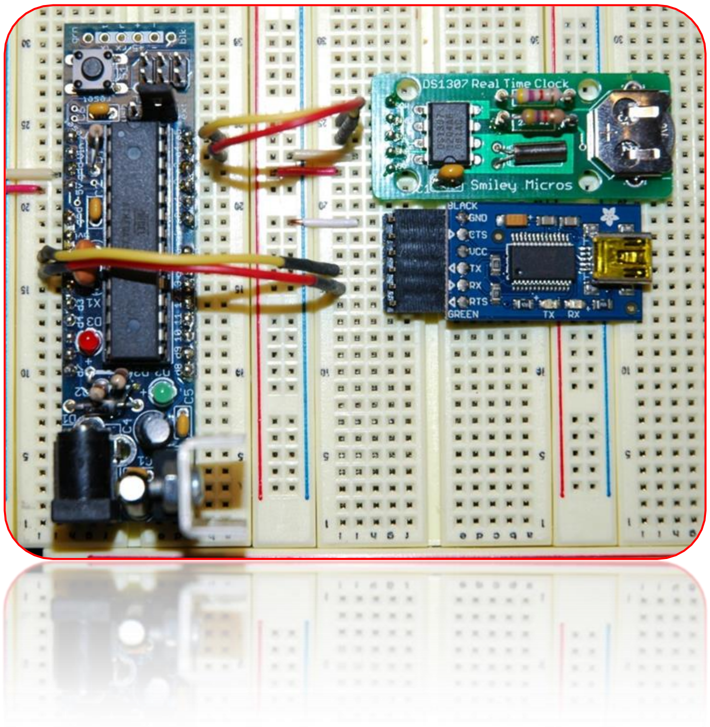

Serial Interfaces: SPI, I2C, UART Demystified

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Objective: learn how to use SPI, I2C, and UART on your AVR microcontroller.

1) INTRODUCTION

It took me a long time to get here. I've used various flavors of AVR microcontrollers, writing to them in assembly, C, and Arduino "wiring/processing". For some reason, I always avoided using the built-in serial communication hardware. Often I used someone else's serial library. Sometimes I emulated the protocol using GPIO pins. But eventually I realized that using the built-in interfaces isn't difficult after all. Here is my collection of quick-'n-dirty serial interface routines. This is all hobby-grade material: no fancy objects, no long list of initialization options, or interrupt-driven code with ring buffers. But follow along, and you'll be able to use the serial hardware with minimal fuss and minimal code. At the end I'll use the UART and I2C interfaces in a small RTC project.

2) SERIAL PERIPHERAL INTERFACE (SPI)

At its core, the SPI algorithm is very straightforward:

- Put a data bit on the serial data line.
- Pulse the clock line.
- Repeat for all the bits you want to send, usually 8 bits at a time.

You must set the microcontroller's SPI control register (SPCR) to enable SPI communication. This is an eight-bit register that contains the following bits:

SPCR = 0x50:

bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
SPIE	**SPE**	DORD	**MSTR**	CPOL	CPHA	SPR1	SPR0
0	**1**	0	**1**	0	0	0	0

The first bit on the left, SPIE, enables the SPI interrupt and is not needed for this application. The SPE bit enables SPI. DORD determines the data direction: when 0, the most-significant bit is sent & received first. MSTR determines if the micro acts as a master (1) or slave (0) device. CPOL and CPHA together determine the transfer mode. Our TFT display works well with Mode 0, in which both bits are zero. Finally, SPR1 and SPR0 determine the transfer speed, as a fraction of the microcontroller's oscillator. When both are 0, the SPI transfer speed is osc/4, which on my 16 MHz micro is 16/4 = 4 MHz. When both bits are 1, the transfer speed is osc/256 = 62.5 kHz.

Using an SPCR value of 0x50, SPI is enabled as Master, in Mode 0 at 4 MHz. The code to open SPI communication can be as simple as the following:

```
void SPI_Init()
{
    SPCR = 0x50;                        // SPI enabled as Master, Mode0 at 4 MHz
}
```

To close SPI, just set the SPE bit to 0. This will stop SPI and return the four dedicated SPI lines (MOSI, MISO, SCLK, SS) to the general purpose I/O functions:

```
void SPI_Close()
{
    SPCR = 0x00;                        // clear SPI enable bit
}
```

Only one more routine is needed: the SPI transfer routine. SPI is a bidirectional protocol, with two separate data lines. The data is transmitted over MOSI and received over MISO *at the same time*. Even if we only want to send, we are always going to receive. And vice versa. If you aren't expecting any received data, just ignore what is returned to you.

The data transfer register is SPDR. Load this register with a value, and the data transfer will start automatically. A bit in SPSR, the status register, will tell us when the transfer is complete. As the data bits are serially shifted out of the transfer register, the received bits are shifted in. When the transfer completes, SPDR will hold the received data:

```
byte SPI_Xfer(byte data)                // you can use uint8_t for byte
{
    SPDR = data;                        // initiate transfer
    while (!(SPSR & 0x80));             // wait for transfer to complete
    return SPDR;
}
```

3) TESTING THE SPI INTERFACE

The three routines above are all we need for SPI. Let's make sure they work by doing a serial loop-back test. In this test, the output data on MOSI is looped-back as the input on MISO. Whatever value we put into the data register should come right back in.

