Content:

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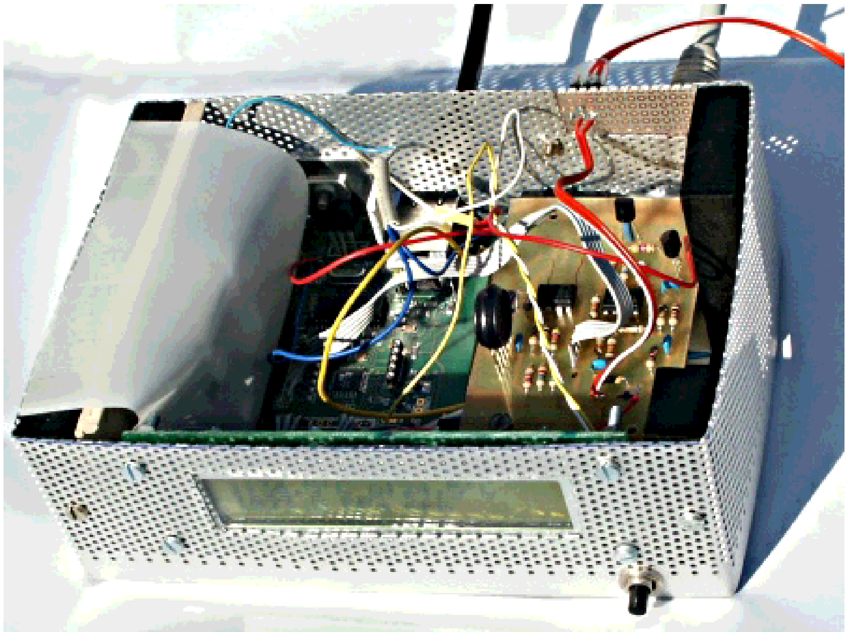
An ethernet weather station



Abstract:

Using an add-on card to the already existing avr ethernet board we build a weather station. That is: A weather station with a build-in webserver. The related articles which describe how to build the AVR web server are here:

1. An AVR microcontroller based Ethernet device
2. HTTP/TCP with an atmega88 microcontroller (AVR web server)

The components for building this weather station can be ordered from http://shop.tuxgraphics.org

The system is modular. You can either build a pure Ethenet weather station or an Ethenet weather station with an additional local LCD display.

Sensors

My original plan was to have sensors for temperature, air pressure and wind. I started a prototype and it worked very well except for the wind measurement part. I have written a separate article about it: wind-vane-ver01.shtml. I plan to improve the wind measurement hardware and add it at a later point in time.

For now the weather station has 2 temperature sensors and an air pressure sensor. It works reliable and precise even after several month of testing.

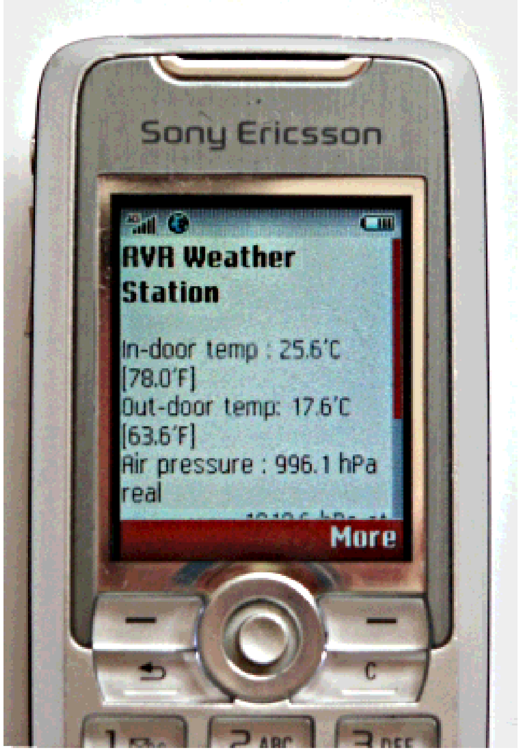
For the sensors we will use:

- For temperature measurements: LM335. This sensor is cheap and has a linear curve over a wide temperature range. This will give us very accurate temperature readings over a wide range. The accuracy will be almost constant over the whole range.

- A Motorola/Freescale MPX4115A absolute air pressure sensor. This sensor is already calibrated at production time. The MPX4115A is not made for out-door use but that is not a problem. The circuit can be in a save and dry location inside the house as the air pressure is exactly the same inside and outside the house.

What’s the weather at home?

You can connect it straight to the Internet by enabling port forwarding in your DSL router. There is however a security issue with such a straight forward solution. How to manage security and make it really secure is described in the Using the AVR microcontroller based web server article (available via the tuxgraphics electronics section http://tuxgraphics.org/electronics/).



AVR Weather Station

In-door temp : 25.6'C [78.0'F]
Out-door temp: 17.6'C [63.6'F]
Air pressure : 996.1 hPa real

