Simple I2C routines for PIC16

1 INTRODUCTION

There are numerous I2C routines available on the web, from Microchip and other sources. The great many of them have one thing in common, there are quite complex to understand and use. As a matter of fact they are much too complex for most needs.

It is true that in some systems this complexity is useful and even required, but in most cases one master controls 1 to 3 or 4 peripherals, one at a time, and no complexity is required in these cases.

Interrupts driven routines are also not typically required for simple cases when things unfold quite linearly as the program executes. So here we do not use interrupts.

This document does not explain what is I2C, and its operation, there is plenty of information not only on the web, but in nearly any data sheet for devices using I2C. Here, we show a few simple routines, to address most needs in a system with 1 master and 1 or more peripherals.

These examples have been used on a Microchip PIC16(L)F15376 but have also been used on other PIC16 devices with just a few modification in register names.

2 BUILDING BLOCKS

Looking in data sheets for devices using I2C, the same “actions” are always required. They are:

- I2C initialize
- Start
- Stop
- Repeated Start
- Read I2C (8 bits)
- Write I2C (8 bits)

So if we have a routine for each of these actions, we have a working I2C interface.

In most systems, there will be no need for bus busy detection, collision detection or other advanced functions.

In Microchip parlance, I2C interfaces are called MASTER SYNCHRONOUS SERIAL PORT (MSSPx) MODULES. Here we are using the MSSP1 for I2C communications.

This has been set up using the MCC. The MCC is a Microchip GUI, provided with their IDE, that can be used to configure the various sections of the MCU, in particular here, the MSSP1. The MCC generates ready to use source files for the compiler. The other way to produce these files is to write them, simply by reading the relevant section of the data sheet and setting up the needed registers.

Let’s look at each of these blocks in more details.

```
#include "i2c1.h"

void I2C1_Initialize(void)
{
    // SMP High Speed; CKE disabled;
    SSP1STAT = 0x00;
    // SSPEN enabled; SSPM FOSC/4_SSPxADD_I2C;
    SSP1CON1 = 0x28;
    // SBCDE disabled; BOEN disabled; SCIE disabled; PCIE disabled;
    // DHEN disabled; SDAHT 100ns; AHEN disabled;
    SSP1CON3 = 0x00;
    // SSPADD 4; 400 kHz
    SSP1ADD = 0x04;

    // clear the interrupt flags
    PIR3bits.SSP1IF = 0;
    PIR3bits.BCL1IF = 0;

}
```

Figure 1. I2C initialization routine

#include "i2c.h" introduces the functions prototypes to the compiler.

SSP1STAT = 0x00; This register mainly reflects the status of MSSP1. Two bits needs to be set[1], the SMP bit for high speed (400 kHz as I am using) and the CKE bit for the voltage thresholds to be I2C compatible.

SSP1CON1 = 0c28; One of the control registers. Here the SSPEN bit enables the MSSP1 to act as an I2C interface, setting up the SDA and SCL pins and the SSPM bits set the interface to "I2C Master mode, clock = FOSC / (4 * (SSPxADD+1))", in my case 400 kHz.

SSP1CON2 is not set up here as it is used only during I2C operation as we will see below.

SSP1CON3 = 0x00; Another control register. SBCDE disabled, we are not concerned with bus collision as we have a simple 1 master, 1 or more slaves. Bus collisions cannot occur. Note that this bit is for slave mode, the master turns into a slave when it is served data, but again this does not concern our simple case. BOEN disabled is also of no concern in our simple case. SCIE disabled of no concern since we do not use interrupts for I2C operation. PCIE disabled since we do not use interrupts. DHEN disabled, this is not needed in our simple and straightforward case. SDAHT 100 ns, this is the normal case. One could change this if it is required by one of the slave devices used. AHEN disabled, this is the normal case.

SSP1ADD = 0x04; This sets the clock rate at 400 kHz. SCL pin clock period = ((ADD<7:0> + 1) *4)/FOSC. My system is running at 8 MHz, this has to be changed for different clock speeds.

Lets now look at the Start routine.

```
void Send_I2C_Start(void)
{
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1CON2bits.SEN = 1;     // send start bit
    while(!PIR3bits.SSP1IF); // Wait for the SSPIF bit to return high

}
```

Figure 2. Our Start routine.