Without a working display, we need a way to verify the data. You might want to use your fancy debugger, or send the value to a monitor via UART, but here is something even simpler: flash the LED on your controller board. Most AVR boards have a connected LED. On many AVR boards, including the Arduino, the status LED is on PB5. Here is a routine to flash it:

```
void FlashLED(byte count)
// flash the on-board LED at ~ 2 Hz
{
    DDRB |= _BV(DDB5);                    // Set PB5 as output
    for (;count>0;count--)
    {
         PORTB |= _BV(PORTB5);            // turn LED on
         _delay_ms(250);                  // wait
         PORTB &= ~_BV(PORTB5);           // turn LED off
         _delay_ms(250);                  // wait
    }
}
```

Now, disconnect the microcontroller's MOSI (digital 11, PB3) from the TFT display, and connect it to the microcontroller's MISO line (digital 12, PB4). Run the following code:

```
void SPI_LoopbackTest()
{
    SPI_Init();                         // start communication to TFT
    char i = SPI_Xfer(5);               // MISO to MOSI -> returns 5
                                        // MISO to +5V  -> returns 255
                                        // MISO to Gnd  -> returns 0
    SPI_Close();                        // return portB lines to general use
    FlashLED(i+1);                      // flash (returned value + 1)
}
```

What happens? If all goes well, the LED will flash 6 times. The value 5 is sent out the MOSI line, comes back in on the MISO line, and is returned from the SPI xfer routine.

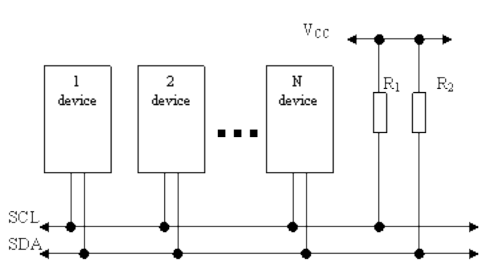
You may wonder if Xfer worked at all. Maybe nothing was transferred: the value 5 could have stayed in the transfer register 'untouched'. How can we know for sure?

For the doubters out there like me, take your wire on the MISO line and put to ground (logic 0). Now, all bits shifted-in will be 0, and the value returned should be 0x00000000 = 0. If you run the program now, the LED should flash only once. To further convince you, connect MISO to +5V. Now, all bits shifted-in will be one, and the value returned will always be 0x11111111 = 255. The LED should not flash at all, since 255+1 = 256 = 0, for byte-sized variables.

I have posted an SPI project that drives a TFT display at http://w8bh.net/avr/AvrTFT.pdf

4) THE I^{2}C INTERFACE

Atmel calls their version of I2C the "two-wire" interface, or TWI. It is a serial-data protocol which uses two data lines for communication: a data line (SDA) and a clock (SCL). Devices on the I2C bus can either be masters or slaves. Masters initiate data transfers, and slaves react only to master requests. In this article, the AVRmega328 is the master, and the RTC is always the slave. Slaves are specified by a 7-bit address, plus a read/write bit. The device address for the DS1307 is fixed at 0xd0.



The interface circuit is "open collector", which means that the data lines are passively kept high by resistors to

Vcc. Any device on the bus can actively pull a data line low. Up to 128 devices can be put on the same data bus.

There are plenty of good articles on TWI/I2C programming for AVR microcontrollers. Check out the following for a good start:

1. Non-GNU.org: http://www.nongnu.org/avr-libc/user-manual/group__twi__demo.html
2. AVR beginners: http://www.avrbeginners.net/architecture/twi/twi.html
3. ATMEL AVR315: http://www.atmel.com/Images/doc2564.pdf

Compared with SPI, using I2C is a bit more involved. The first job is to set the frequency of the serial data clock. Typically, the clock frequency is 10 (slow mode), 100 (standard mode), or 400 (fast mode) kHz.   The maximum clock rate is determined by the slowest device on the bus, as well as bus capacitance. As a practical matter, most I2C devices run at 100 kHz. The DS1307 runs at 100 kHz.

Again, keep in mind there are already libraries available for using I2C with your AVR or arduino. You do not need to do this yourself. A search for 'I2C master library' will turn up a few alternatives. Keep reading if you'd like roll your own.

There are two special registers on the ATmega which control the SCL frequency: TWSR and TWBR. TWSR is the TWI status register, and contains prescalar bits used to divide the CPU clock frequency.   We do not need a prescalar, so we can ignore these bits. The TWBR is the bit-rate register. The SCL frequency is a function of the CPU frequency and this register, according to the following formula: F_SCL in MHz = F_CPU/(16+2(TWBR)). Kinda complicated, isn't it? To determine the value of TWBR we can rewrite it like this: TWBR = ((F_CPU/F_SCL)-16)/2.   My CPU has a 16 MHz clock, and I want to run the interface in standard 100 kHz mode. So the value of TWBR must be ((16/0.1)-16)/2 = (160-16)/2 = 72.

```
#define F_CPU         16000000L         // CPU clock speed 16 MHz
#define F_SCL         100000L           // I2C clock speed 100 kHz

void I2C_Init()
// at 16 MHz, the SCL frequency will be 16/(16+2(TWBR)), assuming prescalar of 0.
// so for 100KHz SCL, TWBR = ((F_CPU/F_SCL)-16)/2 = ((16/0.1)-16)/2 = 144/2 = 72.
{
    TWSR = 0;                           // set prescalar to zero
    TWBR = ((F_CPU/F_SCL)-16)/2;        // set SCL frequency in TWI bit register
}
```

Here is the protocol for sending data from master to slave: "MT" (master transmit) mode

- Master generates Start Condition, status code 0x08 is returned
- Master sends slave address (0xd0), slave device returns ACK, status code 0x18
- Master sends one or more data bytes, slave device returns ACK, status code 0x28
- Master generates Stop Condition, no status code returned

After each operation, the 'ready' bit in TWCR will go to logic 0, and return to logic 1 when the operation is completed. Byte-sized data is sent/received via the special TWDR register. The start, stop, and data transfer conditions are specified by the TWCR control register. And the status codes are put in the TWSR register. Let's look at the code and compare it to the protocol. Here is how to generate a start condition:

```
#define TW_START      0xA4           // send start condition (TWINT,TWSTA,TWEN)
#define TW_READY     (TWCR & 0x80)   // ready when TWINT returns to logic 1.
#define TW_STATUS    (TWSR & 0xF8)   // returns value of status register

byte I2C_Start()
//  generate a TW start condition
{
    TWCR = TW_START;                  // send start condition
    while (!TW_READY);                // wait
    return (TW_STATUS==0x08);         // return 1 if found; 0 otherwise
}
```