The Ethenet Weather Station as seen from a Mobile Phone

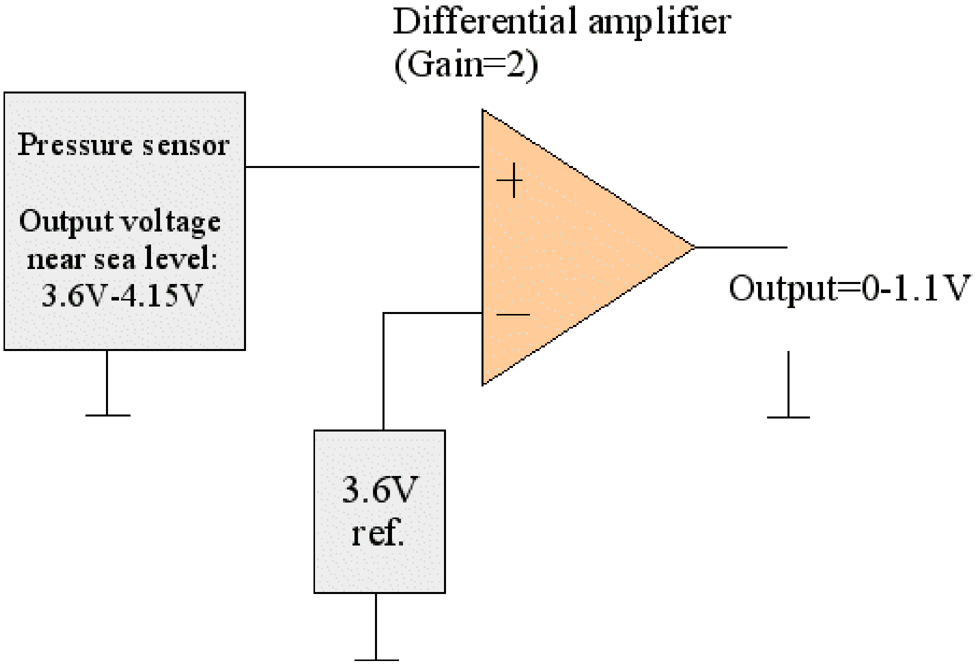
The analog to digital converter (ADC) of the AVR

The atmega88/168 has one build in ADC and a multiplexer which allows us to select the pin on the chip where the voltage should be measured. In other words even though there is just one ADC it appears as if it had several ADCs. The one ADC can measure the voltage on several pins quickly after each other. It has also an internal reference of 1.1V. The 1.1V correspond to an ADC reading of 1023 and 0V to an ADC reading of 0. The measured voltage is therefore:

```
   ADCreading
U= ---------- * 1.1V
      1024
```

If we now look at the specification of our sensors we will see that the range we want to measure does not correspond to 0-1.1V. We could just add a voltage divider (two resistors) to reduce the max. voltage to 1.1V but then we will loose accuracy as this will map the interesting range to just a few ADC values and we will never use the full range from 0-1023.

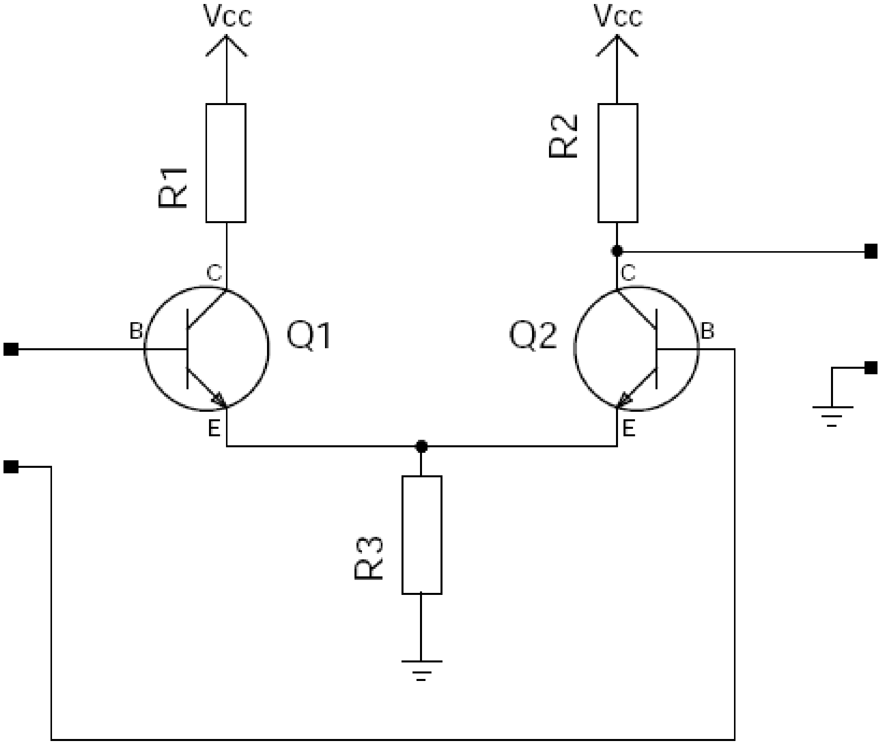
The solution is a differential amplifier. With such an amplifier we can map e.g a range from 3.6V to 4.15V into 0-1.1V:



Mapping of a voltage range into the ADC input range from 0-1.1V

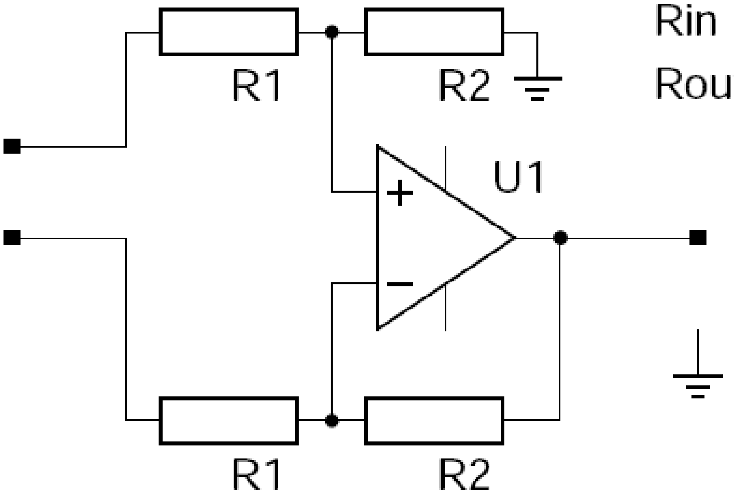
Differential amplifiers

An easy way to build such a differential amplifier is to use two transistors.



