A DIGITAL ALTIMETER

Add new dimensions to your next trip to the mountains with our pocket-sized electronic altimeter.

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IF YOU ENJOY HIKING OR DRIVING through mountainous country—but without knowing how far above sea level you are—this project will be of interest. It's a simple, easy-to-build, compact electronic altimeter that provides altitude readings from zero to 1999 feet with a resolution of 1 foot. The device has a 3½-digit LCD readout and is powered by a common 9-volt battery.

The altimeter's small size and light weight allows it to be easily carried wherever you travel. The modest power drain of the circuit ensures many hours of operation on a single 9-volt battery. If desired, the instrument can also be powered by the 12-volt electrical system of any vehicle.

The electronic altimeter is a pneumatically operated device that responds to absolute atmospheric air pressure. It operates on the same principle as the aneroid altimeters found in every aircraft.

Absolute atmospheric pressure is a mathematically definable parameter that varies inversely with altitude. At sea level the pressure is 14.7 pounds per square inch, and decreases as altitude increases.

The heart of the altimeter is a high-quality solid-state absolute-pressure sensor that is sensitive enough to detect changes in altitude as small as one foot. The surrounding circuitry amplifies the analog voltage output of the sensor, and converts it to digital form to drive the display.

The sensor

The pressure sensor was developed by Motorola Semiconductor Products, Inc., Phoenix, AZ. It's designed to respond to absolute atmospheric pressure, which is defined as pressure measured with respect to a perfect vacuum (zero pounds per square inch absolute, or 0 PSIA). Over the altimeter's range of interest, 0 to 1999 feet, the absolute atmospheric pressure varies from 14.696 PSIA to 13.67 PSIA (which corresponds to 29.92 to 27.82 inches of mercury, respectively).

Inside the sensor is a monolithic silicon piezoresistor that is ion-implanted on a thin silicon diaphragm. The pressure sensor contains two chambers separated by the silicon diaphragm. One of the sensor's chambers is exposed to atmospheric pressure by means of an external port. The other chamber is evacuated to as perfect a vacuum as possible, and sealed. That way the diaphragm of the sensor is under constant stress in accordance with the difference between atmospheric pressure on one side, and an essentially "perfect" vacuum on the other. The mechanical stress placed on the diaphragm (and the piezoelectric resistor) causes the sensor to generate an output voltage that is proportional to the applied pressure as seen by the open port of the solid-state sensor.

Refer to the schematic of the altimeter circuit shown in Fig. 1. The piezoresistor within the sensor (IC4) is connected between pins 1 and 3, and is driven by the 5-volt power supply in the circuit. The taps on the resistor, connected transversely across the element, are brought out to pins 2 and 4 of the sensor.

Under normal conditions in which atmospheric pressure causes a stress on the piezoelectric resistor, the sensor differential output voltage is a finite but very small value—about 20 millivolts. Over the range of interest for climbers (0 to 1999 feet), the sensor's output voltage will change only about 1.4 millivolts.

A differential amplifier, composed of three sections of an LM324N quad op-amp (IC1), provides voltage amplification of the sensor output. The gain of the amplifier can be adjusted by potentiometer R3 to allow for the normal tolerance difference between different sensors. The DC voltage level at pin 8 of IC1 is set to 2.5 volts when the altimeter is at zero altitude (sea level). At 1999 feet, the amplifier output falls to about 2.4 volts.

The DC voltage from the differential amplifier (IC1) drives an ICL7106CPL analog-to-digital (A/D) converter (IC3). That chip, which is used in many commercial DMM's, converts the differential voltage from IC1 to digital form and drives the 3½-digit liquid crystal display (DSP1). An external reference voltage, generated by R14–R17, provides the proper conversion factor between the analog input voltage and the desired digital display in feet.

