

A Low Cost High Precision Temperature Pressure Humidity Monitoring circuit for INO Detector

Sampriti Bhattacharyya, TIFR, INO group

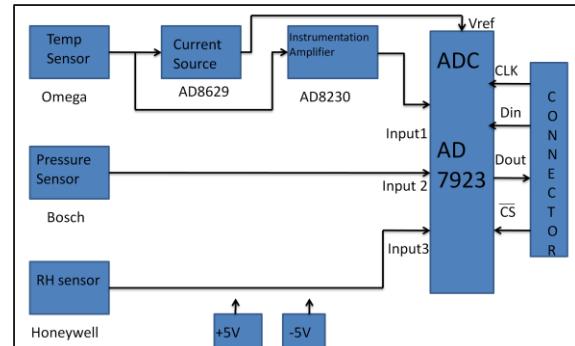
Abstract

The Indian Neutrino Observatory (INO) is a proposed experiment to study the weakly interacting particles – the neutrinos. Understanding the neutrinos requires a set of suitable detectors – the resistive plate chambers which are sandwiched between the iron calorimeters. The activities within the chambers are monitored and analyzed. Apart from the usual collision data collection, it is also important to monitor the chamber parameters like temperature, pressure, humidity and voltage. Such factors control the gain of RPC. Commercial units for monitoring ambient conditions are expensive, large size for this purpose, and low in precision for the cost. The purpose of this document is to describe the development of a low cost high precision temperature pressure and humidity (TPH) monitoring system, small in size which can fit in the specified 14 mm gap between the chambers and the iron calorimeter.

Introduction

For measurement of gas temperature which affects the gas density and in turn the RPC gain, a high precision monitoring system is essential. Commercial systems that are already in use in our INO laboratory at Tata Institute of Fundamental Research comes at a price of ~\$250 [Picotech RHO2] and more advanced ones cost as much as \$500. Such units are often too big to be squeezed into the 14mm gap between the RPC and the ICAL. So we built a unit customized for this purpose. Our final unit is 3x3 inches printed circuit board, on which it houses a temperature sensor – the Omega F2020/100-1/3B platinum RTD (and has a precision of .1 deg C), a pressure sensor SMD085 manufactured by BOSCH, a humidity sensor HIH 4030 manufactured by Honeywell. In addition there is an ADC- the AD7923 and electronics required for the RTD: an AD8629 chip that acts as a current source and an AD8230 instrumentation amplifier. In our present setup the ADC sends the data to an ARMmite microcontroller

manufactured by Coridium (which uses a LPC2103 microcontroller). The latter contains the program in C which converts the required voltages from the different sensors to the respective parameters which are then displayed on a computer.



BLOCK DIAGRAM FOR TPH SENSOR BOARD

Temperature Sensor

The main requirement for the temperature sensor was high precision for a low cost (taking into consideration we are going to use ~ 1000 or more of such units for the final ICAL). Some of the probable sensors for this purpose were DS1825, AD592 and F2020-100-1/3B. Each had its advantage and disadvantages. DS1825 has its own ADC and can be used as a one wire chip. This enables a number of DS1825 to be mounted on a single wire, and read from it. It is priced at \$2 per chip. However, the precision of it is only .5°C. AD592CNZ needed an additional amplifier chip, and ADC, but its precision varies from .3°C to .5°C and costs \$8 per chip. In case of F2020-100-1/3B, each RTD costs a \$2.25 each (when purchased in packs of 100) and has a precision of .1°C. However it requires precision current source, and a 4-wire setup to cancel affect of wire resistance when the RTD is to be placed at a longer distance in contact with a surface.. Commercial units to do this cost ~\$80 and are *not* designed for multiplexing. For our purpose the RTD was best suited and hence we used it for the temperature sensor in this unit.