The problem is that this circuit has a temperature dependent amplification factor. This is even the case if we use additional resistors for degenerative feedback because the amplification factor of this circuit is too low. We would need to add more transistors.

The most common solution to the problem is an operational amplifier. Here the amplification factor can be made dependent only on external resistors and therefore temperature independent.



Gain= R2/R1

Rin = R1+R2

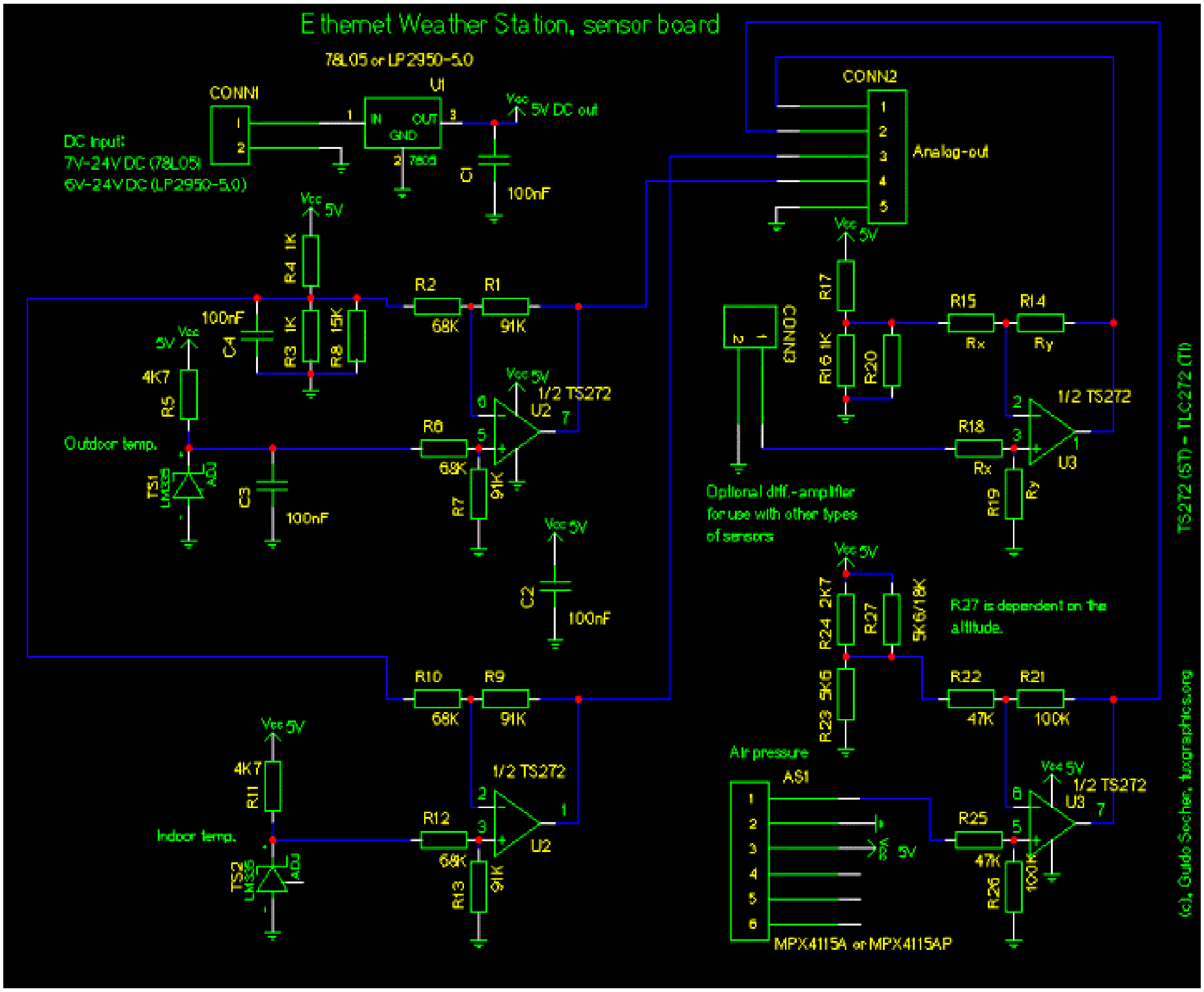
Rout= nearly zero ohm

A differential amplifier with adjustable gain based on an operational amplifier.

Most operational amplifiers need +12 and -12 supply voltage and that is not really usable here. We would like to have a single exact +5V power source as the air pressure sensor needs exactly 5V. Fortunately there are some special operational amplifiers which can work from a single power supply and still work with voltages as low as 5V. The TLC272 is such an amplifier and that is what we will use here.

The weather station circuit diagram (add-on board)

The circuit diagram below shows the circuit diagram of just the add-on sensor board. It connects via CONN2 to a any tuxgraphics avr ethernet board.



Click on the picture to get a high resolution PDF drawing.

The TLC272 is a dual op-amp. For 3 sensors we need therefore two TLC272 and we could actually connect 4 sensors. CONN3 is therefore available for you to put any other additional sensor. You can e.g connect a Honeywell HIH-4000 humidity sensor. This humidity sensor can however also be connected directly via a voltage divider to the adc. It’s just an idea. At the moment the humidity sensor is not part of this software/solution.

If you don’t want to use the extra connector then insert a wire bridge instead of R14 and R19. All other resistors around that operational amplifier can then be left open.