To generate a start, load TWCR with 0xA4 and wait. That's all there is to it. Why 0xA4? 0xA4 is binary 10100100. The three '1' values correspond to the TWINT, TWSTA, and TWEN bits of the control register. These bits enable the TWI interrupt, the start-condition, and the whole TWI module. You will see many people write it like this: TWCR = (1<<TWINT) | (1<<TWSTA) | (1<<TWEN). Most think that this 'self-documenting' style of coding is preferable, so please use it if you like. For me, start is simply code 0xA4.

The next thing to do is send the bus address of the slave we are communicating with. For example, the DS1307 real-time clock has a bus address of 0xd0. Here is our code to do that:

```
#define DS1307        0xD0           // I2C bus address of DS1307 RTC
#define TW_SEND       0x84           // send data (TWINT,TWEN)

byte I2C_SendAddr(addr)
//  send bus address of slave
{
    TWDR = addr;                      // load device's bus address
    TWCR = TW_SEND;                   // and send it
    while (!TW_READY);                // wait
    return (TW_STATUS==0x18);         // return 1 if found; 0 otherwise
}
```

Put the address of the slave device into TWDR, put the send command in TWCR, and wait. The next operation, sending a data byte, looks almost exactly the same. Notice that the returned status code will be different, however:

```
byte I2C_Write (byte data)           // sends a data byte to slave
{
    TWDR = data;                     // load data to be sent
    TWCR = TW_SEND;                  // and send it
    while (!TW_READY);               // wait
    return (TW_STATUS!=0x28);        // return 1 if found; 0 otherwise
}
```

For the DS1307 we will do this Write operation twice: once to set the address pointer on the RTC, and again to supply the data for that address.

The last step is the send the Stop condition. Here we just set the command register to 0x94, the value for TW_STOP. Again, this value sets the TW enable, TW interrupt, and TW stop bits. Go ahead, use (1<<TWINT) | (1<<TWEN) | (1<<TWSTO) if you prefer. We do not have

to wait or check for status codes, so it is just a one-line command. Instead of writing a routine I made a macro instead:

```
#define TW_STOP       0x94            // send stop condition (TWINT,TWSTO,TWEN)
#define I2C_Stop()    TWCR = TW_STOP  // inline macro for stop condition
```

Just a quick note on the status codes: I've written my routines to check the status, but I ignore the results. In my simple setup this works OK. You may want to check each code and show error messages when appropriate.

Reading data is little trickier: we have to write to the device first, to set its internal address pointer, and then read to get the data at that address. Here is the protocol for receiving data from the slave.

- Master generates Start Condition, status code 0x08 is returned
- Master sends slave bus address (0xd0), DS1307 returns ACK, status code 0x18
- Master sends address pointer, slave device returns ACK, status code 0x28
- Master generates another Start Condition = restart, status code 0x10 returned
- Master sends slave bus address + read bit (0xd1), slave returns ACK, status code 0x40
- Master requests data byte with NACK, slave returns byte, status code 0x58
- Master sends Stop condition, no status code returned

The only new code required for reading is the read operation in the next to last step. It looks very similar to the write operation. NACK is used to a request of a single (or last) byte of data.

```
#define TW_NACK       0x84            // read data with NACK (last byte)
#define READ          1

byte I2C_ReadNACK ()                  // reads a data byte from slave
{
    TWCR = TW_NACK;                   // nack = not reading more data
    while (!TW_READY);                // wait
    return TWDR;
}
```

Putting it all together, here are sample routines for reading and writing registers on the slave device. You will need to check the datasheet of the slave device you intend to use; each device may have its own unique protocol for addressing its registers, memory contents, etc.

```
void I2C_WriteRegister(byte deviceRegister, byte data)
{
    I2C_Start():
    I2C_SendAddr(DS1307);             // send bus address
    I2C_Write(deviceRegister);        // first byte = device register address
    I2C_Write(data);                  // second byte = data for device register
    I2C_Stop();
}


byte I2C_ReadRegister(byte deviceRegister)
{
    byte data = 0;
    I2C_Start();
    I2C_SendAddr(DS1307);             // send device bus address
    I2C_Write(deviceRegister);        // set register pointer
    I2C_Start();
```

```
        I2C_SendAddr(DS1307+READ);          // restart as a read operation
        data = I2C_ReadNACK();              // read the register data
        I2C_Stop();                         // stop
        return data;
    }
```

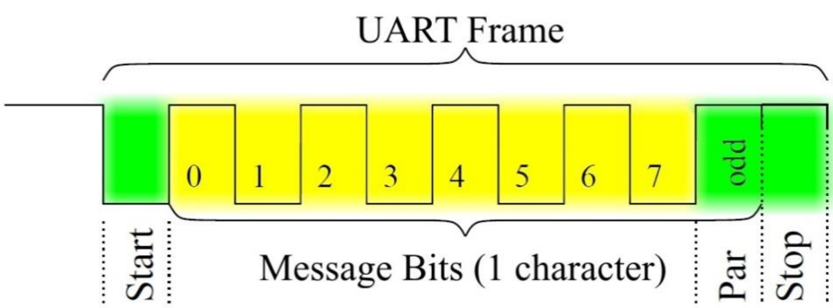
I wrote a RTC tutorial using the I2C interface at http://w8bh.net/avr/AvrDS1307.pdf

5) THE UART INTERFACE

Compared to I2C, using the UART is darn-easy. UART stands for Universal Asynchronous Receive/Transmit. The hardware can also run in synchronous mode, so it is often called a USART. A good article about the hardware is at avrbeginners.net. And a good programming reference is Dean Camera's UART article at fourwalledcubicle.com.