1. I am using "set" to mean adjusted and not in the sense set (to 1) the opposite of reset (set to 0).

Things are now getting considerably simpler. Here we first make sure the interrupt flag is zero. We do not use interrupts, but this flag will be set when the start sequence is finished. We then initiate a Start condition (SEN = 1;) and we wait for the interrupt flag to return 1, indicating the action is complete.

The Stop routine.

```
void Send_I2C_Stop(void)
{
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1CON2bits.PEN = 1;     // Initiate the Stop condition
    while(!PIR3bits.SSP1IF); // Wait for the SSPIF bit to return high

}
```

Figure 3. Our Stop routine.

The same comment as above applies, but here we initiate a Stop condition (PEN = 1).

The Restart routine

```
void Send_I2C_R_Start(void)
{
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1CON2bits.RSEN = 1;    // initiate restart condition
    while(!PIR3bits.SSP1IF); // Wait for the SSPIF bit to return high
}
```

Figure 4. The Restart routine.

Not used that often, it makes use of the RSEN bit.

The Read routine.

```
unsigned char Read_I2C(unsigned char ack) // 1 = ACK, 0 = NAK
{
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1CON2bits.RCEN = 1;    // set the receive enable bit to initiate a read
    while(!PIR3bits.SSP1IF); // Wait for interrupt flag to return high
    if (ack){SSP1CON2bits.ACKDT = 0;} else {SSP1CON2bits.ACKDT = 1;}
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1CON2bits.ACKEN = 1;   // send acknowledge sequence
    while (!PIR3bits.SSP1IF) ; // wait for a flag to be set
    return (SSP1BUF);         // Received data is now in the SSP1BUF
}
```

Figure 5. Reading 1 byte from the slave terminating either with a ACK or a NACK.

Reading a byte from a slave devices may either need to be terminated by a acknowledge (ACK) or a non-acknowledge (NACK). This routine does either by calling it with the ack parameter at 1 or 0.

As previously we first clear the SSP1IF interrupt flag and we initiate the byte transfer (RCEN = 1).

We then wait for the transfer to be complete (SSP1IF returns high). At this stage we set the ACKDT bit to either send an ACK or a NACK, and after resetting the interrupt flag, we initiate the ACK/NACK operation. When this is complete (SSP1IF returns high), we simply return the content of the receive buffer.

The Write routine

```
void Write_I2C (unsigned char data)
{
    PIR3bits.SSP1IF = 0;      // clear interrupt flag
    SSP1BUF = data;           // Transmit begins as soon as SSP1BUF is written
    while(!PIR3bits.SSP1IF); // Wait for interrupt flag to return high
}
```

Figure 6. The write routine

Finally our I2C write routine. Writing the data to transmit in the SSP1BUF initiate the transfer, which is complete once the interrupt flag returns to high.

These are all the building block we need to write our I2C routines.

We are now presenting routines for a few specific devices below, to demonstrate the use of these blocks.

3 EEPROM ACCESS

Microchip has a range of serial access EEPROMs similar to the 24AA64 shown here.

3.1 Writing to the EEPROM

The following is the write sequence as shown in the 24AA64 data sheet.

