

Using the USI I²C Code Library

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ABSTRACT

This document serves as an overview of the master and slave code libraries for I²C communication using the USI module as found on the MSP430F20xx. The USI I²C 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 I²C 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 I²C library is especially useful for lower-pin-count devices that do not include a hardware module dedicated to I²C communication. The USI I²C 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 I²C 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 I²C communication.

2 I²C Master Library

The I²C 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 I²C 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 I²C routine.

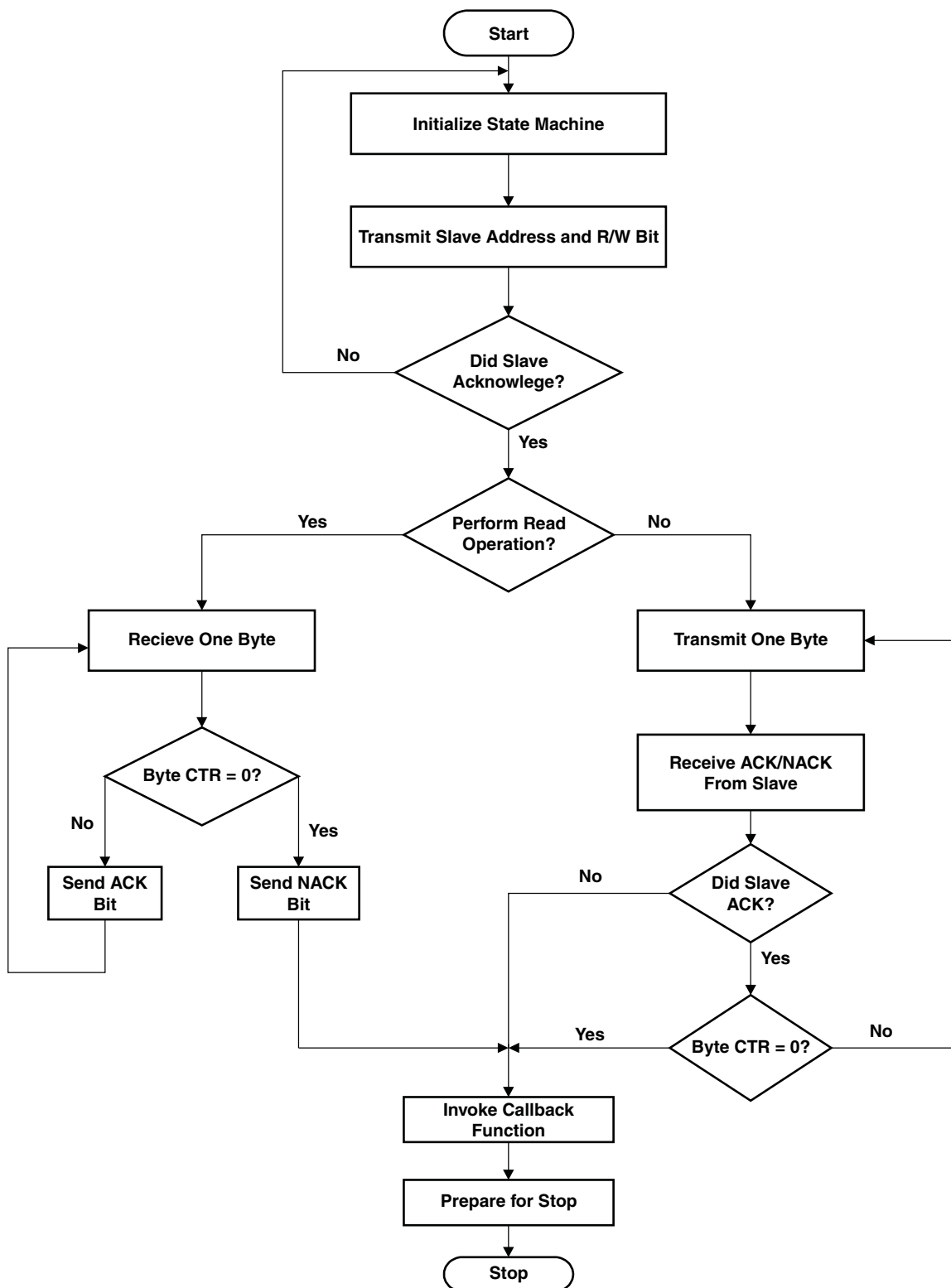


Figure 1. Program Flow for Master Code Library

2.1 Usage From C

```

Void main(void)
{

    WDTCTL = WDTPW+WDTHOLD;                // Stop watchdog
    BCSCTL1 = 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)*/