	SPI	I2C	UART
Typical speed	1-20 MHz	100-400 kHz	9 – 56 kHz
Typical use	High-speed hardware	Multiple devices on a common bus	Keyboard, character LCD/Monitor

As opposed to SPI and I2C, which are often used for binary data exchange between hardware devices, UART is often used for transmission of (slower) ASCII data. For example, you might use the UART for keyboard input or monitor/character LCD output. Speedy SPI transfers data to dedicated hardware devices at MHz speeds, while UART transfers are a thousand times slower.



Each data frame consists of a start bit, a variable number of data bits, an optional parity bit, and 1 or 2 stop bits. The most common configuration is 1 start bit, 8 data bits, no parity bit, and 1 stop bit ("8N1").

In asynchronous mode, there is no clock line: data is transmitted on the transmit line (Tx) and received on the receive line (Rx). The UART is initialized by configuring control registers that determine the baud rate, parity, number of stop bits:

```
#define BAUDRATE 9600

void UART_Init()
{
    UBRR0  = F_CPU/(BAUDRATE*16L)-1;    // set speed according to BAUDRATE define
    UCSR0B = 0x18;                      // enable UART: set Rx,Tx enable bits
    UCSR0C = 0x06;                      // set mode: 8 data bits, no parity, 1 stop bit
}
```

The first control register, UBRR0, controls the data transmission rate. The value is determined from the desired baud rate and CPU frequency. For example, a baud rate of 9600 bps on my

16 MHz controller requires a register value of (16000000/9600/16)-1 = 130. Setting bits 4 and 3 in the second control register UCSR0B, enables the special Rx & Tx data lines. The third control register, UCSR0C, sets the data frame format. For 8N1, the most common data frame format, the register value should be set to 0x06. Check out the AVRmega328 datasheet for information on all of the available options.

Once initialized, the controller handles all of the implementation details. Reading & writing byte-sized data from/to the UART data register, UDR0, looks like this:

```
#define RX_READY (UCSR0A & 0x80)        // check bit7 of UCSRA0
#define TX_READY (UCSR0A & 0x20)        // check bit5 of UCSRA0

void UART_Write(byte data)
{
    while (!TX_READY);                  // wait until ready to send
    UDR0 = data;                        // OK, send it now!
}

byte UART_Read()
{
    while (!RX_READY);                  // wait until byte rec'd
    return UDR0;                        // OK, return it.
}
```

In both routines, the first line waits until the UART is ready to send/receive. The second line writes/reads the data register. That's pretty simple, isn't it?

6) TESTING THE UART INTERFACE

The UART uses two data lines, so try a loopback test like the one for SPI. Tie the Tx (PD1/TxD) and Rx (PD0/RxD) lines together, and run the following routine:

```
void UART_LoopbackTest()
{
    UART_Write(5);                      // send a '5' out the Tx line
    byte b = UART_Read();               // listen on Rx line
    FlashLED(b);                        // indicate value returned
}
```

If all goes well, the LED should flash 5 times.

7) MAKING LIBRARIES

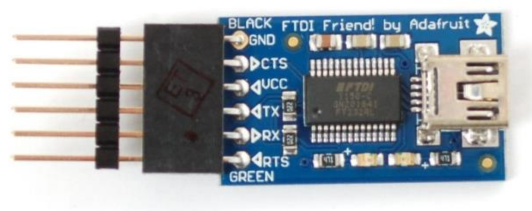
Each of the interfaces is a great candidate for a library. For example, put the three SPI routines in a file called spi.c. Then make a header file called spi.h that includes only the function declarations. Do the same for UART and I2C. Now you can include whichever interface you need like this:

```
include "spi.h"
```

