A digital thermometer or talk I2C to your atmel microcontroller

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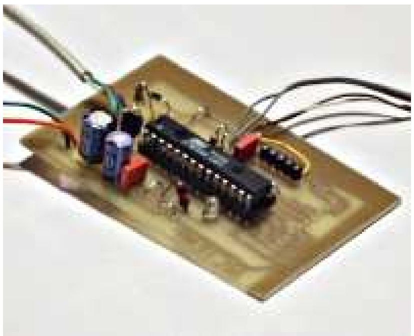
About the author:

Guido likes Linux because it is a really good system to develop your own hardware.



Abstract:

The Atmega8 microcontroller from Atmel has plenty of digital and analog input/output lines. It is the ideal device to develop any kind of measurement equipment.

In this article we see how to interconnect the microcontroller to a linux PC over a physical RS232 interface without the extra MAX232 chip.

Introduction

A pre-requisite for this article is that you have the GCC AVR programming environment installed as described in my "Programming the AVR microcontroller with GCC, libc 1.0.4" article. If you want to avoid troubles with the installation you can of course use the AVR programming CD from http://shop.tuxgraphics.org/

When you use such an advanced device as a microcontroller to measure analog or digital signals then you want of course interfaces to evaluate the data or send commands to the microcontroller. In all the articles presented here in the past we always used rs232 communication with the UART that is included in the microcontroller. The problem is that this requires an additional MAX232 chip and 4 extra capacitors. Atmel suggests also that an external crystal oscillator is required for the UART communication to work reliably. In any case it is a lot of extra parts..... and we can avoid them!

The amount of data to transfer between PC and microcontroller is usually very small (just a few bytes). Speed it therefore no issue at all. This makes the I2C bus/protocol suitable for this task.

I2C (prounouce "eye-square-see") is a two-wire bidirectional communication interface. It was invented by Philips and they have protected this name. This is why other manufacturers use a different name for the same protocol. Atmel calls I2C "two wire interface" (TWI).

Many of you might already be using I2C on their PCs without knowing it. All modern motherboards have an I2C bus to read temperatures, fan speed, information about available memory.... all kind of hardware information. This I2C bus is unfortunately not available on the outside of the PC (there is no physical connector). Therefore we will have to invent something new.

But let’s first see how the "two wire interface" (=TWI = alternative name for I2C) works.

How I2C/TWI works

The datasheet of the Atmega8 (see references) has actually a very detailed description starting on page 160. I will therefore present here just an overview. After this overview you will be able to understand the description in the datasheet.

On the I2C bus you always have one master and one or several slave devices. The master is the device that initiates the communication and controls the clock. The two wires of this bus are called SDA (data line) and SCL (clock line). Each of the devices on the bus must be powered independently (same as with traditional rs232 communication). The two lines of the bus are normally connected via 4.7K pullup resistors to logically "High" (+5V for 5V ICs). This gives an electrical "or" connection between all the devices. A device just puls a line to GND when it wants to transmit a 0 or leaves it "High" when it sends a 1.

The master starts a communication by sending a pattern called "start condition" and then addresses the device it wants to talk to. Each device on the bus has a 7 bit unique address. After that the master sends a bit which indicates if it wants to read or write data. The slave will now acknowledge that it has understood the master by sending an ack-bit. In other words we have now seen 9 bits of data on the bus (7 address bits + read_bit + ack-bit):

```
| start | 7-bit slave adr | read_data bit | wait for ack | ... data co
```

What’s next?

Next we can receive or transmit data. Data is always a multiple of 8 bits (1 byte) and must be acknowledged by an ack-bit. In other words we will always see 9-bit packets on the bus. When the communication is over then the master must transmit a "stop condition". In other words the master must know how much data will come when it reads data from a slave. This is however not a problem since you can transmit this information inside the user protocol. We will e.g use the zero byte at the end of a string to indicate that there is no more data.

The data on the SDA wire is valid while the SCL is 1. Like this:

```
SDA H -\      /---\     /---\          /---\
    L   \-----/     \---/     \--------/     \------....

SCL H ----\     /-\       /-\     /-\    /-\    /-\
    L      \---/   \-----/   \---/   \--/   \--/   \-....


  | START |      1 |       1 |     0 |    1 |    0 |
```

One of the best things about this protocol is that you do not need a precise and synchronous clock signal. The protocol does still work when there is a little bit jitter in the clock signal.