Specifications for Omega F2020-100-1/3B

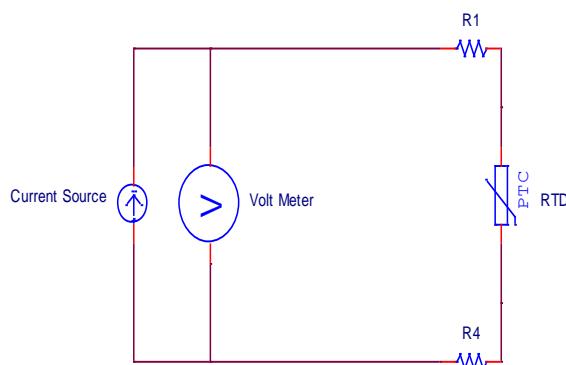
- Resistance (in ohms) = $100 + .39 \times T - 5.775 \times 10^{-5} \times T^2$
where T is temperature in $^{\circ}\text{C}$
- Accuracy: .1C
- Cost: \$2.25 each in a pack of 100.
- Extremely sensitive
- Excitation current 1mA maximum

The schematic of our sensor board is given in Page 3. The circuit diagram shows the use of the chip AD8629 which acts as a current source. The two $100\text{ k}\Omega$ allows a voltage of 2.5V at pin 5. Assuming the amplifier has an infinite gain, the voltage at pin 6 and pin 3 is 2.5V as well. The voltage across R_c ($2.5\text{ k}\Omega$) is 2.5 volts, and hence the current is 1mA which must be flowing through the RTD (the maximum rated current for the RTD).

Use of 4 wire system

The RTD is implemented with a 4 wire system. This has been done keeping in mind we might put the RTD away from our board in contact with some surface, in which case the wire resistance comes into play, especially for such a high precision system. The four wire system helps to cancel out the error due to wire resistances. This can be explained as below:

2 wire system



In this case, $V = I * (R1 + R4 + R_{RTD})$ where $R1$ and $R4$ are the wire resistances and R_{RTD} is the resistance of the RTD itself and V is the voltage measured by say, a voltmeter.

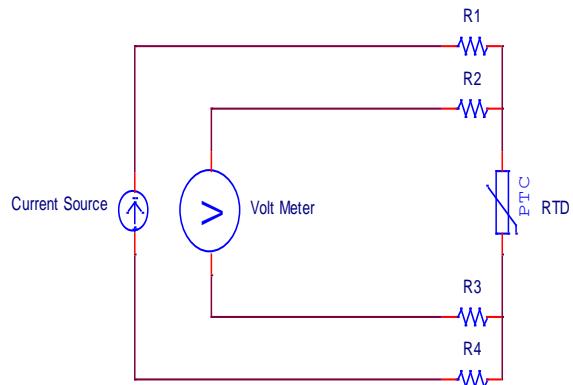
Now, a rise of .1C corresponds to resistance change of 0.039Ω of the RTD unit, i.e

$$\Delta T = 0.1C \rightarrow \Delta R = 0.039\Omega$$

Typical 3 gauge cable has a resistance of $\sim 0.21\Omega/\text{m}$. If the RTD is kept 10cm away, there is 20cm of wire contributing 0.04Ω – comparable to the required resolution in resistance. So, even for short distances, wire resistance matters.

To overcome this problem we implement the 4 wire system.

4 wire system



In this set up, the following occurs:

- High impedance voltmeter.
- Negligible current through $R2$ and $R3$
- Voltage drop across $R1$ and $R4$ does not affect measurement

So wire resistance wouldn't affect the measurement in this case.

Note a 4-wire can be used as 2-wire, but 2-wire systems cannot be used as 4-wire.

Pressure Sensor

The Bosch SMD 8085 has been chosen as the pressure sensor of our unit for its low cost and good precision. The Bosch SMD requires a positive 5 Volts and a ground, and its output can be read from pin 3 directly by the ADC.

Specifications

- Strain gauge sensor with built-in electronics to produce voltage output

$$P = (V_{\text{output}} - .003) / .03945$$

$$(V \text{ in volts, } P \text{ in KPa})$$
- Easy to implement, direct readout by ADC
- Cost: \$6.27 each in pack of 100
- Accuracy: 10% without calibration
- Current 12 mA

Humidity Sensor

The HIH 4030 manufactured by Honeywell has been used for the Relative Humidity. It is precise and cheap, about \$14 per piece. It has an accuracy of +/- 3.5%RH. The input voltage can vary from 4V to 5.8 volts. The output is directly fed into the ADC.

Specifications

- Capacitive sensor with built in electronics to generate voltage output.

