Barometric Altimeter

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In this project a piezoresistive transducer measures the atmospheric pressure, enabling a PIC microcontroller to use the ISA model (with temperature compensation) to display your current height above sea level (ASL) on an LCD.

Whereas office managers typically associate 'height' with promotion, career building and a desk on the top floor, everyone else with a healthier mind will be looking up towards the skies, down into chasms or valleys, or for a safe place to land.
When mountaineering, climbing, para-sailing, hang-gliding or flying ULs (ultralights), it's plain essential to know your 'ASL': height above sea level.

Pressure — in theory

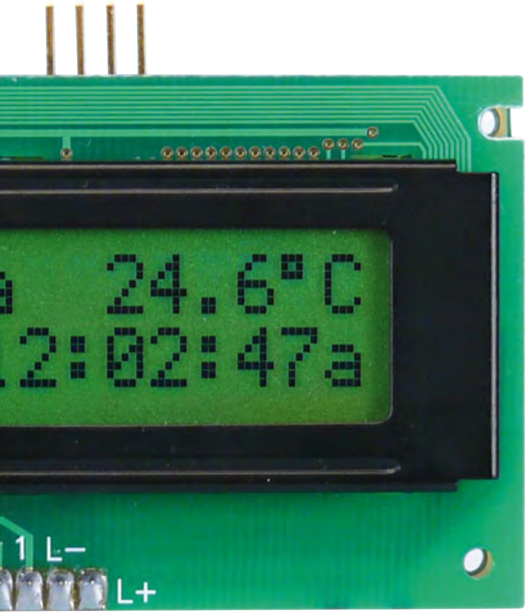
Since barometric pressure is closely approximated by the hydrostatic pressure caused by the weight of the air above you, your altitude on the planet above a reference level can be calculated fairly easily and shown on a display. The altimeter described here is calibrated to show your altitude above the mean sea level (MSL) based on a mathematical model called International Standard Atmosphere (ISA). The ISA model describes the troposphere range with a linear temperature distribution and although that's unlikely to change with time, it does as a function of temperature, with barometric pressure as an inherent dependency. Right, this project does take temperature deviation into account to compensate the altitude reading!

ISA rulez: the components…

For accurate and reliable ASL readings a temperature measurement device has to be included in the project. So let's list the crucial components: a PIC18F2423 microcontroller, an MPXHZ6115A pressure transducer and a digital temperature sensor type TC77-5.0. Freescale's MPXHZ6115A (**Figures 1 and 2**) is a monolithic, signal conditioned, silicon pressure sensor with an on-chip bipolar op amp circuit and thin film resistor networks to provide a high output signal and temperature compensation from –40°C to +125°C.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. With a typical current consumption of 6 mA (at 5 V), it's necessary to keep the sensor in the off state when not in use.
Note that it requires about 20 ms to warm up, i.e. before taking any reading. Maximum error is 1.5% over 0° to 85 °C, and the component provides the transfer function

Mountaineers, delta glider and UL pilots — this one's 4 U



Specification and features

- Altitude range: 0 to 11,000m A(M)SL
- Compliant with ISA model, extended with temperature compensation
- Barometer range: 15 kPa to 115 kPa
- Resolution: 3 m.
- Temperature range: –55 °C to +125 °C
- Real Time Clock
- Supply voltage: 6–15 VDC;
- Current consumption
  - LCD backlight on: 18 mA;
  - LCD backlight off: 8 mA;
  - Standby: 20 μA
- Menu controlled
- Software: C for PIC

$$V_{out} = V_s \times (0.009 \times P - 0.095) \pm (PE \times TF \times 0.009 \times V_s) \qquad \text{[Eq. 1]}$$

where P is the applied pressure, V_s is the supply voltage, PE is the pressure error and TF the temperature factor.
The output from the pressure sensor is measured using the microcontroller's internal ADC. Altitudes below 11,000 m (33,000 ft) can be calculated using the barometric formula:

$$h = \frac{(1-(P/P_{ref})^{0.19026} \times 288.15}{0.0065} \qquad \text{[Eq. 2]}$$

where P_{ref} is the pressure at the base (i.e. at MSL), and h the altitude in metres.
The TC77-5.0 temperature sensor from Microchip is a serially accessible digital temperature sensor with a resolution of 0.0625 °C and a maximum accuracy of ± 1 °C within the +25 °C to +65 °C range. Temperature data is available as a 13-bit 2's complement format, and covers a range of –55°C to +125 °C. with a maximum accuracy of ±3 °C. A band-gap type temperature sensor, a 12-bit plus sign (13-bit) Sigma-Delta ADC, an internal conversion oscillator (approx. 30 kHz) and an SPI-compatible serial input/output port — the works!

… and the software

The ISA model is based on air pressure at sea level of 101.325 kPa and a temperature of +15 °C. The temperature at 11,000 m is taken to be –56.5 °C, so temperature decreases 6.5 °C for every 1,000 m, up to about 11,000 m. The actual atmospheric temperature can deviate considerably from this model, requiring a correction for altitude readings to be applied.
The temperature correction can be calculated with help of Charles's Law for ideal gases. It states that the volume of the gas is proportional to absolute temperature, or

$$V / T = k \qquad \text{[Eq. 3]}$$

where V = volume of gas; T = absolute temperature and k = constant.
For a column of air with base area A and height h, the formula can be written as

$$h \times A / T = k \qquad \text{[Eq. 4]}$$

Comparing standard atmosphere with actual conditions, k is still constant and for a column of air with the same base area A becomes a constant, too, and the variations are in h and T. Using index s from he ISA model and r for the real ambient air we can write

$$h_r / T_r = h_s / T_s \qquad \text{[Eq. 5]}$$

or

$$h_r = (h_s / T_s) \times T_a \qquad \text{[Eq. 6]}$$

The software is written to calculate and solve the above equations and you need not worry about it! C code munchers delve into file **080444-11.zip** available free from the Elektor website! [1]

QNH setting

'QNH' is a Q code rather than the latest PIC mnemonic. It is a pressure set-

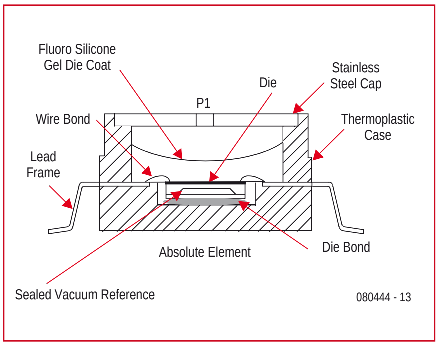


Figure 1. Internal structure of the MPXHZ6115A pressure transducer. (source: Freescale)

ting used by pilots, air traffic controllers and weather beacons to enable altimeters to read altitude above MSL within a certain region. QNH is calculated from the barometric pressure at ground level using ICAO STD atmosphere for the part between the MSL and ground level. It's essentially identical to ISA, but extends the altitude coverage up to 80 km.

You can set the QNH in this altimeter in two ways: either directly enter the QNH using the menu screen, or enter the known altitude for your location.

Circuit description

At the heart of the circuit shown in **Figure 2** sits a Microchip PIC18F2423 nanowatt technology, flash microcontroller with 12-bit ADC. The device also sports 16 K code space, 768 bytes of RAM, 256 bytes of EEPROM and an internal oscillator. Here a standard 32.768 kHz watch crystal (X1) with two 15 pF load capacitors are the hardware elements of the (otherwise invisible) real time clock.

Since the pressure sensor, IC4, is ratiometric within the specified excitation range and supplied from the ADC reference terminal, it is not necessary to use a precision reference voltage. The sensor is shut down and woken up using MOSFET T2 on port line RA5.