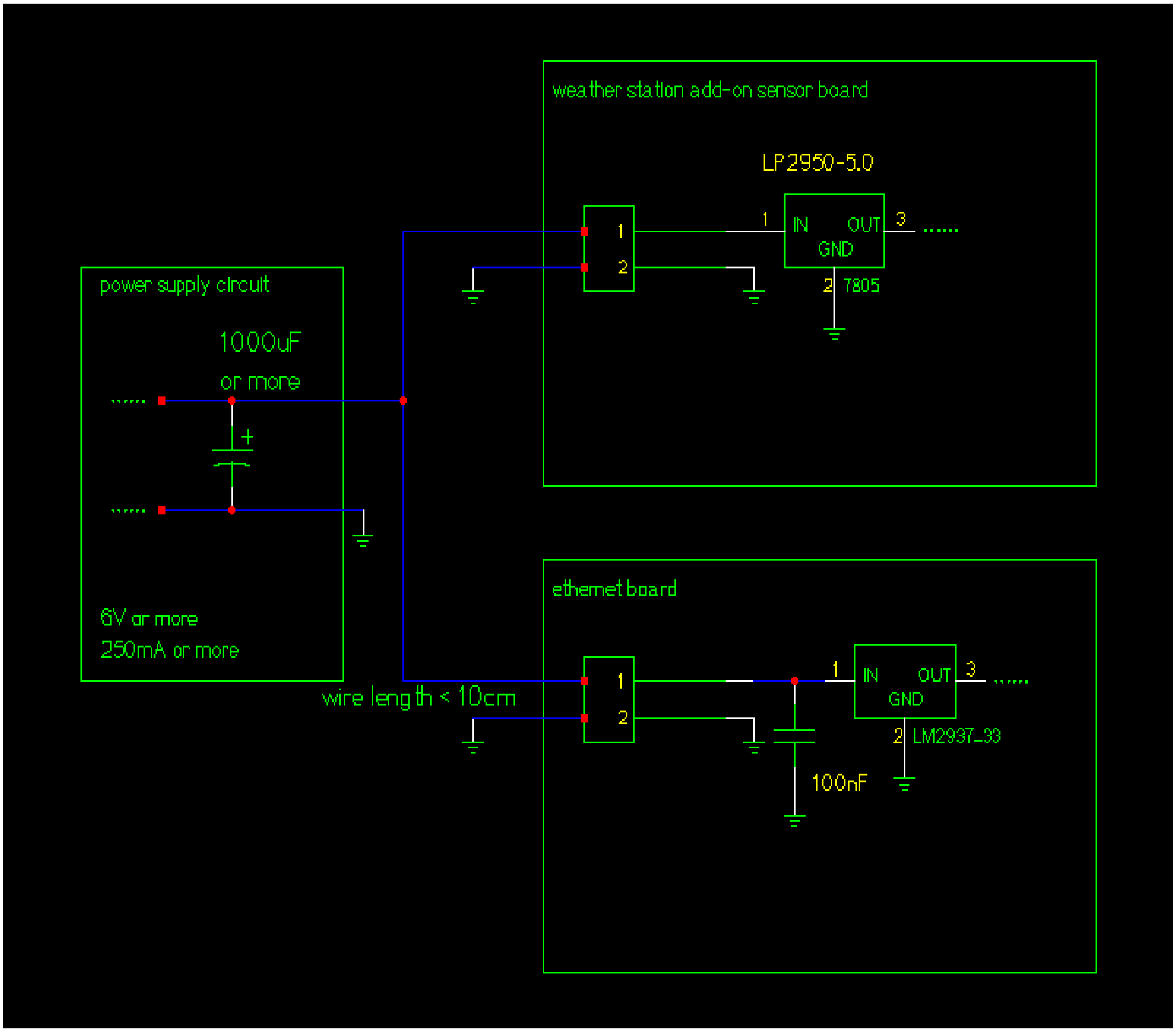
R27 is dependent on the altitude where you are. For 0-400m above sea level you should use 5.6K and for 400-1000m 18K above 1000m you should remove R27 and much higher you will have to change R24. This because the air pressure is very dependent on the altitude.

The circuit has an on-board voltage regulator because it is important to have a clean and very stable supply voltage to get exact sensor readings. The 4 analog output lines (CONN2) connect then to the ADC channels ADC0-ADC3 on the avr webserver board.

If you use the same power source for this add-on sensor board and the avr webserver then you should make sure you connect GND only once to avoid ground loops (CONN2 has also a GND pin). Ground loops cause the circuit to be sensitive to magnetic fields (transformers). If you use e.g a 7.5V power supply then you connect the +7.5V to both the avr webserver board and the add-on sensor board but you connect the GND of the power supply only to the avr webserver board and the add-on sensor board gets it’s GND connection via the GND pin on connector CONN2.

Power supply requirements

Ethernet works reliably over 100m long cables. It needs therefore a bit of power. The main power consumer is the ethernet chip. The rest of the circuit needs so much less that it can be totally neglected in any power consumption calculations.



Click on the picture to get a high resolution PDF drawing.

The ethernet chip needs in average 150-180mA at 3.3V. This is however an average. At the moment of packet processing it needs twice as much for a few milliseconds. It is therefore important that the power supply circuit contains a large capacitor which can buffer that peek. The tuxgraphics ethernet board has already a number of capacitors on board to make the peek more round but it still needs a good external power source.

If you use a ready made switched power supply (as I did) then it is often unknown how big the internal capacitors are. It is however very easy to test if the capacitors are big enough: Click several times the reload button in the web browser and observe the temperature readings. If the temperature values are changing all the time then the power breaks down so much that the sensor board is influenced by that. Just add a 1000uF capacitor in this case. Note that the pressure sensor may fluctuate behind the decimal point. That is normal.

The main power design guidelines are therefore:

- Use a big capacitor (1000uF or more) in power circuit
- Avoid ground loops.
- Keep the wires short.