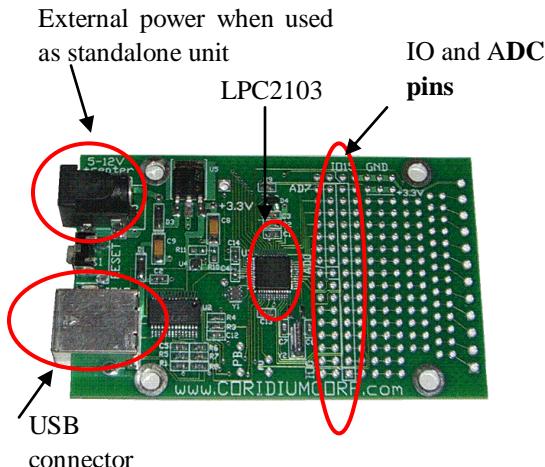
$$RH = (V_{\text{out}} - 0.958) / 0.0307$$
- Easy to implement, direct readout by ADC.
- Cost: \$11 each in a pack of 100.
- Current: 200 μ A

Readout System

The readout system consists of ADC 7923 and the microcontroller board ARMmite manufactured by Coridium. The AD7923 is a 12 bit, low power, 4 channel SAR ADC. The ADC requires an input power of +5Volts with a 1% precision to pin 15. For achieving this we use the LT1461DHS positive 5V regulator.

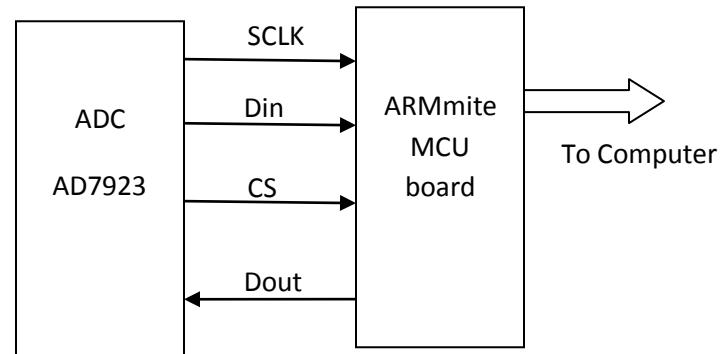
The ARMmite board (Fig) uses LPC2103 processor, and is programmed in GCC. The ARMmite communicates with the computer through the "MakeItC" software loaded into the latter. The

software allows a Terminal Window to be opened after compilation, which displays the temperature, pressure and Relative humidity corresponding to the time. The MCU also has a USB port.



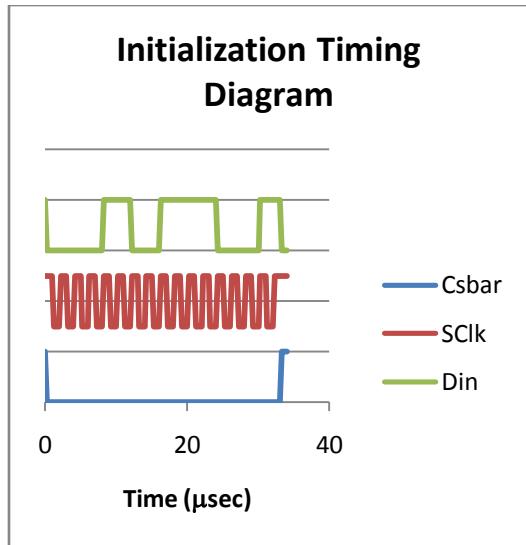
Specifications of Coridium ARMmite MCU Board

- Processor: LPC 2103
- Processor Speed: 32 bit ARM7, 60 MHz
- Power: 5-12 V DC
- Ram size: 8K
- Price: \$49 per unit
- Programming Language: C/Basic