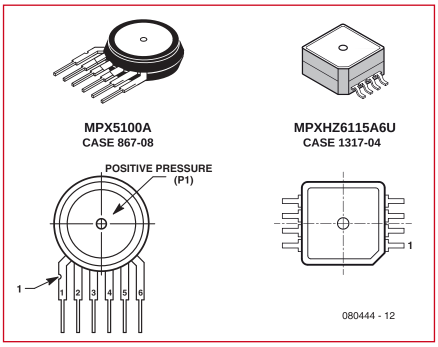


Figure 2. Case shapes of the two pressure transducers that may be used on the Altimeter board. (source: Freescale)

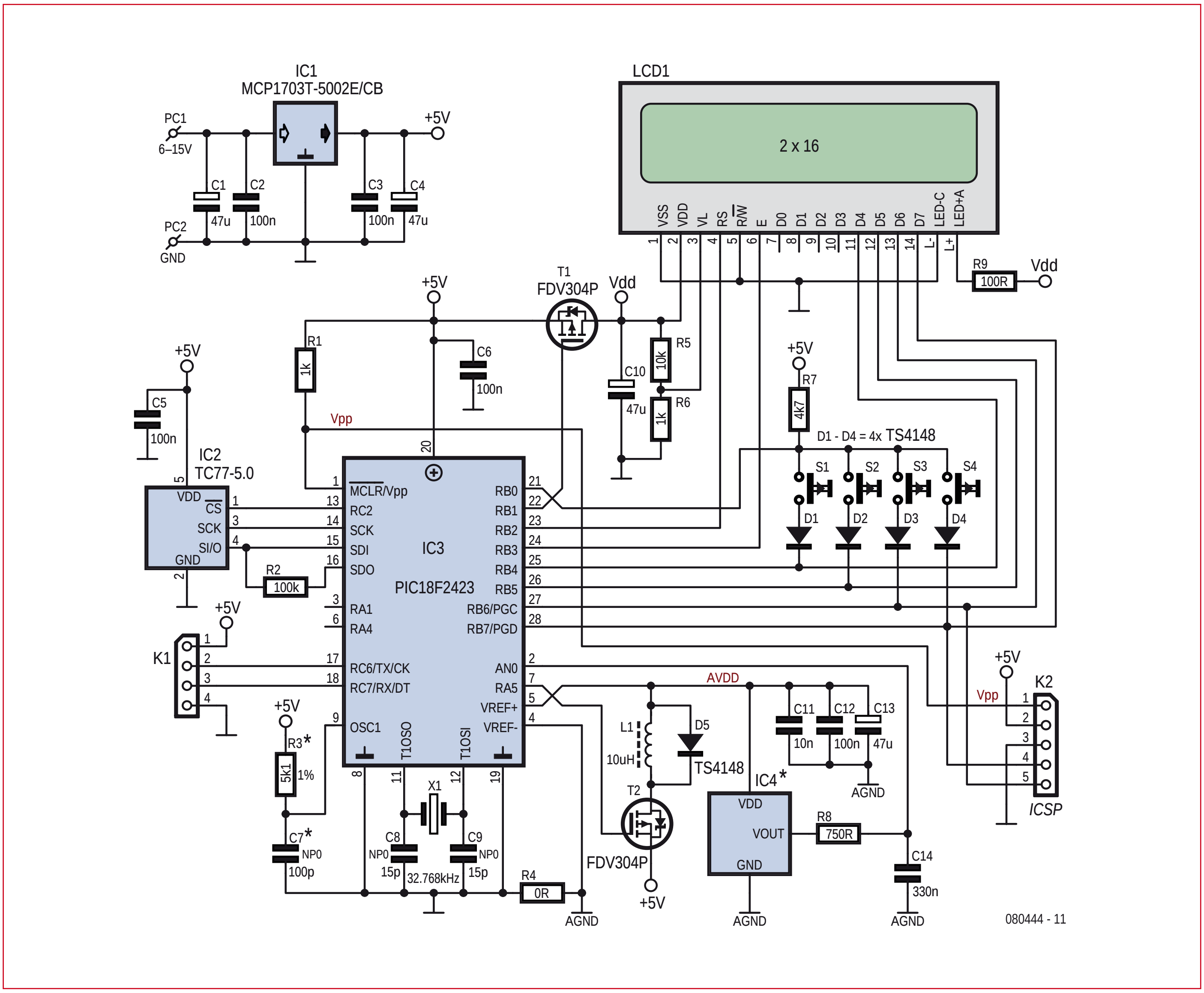


Figure 3. Circuit diagram of the Barometric Altimeter. Note the difference between A(nalog)GND and digital ground.