Converting voltages into "weather" readings

The temperature and air pressure readings arrive now on the avr webserver as ADC reading. Numbers between 0 and 1023. The main task of the software is now to convert this back into Celsius, Fahrenheit or hPa and display it on a web page.

The LM335 temperature sensor produces 10mV/K (mV/K= Milli_Volt/Kelvin). This is however only valid if the measurements are taken with very high impedance. The impedance of our differential amplifiers is 91K + 68K = 159K. The datasheet of the LM335 does unfortunately not explain what will happen but the voltage drop at a load of 159K should be very low given that the impedance of the LM335 must be much less than 4.7K (the pull-up to 5V). The amplification factor of the amplifier is 91K/68K=1.338. The ADC produces a reading of 1024/1100 per mV. In other words we get 12 ADC-steps per Kelvin:

```
10mV/K * 91K/68K * 1024/1100mv = 12.4 ADCsteps/K
```

The whole conversion can be fine tuned in the file config.h (see source code download at the end of this article) and the parameters KELVINPERADC0 and KELVINPERADC1 correspond to this ADCsteps/K times 10. If neither the resistors nor the LM335 had any tolerances then both KELVINPERADC0 and KELVINPERADC1 should have 124. The file config.h contains in the temperature section also the parameters OFFSET1 and OFFSET0. This is an offset to 0’C. The offset may change if the supply voltage is not exactly 5V (the reference for the differential amp. changes then).

If you don’t have a very accurate reference to calibrate the temperature readings then I suggest to not change too much in config.h It will be almost correct. What you can do is this: Take some tape and stick both LM335 together. Wait 10min for them to have exactly the same temperature then check what the readings are. Now change KELVINPERADC2 and KELVINPERADC1 such that the two temperature readings are the same for both sensors and meet in the middle (increase the one which is too low and the lower the one which is too high).

The air pressure sensors is just slightly more complicated. First of all you should know that the air pressure changes maybe by 1-5 hPa over the day. A weather dependent high pressure zone might have 1030 hPa and a low pressure zone 1010 hPa. The air pressure is however much more dependent on the hight above sea level. If you change your altitude by just 100m then the pressure will change by 12 hPa. It is therefore a convention that all weather stations report a pressure reading normalized to sea level. The pressure offset to sea level is:

```
Poffset=1013hPa * (1-(1- 0.0065 * h/288)^5.255)
```

```
h=height above sea level.
```

```
The formula can be derived from the Barometric formula.
See http://en.wikipedia.org/wiki/Atmospheric_pressure
and http://en.wikipedia.org/wiki/Barometric_formula
```

The file config.h contain the parameter SEALEVELOFFSET which is exactly this Poffset times 10 rounded to the next integer value. Here is a javascript calculator to calculate the SEALEVELOFFSET parameter for you:

Your hight above sea level in meter: calculate => = SEALEVELOFFSET reset

Some encyclopedias and local maps will usually show at what hight above sea level your town is. If you live in a high building then you need to take this also into consideration.

The reference voltage for the differential amplifier depends on R27 which is to be selected dependent on your altitude. Since most people on earth live near sea level you will either use 5.6K (0-400m) or 18K (400-1000m) for R27.

The reference voltage (the voltage over R23) is calculated as follows:

```
Refvoltage=5V *  5.6K/( 5.6K + 1/(1/R27 + 1/2.7K))
```

R27 in KOhm: calculate => = op-amp reference voltage reset

The differential amplifier amplifies the difference between this reference voltage and the voltage from the air pressure sensor. Now we just need a formula that gives us the air pressure for a given output voltage of the air pressure sensor and we are almost done with the calculations:

```
Vout=5V* ((0.0009*P/hPa)-0.095)+Error

Vout= output voltage in V at the MPX4115A pressure sensor
P=air pressure in hPa
Error=an error term caused by tolerances during the manufacturing
      of the MPX4115A.

Therefore P is:
P=((Vout+Error)/5V+0.095)1111.11 hPa

P=(Vout+Error)*1/V*222.222 hPa +105.555 hPa

If we convert Vout into ADC steps  and included also
the error term there then we get:
P=(adc/1024*1.1/Gain +Refvoltage/V)*222.222 hPa +105.555 hPa

The gain of the differential amplifier is 100/47=2.1
We insert this into the equation:

     adc *1.1 * 222.222 hPa
P = ----------------------- + (222.222 *Refvoltage)hPa/V + 105.555hPa
       1024 * 2.1


     adc *10
P = --------- hPa + (222.222 *Refvoltage)hPa/V + 105.555hPa
     87.8

In the config.h file I have included a REFTERM_A parameter which is
this term to the right of the above equation:

     adc *10
```

```
P = --------- hPa + (REFTERM_A/10) hPa
     87.8
```

Now that is a lot of math but don’t worry the software is already written. If you just want to use it then measure the voltage above R23 or use the above javascript calculator and then calculate REFTERM_A with the following calculator. Insert REFTERM_A in the config.h file and you are done.

op-amp reference voltage (voltage over R23 in Volt):	calculate =>	= REFTERM_A	reset

Something we have now discarded a bit is the Error term in the formula for the MPX4115A pressure sensor. It is part of the adc variable in the above formulas. In the config.h file I have included a parameter called ERROR_A. If you have no reference available then just set it to zero. If you have some weather station readings from a station near by then you use that to tune the Error term. Here are e.g some weather forecasts including readings from the current day:

- http://www.wetterzentrale.de/topkarten/fsmetgrg05.html, a map from Europe, click on the map

