ABSTRACT

This document serves as an overview of the master and slave code libraries for I^2C communication using the USI module as found on the MSP430F20xx. The USI I^2C master and slave libraries encapsulate all the functions necessary to transmit and receive multiple bytes. The functions are written in assembly and can be accessed by any C program that includes the required header files.

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1 Introduction

The USI module provides the basic functionality needed to support synchronous serial communication. When configured in the I^2C mode, the USI module is an 8-bit shift register that can output a stream of serial data. With minimal software, it can be used to setup a master/slave relationship to implement serial communication. A software I^2C library is especially useful for lower-pin-count devices that do not include a hardware module dedicated to I^2C communication. The USI I^2C libraries offer the functionality needed to configure the MSP430 as either a master or a slave device capable of transmission and reception of multiple bytes. The library functions are capable of servicing interrupts while allowing I^2C transactions to take place in the background, without interfering with user applications. The definitions of the interrupt service routines, however, prevent the master and slave libraries from existing on the same device. The example files include a master MSP430 interface to a slave EEPROM device and to a slave MSP430 device.

Note: Internal pullup resistors are enabled on the MSP430F20xx to support I^2C communication.

2 I^2C Master Library

The I^2C master initiates data transfer and generates the clock signal SCL. It can be used in two modes:

- Master transmit
- Master receive

The master code library provides the necessary functionality to support multiple byte and word transmission and reception. It allows the user to switch between transmit and receive operations on the fly using a repeated start condition. The library can execute in both blocking and nonblocking modes. While operating in the nonblocking mode (callback function provided), the I^2C function returns immediately and communication takes place in the background. In this mode, the result of the operation (ACK/NACK) is passed as an argument to the callback function. In the blocking mode (no callback function provided), the functions in the library are executed exclusively (without parallel application code) and provide a valid return value in the end. The return value reflects the result of the operation. Also, the CPU operating mode can be changed or modified using callback functions defined at the application level. Figure 1 is a high-level flow diagram explaining the state transitions in an I^2C routine.
Figure 1. Program Flow for Master Code Library
2.1 Usage From C

Void main(void) {

    WDTCTL = WDTPW+WDTHOLD;       // Stop watchdog
    BCSCCTL1 = CALBC1_1MHZ;       // Load DCO constants
    DCOCTL = CALDCO_1MHZ;
    P1DIR |= 0x01;                // P1.0 as output (LED)
    P1OUT = 0x00;

    /* Initialize USI module, clock ~ SMCLK/128 */
    TI_USI_I2C_MasterInit(USIDIV_7+USISSEL_2+USICKPL, StatusCallback);

    /* Acknowledge polling function - LED blinks continuously until slave device
       provides an ACK
    TI_USI_I2CSelect(unsigned char SlaveAddress) */
    while(TI_USI_I2CSelect(0x50))
    {
        P1OUT ^= 0x01;              // Toggle LED
        for (i = 0; i < 0x3000; i++);  // Delay
    }
    P1OUT =0;                     // Slave acknowledged, LED off

    /* Transmit data to the EEPROM device, prefixed by page address 0x01
    TI_USI_I2CWrite(SlaveAddress, Length, Multi, TxData) */
    __disable_interrupt();
    TI_USI_I2CWrite(0x50,9,0,TxData0);
    __bis_SR_register(LPM0_bits + GIE);

    /* Acknowledge polling function - loops continuously until slave device
       provides an ACK */
    while(TI_USI_I2CSelect(0x50));

    /* Transmit data to the EEPROM device, prefixed by page address 0x08
    TI_USI_I2CWrite(SlaveAddress, Length, Multi, TxData)*/
    __disable_interrupt();
    TI_USI_I2CWrite(0x50,3,0,TxData1);
    __bis_SR_register(LPM0_bits + GIE);  //*/

    /* Acknowledge polling function - loops continuously until slave device
       provides an ACK */
    while(TI_USI_I2CSelect(0x50));