As described earlier, the output voltage of the amplifier section is set to 2.5 volts by R3 when the altimeter is at sea level. That voltage is fed to the negative analog input of IC3 (pin 30). Since the altimeter must read zero at sea level, the positive input of IC3 (pin 31) must see a constant 2.5-volts. That way the differential input voltage between the positive and negative inputs will be zero, and the display will read 000 as desired. As the elevation of the altimeter increases, the voltage fed to pin 30 decreases while the voltage at pin 31 remains constant. As a result, the net difference in voltage is detected by IC3 and converted into an increasing digital display readout of altitude.

There is one other factor that must be taken into consideration in a pneumatically sensing altimeter of this type. Changing weather conditions cause changes in barometric pressure from the standard value of 14.7 PSI (or 29.92 inches of mercury at sea level). As with any altimeter that reacts to absolute air pressure, the effect of changing barometric pressure must be canceled out.

In this project the effect of barometric pressure is canceled out by means of BARO SET potentiometer R11 which can be adjusted for about 2.4 to 2.6 volts at its wiper. Therefore, R11 must be set so that the voltage at pin 14 of IC1-d causes the display to indicate the correct known altitude at any reference location. Once that is done, the altimeter is calibrated for the current barometric reading—but changing weather conditions can change the readings significantly. You will probably have to recalibrate the altimeter before each use, or simply set it to zero and use it to measure a relative altitude.

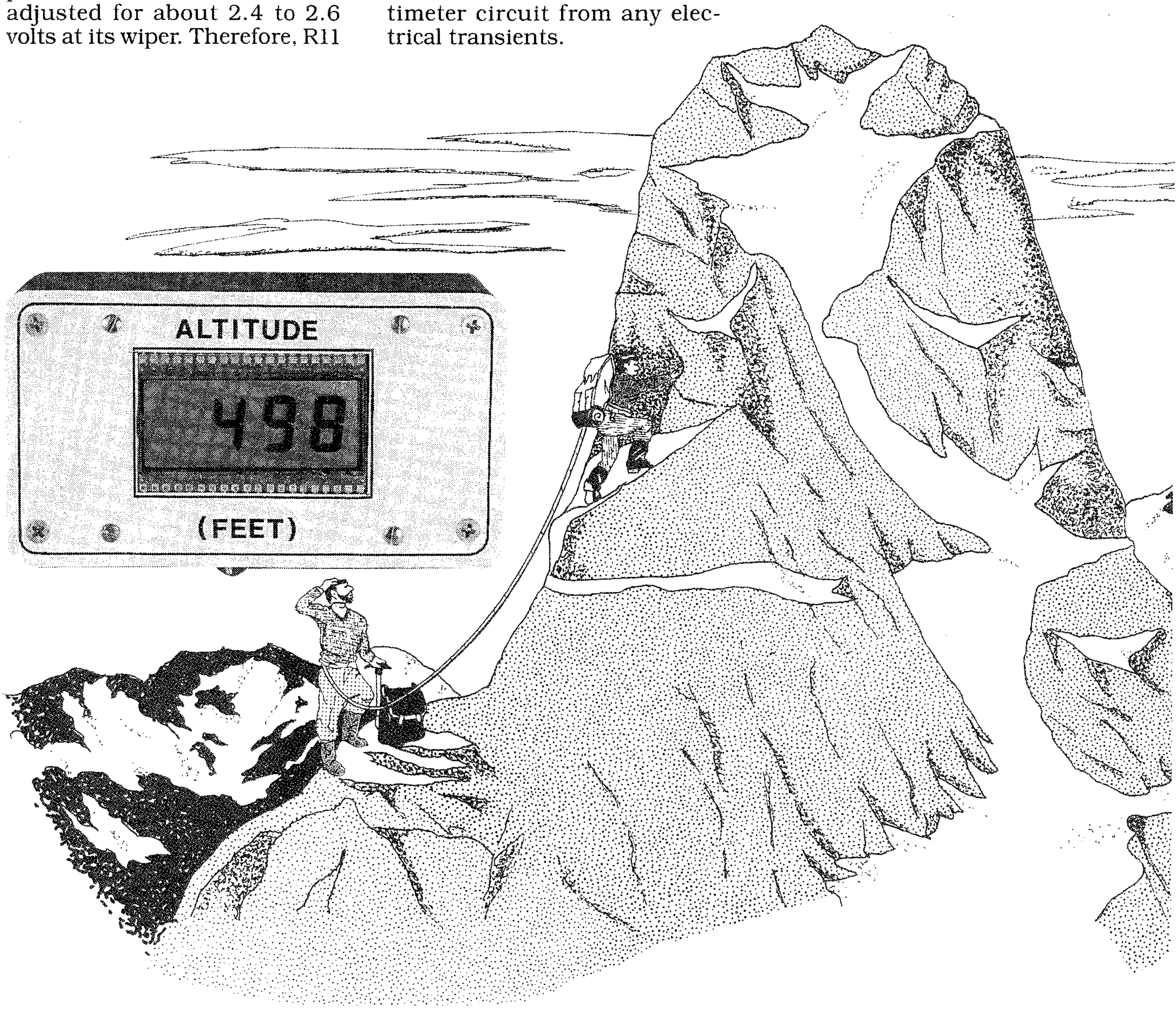
Power for the altimeter comes from a 9-volt battery or from a vehicle's 12-volt electrical system. Either source is fed to an AN78L05 fixed 5-volt regulator (IC2). The altimeter's modest current drain of about 6½ millamperes allows many hours of operation from a 9-volt battery. When 12 volts is used as the power source, a resistor and diode are used to isolate the altimeter circuit from any electrical transients.