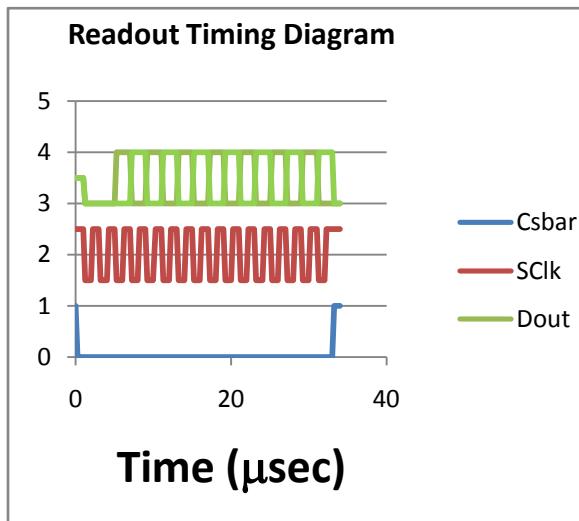


Interfacing between ADC and MCU

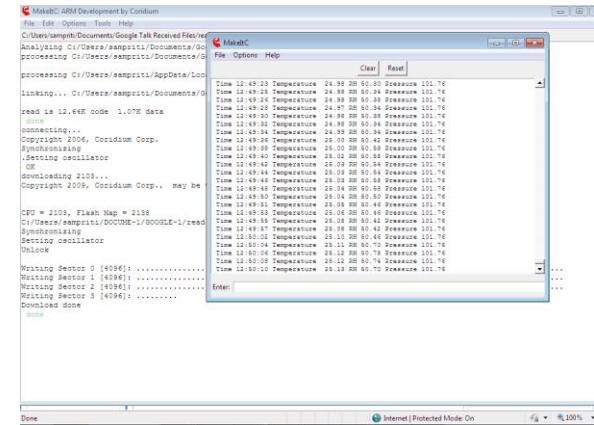
The control register is loaded with the bits, 10, 7, 6, 5, 4, 3, and 0 on. The timing diagram for initializing is given as below. During initialization Din is fed into the ADC and Dout is ignored (so is not shown). Data transfer takes place during the transition of the SClk.



The readout timing diagram is given as below. Here D_{in} is ignored and not shown. Out of the 16 bits data, the first two leading bits are zeroes, next two bits gives the channel number and the rest twelve bits carry the actual conversion result.



A screen shot of the terminal window of the “MakeItC” interfacing software displaying the temperature pressure and humidity is given as below:



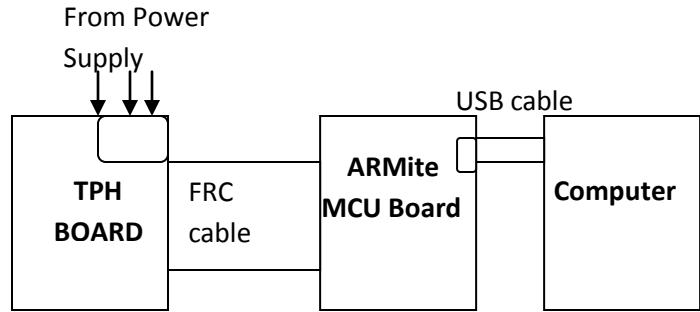
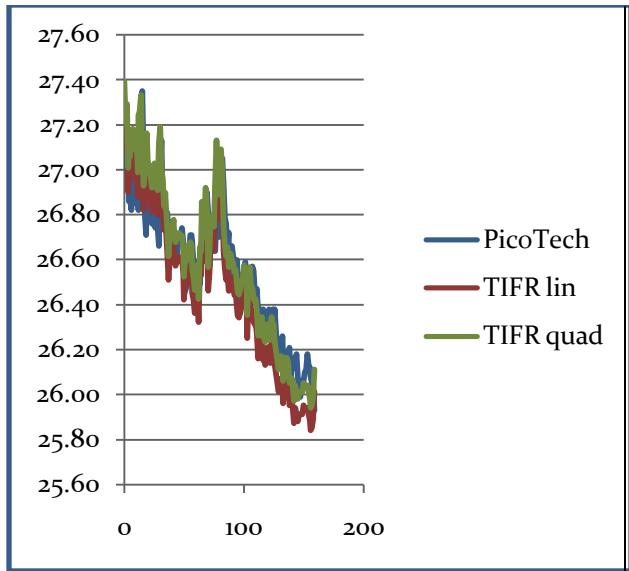
Calibration

Temperature: One of the important objectives of manufacturing this unit was to obtain a high temperature precision of about $.1\text{C}$. This has been implemented by using high precision electronics, and a precise RTD. However for reliable readout it is necessary to calibrate the TPH board for correct readout. This is done by adjusting the potentiometer mounted on the board. It is known from the RTD specification, the value of R_0 is 100Ω . Which means the RTD reads 100Ω at 0C . Taking this into account, the calibration is carried out by replacing the RTD by a $.1\%$ precise 100Ω resistor and reading out the corresponding temperature in the Tcl^* window of the MakeItC software. If the temperature does not read zero, the potentiometer is adjusted till the temperature readout is zero. After the value reaches stability, the RTD is swapped back into the circuit. A precise readout is obtained.