The software

Just download the eth_rem_dev_weatherstatio-x.y.tar.gz file at the end of this article. Unpack it (tar zxvf eth_rem_dev_weatherstatio-*). Most of the above formulas are implemented in the file analog.c but the configuration is done via the header file config.h. Edit also the main.c file and insert the IP address you would like to use. Compile the software with the command "make". After that just download the eth_rem_dev_weather.hex into the microcontroller:

```
avrdude -p m88 -c stk500v2 -e -B 2 -U flash:w:eth_rem_dev_weather.hex
```

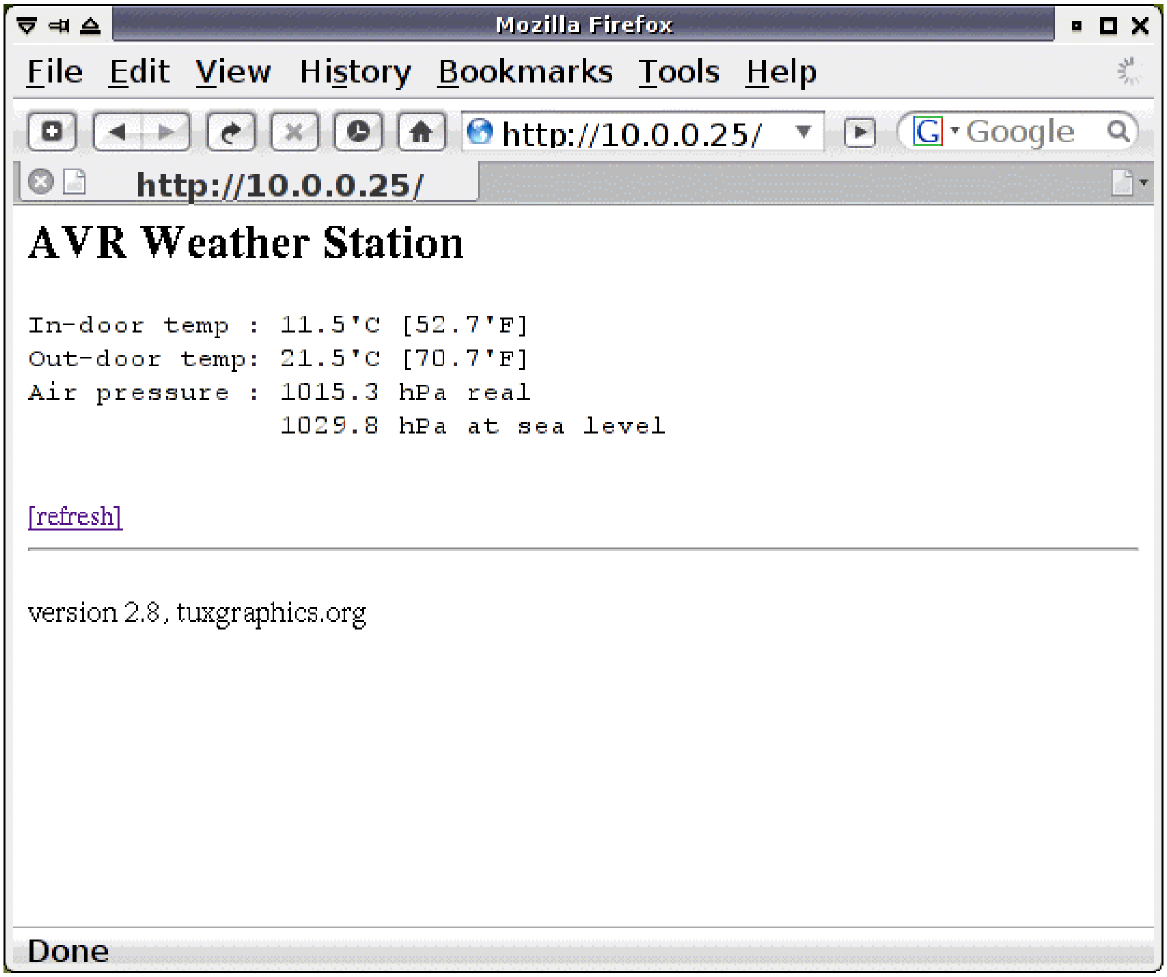
That’s all!
Point your web browser to the selected IP address (e.g htpp://10.0.0.25) and see what the weather will be like.

Mounting the out door sensor

It is probably possible to seal the LM335 out-door sensor in resin or glue to make it water proof. I personally don’t believe in such methods because one day some water will get in, stay there and corrode the wire. It is better to just shield it against heavy rain and otherwise make sure that it can always dry again. A half open tube is very good for that. I use a felt-tip cap:

The out-door sensor. Protected by a felt-tip cap.

The weather station as seen from firefox



AVR Weather Station

```
In-door temp : 11.5'C [52.7'F]
Out-door temp: 21.5'C [70.7'F]
Air pressure : 1015.3 hPa real
               1029.8 hPa at sea level
```

[refresh]