    /* Reset address counter of the EEPROM device by transmitting the page
       address to be read from (0x00) (Dummy write)
    TI_USI_I2CWrite(SlaveAddress, Length, Multi, TxData)*/
    __disable_interrupt();
    TI_USI_I2CWrite(0x50,1,1,TxData0);
    __bis_SR_register(LPM0_bits + GIE);

    /* Read data from the EEPROM device, starting at page address 0x00
    TI_USI_I2CRead(SlaveAddress, Length, Multi, RxData)*/
```c
__disable_interrupt();
TI_USI_I2CRead(0x50, 10, 1,RxData);
__bis_SR_register(LPM0_bits + GIE);

/* This function can be used to end any open I2C transaction.
   Use only if I2C transaction was left open previously by setting stop
   condition bit =1 */
TI_USI_I2CStop();

// check data for validity
for (j = 0; j<10; j++)
{
    if (RxData[j]!=j)
    {
        while(1);    // data invalid, stay in loop
    }
}
P1OUT |= 0x01;    // data valid, LED on
while(1);    // program ends here

int StatusCallback(unsigned char c)
{
    return TI_USI_EXIT_LPM;    // Exit active for next transfer
}
```

The file USI_I2CMaster.h must be included to initialize variables and functions when using the library from a C program. The TI_USI_I2C_MasterInit(...) function needs to be called only once at the start to initialize the USI module in master mode.

In the previous example (example_EEPROM.c), the MSP430 master transmits a stream of data to the AT 24C02, a two-wire serial EEPROM device. The device requires an 8-bit data word address following the device address before data bytes can be written to it. The internal word address counter of the EEPROM maintains the last address accessed during the previous data transmission. Hence, before a read, the internal counter needs to be reinitialized by transmitting to the required data word address. At the end of every write operation, the EEPROM enters an internally timed write cycle and does not respond until the write operation is complete. At this time, it can be polled by the master device for an acknowledge (ACK) using the TI_USI_I2CSelect function. This function returns a nonzero value if the slave sends a No Acknowledge (NACK). Once the slave has acknowledged, the data is ready to be read from the EEPROM. The transmitted and received data are compared and, if found to be valid, the LED is turned on. The data can also be viewed in the memory through a watch window. The callback function is used to modify the low-power mode for the next operation. The result of the previous operation is passed as an argument to the callback function. A zero indicates that the previous operation was successful. An additional example application to communicate with a dedicated slave MSP430 device is provided in the file example_master430interface.c.

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**Note:** If C callback functions are used, the library needs to preserve additional CPU registers (C scratch registers) across the callback function call, as these registers could be affected by the callback function. If it can be ensured that the callback function does not modify the C scratch registers, they need not be preserved. Preserving the C scratch registers consumes additional code space and execution cycles. Therefore, the end user is given the option of using a predefined macro within the library to preserve the C scratch registers (USE_C_CONTEXT_SAVE is included) or leaving the registers as is (USE_CCONTEXT_SAVE is commented out). See the compiler documentation for more details regarding C calling conventions.[2]
### 2.2 Usage From Assembly

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<th>Description</th>
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<td>Poll_0</td>
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<td>Poll_1</td>
<td>Slave acknowledged, LED off</td>
</tr>
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<td>Poll_2</td>
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</tr>
<tr>
<td>Poll_3</td>
<td>Slave acknowledged, LED off</td>
</tr>
</tbody>
</table>

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Using the USI \( ^2 \)C Code Library

SLAA368–September 2007

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In assembly, the usage of the library is the same as in C. Arguments are passed using the C calling convention (making the library functions compatible to both C and assembly usage). The first two parameters are passed using registers R12 and R14; all others are pushed onto the stack.[2]

### 2.3 Function Description

The following functions are defined in the master code library.