A calibration against a commercial RHO2 temperature sensor which is manufactured by PicoTech gives the following graph. The specified accuracy of RHO2 unit is $.2^{\circ}\text{C}$ and that of omega F2020-100-1/3B is $.1^{\circ}\text{C}$.

The two units have an average difference of .1C as defined from the graph.

“TIFR lin” gives the temperature value from the linear relation and “TIFR quad” gives the value by counting the quadratic terms.



The figure above shows the block diagram set up of the system. However the detailed circuit diagram is given as below. The circuit shows the connection of the three sensors, finally outputting to the pins 10, 11 and 12 of the AD 7923.

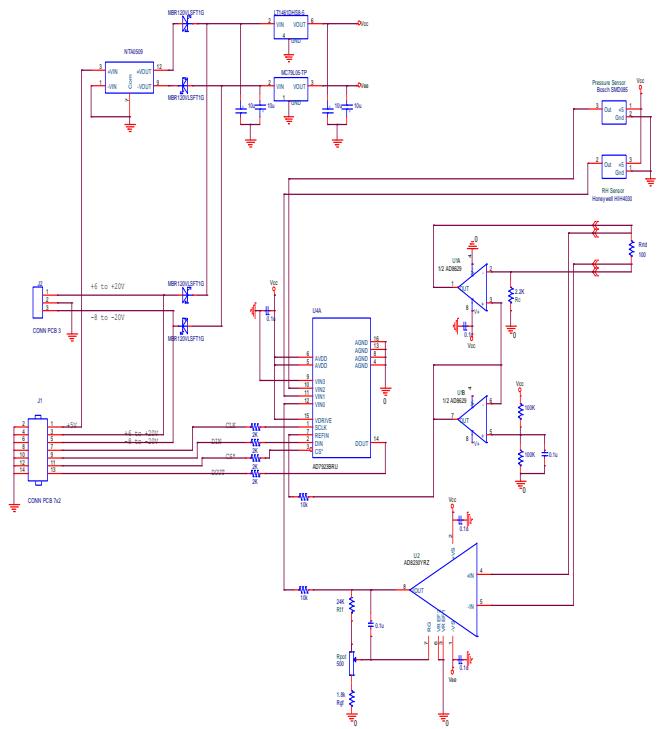
Pressure: Bosch SMD085 is rated ± 1 KPa. It can be calibrated to higher precision, but no stability information (beyond the ± 1 KPa).

Humidity: HIH4030 is rated at $\pm 5\%$ for $RH < 60\%$ and $\pm 8\%$ for $RH > 60\%$. It is stable and reproducible to 0.5% . It can be calibrated for higher precision.

The circuit has a high stability and hence it eliminates the need for frequent calibration.

Set up & Circuit Diagram

In our present set up, the TPH board is powered by a power supply manufactured by APLAB. The supply can be set to a voltage of $+/-8$ volts (or $+6$ volts and -8 volts) and maximum current of $15mA$ (or $20mA$ in positive channel and $10mA$ in the negative channel). The MCU is connected to the computer via an USB cable. To read out the TPH board, it is powered up, connected to the MCU with a FRC cable and, the required program is then loaded in “MakeItC” software interface (the program is Read.c). The set up is explained in the following block diagram.



Error Contribution

In our circuit, Vref (pin 7 of AD7293) is directly related to Vcc, that is $V_{ref}=1/2 V_{cc}$. This eliminates error due to voltage variation. This can be explained as below for each of the three sensors.

For pressure sensor, we have,

- Output “ratiometric:” Scales with supply V_{cc}

$$V_{sensor} = (V_{cc} / 5V) \times (.03945 \times P + .003)$$
- ADC reading scales with reference V_{ref}

$$ADC = (V_{sensor}/V_{ref}) * 2048$$

 Now,
 ➤ $V_{ref} = \frac{1}{2} V_{cc}$

$$ADC = (V_{sensor}/V_{cc}) \times 4096$$

$$= (4096/5V) \times (.03945 \times P + .003)$$
- **No** contribution from voltage errors.

Similarly like pressure, for RH sensor, the output is “ratiometric” (scales with power supply).