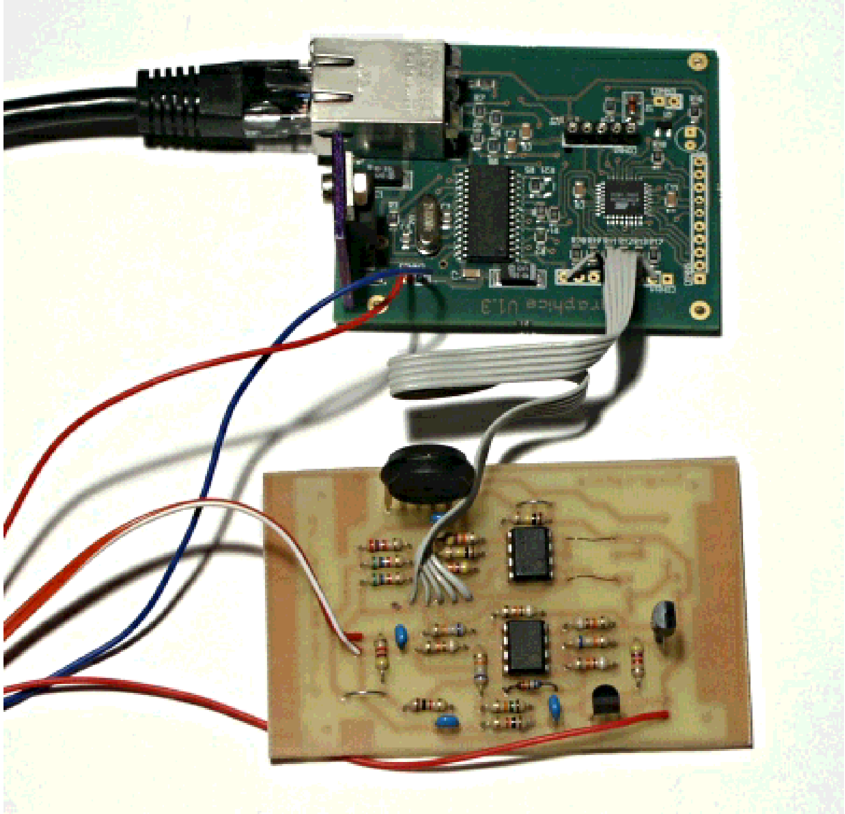
version 2.8, tuxgraphics.org

A screen shot of mozilla firefox

High air pressure (above 1020hPa) is generally an indication for coming good weather. Low pressure may bring rain. If you see the air pressure increasing in the evening then it is a good indication that there will be no more rain the next day.

The final circuit without LCD

The whole weather station circuit is very modular. You can use it with and without air pressure sensor and the LCD display is also optional. Below is a photo of the weather station without LCD display.

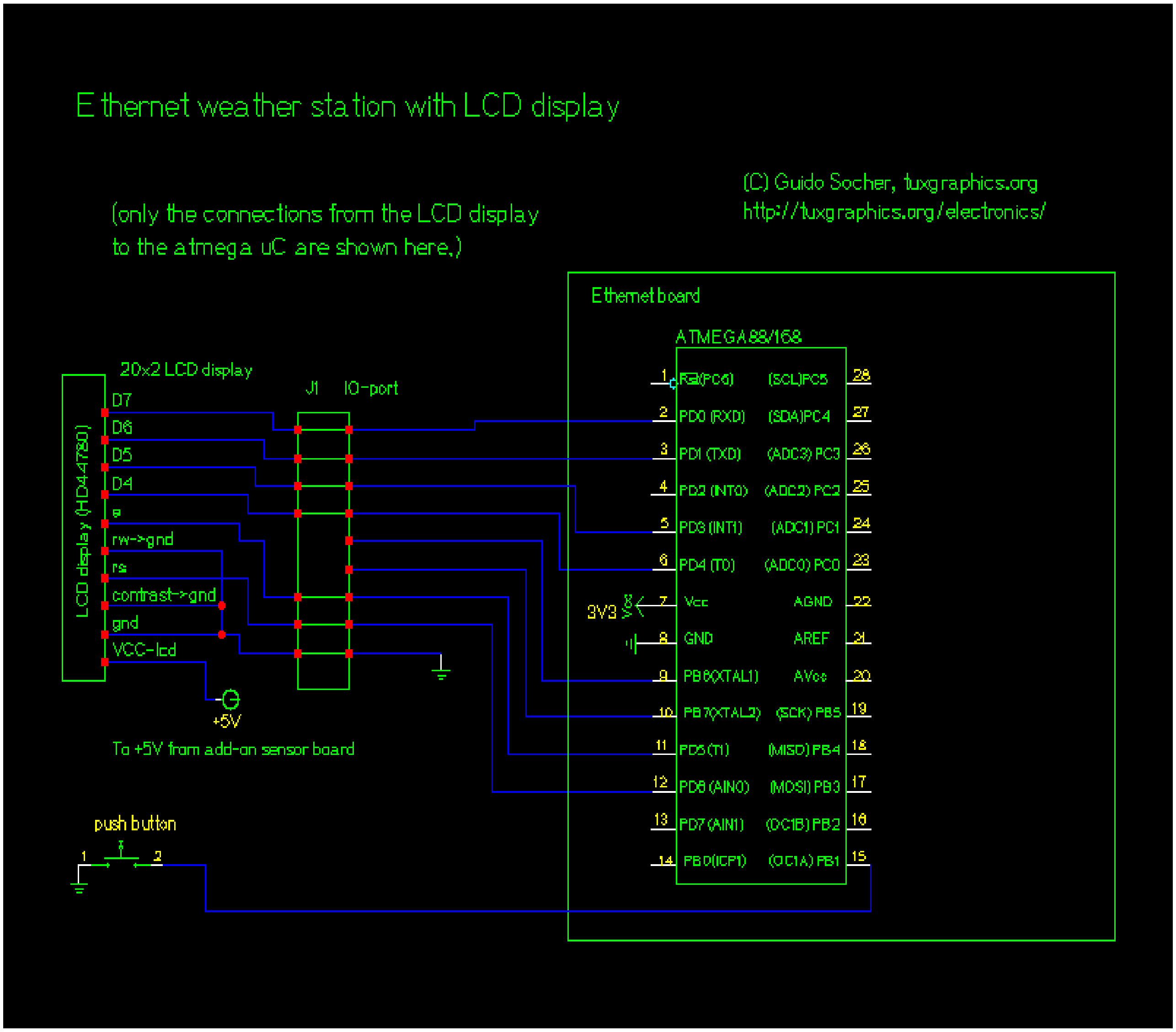


The bare Ethernet weather station circuit without LCD

The software made for the weather station with LCD (eth_rem_dev_weatherstation-3.X) will also run on the one without but I recommend to use eth_rem_dev_weatherstation-2.X which does not use the digital IO port of the ethernet card and is made for the weather station without LCD.