#### 2.3.1 `TI_USI_I2C_MasterInit(…)`

The function initializes the USI module for I2C communication. The parameters passed as arguments are:

- `unsigned char ClockConfig`
  
  This value contains the clock select, frequency divider, and clock polarity bits that are to be loaded onto the control register USICTL0.

- `int (* StatusCallback)(unsigned char)`
  
  This function is called on the transmission/reception of the last byte in the communication stream. The result of the previous operation (ACK/NACK) is passed as an argument to this function. The function returns a zero if the existing low-power mode should be maintained or a nonzero value if the low-power mode should be exited.

#### 2.3.2 `TI_USI_I2CSelect(…)`

This function detects the presence of a slave by addressing it and determining if the slave responds with an ACK/NACK. The following parameter is passed as an argument:

- `unsigned char SlaveAddress`
  
  This is the device address of the slave.

  The return value is the result of the operation. The function returns a zero if the slave is present and has acknowledged, and it returns a nonzero value if the slave is absent or not ready to acknowledge. For example, this function can be used to poll slower slave devices like EEPROM while waiting for it to complete an internally timed write cycle.
2.3.3 TI_USI_I2CRead(…)

This function implements block-read master receiver functionality. The parameters passed as arguments are:

unsigned char SlaveAddress
   This is the device address of the slave.

unsigned int Length
   This value is the number of bytes to be received.

unsigned char Multi
   This variable is used to suppress the generation of I²C stop condition if the user wants to leave the channel open for further transactions.

decl void *RxData
   This pointer variable points to the memory location where the received data should be stored.

The function returns a zero if the operation was successful and a nonzero value if a NACK was received at any time during the I²C transaction. It is valid only when no callback function is provided. Otherwise, the function returns immediately, and the I²C transaction takes place in the background.

2.3.4 TI_USI_I2CWrite(…)

This function implements block-write master transmitter functionality. The parameters passed as arguments are:

unsigned char SlaveAddress
   This is the device address of the slave.

unsigned int Length
   This value is the number of bytes to be transmitted.

unsigned char Multi
   This variable is used to suppress the generation of I²C stop condition in case the user wants to leave the channel open for further transactions.

decl void *TxData
   This pointer variable points to the memory location of the data to be transmitted.

The function returns a zero if the operation was successful and a nonzero value if a NACK was received at any time during the I²C transaction. It is valid only when no callback function is provided. Otherwise, the function returns immediately, and the I²C transaction takes place in the background.

2.3.5 TI_USI_I2CStop( )

This function generates the I²C stop condition and can be used to end an open I²C transaction. It is typically not used, as both transmit and receive functions generate a stop condition by default. It can be used in conjunction with a read or write function when the Multi parameter has a nonzero value.

2.4 Included Library Files

USI_I2CMaster.s43
This library file includes all the functionality necessary to transmit and receive single and multiple bytes as an I²C master device. It also contains the acknowledge polling function, which polls for the presence of a slave device.

USI_I2CMaster.h
This header file has the necessary definitions and functions for the master library and must be included in any C program that uses the library.
3 \textit{I}^2\textit{C} Slave Library

The \textit{I}^2\textit{C} slave does not control the clock and can be used in two modes:
- Slave transmit
- Slave receive