The pressure sensor output is connected to the microcontroller's ADC channel 0 (AN0) via an RC low-pass filter with cut-off frequency of about 650 Hz. The 750-Ω resistor (R8) allows a low source impedance to be matched to the PIC's on-chip ADC, thus minimising the offset voltage at the analogue input [2][3]. The pressure sensor is supplied via an LC filter (L1, C11, C12 and C13) where D5 is a free-wheel diode.
The LCD is wired to the PIC micro in 4-bit mode, requiring data to be sent twice using the upper nibble of PORTB, with the port also doing the key scanning and multiplexing. Supply power to the LCD arrives via MOSFET T1, which is controlled by port line RB1.
Since the PIC has an SPI module, it is not too difficult to get it interfaced to the TC77-5.0 temperature sensor chip (IC2). The TC77-5.0 starts to send data when its $\overline{CS}$ input is pulled logic Low by port line RC2.
The PIC micro may be programmed in-circuit via ICSP connector K2. Push buttons S1–S4 are read in multiplex fashion.
Components R3 and C7 are **not required** with the supplied firmware, because the internal oscillator is being used.
If you do not wish to use the LCD backlight, R9 should be omitted.
The rest of the circuit is no more than the expected low-dropout power supply (IC1) and an array of supply decoupling caps at crucial locations (C1–C4, C5, C6, C11, C12, C13).

Software

The program was written in C and compiled using Microchip's C18 compiler. The PIC can be programmed using simple homebrew programmers like the MultiPIC Programmer [4] and ICProg. Be sure to **disconnect the LCD while ICSP-ing the PIC**.
All is revealed in the C source code file found in archive # 080444-11 supplied for the project. Timer1 is initialised to 0x8000h, causing it to overflow every second. It continues operating in sleep mode (consuming a few microamps only) so it's unnecessary to use an external RTCC chip for timekeeping.
The altitude is determined by using Eq. [2] and is displayed along with the atmospheric pressure. The firmware uses 32-bit floating point arithmetic.
The conversion starts when the ADGO bit is set, and is cleared after completion of the conversion. After conversion, the result is available in the ADRESH:ADRESL register pair, and it is right-aligned (i.e. first four bits of ADRESH read as zeros). This 10-bit result can be directly converted to pressure by multiplying it with a constant and adding the pressure offset.
The ADC acquisition times for the PIC micro (i.e. the time required to charge C_{HOLD} in the internal sample and hold circuit) is about 2.96 μs; this must also observed before taking readings.

Construction

A double-sided through-plated circuit board was designed for the project — see **Figure 4** and pdf file 08044-1 from [1].
The PCB accommodates SSOP cased pressure sensors like the MPXH-Z6115A6U used in our prototype, as well as UP (Unibody Package) through-hole devices like the MPX5100A.
The PCB was designed with two ground planes: one for the analogue part of the circuit (comprising the sensor, RC low-pass filter and the sensor's decoupling capacitors), and the other for the digital circuitry, i.e. the remaining part of the circuit.
The PCB ground planes are interconnected at a single point only by means of zero-ohm resistor R4 (a wire link or a drop of solder is also an option). This bridge provides a single path for return currents. The only necessary trace