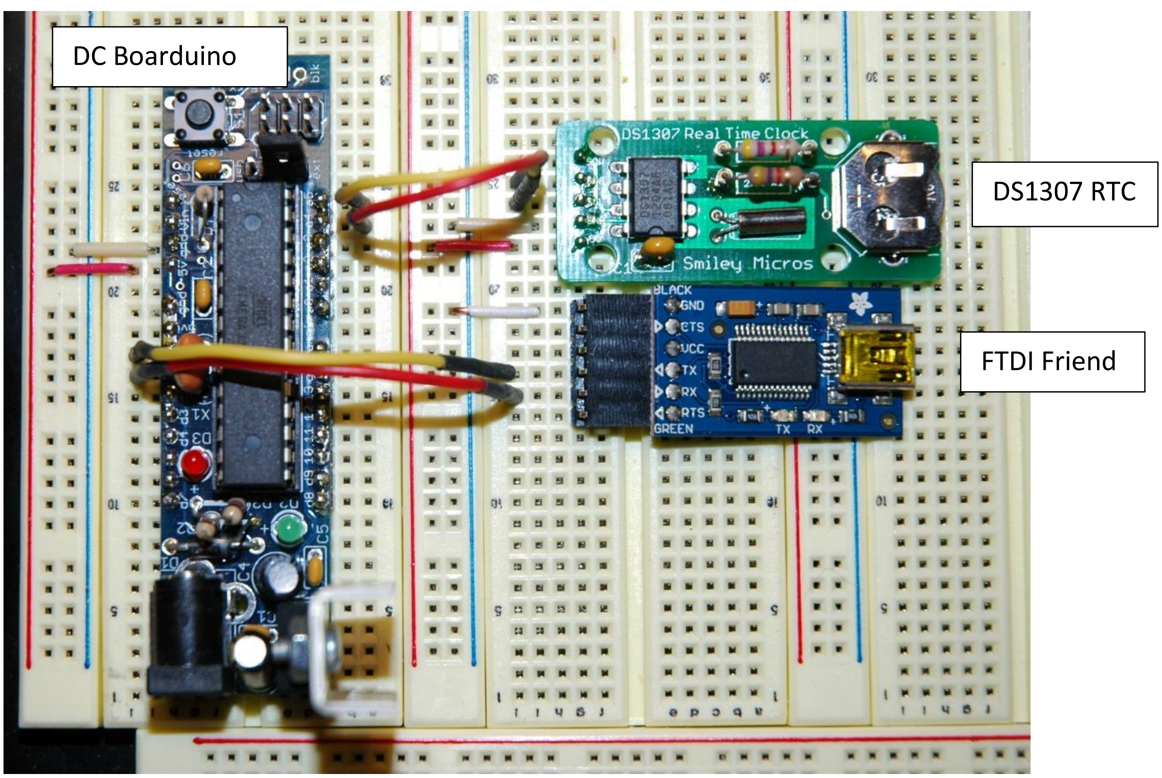
8) DS1307 RTC REVISITED

In the DS1307 tutorial I used a character LCD for output. Let's use the UART interface to use our computer screen instead. The AVR TxD and RxD lines require additional hardware to connect back to your PC. In the 'old days', all PCs had RS232 serial ports, and you would use a Max232 chip to convert the +/- 12V signals from the computer to the TTL (+5V) logic levels on the micro. A quick internet search for "Max232 module" will give you several options costing around $5. To the left is one available for around $3 at NewEgg.

However, most modern PCs have abandoned RS232 ports and use USB ports instead. To connect AVR serial lines to USB I use the "FTDI friend" adapter from Adafruit. It will set you back about $15. Connect TxD to the adapter input line (Rx), RxD to the output line (Tx), and GND to ground.



Next, connect your DS1307 module. Run the SDA line to A4/PC4. Run the SCL line to A5/PC5. And power the module with +5V and GND. Your module must include pullup resistors on the SDA and SCL lines.



You should have two lines running from the clock module to the micro, and two lines from the micro your USB adapter.

Once everything is connected, verify that your computer recognizes the FTDI board. Connect a USB cable between your computer and the adapter, and then check the computer's device manager -> ports. You should see a USB serial port listed, such as 'COM9'. If not, follow the device manufacturer's recommendation for installing the appropriate driver.

Next, you need a console application. Windows used to have a preinstalled application called 'Hypertext', but it is no longer available on all computers. I recommend one called 'PuTTY', which available at putty.org and elsewhere. In putty.exe, select connection type: serial and enter the name of the communication port, such as 'COM9', that you got from the device manager.

If you are doing this for the very first time, you can easily verify that the USB adapter and console app are configured correctly: temporarily disconnect both data lines between the micro and the adapter. Now do a loopback test by connecting the adapter's Tx and Rx lines together. Anything you type in the console application will be sent out the Tx line, back into Rx, and be displayed on the console screen. If you have more than one application running on your computer, make sure the console app is 'on top' and has focus.

Once the console app and USB adapter are working, let's add our microcontroller and extend the loopback test:

```
void Typewriter()
{
    for(char ch=0; ch!='!';)          // wait for stop char '!'
    {
        ch = UART_Read();             // get byte from keyboard
        UART_Write(ch);               // send it to output
        if (ch=='\r')                 // if it is a <return>
            UART_Write('\n');         // add a <newline>
    }
}
```

This code will read a byte from the UART and echo it back to the console. There is a check for the return character, since <return> doesn't bump the cursor to the next line on my console.

Now, instead of writing to the LCD via LCD_Char(), we send the data to the computer screen via UART_Write(). The source code below shows the slightly modified routines. In addition, we can prompt the user for updated time information, and get the information via keyboard input.

Many console applications do terminal-emulation, and allow you to control the cursor and display colors via escape-codes. See http://ascii-table.com/ansi-escape-sequences.php for a list of these codes. In the source code, ANSI escape sequences are used for clearing the screen and for setting cursor position.