The slave code library allows for multiple byte transmission and reception. The library executes in a nonblocking manner and allows for the \textit{I}^2\textit{C} transactions to take place in the background. Callback functions are provided to allow the user to modify the CPU operating mode after each byte is transmitted or received and also store the received data for application use. Figure 2 is a high-level flow diagram explaining the state transitions in an \textit{I}^2\textit{C} slave routine.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{flowchart.png}
\caption{Program Flow for Slave Code Library}
\end{figure}
3.1 Usage From C

```c
void main(void)
{
    WDTCTL = WDTPW + WDTHOLD;       // Stop watchdog
    BCSCTL1 = CALBC1_1MHZ;          // Set DCO
    DCOCTL = CALDCO_1MHZ;
    P1DIR |= 0x01;                   // Enable P1.0 as output
    P1OUT = 0;
    FCTL1 = FWKEY + ERASE;          // Enable flash erase
    FCTL2 = FWKEY + FSSEL_2 + FN0;  // Flash timing setup
    FCTL3 = FWKEY;                  // Disable lock
    *((unsigned int *)0x1000) = 0;   // Dummy write to erase flash
    FCTL1 = FWKEY;
    FCTL3 = FWKEY+LOCK;             // Disable flash write

    /* Initialize USI module in Slave mode */
    TI_USI_I2C_SlaveInit(OwnAddress,StartCallback,RxCallback,TxCallback);
    while(1)
    {
        __disable_interrupt();
        __bis_SR_register(LPM4_bits + GIE);  // enter LPM, enable interrupts
        __no_operation();
    }
}

void StartCallback()
{
    P1OUT |= 0x01;                     // start received, turn LED on
}

int RxCallback(unsigned char RxData)
{
    // Received data byte is stored in flash
    FCTL3 = FWKEY;
    FCTL1 = FWKEY+ WRT;               // Enable flash write
    *(unsigned char*)ptr_rx = RxData; // Write data to flash
    ptr_rx++;
    // Increment Rx pointer
    FCTL1 = FWKEY;
    FCTL3 = FWKEY + LOCK;
    return TI_USI_STAY_LPM ;         // stay in LPM
}

int TxCallback(int* TxDataPtr)
{
    // Data byte to be transmitted is passed through reference to the library
    *(unsigned char*)TxDataPtr = *(unsigned char*)ptr_tx;
    ptr_tx++;
    // Increment tx pointer
    return TI_USI_STAY_LPM ;         // stay in LPM
}
```
The file USI_I2CSlave.h must be included to initialize variables and functions when using the library from a C program. The TI_USI_I2C_SlaveInit(...) function needs to be called only once at the start to initialize the USI module in slave mode. The slave program (example_slave430interface.c) runs on the dedicated slave MSP430, while the master program (example_master430interface.c) runs in parallel on the dedicated master MSP430 device. The slave device uses the Info D segment (0x1000 to 0x104F) to emulate an EEPROM with 64-byte data storage. On reception of the start condition from the master, the StartCallback() function is called. This function can be used to refresh data pointers before a transmit or a receive operation.

In the previous example, the StartCallback() function turns on the LED to indicate that the I²C transaction has started. The master MSP430 transmits 16 bytes of data and then reads it back from the slave MSP430. On the reception of each data byte, the RxCallback() function is called. The received data byte is passed as an argument to this function, and the return value is used to modify the low-power mode. The TxCallback() function is called before each transmit operation. The function passes the data byte to be transmitted indirectly using a reference pointer. It also returns a zero if the existing low-power mode should be maintained or a nonzero value if the low-power mode should be exited. The data can be validated by viewing the Info D segment of flash.