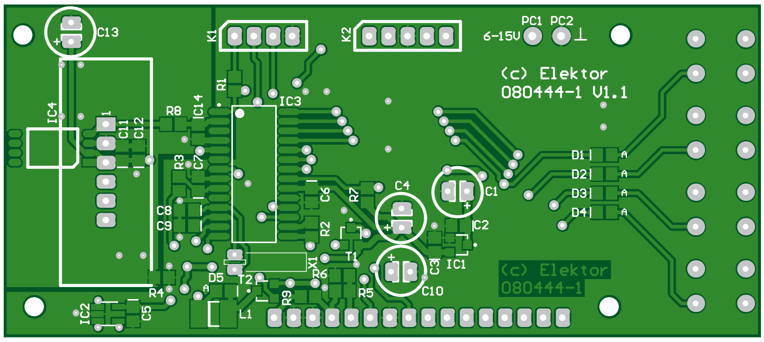


Figure 4. Top side component mounting plan (double-sided board). Copper track layouts available free from www.elektor.com/080444.

COMPONENTS LIST

Resistors
(1%, SMD 0805)
R1, R6 = 1kΩ
R2 = 100kΩ
R3 = not fitted (see text)
R4 = 0Ω
R5 = 10kΩ
R7 = 4.7kΩ
R8 = 750Ω
R9 = 100Ω

Capacitors
C1,C10 = 47μF /35V radial electrolytic, lead pitch 2.54mm (0.1'')
C2,C3,C5,C6,C12 = 100nF 50V ceramic, X7R, SMD 0805
C4,C13 = 10μF 16V radial electrolytic, lead pitch 2.54mm (0.1'')
C7 = not fitted (see text)
C8,C9 = 15pF ceramic, NP0, SMD 0805
C11 = 10nF 50V ceramic, X7R, SMD 0805
C14 = 330nF ceramic, X7R, SMD 0805

Semiconductors
D1–D5 = TS4148, SMD 0805 (Farnell # 8150206)
IC1 = MCP1703T-5002E/CB, SOT-23, (Farnell # 1439519)
IC2 = TC77-5.0, SOT-23 (Farnell # 1292291)
IC3 = PIC18F2423, SO-Wide, programmed, Elektor Shop # **080444-41**
IC4 = MPXHZ6115A6U or MPX5100A (Freescale), SSOP (see text)
T1,T2 = FDV304P, SOT-23 (Farnell # 9846123)

Miscellaneous
K1 = 4-way SIL pinheader, right angled solder pins, lead pitch 2.54mm (0.1'')
K2 = 5-way SIL pinheader, right angled solder pins, lead pitch 2.54mm (0.1'')
L1 = 10μH ferrite inductor, SMD 1812 (Farnell # 1174073)
LCD1 = 2x16, alphanumeric, DEM16217 SYH-PY /V, e.g. Elektor Shop # **030451-72**
PC1,PC2 = solder pin, 1mm diam.
S1–S4 = switch, tactile, SPNO
X1 = 32.768kHz quartz crystal, cylindrical case
4 PCB supports, nylon, 12mm height, 4.6mm diam. (Farnell # 1325986)
PCB, ref. **080444-1** from www.thepcbshop.com

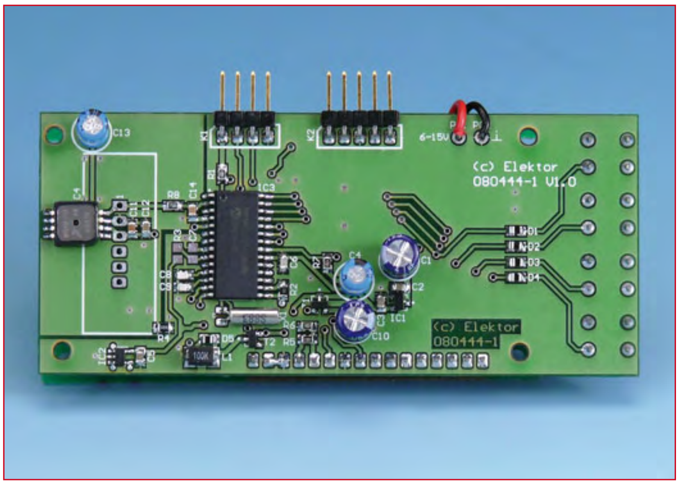


Figure 5. Finished board with MPXHZ6115A SMD pressure sensor mounted at far left of the board.