```

```

__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.

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]

2.2 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	#0x01,&P1DIR	; P1.0& 1.1 as output
	bic.b	#0x01,&P1OUT	
InitCall	mov.b	#0xEA,R12	; USIDIV_7+USISSEL_2+USICKPL
	mov.w	#StatusCallback,R14	; Callback fn. pointer
	call	#TI_USI_I2C_MasterInit	; Initialize USI master
SlaveDetect			
	xor.b	#0x01,&P1OUT	; Detect if slave is present...
	mov.w	#0xFFFF,R5	; ... LED toggles until slave ACKS
L1	dec.w	R5	
	jnz	L1	
Poll_0	call	#AcknowledgePoll	; Slave device present?
	cmp.b	#0,R12	; Is result zero (ACK)?
	jnz	SlaveDetect	; Loop until device acknowledges
	clr.b	&P1OUT	; Slave acknowledged, LED off
TransmitCall_1			
	mov.w	#0x50,R12	; Slave address
	mov.w	#9,R14	; length = 9
	push.w	#Transmit1	; pointer to data buffer
	push.w	#0x00	; generate stop
	call	#TI_USI_I2CWrite	; transmit data stream #1
	add.w	#4,SP	; compensate SP on return
	bis.w	#LPM0+GIE,SR	; enter LPM, enable interrupts
Poll_1	call	#AcknowledgePoll	; Device ready for next transfer?
	cmp.b	#0,R12	; Is result zero (ACK)?
	jnz	Poll_1	; Loop until device acknowledges
TransmitCall_2			
	mov.w	#0x50,R12	; Slave address
	mov.w	#3,R14	; length = 3
	push.w	#Transmit2	; pointer to data buffer
	push.w	#0x00	; generate stop
	call	#TI_USI_I2CWrite	; transmit data stream #2
	add.w	#4,SP	; compensate SP on return
	bis.w	#LPM0+GIE,SR	; enter LPM, enable interrupts
Poll_2	call	#AcknowledgePoll	; Device ready for next transfer?
	cmp.b	#0,R12	; Is result zero (ACK)?
	jnz	Poll_2	; Loop until device acknowledges
TransmitCall_3			
	mov.w	#0x50,R12	; Slave address
	mov.w	#1,R14	; length = 1
	push.w	#Transmit1	; pointer to data buffer
	push.w	#0x01	; generate stop
	call	#TI_USI_I2CWrite	; transmit to reset internal counter
	add.w	#4,SP	; compensate SP on return
	bis.w	#LPM0+GIE,SR	; enter LPM, enable interrupts
ReceiveCall			
	mov.w	#0x50,R12	; Slave address
	mov.w	#10,R14	; length = 10
	push.w	#Receive	; pointer to data buffer
	push.w	#0x01	; do not generate stop
	call	#TI_USI_I2CRead	; receive stream#1,#2
	add.w	#4,SP	; compensate SP on return
	bis.w	#LPM0+GIE,SR	; enter LPM, enable interrupts

```

StopTransaction
    call    #TI_USI_I2CStop        ; Stop I2C transactions
CheckResult
    mov.w   #Receive,R6            ; store received data location
    clr.b   R4
Compare
    cmp.b   R4,0(R6)
    jz      Increment              ; data valid, continue
    clr.b   &P1OUT                  ; data invalid, LED off
    jmp     EndProgram
Increment
    inc.b   R4
    inc.w   R6
    cmp.b   #10,R4
    jnz     Compare                ; if all 10 bytes are correct.
    bis.b   #0x01,&P1OUT            ; ... turn on LED
EndProgram  jmp     $               ; program ends here
AcknowledgePoll
    mov.b   #0x50,R12              ; slave address
    call    #TI_USI_I2CSelect      ; Ack polling function
    ret
StatusCallback
    mov.w   #1,R12                 ; wake up on exit
    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 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.

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.

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 I²C Slave Library

The I²C 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 I²C 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 I²C slave routine.