Construction

The altimeter is built using two single-sided PC boards—one analog and one digital.

The two PC boards can be made using the foil patterns we've provided, or they can be purchased from the source mentioned in the Parts List. Point-to-point wiring can also be used. Parts-placement diagrams for the analog and digital boards are shown in Figs. 2 and 3, respectively.

You should use sockets for the two DIP IC's, but because of the limited space in the prototype's enclosure, only low-profile sockets would fit. Do not install the IC's in the sockets until instructed to do so. Note that the altimeter's accuracy will suffer if metal-film resistors, where specified, are not used. Also



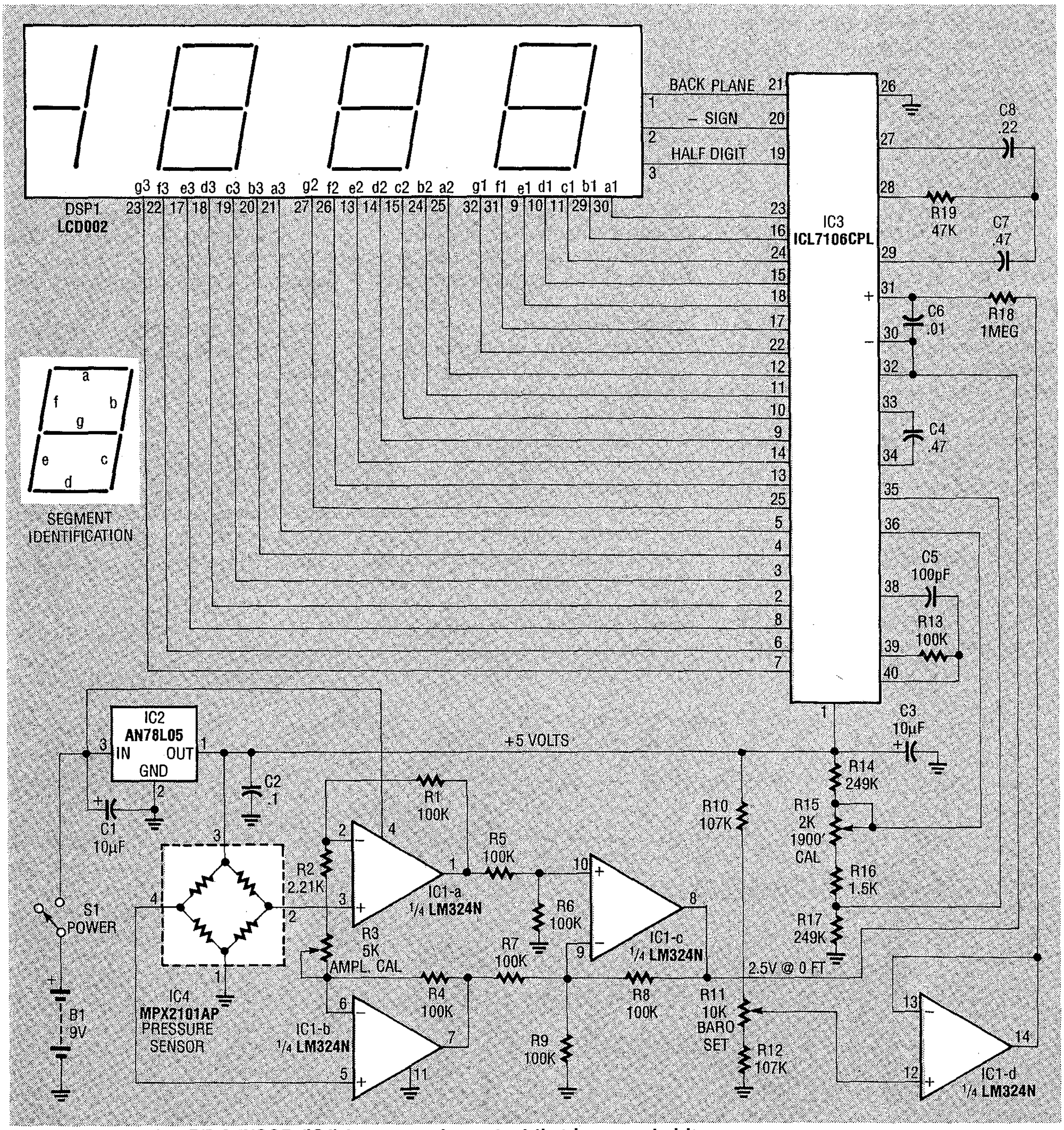


FIG. 1—THE PRESSURE SENSOR (IC4) has an analog output that is converted to digital form by IC3 and then displayed on the LCD.

note that R20 and D1 (shown on the analog board in Fig. 2) are to be installed only if you wish to power the unit from a vehicle's 12-volt source.

The pressure sensor should be handled with care. Its leads must be bent at right angles so that the sensor lies flat on the analog board. Use two long-nose pliers when bending the leads—one to prevent stress on the lead where it enters the plastic body and the other to bend it. Before forming the leads, locate pin 1 of the sensor; it's identified by a notch cut into the lead. Then you'll be able to form the leads in the correct direction. Mounting hardware for the sensor is optional because the leads will hold it in place. No pneumatic connection to the sensor's pressure port is required, except calibration.

The LCD module can also be mounted in a socket if you like; you can make one for it by cutting a 40-pin DIP socket in half lengthwise. To keep the altimeter as compact as possible, the LCD module is mounted on the copper side of the digital board, *after* all of the components are installed on the component side. (You can install a socket for the LCD now, but don't install the LCD just yet.) Mounting the LCD on the copper side allows the digital board to be mounted on the cover of the enclosure.