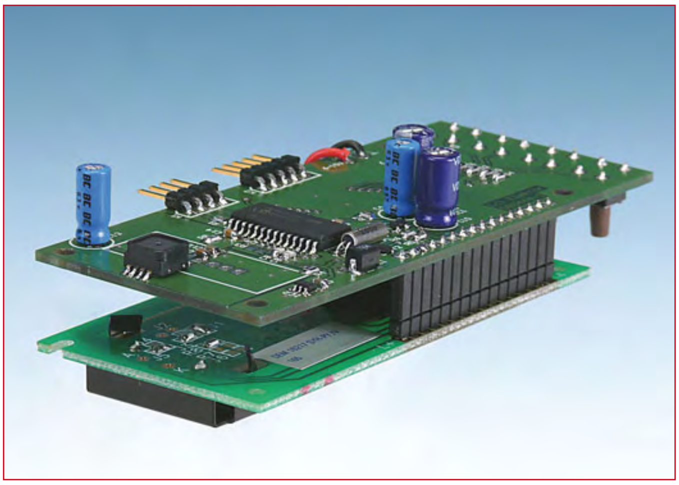


Figure 6. The Altimeter board and the LCD are connected by a 16-way SIL pinheader/socket combination.

that's routed from the digital to the analogue ground plane carries the sensor's supply voltage and is intentionally routed underneath the bridge. This way we have two equal currents flowing in opposite directions causing the resulting electromagnetic fields to cancel out.

Assuming you've some experience in soldering SMD parts whether reflow-style or manually, the critical ones are the PIC and the pressure sensor. The push buttons and the 16-way LCD connector are mounted **at the top side of the board**.

Run a careful check on your soldering and component mounting before applying power for the first time. All in order and your mind at ease, apply power and check if the LCD contrast is as desired. If not, adjust the values of resistors R5 and R6 until you're happy.

For construction standards, the photographs in **Figures 5 and 6** show the levels to match or surpass by your efforts.

(080444-I)

Send us photos of the readout at low-oxygen heights

Acknowledgement
The help of Prof. T. K. Mani, Principal College of Engineering Cherthala, India, is gratefully acknowledged.

Internet Links

[1] www.elektor.com/080444

[2] http://www.freescale.com/files/sensors/doc/app_note/AN1646.pdf

[3] http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en026428

[4] www.hamradio.in/circuits/feng.php

[5] http://wiki.motionbased.com/mb/Barometric_Altimeter

Practical use

Initially the EEPROM is programmed with typical values of the calibration constants, so apart from the time there's nothing to set unless a solid reference is available for your current altitude.

For the instrument to work correctly, a few calibration adjustments are required. A menu system is provided. Using the four buttons (top to bottom):

Menu / Cursor position

Up / *Power On*

Down / *Power Off*

Esc / Save

you can easily set all calibration parameters correctly.

The second function of each key is accessed if the key is held down for about one second.

Enter the menu system by pressing and releasing the Menu button (S1). The first menu item will be displayed on the LCD. To go to next menu, press Up (S2) or Down (S3). To enter the selected menu, press the Menu key again.

The menu contains following items.

Set Pressure: this screen is used to calibrate the pressure sensor.

Set Altitude: this is the first method to set the pressure at MSL. The known value of altitude is entered here. Based on the ambient temperature and pressure, the software will find out the pressure at MSL and save it to memory.

Set QNH: directly enter the pressure for MSL based on QNH information.

Set Time: set / adjust time

To change the value of the selected parameter(s), use the Up (increase) or Down key (decrease) to adjust the value. The underscoring cursor indicates the digit subject to changing, if necessary, by a short press of the Menu key. To exit from the selected menu press Esc (S4).

The altimeter is turned off by keeping the Down key pressed for more than one second. This is actually the power-down mode, and the RTC will continue to keep the time. In this state the processor consumes only minimum power (approx. 20 μA average for the whole circuit). Switch on again with the Up key.