Exactly this property makes it possible to implement the I2C protocol in a user space application without the need for a kernel driver or special hardware (like a UART). Cool isn’t it?

The plan

As said before we cannot use the PCs internal I2C bus but we can use any external interface where we can send and receive individual data bits. We will just use the RS232 hardware interface of our PC. In other words our communication interface is still the same as in previous articles but we save the

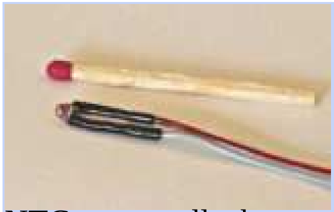
MAX232 hardware, capacitors, etc...

The tough part is of course to implement the I2C protocol from scratch. It took me 5 weeks to learn it and debug it but now it is done and you can just copy it :-). I hope you remember the value of this code when you use it.

As an example application we will build a thermometer. You can of course measure something else or just switch on/off lights. It’s up to you.

In a second article we will add a local LCD display. In other words you will have a thermometer where you can read the temperature directly from the display and/or you can read it out with your linux PC. The display comes in a second article in order not to overload this one.

The temperature sensor


NTCs are small, cheap and accurate enough

It is possible to get already calibrated temperature sensors (some of which talk I2C ;-) but they are quite expensive. NTCs are cheaper and almost as good even without individual calibration. If you calibrate them a bit then it is possible to achieve accuracy behind the decimal point.

One problem with NTCs is that they are non linear. It is however just a matter of semiconductor physics to find the right formula to correct the non linear curve. The microcontroller is a little computer therefore mathematical operations are not a problem. NTCs are temperature dependent resistors. The value R of the NTC at a given temperature is:

$$R = R_N \cdot e^{B(\frac{1}{T} - \frac{1}{T_N})}$$

where

$$R_N = \text{Value of NTC at } T_N$$

$$T_N = 25 \frac{o}{K} + 273K$$

$$B = \text{see datasheet of NTC}$$

$$T = T_C + 273K$$

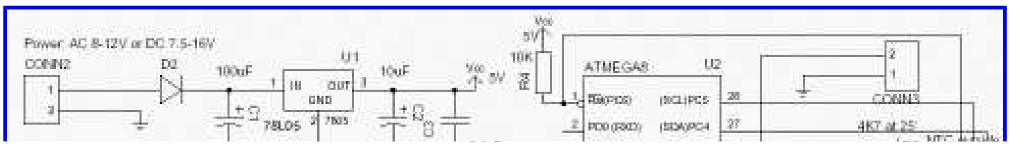
thus T_C *can be written as*

$$T_C = \frac{1}{\frac{1}{B}\ln(\frac{R}{R_N}) + \frac{1}{T_N + 273}} - 273$$

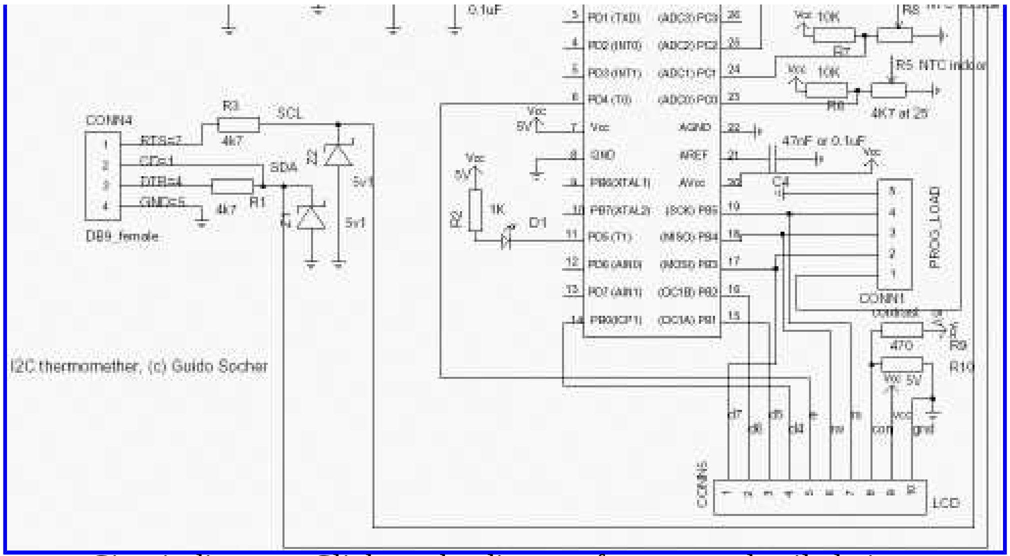
T or Tc is the temperature value that we are looking for. Rn is the resistive value of the NTC at 25’C. You can buy 4k7, 10K, ... NTCs so Rn is this value.