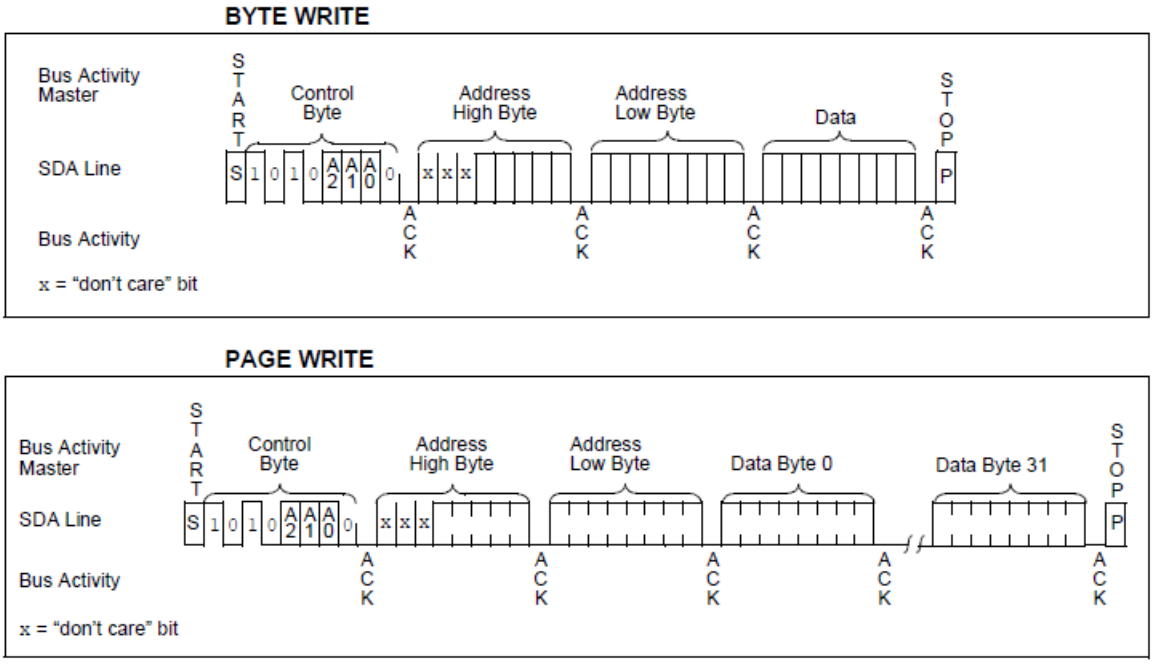


Figure 7. The write sequences for the 24AA64 EEPROM

Setting up our write access routine consists in assembling our building blocks according to this figure.

Single byte write: Start, EEPROM address, 2 bytes of memory address, data transfer and Stop. This is shown below.

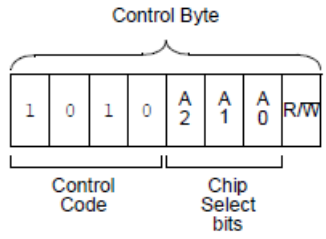
```
void EEPROM_write(unsigned int addr, unsigned char mydata)
{
unsigned char msb, lsb;
   lsb = addr & 0x00ff;
   msb = addr >> 8;
   Send_I2C_Start();
   Write_I2C(EEP | WRITE);
   Write_I2C(msb);      //Hi address
   Write_I2C(lsb);      //L0 address
   Write_I2C(mydata);   //data
   Send_I2C_Stop();
}
```

Figure 8. Single byte write to the EEPROM

The call to the routine passes the address of the memory array and the byte to be written.

Here I use a fixed address for the EEPROM (`EEP`) since I only have 1 in my system.

Following are a few considerations on the device address. An I2C address normally consists of 7 bits plus 1 for R/$\overline{W}$. There are 2 ways to represent this address, left justified or right justified. Microchip calls it the control byte and represents it as shown below left. In my system, the chip select bits are all at zero.



1 0 1 0 0 0 0 x = 0xA0 for writing
and 0xA1 for reading

disregarding the R/$\overline{W}$ bit, this address can be written as:

0 1 0 1 0 0 0 0 = 0x50

It is then shifted left by 1 and OR'd with the R/$\overline{W}$ bit.

Figure 9. Two representations of the chip address

The representation at right, seen in some documentation is both misleading and complex, needing a shift operation and an OR operation to obtain the actual byte to be sent to the device. The one on the right is simpler, requiring only an OR operation to obtain the final address. This is the one I use. In my case EEP is declared as 0xA0 and OR'd here with either WRITE (which is declared as 0) or READ (see below which is declared as 1).

So in this routine, we first split the 16 bit address into 2 bytes. Then send a Start, then the chip address (control byte) with the Write bit set to 0, then the high address, then the low address, then the data, then a Stop, exactly as described in the data sheet sequence reproduces on Figure 7 top.

Below is the routine for page write. Again it follows exactly the sequence represented in Figure 7 bottom. Here we pass the base address of the page to be written to the routine, and the size (number of bytes) of the desired transfer. We also pass a whole table of the bytes to be written (`a[ ]`). Note that in C, the table is not passed by value as for the address and size, but is passed by reference. This is not important here, but will be in the case of the page read shown below. So we first split the 16 bit page address in 2 bytes, and following the Figure 7 bottom, we send a Start, the chip address in Write mode, the high

page address, the low page address, and now we send the buffer one byte at a time followed by a Stop.

```
void EEPROM_write_p(unsigned int addr, unsigned char size, unsigned char a[])
{
unsigned char msb, lsb, i;
   lsb = addr & 0x00ff;
   msb = addr >> 8;
   Send_I2C_Start();
   Write_I2C(EEP | WRITE);
   Write_I2C(msb);    //Hi address
   Write_I2C(lsb);    //LO address
   for (i = 0; i < size; i++){
   Write_I2C(a[i]);  // address auto increments
   }
   Send_I2C_Stop();
}
```