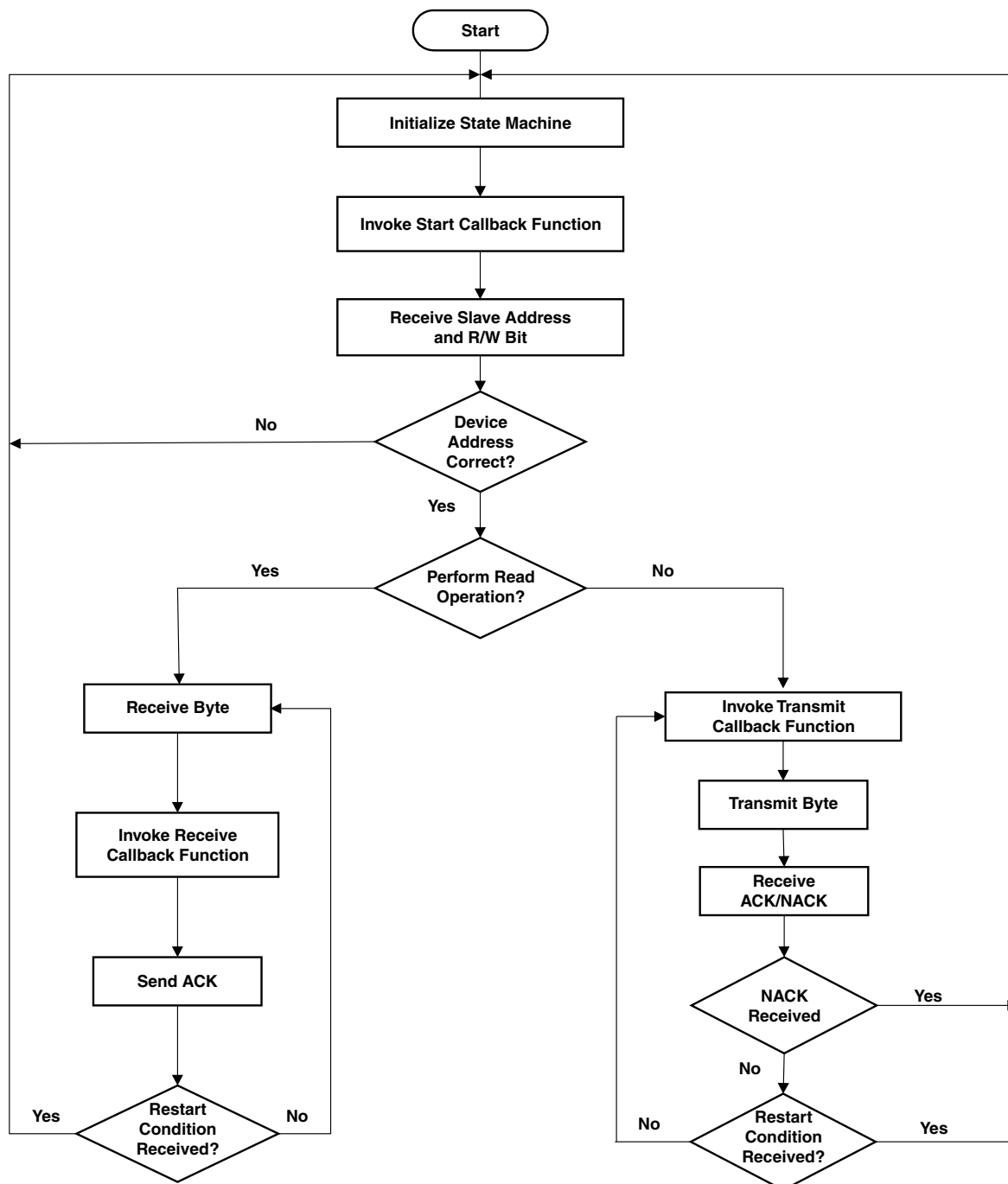


Figure 2. Program Flow for Slave Code Library

3.1 Usage From 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;                       // Disable flash write
    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	#FWKEY,&FCTL3	; Clear lock bit
	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:

unsigned char OwnAddress

This is the address of the slave MSP430 device.

int (* StartCallback) (void)

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

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.

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.

Table 1. Code Size (IAR)

CODE LIBRARY	USE_C_CONTEXT_SAVE	SIZE (bytes)
Master	0	616
	1	628
Slave	0	408
	1	444

5 References

1. *MSP430x2xx Family User's Guide* ([SLAU144](#))
2. *IAR MSP430 C/C++ Compiler Reference Guide* (<http://ftp.iar.se/WWWfiles/msp430/guides/oc430.pdf>)
3. *I²C-Bus Specification and User Manual*, NXP Semiconductors, 2007 (http://www.nxp.com/acrobat/usermanuals/UM10204_3.pdf)

Revision History

Revision	Comments
SLAA368	Initial release
SLAA368A	Updated associated zip file (slaa368.zip); no changes to document

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

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