The circuit

Now we have all we need to build a digital thermometer. We add two NTC sensors, one for



inside temperature and one for outside. You can add more if you want (conn3, pin PC2 is e.g free). In the circuit diagram I add already the needed wires for the connection of an LCD display because I don’t want you to build a complete new circuit for the next article.



Circuit diagram. Click on the diagram for a more detailed view.

There is also an LED connected. It does not cost much and is really useful for basic debugging. I used it e.g to debug the I2C state machine when I developed the I2C communication between PC and microcontroller. During normal operation we can just leave it blinking to indicate that measurements are taken.

The circuit is otherwise straight forward. The analog to digital converter in the microcontroller is used to measure the voltage on the NTC which will then be converted into a temperature value.

The Atmega8 has two options on what is used as a reference voltage for the analog to digital converter. It can use either the 5V (AVcc) or an internal 2.56V reference. For the inside temperatures we will not need a temperature range which is as big as for the outside sensor. +10’C to +40’C should normally be sufficient. We can therefore use the 2.56V reference when we measure the indoor sensor. This gives very high accuracy as the 1024 possible digital values are then spread over only 0-2.56V that is we get a resolution of 2.5mV (more accurate than most digital voltmeters!).

The CD-pin on the RS232 is an input line and it is connected to SDA on the I2C bus. We use it to read data from the microcontroller. DTR and RTS are output lines. When the PC puts data-bits on the SDA line then it just toggles DTR. The I2C-master (here the linux PC) controls the SCL (clock) line. In other words the clock line is an output line on the rs232.

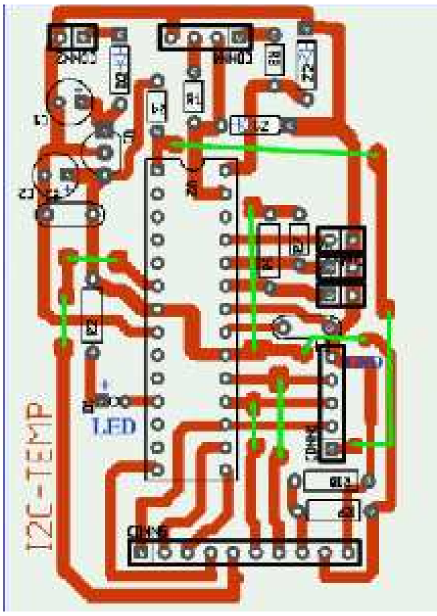
The 78L05 is used to generate a stable power supply and reference voltage. You can use almost any type of power supply AC or DC between 7.5V and 12V. 9V is a good choice.

Making the board

You can of course re-use the prototyping board which we used in the previous article. Just re-connect the LED to pin 11 and add all new things.


tuxgraphics.org sells all the parts needed for this article together with a properly etched board.

If you want to have a nice and good looking circuit then it makes sense to use a new board. Because the circuit is much more complicated it makes a lot of sence to properly etch a printed circuit board. After reading Iznogood’s linuxfocus article on gEDA I decided to also use gEDA instead of Eagle. gschem the schematic drawing tool for gEDA is very good. It does not have a library of symbols as big as Eagle and I had to create the symbol for the Atmega8 but it is very easy to use and as good as Eagle. Quite a bit more problematic is pcb, the tool to draw PCBs. When you come from Eagle you will first of all notice that it is possible to disconnect the parts from the rubber bands. To be sure that the right rubber band is connected to the right pin you have to run Connects->Optimize rats-nest once in a while. You should first complete the circuit diagram and then make the board. Annotation between the two is only manual.