Figure 10. The page write routine

Another important routine is needed to complete our description of the write operation. The data sheet mentions that the device is not available during the write cycle which can last up to 5 ms. In order to prevent writing during this interval it is desirable to wait this time out. One way to do this, outlined in the data sheet is to poll the device until it answers. This is shown in the routine below which only returns once the EEPROM is again available.

```
void EEPROM_poll(void)
{
  do { Send_I2C_Start();
       Write_I2C(EEP | WRITE);
     } while (SSP1CON2bits.ACKSTAT);  // wait for ack
     Send_I2C_Stop(); // release SDA
}
```

Figure 11. Acknowledge polling the EEPROM

3.2 Reading from the EEPROM

We once again turn to the data sheet to extract the following sequences.

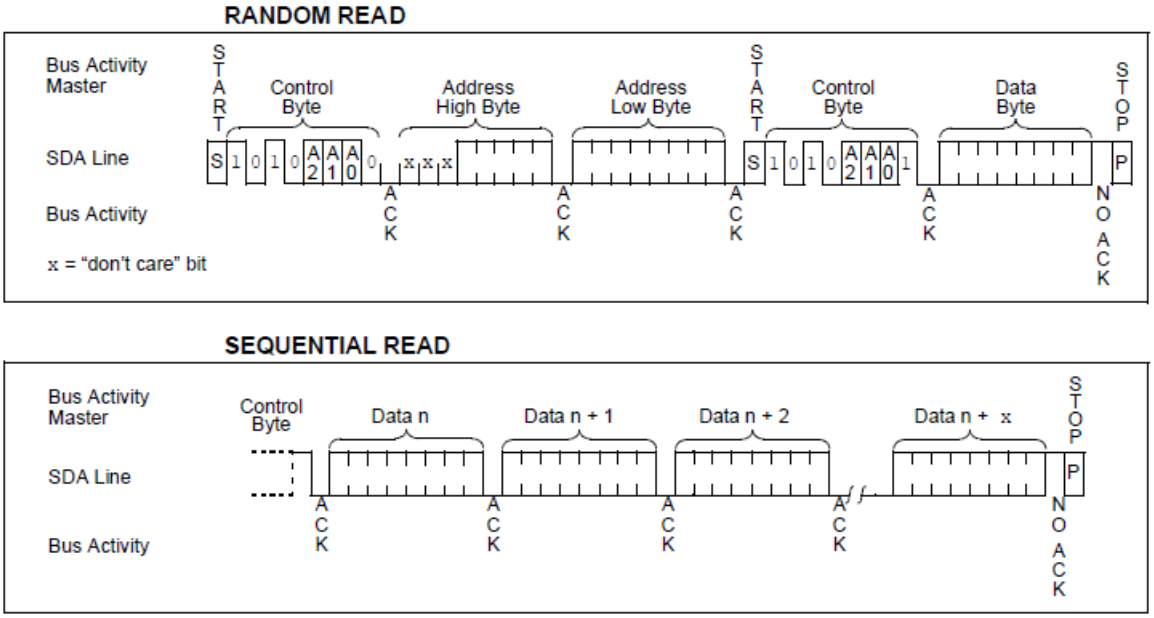


Figure 12. The read sequences for the 24AA64 EEPROM

Let's first look at reading 1 byte from the EEPROM - Figure 12 top. The sequence is quite straightforward, except that we need a Start in the middle and a NO ACK near the end. This is provided by the routine below.

```
unsigned char EEPROM_read(unsigned int addr)
{
 unsigned char msb, lsb, mydata;
   lsb = addr & 0x00ff;
   msb = addr >> 8;
   Send_I2C_Start();
   Write_I2C(EEP | WRITE);
   Write_I2C(msb);         // Hi address
   Write_I2C(lsb);         // Lo address
   Send_I2C_Start();       //
   Write_I2C(EEP | READ);
   mydata = Read_I2C(NAK);  //
   Send_I2C_Stop();
   return mydata;
}
```

Figure 13. Single byte reading from the EEPROM

The routine will return the byte read at the address provided. As usual, we split the address into 2 bytes, and send a Start. Then the chip address with the Write bit set to 0, then the 2 byte address. We follow with a Start bit and the chip address in Read mode. We are then instructed to read the byte from the EEPROM with a NACK, which we do, followed by a Stop. This conforms to the requirements outlined on Figure 12 top.