**Note:** If C callback functions are used, the library needs to preserve additional CPU registers (C scratch registers) across the callback function call, as these registers could be affected by the callback function. If it can be ensured that the callback function does not modify the C scratch registers, they need not be preserved. Preserving the C scratch registers consumes additional code space and execution cycles. Therefore, the end user is given the option of using a predefined macro within the library to preserve the C scratch registers (USE_C_CONTEXT_SAVE is included) or leaving the registers as is (USE_C_CONTEXT_SAVE is commented out). See the compiler documentation for more details regarding C calling conventions.[2]
### 3.2 Usage From Assembly

```
RESET       mov.w  #SFE(CSTACK),SP ; Initialize stackpointer
StopWDT     mov.w  #WDTPW+WDTHOLD,&WDTCTL ; Stop WDT
SetupDCO    mov.b  &CALBC1_1MHZ,&BCSCTL1 ; Load DCO calibration constants
mov.b  &CALDCO_1MHZ,&DCOCTL
SetupPx     bis.b  #0x03,&P1DIR ; P1.0 and 1.1 as output
EraseFlash  mov.w  #FWKEY+ERASE,&FCTL1 ; Set erase bit
mov.w  #FWKEY+FSSEL_2+FN0,&FCTL2 ; Set flash timing
mov.w  #0,&0x1000 ; Dummy write to start Flash erase
mov.w  #FWKEY,&FCTL1
mov.w  #FWKEY+LOCK,&FCTL3
mov.w  #0x1000,&RxFlashPtr ; Initialize Rx pointer
mov.w  #0x1000,&TxFlashPtr ; Initialize Tx pointer
SlaveCall   mov.b  #0x48,R12 ; Address of slave
mov.w  #StartCallback,R14 ; StartCallback fn. ptr
push.w  #TxCallback ; Tx Callback fn. ptr
push.w  #RxCallback ; Rx Callback fn. ptr
call    #TI_USI_I2C_SlaveInit ; I2C Slave initialize
add    #4,SP ; compensate stack pointer
bis.w  #LPM4+GIE,SR ; enter LPM, enable interrupts
jmp     $ ;
StartCallback
bis.b  #0x01,&P1OUT ; start received, LED on
ret
TxCallback  mov.w  &TxFlashPtr,R6 ; pass data to be transmitted ...
mov.b  @R6,0(R12) ; ... to the library
inc.w  &TxFlashPtr ; increment tx pointer
mov.w  #0,R12 ; stay in LPM
ret
RxCallback  mov.w  #FWKEY+WRT,&FCTL1 ; Set WRT bit
mov.w  #FWKEY,&FCTL3 ; Clear lock bit
mov.w  &RxFlashPtr,R6 ; Move rxed byte to ...
mov.b  R12,0(R6) ; ... flash location
mov.w  #FWKEY,&FCTL1
mov.w  #FWKEY+LOCK,&FCTL3 ; lock flash
inc.w  &RxFlashPtr
mov.w  #0,R12 ; stay in LPM
ret
```

In assembly, the usage of the library is the same as in C. Arguments are passed using the C calling convention (making the library functions compatible for both C and assembly usage). The first two parameters are passed using registers R12 and R14; all others are pushed onto the stack.[2]
3.3 **Function Description**

The following functions are defined in the slave code library:

3.3.1 **TI_USI_I2C_SlaveInit(...)**

This is the slave initialization function. The following parameters are passed as arguments to this function:

```c
unsigned char OwnAddress
```

This is the address of the slave MSP430 device.

```c
int (* StartCallback) (void)
```

This function is called on the detection of the start condition.

```c
int (* RxCallback) (unsigned char)
```

This function is called on the reception of a data byte. The received data is passed as an argument to the function. The function returns a zero if the existing low-power mode should be maintained or a nonzero value if the low-power mode should be exited.

```c
int (* TxCallback) (int*)
```

This function is called before the transmission of a data byte. The data byte to be transmitted is stored at the location provided as an argument to this function. The function returns a zero if the existing low-power mode should be maintained or a nonzero value if the low-power mode should be exited.

3.4 **Included Library Files**

**USI_I2CSlave.s43**

This library file includes all the functionality necessary for an I²C slave device to transmit and receive single and multiple bytes.

**USI_I2CSlave.h**

This header file has the necessary definitions and functions for the slave library and must be included in any C program that uses the library.

4 **Code Size**

Table 1 shows the code size for the master and slave code libraries in IAR.

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<th>USE_C_CONTEXT_SAVE</th>
<th>SIZE (bytes)</th>
</tr>
</thead>
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<tr>
<td>Master</td>
<td>0</td>
<td>616</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>628</td>
</tr>
<tr>
<td>Slave</td>
<td>0</td>
<td>408</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>444</td>
</tr>
</tbody>
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5 **References**

1. **MSP430x2xx Family User’s Guide** ([SLAU144](http://www.ti.com))
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