I used the orange colored layer for drawing. Somehow the other layers would not generate any output when printing. The problem is that the orange colored layer is acutally on the side of the board where the parts are. If you write text in this layer then it has to be mirrord when you print it on the physical board. Therefore I made the basic layout with pcb and all the rest with gimp.

Thanks to shop.tuxgraphics.org you will not have to deal with hazardous chemicals and run around town to find the right components. They sell all the parts needed for this article. This way you can concentrate on the fun part and successfully assemble this circuit.

Putting everything together

When you assemble the circuit then pay attention to the parts where polarity is important: Electrolyte capactitors, the diode, Z-diodes, 78L05, LED and the microcontroller.

Before you put the microcontroller into the socket you should verify the power supply part. If this does not work you will not only get incorrect temperature readings but you may also destroy the microcontroller. Therefore connect external power (e.g a 9V battery) and verify with a voltmeter that you get exactly 5V on the socket pin of the microcontroller. As a next step connect the circuit to the rs232 port of your linux PC and run the porgram i2c_rs232_pintest with various combinations of signals.

```
i2c_rs232_pintest -d 1 -c 1
i2c_rs232_pintest -d 0 -c 1
i2c_rs232_pintest -d 1 -c 0
```

This program sets the voltage levels on the RTS (used as SCL, option -c) and DTR (used as SDA, option -d) pins of the rs232 port. The rs232 port has voltage levels of about +/- 10V. Behind the Z-diode you should however measure only -0.7 for a logical zero and +4-5V for a logical one.

Insert the microcontroller only after your circuit has passed the above tests.

Using the I2C communication

Download (see references) the linuxI2Ctemp tar.gz file and unpack it. The I2C communication is implemented in 2 files:

```
i2c_avr.c -- the i2c statemachine for the atmega8
i2c_m.c   -- the complete i2c protocol on the linux side
```

I have given the atmega8 the slave address "3". To send the string "hello" to the atmega8 you would execute the following C functions:

```
address_slave(3,0); // tell the slave that we will send something
i2c_tx_string("hello");
i2cstop(); // release the i2c bus

on the microcontroller side you would receive this "hello" string with
i2c_get_received_data(rec_buf);
```

Very easy. Reading data from the microcontroller is similar. Look at the file i2ctemp_avr_main.c to see how it works when the temperature readings are done.

How warm is it?

To compile and load the code for the microcontroller run the following commands from the linuxI2Ctemp package directory.

```
make
make load
```

Compile the two programs i2c_rs232_pintest and i2ctemp_linux

```
make i2c_rs232_pintest
make i2ctemp_linux
```

... or just use the pre-compiled versions in the "bin" subdirectory.

To read temperatures simply run:

```
i2ctemp_linux
```

... and it will print indoor and outdoor temperatures. To make this data available on a website I suggest to not directly run i2ctemp_linux from the webserver because the i2c communication is very slow. Instead run it from a cron job and write from there to a html file. An example script is included in the README file of the linuxI2Ctemp package.

Conclusion

The I2C protocol requires very little extra hardware and is optimized for transmitting or receiving small amounts of data. That is exactly what we need when we want to communicate with our own microcontroller hardware. It is really a very nice solution!

In this article I have focused very much on the hardware part. If you like this article then I will also write a second one where I describe how the software works. Especially how to do analog to digital conversion and how the I2C protocol implementation works. In this next article we can also add an LCD display and add conversion between Farenheit and Celsius.

References

- **Download** page for this article: the linuxI2Ctemp software, diagrams, software updates
- How to program the atmega8 with gcc: November2004 article 352
- Datasheet for the Atmega8: go to http://www.atmel.com/ and select products->Microcontrollers ->AVR-8 bit RISC->Documentation->datasheets (local copy, pdf, 2479982 bytes)
- The tuxgraphics shop. A really great online shop :-): shop.tuxgraphics.org
  Here you can get the Linux AVR programming CD, all parts for this article, LCD displays and microcontrollers.

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