9) SOURCE CODE

```
//-----------------------------------------------------------------------------
//  Serial interfaces:  useful SPI, I2C, and UART routines
//
//  Author    :  Bruce E. Hall <bhall66@gmail.com>
//  Website   :  http://w8bh.net/avr/serial.pdf
//  Version   :  1.0
//  Date      :  12 May 2014
//  Target    :  ATmega328P microcontroller
//  Language  :  C, using AVR studio 6
//  Size      :  1994 bytes
//
//  Fuse settings:  8 MHz osc with 65 ms Delay, SPI enable; *NO* clock/8
//
//  Demo will get time & date info from from DS1307-RTC module via I2C
//  and display time & date on computer console via UART.
//

//      ---------------------------------------------------------------------------
//      GLOBAL DEFINES

#define F_CPU          16000000         // run CPU at 16 MHz
#define LED         5                   // Boarduino LED on PB5
#define ClearBit(x,y) x &= ~_BV(y)      // equivalent to cbi(x,y)
#define SetBit(x,y) x |= _BV(y)         // equivalent to sbi(x,y)

//      ---------------------------------------------------------------------------
//      INCLUDES

#include <avr/io.h>                     // deal with port registers
#include <util/delay.h>                 // used for _delay_ms function
#include <stdlib.h>                     // used for itoa, atoi

//      ---------------------------------------------------------------------------
//      TYPEDEFS

typedef uint8_t byte;                   // I just like byte & sbyte better
typedef int8_t sbyte;

//      ---------------------------------------------------------------------------
//      GLOBAL VARIABLES


//      ---------------------------------------------------------------------------
//      MISC ROUTINES

void msDelay(int delay)                // put into a routine
{                                      // to remove code inlining
    for (int i=0;i<delay;i++)          // at cost of timing accuracy
    _delay_ms(1);
}

void FlashLED(byte count)
// flash the on-board LED at ~ 3 Hz
{
    SetBit(DDRB,LED);                  // make sure PB5 is an output
    for (;count;count--)
    {
         SetBit(PORTB,LED);            // turn LED on
         msDelay(100);                 // wait
         ClearBit(PORTB,LED);          // turn LED off
         msDelay(200);                 // wait
    }
}

long IntToBCD (int i)
// converts an integer into its Hex BCD equivalent.  Ex: decimal 32 --> 0x32
{
```

```c
    long ans = 0;
    byte digit, shiftvalue = 0;
    while (i>0)
    {
        digit = (i % 10);               // get least significant decimal digit
        ans += (digit << shiftvalue);   // add it in proper position
        i /= 10;                        // remove least significant digit
        shiftvalue += 4;                // bump up digit position in answer
    }
    return ans;
}


//      ---------------------------------------------------------------------------
//      SPI ROUTINES
//
//  How to use the SPI:
//
//  1.  The data rate is set in SPI_Init, by setting bits in the SPCR (below).
//      By default, the rate is FCPU/2 = 8 MHz for a 16 MHz board.
//      The microcontroller is Master, and the external device is Slave.
//  2.  Connect the transmit line (MOSI/D11/PB3) to the external device MOSI line.
//  3.  Connect the receive line (MISO/D12/PB4) to the external device MISO line.
//  4.  Connect the serial clock (SCK/D13/PB5) to the external device SCK line
//  5.  Ground the external device select line; usually select is active-low.
//  6.  Start the SPI with SPI_Init.
//  7.  Transfer bytes between micro and device with SPI_Xfer
//
//  SPI Status Control Register (SPCR) ---------
//
//          b7    b6    b5    b4    b3    b2    b1    b0
//  SPCR:   SPIE  SPE   DORD  MSTR  CPOL  CPHA  SPR1  SPR0
//          0     1     0     1  .  0     0     0     1
//
//  SPIE - enable SPI interrupt
//   SPE - enable SPI
//  DORD - 0=MSB first, 1=LSB first
//  MSTR - 0=slave, 1=master
//  CPOL - 0=clock starts low, 1=clock starts high
//  CPHA - 0=read on rising-edge, 1=read on falling-edge
//  SPRx - 00=osc/4, 01=osc/16, 10=osc/64, 11=osc/128
//
//  SPCR = 0x50:  SPI enabled as Master, mode 0, at 16/4 = 4 MHz

void SPI_Init()
{
    SPCR = 0x50;                        // SPI enabled as Master, Mode0 at 4 MHz
    SetBit(SPSR,SPI2X);                 // double the SPI rate: 4-->8 MHz
}

void SPI_Close()
{
    SPCR = 0x00;                        // clear SPI enable bit
}

byte SPI_Xfer(byte data)
{
    SPDR = data;                        // initiate transfer
    while (!(SPSR & 0x80));             // wait for transfer to complete
    return SPDR;
}


//      ---------------------------------------------------------------------------
//      I2C (TWI) ROUTINES
//
//  How to use the I2C:
//
//  1.  Set the data transmission speed in the F_SCL define.
//      Common speeds are 100 kHz (100000L) and 400 kHz (400000L).
//      The microcontroller is Master, and the external device is Slave.
```

```
//  2.  Connect the data line (SDA/PC4) to the external device SDA line.
//  3.  Connect the clock (SCL/PC5) to the external device SCL line
//  4.  Attach 3.3K pullup resistors from SDA to Vcc and SCL to Vcc.
//  5.  Start the SPI with I2C_Init.
//  6.  Reading & Writing data to is often device specific:
//      use I2C_Send to send a 'raw' byte over the bus
//      use I2C_Write to send a byte to a specific bus address
//      use I2C_WriteRegister to send a byte to a specific device register
//      use I2C_ReadAck to read a byte from slave, with an acknowledgment
//      use I2C_ReadNACK to read a byte from slave, with no acknowledgment
//      use I2C_ReadRegister to read a byte from a specific device register


#define F_SCL         100000L          // I2C clock speed 100 KHz
#define READ          1
#define TW_START      0xA4             // send start condition (TWINT,TWSTA,TWEN)
#define TW_STOP       0x94             // send stop condition (TWINT,TWSTO,TWEN)
#define TW_ACK        0xC4             // return ACK to slave
#define TW_NACK       0x84             // don't return ACK to slave
