td>
<td>0xC9, 0x03</td>
</tr>
<tr>
<td>Erase sector</td>
<td>0x45</td>
<td>0xC5, 0xFC</td>
<td>0xC5, 0x03</td>
</tr>
<tr>
<td>Write</td>
<td>0x57</td>
<td>0xD7, 0xFC</td>
<td>0xD7, 0x03</td>
</tr>
<tr>
<td>Read</td>
<td>0x52</td>
<td>0xD2, data</td>
<td>0xD2, 0x03</td>
</tr>
<tr>
<td>Quit</td>
<td>0x51</td>
<td>no acknowledge</td>
<td>no acknowledge</td>
</tr>
</tbody>
</table>

- **Hook up command**

  The received data package of Hook up command (coded as 0x02) is as given below.

<table>
<thead>
<tr>
<th>Total data length (4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>Data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0x02</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>CS</td>
</tr>
</tbody>
</table>

  The Command acknowledge is given below.

<table>
<thead>
<tr>
<th>Command (1 byte)</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x82</td>
<td>0xFC/0x03</td>
</tr>
</tbody>
</table>

  - If the status received is 0xFC, it indicates that the target board is working in boot loader mode, and gets ready to communicate with the convert board.
  - If the status received is 0x03, it indicate that it is in the user mode, and can’t receive other command.

- **Ident command**

  The received data package of Ident command (coded as 0x49), is shown in the following table.

<table>
<thead>
<tr>
<th>Total data length (4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0x49</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>CS</td>
</tr>
</tbody>
</table>

  The required MCU information is given below.

  - Protocol version—1 byte
  - System Device Identification Register (SDID) content, r(13–16 bits) is the chip revision number reflecting the current silicon level — 2 bytes
  - Number of reprogrammable memory areas—4 bytes
  - Start address of the reprogrammable area—4 bytes
  - End address of reprogrammable memory area—4 bytes
  - Address of the original vector table (1KB)—4 bytes
  - Address of the new vector table (1KB)—4 bytes
  - Length of the MCU erase blocks—4 bytes
  - Length of the MCU write blocks—4 bytes
  - Identification string, zero terminated—n bytes

  One structure body for ident information is shown in the following code snippet.
typedef uint32_t addrtype;
typedef struct
{
    unsigned char Reserve;  // reserve bytes for 4 bytes align
    unsigned char Version;  //** version */
    uint16_t Sdid;          //** Sd Id */
    addrtype BlocksCnt;     //** count of flash blocks */
    addrtype FlashStartAddress; //** flash blocks descriptor */
    addrtype FlashEndAddress;
    addrtype RelocatedVectors;  //** Relocated interrupts vector
    addrtype InterruptsVectors;  //** Interrupts vector table */
    addrtype EraseBlockSize;   //** Erase Block Size */
    addrtype WriteBlockSize;   //** Write Block Size */
    char IdString[ID_STRING_MAX];  //** Id string */
}FC_IDENT_INFO;

Command acknowledge is shown below.

<table>
<thead>
<tr>
<th>Command (1 byte)</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xC9</td>
<td>Ident information</td>
</tr>
</tbody>
</table>

**Erase command**

The received data package of the Erase command (coded as 0x45) is shown in the following table.

<table>
<thead>
<tr>
<th>Total data length (4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>Data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0x45</td>
<td>Address</td>
<td>-</td>
<td>-</td>
<td>CS</td>
</tr>
</tbody>
</table>

The command acknowledge is given below.

<table>
<thead>
<tr>
<th>Command (1 byte)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xC5</td>
<td>0xFC/0x03</td>
</tr>
</tbody>
</table>

**Write command**

The received data package of the Write command (coded as 0x57), is given below.

<table>
<thead>
<tr>
<th>Total data length (4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>Data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>0x57</td>
<td>Address</td>
<td>-</td>
<td>-</td>
<td>CS</td>
</tr>
</tbody>
</table>

The command acknowledge is shown in the following table.

<table>
<thead>
<tr>
<th>Command (1 byte)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xD7</td>
<td>0xFC/0x03</td>
</tr>
</tbody>
</table>

**Read command**

The received data package of the Read command (coded as 0x52), is given below.

<table>
<thead>
<tr>
<th>Total data length (4 bytes)</th>
<th>Command (1 byte)</th>
<th>Address (4 bytes)</th>
<th>Number of data (1 byte)</th>
<th>Data</th>
<th>Checksum (1 byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>0x52</td>
<td>Address</td>
<td>Data length to be read</td>
<td>-</td>
<td>CS</td>
</tr>
</tbody>
</table>
Command acknowledge is given below.

<table>
<thead>
<tr>
<th>Command (1 byte)</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>0xD2</td>
<td>data</td>
</tr>
</tbody>
</table>

- **Quit command**
  
  This command does not need any acknowledge.
  
  After receiving this command, it is required to modify flag and jump to the start address of new interrupt vector table.

## 4 Memory allocation

The boot loader code occupies the first region of the flash memory (the lowest memory address space). See the following figure. This placement moves the beginning of the available memory space and it is necessary to shift this address in the user application linker files (ICF file in IAR and in LCF file in CodeWarrior). An example of the ICF linker files modification is as follows:

**Kinetis E KE02Z**

An example of modification of ICF file in IAR6.5 is given by the following code snippet.

```c
// default linker file
define symbol __ICFEDIT_region_ROM_start__ = 0x00;

// modified Linker file for KE02Z 64k flash
define symbol __ICFEDIT_region_ROM_start__ = 0x1000;
```
5 Conclusion

This document introduces a way of implementing IIC boot loader on Kinetis E series MCUs using a bridge board as the convert board, and the other board as target board (KE02Z-FRDM). The users can also add boot loader by themselves in the application software.

6 References

The following reference documents are available on freescale.com

- KE02Z64M20SF0RM: KE02 Sub-Family Reference Manual
- AN2295: Developer’s Serial Bootloader for M68HC08 and HCS08 MCUs

7 Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver/Transmitter</td>
</tr>
<tr>
<td>IIC</td>
<td>Inter-Integrated Circuit</td>
</tr>
<tr>
<td>FCCOB</td>
<td>Flash Common Command OBject</td>
</tr>
<tr>
<td>WDOG</td>
<td>Watchdog</td>
</tr>
<tr>
<td>MCG</td>
<td>Multipurpose Clock Generator</td>
</tr>
</tbody>
</table>
## 8 Revision history

<table>
<thead>
<tr>
<th>Revision number</th>
<th>Date</th>
<th>Substantial changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>07/2013</td>
<td>Initial release</td>
</tr>
</tbody>
</table>