- $V_{out} = (V_{cc}/5V) \times (.0307 \times RH + .958)$
- $ADC = (4096/5V) \times (.0307 \times RH + .958)$
- **No** contribution from voltage errors.

In case of RTD, the calculation can be shown as below:

- $I_{RTD} = V_{ref} / R_c$
- $V_{out} = G \times I_{RTD} \times R_{RTD}$
- Gain G set by resistors
- $ADC = 2048 \times V_{out}/V_{ref}$

$$= 2048 \times G \times R_{RTD} / R_c$$
- **No** contribution from voltage errors.

Key Components:

Referring to the circuit diagram of the TPH board, it is necessary to explain the role of some of the key components in the circuit.

AD8629: Auto-zero Operational amplifier. Used as a precision current source for the RTD.

AD8230: Auto-zero Instrumentation amplifier, Transfers voltage drop across RTD to the ADC.

LT1461: ~0.1% precision +5V reference, used as a 5V regulator. Precision is important for the ADC.

MC79L05: Negative 5 volts regulator used by the AD8230 chip.

NTA0509: This is a DC-DC converter to be mounted in case we want to use the +5 V from the microcontroller to power the circuit.

High Precision 13-turn pot: Required for circuit calibration of temperature readout.

A proper voltage regulation is needed in the circuit. This is because, circuit designed to be insensitive to voltage drift. We use metal film resistors since they are more stable over time than IC chips. Also, usual voltage 5V regulators are precise to 5-10%. Whereas our ADC requires $V_{ref}=2.5V \pm 1\%$. Since Vref is obtained from V_{cc} , it means V_{cc} (+5V nominal) precise to 1%. This explains the use of the precision voltage regulator LT1461 chip for V_{cc} from which we can derive V_{ref} directly as well.

The use of the negative 5 volts supply should also be explained in this regard. Instrumentation amplifier like AD8230 requires a reference voltage, V_{ref} . (Opamp circuits would as well). To avoid drift, we used $V_{ref}=0$. Opamps (and instrumentation amps) also requires a power more negative than the reference. In case of AD8230, the specification is V_{ee} to be at least 3.5V below V_{ref} . We need $V_{ee} < -3.5V$, so -5V is convenient.

The use of NTA0509 is not mandatory. ICAL will design in the voltages required by this board. DC-DC converter may not be placed on the board. However for present use, it helps to draw power from the MCU instead of the power supply. It also simplifies use in other systems and allows use with a wider variety of systems. This is because most digital systems do not have any negative supply and many of them, do not have voltage above 5V.

Conclusions

The TPH unit is customized for the ICAL detector and is sized to fit in the 14 mm gap between the RPC glass and iron. It is advisable that the unit of such high precision not to be placed near other electronics, since that would contribute to an indeterminate error, and the exact RPC ambient temperature cannot be known. The precision is particularly useful for contact measurement, where the system's 4-wire capability comes into use. The TPH monitoring system has flexibility to support different sensors should the need arise in the future.

The results and methods described here are based on using a ARMmite MCU with USB connection to a PC. In the final ICAL however, it is planned that the data would be read out using Ethernet interface.

Due to lack of precise standard reference devices, the calibration of humidity and pressure sensor has not been possible. The final step should be carried out to further validate the data.

REFERENCES

- 1) Indian Neutrino Observatory website
www.ino.tifr.res.in
- 2) Honeywell HIH 4030 humidity sensor datasheet http://sensing.honeywell.com/index.cfm/ci_id/142958/la_id/1/document/1/re_id/0
- 3) Analog Devices AD7923 datasheet
http://www.analog.com/static/imported-files/data_sheets/AD7923.pdf
- 4) Bosch SMD 085 pressure sensor datasheet
http://www.boschsensortec.com/content/language1/downloads/SMD085_V1_1105.pdf
- 5) Omega F2020 RTD datasheet
http://www.omega.com/prodinfo/oem_rtd/RTD_OEM.pdf
- 6) Analog Devices AD8230 datasheet
http://www.analog.com/static/imported-files/data_sheets/AD8230.pdf
- 7) Analog Devices AD8629 datasheet
http://www.analog.com/static/imported-files/data_sheets/AD8628_8629_8630.pdf
- 8) Information on Coridium Microcontroller
<http://www.coridiumcorp.com/>

- 9) For information on wire resistances
<http://www.daycounter.com/Calculators/AWG.html>