#define TW_SEND       0x84             // send data (TWINT,TWEN)
#define TW_READY     (TWCR & 0x80)     // ready when TWINT returns to logic 1.
#define TW_STATUS    (TWSR & 0xF8)     // returns value of status register
#define I2C_Stop()    TWCR = TW_STOP   // inline macro for stop condition

void I2C_Init()
// at 16 MHz, the SCL frequency will be 16/(16+2(TWBR)), assuming prescalar of 0.
// so for 100KHz SCL, TWBR = ((F_CPU/F_SCL)-16)/2 = ((16/0.1)-16)/2 = 144/2 = 72.
{
    TWSR = 0;                          // set prescalar to zero
    TWBR = ((F_CPU/F_SCL)-16)/2;       // set SCL frequency in TWI bit register
}

byte I2C_Detect(byte addr)
//  look for device at specified address; return 1=found, 0=not found
{
    TWCR = TW_START;                   // send start condition
    while (!TW_READY);                 // wait
    TWDR = addr;                       // load device's bus address
    TWCR = TW_SEND;                    // and send it
    while (!TW_READY);                 // wait
    return (TW_STATUS==0x18);          // return 1 if found; 0 otherwise
}

byte I2C_FindDevice(byte start)
// returns with address of first device found; 0=not found
{
    for (byte addr=start;addr<0xFF;addr++)  // search all 256 addresses
    {
        if (I2C_Detect(addr))          // I2C detected?
        return addr;                   // leave as soon as one is found
    }
    return 0;                          // none detected, so return 0.
}

void I2C_Start(byte slaveAddr)
{
    I2C_Detect(slaveAddr);
}

byte I2C_Send(byte data)                // sends a data byte to slave
{
    TWDR = data;                        // load data to be sent
    TWCR = TW_SEND;                     // and send it
    while (!TW_READY);                  // wait
    return (TW_STATUS!=0x28);
}

byte I2C_ReadACK()                      // reads a data byte from slave
{
    TWCR = TW_ACK;                      // ack = will read more data
    while (!TW_READY);                  // wait
```

```c
    return TWDR;
    //return (TW_STATUS!=0x28);
}

byte I2C_ReadNACK()                      // reads a data byte from slave
{
    TWCR = TW_NACK;                      // nack = not reading more data
    while (!TW_READY);                   // wait
    return TWDR;
    //return (TW_STATUS!=0x28);
}

void I2C_Write(byte busAddr, byte data)
{
    I2C_Start(busAddr);                  // send bus address
    I2C_Send(data);                      // then send the data byte
    I2C_Stop();
}

void I2C_WriteRegister(byte busAddr, byte deviceRegister, byte data)
{
    I2C_Start(busAddr);                  // send bus address
    I2C_Send(deviceRegister);            // first byte = device register address
    I2C_Send(data);                      // second byte = data for device register
    I2C_Stop();
}

byte I2C_ReadRegister(byte busAddr, byte deviceRegister)
{
    byte data = 0;
    I2C_Start(busAddr);                  // send device address
    I2C_Send(deviceRegister);            // set register pointer
    I2C_Start(busAddr+READ);             // restart as a read operation
    data = I2C_ReadNACK();               // read the register data
    I2C_Stop();                          // stop
    return data;
}


//      ---------------------------------------------------------------------------
//      USART ROUTINES
//
//  How to use the USART:
//
//  1.  Set the serial transmission speed in the BAUDRATE define.  Common baud
//      rates are: 300, 1200, 2400, 4800, 9600, 14400, 19200, 28800, 57600.
//      The mode is set at 8 data bits, 1 stop bit, no parity (most common).
//  2.  Connect the transmit line (Tx/PD1) to the external device Rx line.
//  3.  Connect the receive line (Rx/PD0) to the external device Tx line.
//  4.  Start the UART with UART_Init.
//  5.  Send bytes with UART_Write; Receive bytes with UART_Read.

#define BAUDRATE 9600
#define RX_READY (UCSR0A & 0x80)       // check bit7 of UCSRA0
#define TX_READY (UCSR0A & 0x20)       // check bit5 of UCSRA0

void UART_Init()
{
    UBRR0  = F_CPU/(BAUDRATE*16L)-1;   // set speed according to BAUDRATE define
    UCSR0B = 0x18;                     // enable UART: set Rx,Tx enable bits
    UCSR0C = 0x06;                     // set mode: 8 data bits, no parity, 1 stop bit
}

void UART_Close()
{
    UCSR0B = 0x00;                     // disable Rx,Tx
}

void UART_Write(byte data)
{
    while (!TX_READY);                 // wait until ready to send
```

```
    UDR0 = data;                        // OK, send it now!
}

byte UART_Read()
{
    while (!RX_READY);                  // wait until byte rec'd
    return UDR0;                        // OK, return it.
}

byte UART_KeyPressed()
// returns 0x80 if input available; 0 otherwise
{
   return RX_READY;
}

void UART_SendString(char *st)
// send a string to the UART
{
    for (;*st;st++)                     // for each non-nul character
        UART_Write(*st);                // send it to uart
}

char * UART_GetString(char *st)
// get a string of characters [80 max!!] from the UART
// string is returned when <enter> key is pressed
{
    char c;
    byte count=0;
    while ((count<80) && ((c = UART_Read()) != '\r'))
    {
        UART_Write(c);                  // echo char back to console
        st[count++] = c;                // add char to string
    }
    st[count]='\0';                     // add NULL termination
    return st;
}


// ---------------------------------------------------------------------------
// DS1307 RTC ROUTINES

#define DS1307 0xD0                     // I2C bus address of DS1307 RTC
#define SECONDS_REGISTER 0x00
#define MINUTES_REGISTER 0x01
#define HOURS_REGISTER 0x02
#define DAYOFWK_REGISTER 0x03
#define DAYS_REGISTER 0x04
#define MONTHS_REGISTER 0x05
#define YEARS_REGISTER 0x06
#define CONTROL_REGISTER 0x07
#define RAM_BEGIN 0x08
#define RAM_END 0x3F

void DS1307_GetTime(byte *hours, byte *minutes, byte *seconds)
// returns hours, minutes, and seconds in BCD format
{
    *hours = I2C_ReadRegister(DS1307,HOURS_REGISTER);
    *minutes = I2C_ReadRegister(DS1307,MINUTES_REGISTER);
    *seconds = I2C_ReadRegister(DS1307,SECONDS_REGISTER);