Now let's look at page read. We pass by value the address of the page to be read, the number of bytes to be read, and a pointer to a table where to store the data. In C, when passing a table to a function (subroutine), it is passed by reference, meaning the routine gets a pointer to the table. This has the implication that the subroutine is able to modify the content of the table which is here exactly what we want to store the data read.

The sequence start as for byte read, by splitting the address in 2 bytes. Now, looking at the sequence on Figure 12 bottom, we notice that the treatment for the last byte is different, it needs a NACK while all the others need an ACK. so we'll decrease size by 1, to use it as a "ACK bytes" counter.

```
{
 unsigned char msb, lsb, myi;
   lsb = addr & 0x00ff;
   msb = addr >> 8;
   size -=1;           // read 0 to size -1 with ACK
   Send_I2C_Start();
   Write_I2C(EEP | WRITE);
   Write_I2C(msb);     //Hi address
   Write_I2C(lsb);     //L0 address
   Send_I2C_Start();  //
   Write_I2C(EEP | READ);
   for (myi = 0; myi < size; myi++){
   a[myi] = Read_I2C(ACK);      // read 0 to size -1 with ACK
   }
   a[size] = Read_I2C(NAK);     // read last byte with NAK
   Send_I2C_Stop();
}
```

Figure 14. Page read from the EEPROM

This is also convenient to store the last byte since when we say our transmission needs 32 bytes (for instance) they are numbered 0 to 31. So after the usual chip address, base

page address transmission, we start reading (size – 1) bytes that we store into the table we point to.

This being completed, we read the last byte, with a NAK flag and store it in the last place in the table. We can now send Stop to complete the whole transaction.

4 TEMPERATURE SENSOR

Here is another example, controlling a MCP9808 temperature sensor[1]. This devices uses (mostly) 16 bit transfers.

Let's start by a writing routine.