Adding a LCD display

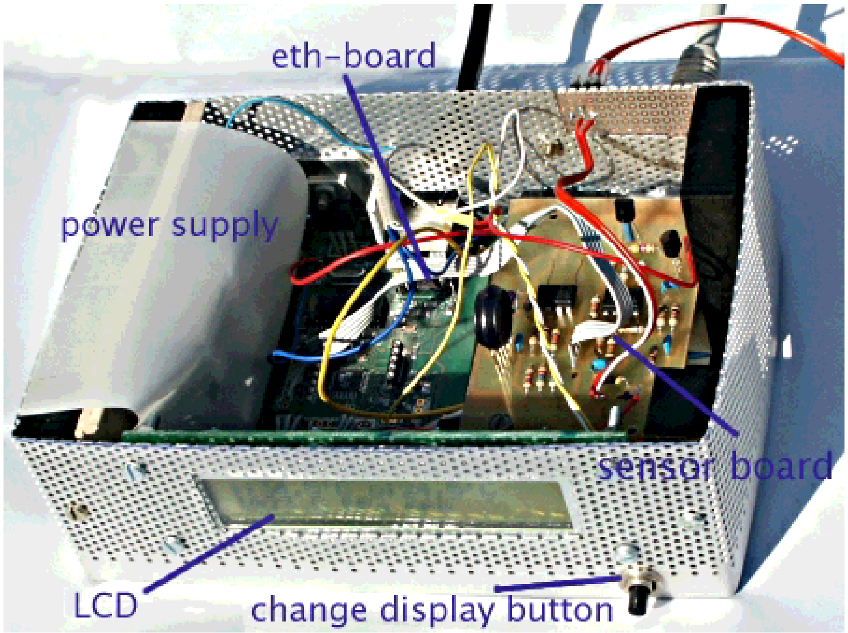
Just connect the LCD display on the exact same pins as in the previous article "A LCD display with ethernet interface":



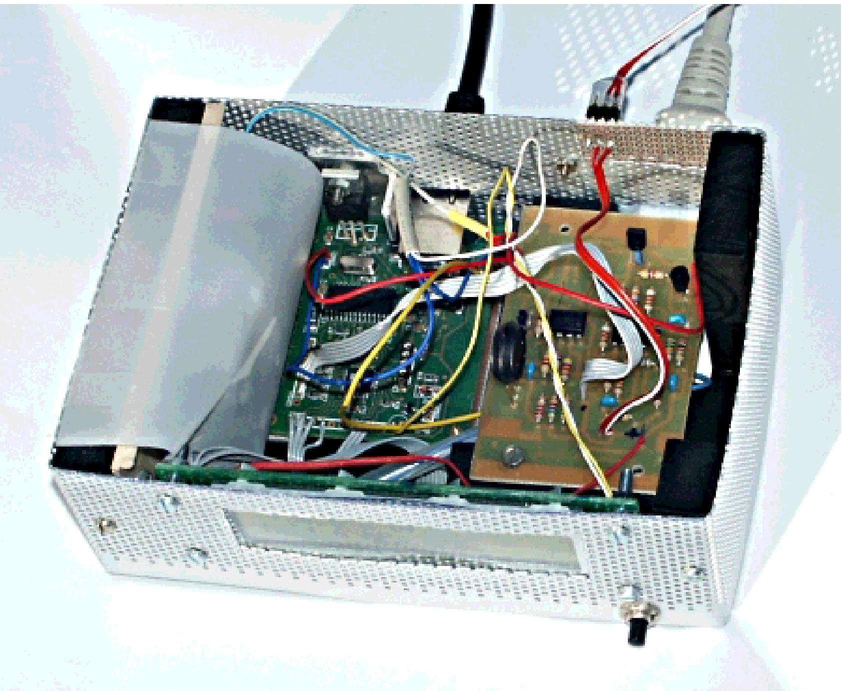
Click on the picture to get a high resolution PDF drawing.

I have decided to connect the button to change the display on PB1 because we don’t need the LED which is normally connected there. The button toggles the display units from ’C to ’F.

Here some photos of the Ethernet weather station which I build. It is very small. On the back you just connect power, ethernet and the out-door sensor.



Ethernet weather station circuit without LCD



Ethernet weather station circuit with LCD, top view

On the software side there really nothing new here. We just display the temperature and air pressure readings locally on the lcd display. A small "+" sign in the lower right corner of the display comes and goes to let any human person know that everything is still working and the display is not frozen (temperature and air pressure change very slowly during the day). The lcd driver code is in the files lcd.c, lcd.h and lcd_hw.h.

Feed a database

The web server displays a web page. That page can not only be evaluated by humans but also by scripts. You might e.g collect the readings every few hours and save it in a file or database. The the command line web browser w3m (http://sourceforge.net/projects/w3m/) can be used for that.

```
w3m -dump "http://10.0.0.25/"
```

That’s all you need to get machine readable readings. You can re-direct the output to a file and then process that file. Very easy.

Download and links

- **Download** page for this article: software and updates

- http://www.city-netz.com/staedte/, a list of towns in Germany and their height above sea level.

- http://en.wikipedia.org/wiki/Atmospheric_pressure, wikipedia page about atmospheric pressure.

- The tuxgraphics shop: shop.tuxgraphics.org
  Here you can get all the components needed to build the small web-server and the add-on sensor card.

- RS componentshttp://www.rs-components.com/full.html
  RS is one of the few distributors who sells the Honeywell HIH-4000 humidity sensor.

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