    if (*hours & 0x40) // 12hr mode:
    *hours &= 0x1F; // use bottom 5 bits (pm bit = temp & 0x20)
    else *hours &= 0x3F; // 24hr mode: use bottom 6 bits
}

void DS1307_GetDate(byte *months, byte *days, byte *years)
// returns months, days, and years in BCD format
{
    *months = I2C_ReadRegister(DS1307,MONTHS_REGISTER);
    *days = I2C_ReadRegister(DS1307,DAYS_REGISTER);
    *years = I2C_ReadRegister(DS1307,YEARS_REGISTER);
}
```

```c
void DS1307_Now(byte *months, byte *days, byte *years, byte *hours, byte *minutes, byte *seconds)
{
    DS1307_GetDate(months, days, years);
    DS1307_GetTime(hours, minutes, seconds);
}

void DS1307_SetTimeDate(byte mon, byte day, byte year, byte hour, byte min)
// note: hours are 0-23, years are 2-digit (2014 is 14).
{
    byte adj = 0;
    if (hour>11)
    {
        hour -= 12;
        adj = 0x40;                     // set 12-hr mode
    }
    I2C_WriteRegister(DS1307,MONTHS_REGISTER, IntToBCD(mon));
    I2C_WriteRegister(DS1307,DAYS_REGISTER, IntToBCD(day));
    I2C_WriteRegister(DS1307,YEARS_REGISTER, IntToBCD(year));
    I2C_WriteRegister(DS1307,HOURS_REGISTER, IntToBCD(hour)+adj);
    I2C_WriteRegister(DS1307,MINUTES_REGISTER, IntToBCD(min));
    I2C_WriteRegister(DS1307,SECONDS_REGISTER, 0x00);           // seconds at :00
}


// ---------------------------------------------------------------------------
// APPLICATION ROUTINES

void Generic_PutChar(char ch)
// called when its time to output a character
// output device can be UART, LCD, whatever...
{
    UART_Write(ch);
}

void TwoDigits(byte data)
// helper function for WriteDate() & WriteTime()
// input is two digits in BCD format
// output is two ASCII numeric characters
{
    byte temp = data>>4;                // get upper digit
    Generic_PutChar(temp+'0');          // send it
    data &= 0x0F;                       // get lower digit
    Generic_PutChar(data+'0');          // send it
}

void WriteDate()
// outputs the current date in mm/dd/yy format
{
    byte months, days, years;
    DS1307_GetDate(&months,&days,&years);
    TwoDigits(months);                  // mm
    Generic_PutChar('/');
    TwoDigits(days);                    // dd
    Generic_PutChar('/');
    TwoDigits(years);                   // yy
    Generic_PutChar(' ');
}

void WriteTime()
// outputs the current time in hh:mm:ss format
{
    byte hours, minutes, seconds;
    DS1307_GetTime(&hours,&minutes,&seconds);
    TwoDigits(hours);                   // hh
    Generic_PutChar(':');
    TwoDigits(minutes);                 // mm
    Generic_PutChar(':');
    TwoDigits(seconds);                 // ss
    Generic_PutChar(' ');
}
```

```c
void UART_SendInt(int data)
// sends the integer value to output console
{
    char st[8] = "";                    // save enough space for result
    itoa(data,st,10);                   // convert to ascii string, base 10
    UART_SendString(st);                // display it on LCD
}

void UART_SendHex(int data)
// sends the hexadecimal value to output console
{
    char st[8] = "";                    // save enough space for result
    itoa(data,st,16);                   // convert to ascii string, base 16
    UART_SendString(st);                // display it on LCD
}

void ANSI_GotoXY(int x, int y)
// send ANSI escape code to console that move cursor to x,y
{
    UART_SendString("\033[");
    UART_SendInt(x);
    UART_Write(';');
    UART_SendInt(y);
    UART_Write('H');
}

void ANSI_ClearScreen()
// sends ANSI escape codes to console that clear the screen
// see: http://ascii-table.com/ansi-escape-sequences.php
{
    UART_SendString("\033[2J\033[;H");    // clear & goto top-left
}

void UART_LoopbackTest()
{
    UART_Write(5);                      // send a '5' out the Tx line
    byte b = UART_Read();               // list on Rx line
    FlashLED(b);                        // indicate value returned
}

int PromptInt(char *prompt)
// prompts user for integer input; returns input value
{
    char st[80];                        // temp buffer for user input
    UART_SendString(prompt);            // display the prompt on console
    UART_GetString(st);                 // get user's input
    return atoi(st);                    // convert to integer & return it
}

int PromptHex(char *prompt)
// prompts user for hexadecimal input; returns input value
{
    char st[80];                        // temp buffer for user input
    UART_SendString(prompt);            // display the prompt on console
    UART_GetString(st);                 // get user's input
    return strtol(st,NULL,16);          // convert to integer & return it
}

void Console_SetTimeDate()
// interactive way to set DS1307 date & time via TTY console
{
    int mon, day, year, hour, min;
    mon  = PromptInt("\r\nEnter the month (1-12, or 0 to skip): ");
    if (!mon) return;
    day  = PromptInt("\r\nEnter the day (1-31): ");
    year = PromptInt("\r\nEnter the 2-digit year: ");
    hour = PromptInt("\r\nEnter the hours (0-23): ");
    min  = PromptInt("\r\nEnter the minutes (0-59): ");
    DS1307_SetTimeDate(mon,day,year,hour,min);
}
```

```
void Typewriter()
{
    UART_SendString("\r\n> Welcome to W8BH.  Type '!' to stop.\r\n");
    for(char ch=0; ch!='!';)           // wait for stop char '!'
    {
        ch = UART_Read();              // get byte from keyboard
        UART_Write(ch);                // send it to output
        if (ch=='\r')                  // if it is a <return>
        UART_Write('\n');          // add a <newline>
    }
    UART_SendString("\r\n> Bye!\r\n");
}



//      ---------------------------------------------------------------------------
//      MAIN PROGRAM

int main()
{
    UART_Init();
    I2C_Init();
    //Typewriter();
    ANSI_ClearScreen();
    Console_SetTimeDate();
    ANSI_ClearScreen();
    UART_SendString("Welcome to W8BH.  Current Time:");
    while(1)                           // forever...
    {
        ANSI_GotoXY(4,6);              // goto line 4, col 6
        WriteDate();                   // show date/time
        WriteTime();
        msDelay(5000);                 // wait 5 seconds
    }
}
```