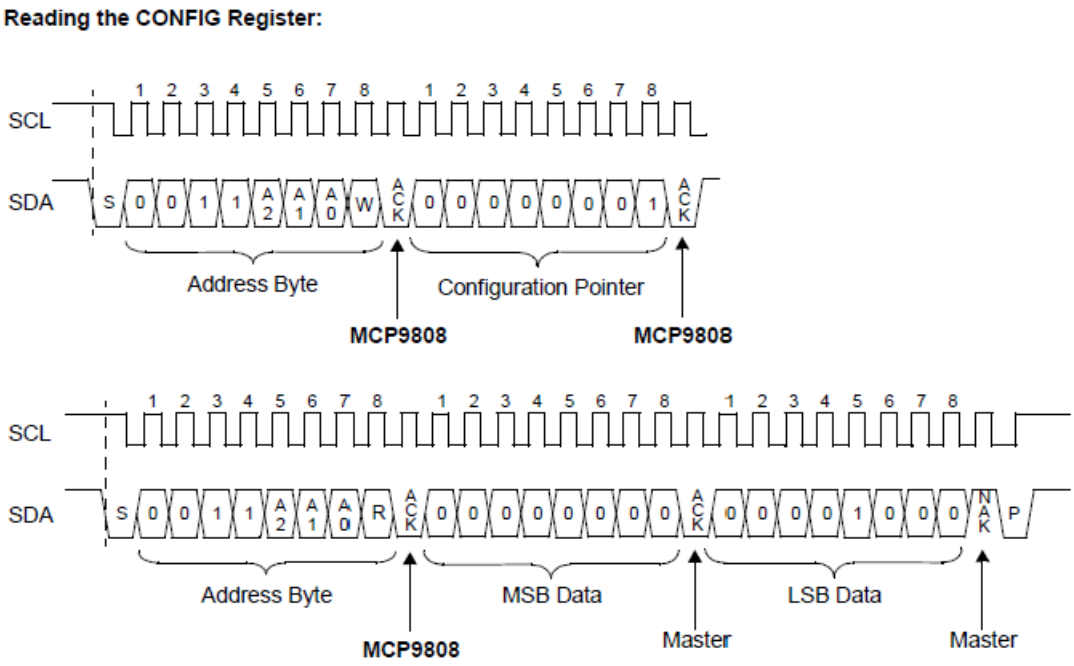


Figure 15. Reading the 16 bit config register

We must first send a Start followed by the chip address with the Write bit set, then an internal 8-bit register pointer, then again after a Start, the chip address, in Read mode, and we now accept 2 bytes, the first one with an ACK, the second one with a NACK.

```
unsigned int MCP9808_read(unsigned char reg)
{
unsigned int mydata;
  Send_I2C_Start();
  Write_I2C(THR | WRITE);
  Write_I2C(reg);              // send pointer
  Send_I2C_Start();
  Write_I2C(THR | READ);
  mydata = Read_I2C(ACK);        // MSB with ACK
  mydata = (mydata <<= 8) | Read_I2C(NAK);  // LSB with NACK
  Send_I2C_Stop();
  return mydata;
}
```

Figure 16. Reading from the temperature sensor.

1. Note that the data sheet for this device provides C-code examples of I2C routines that are very close to the ones described here.

The first one, the MSB, with an ACK and the second one with a NACK, before sending a Stop. The routine returns the 16 bit value just read.

We can now look at a write routine.

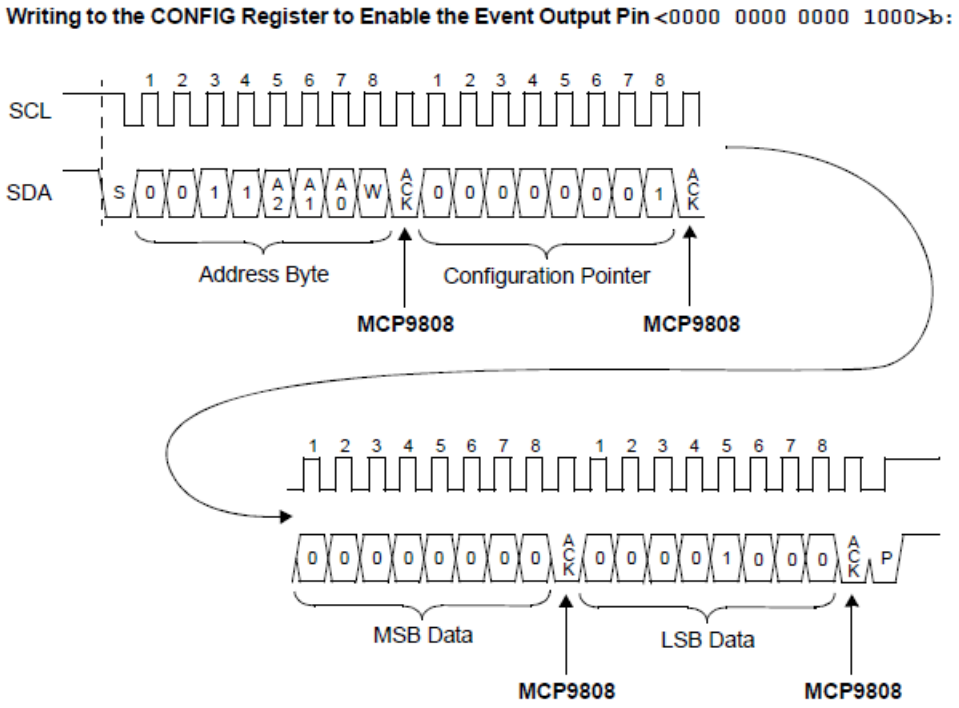


Figure 17. Writing 16-bit data

As before we must first transmit an 8-bit register pointer before writing the 16 bit data.

```
void MPC9808_write (unsigned char reg, unsigned int mydata)
{
unsigned char msb, lsb;
  lsb = mydata & 0x00ff;
  msb = mydata >> 8;
  Send_I2C_Start();
  Write_I2C(THR | WRITE);
  Write_I2C(reg);        // send pointer
  Write_I2C(msb);        //MSB
  Write_I2C(lsb);        //LSB
  Send_I2C_Stop();
}
```

Figure 18. Routine to write 16 bit data

At this stage, this is self explanatory.

5 CONCLUSION

This document has described I2C routines, based on simple building blocks that should be usable for most simple cases. They assume a single master, 1 or more peripherals (slave devices), and do not make use of interrupt.

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