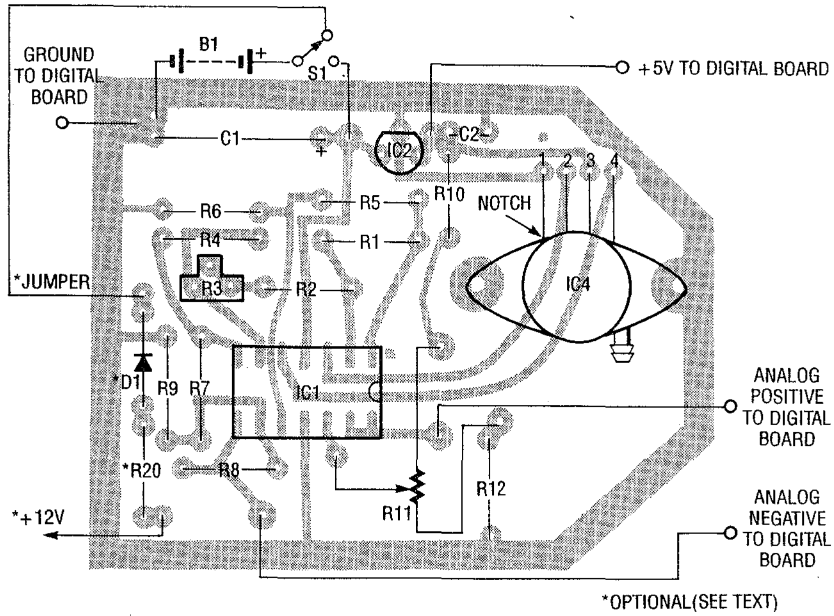


FIG. 2—PARTS-PLACEMENT DIAGRAM for the analog board. Note the components that are optional for 12-volt use. Also note the four connections that must be made to the digital board (see Fig. 3).

Obtain a clip for the 9-volt battery, or salvage a connector taken from an exhausted battery. Be sure to observe proper polarity on the battery connector. Power switch S1 and potentiometer R11 should be installed on the side of the enclosure, easily accessible to the user. If you are dealing with limited space (a small enclosure), use a miniature toggle or slide switch for S1. Once R11 is set, it's best if it can not be accidentally changed during the use of the altimeter. Therefore, R11 should be a screwdriver-adjusted part. If mounting R11 is a problem, the resistor can be epoxied in place next to the power switch. A multiturn potentiometer will make it easier to calibrate the unit.

A number of jumper wires, labelled JU1–JU20, are required on the component side of the digital board to complete the circuit. You must solder a jumper wire between each pair of pads—JU1 to JU1, JU2 to JU2, and so on. Use #24 or #26 insulated stranded wire. Examine both boards carefully for bad solder joints, shorts, and improperly installed components before continuing.

Final assembly

When both boards are completed, power, ground, and the two differential output wires from IC1-c and IC1-d must be connected between the analog and digital boards, as indicated in Figs. 2 and 3. Use insulated stranded wire for those connections and be sure to allow sufficient length to permit proper mounting in the enclosure. In the prototype, the boards are placed one above the other.

12-volt power

If you want the option of powering the altimeter from a vehicle's 12-volt source, R20 and D1 must be installed on the analog board. To allow operation from either the 9-volt battery or 12-volt source, a miniature jack can be installed in the enclosure to allow connection to the vehicle's electrical system and still allow portable use. Be sure to observe proper polarity when wiring the altimeter for 12-volt operation. You can make a power cable by putting a mini plug on one end and, most likely, an automotive cigarette lighter plug on the other. Just be sure to plug the cable into the altimeter first, to avoid having a live male connector completely exposed.

The altimeter can be wired for 12-volt power exclusively, or as a combination 9- and 12-volt unit. Follow the wiring diagrams in Figs. 4 and 5 for the selected power-source option. Give the project one final visual inspection before continuing with the checkout. Figure 6 shows the author's prototype.

Electrical checkout

Before proceeding, make sure the IC's are not in the sockets. You'll need an accurate DC voltmeter with an input resistance of at least 1 megohm to perform the checkout.

Use a fresh 9-volt alkaline battery or a well-regulated DC power supply to power the circuit. If the power supply has current-limiting capability, set the limit to 10 milliamps to protect the project in the event of a malfunction. (The normal current drawn by the circuit is about 6½ millamperes.) Set the supply for 9- or 12-volts output, as applicable.

First, check voltage regulator IC2. Apply power to the circuit and measure its output voltage. Anything between 4.75 and 5.25 volts is good. In case of trouble here, check the orientation of C1 and IC2, and the polarity of the power supply. Measure the terminal voltage of the battery or supply while it is powering the circuit to be sure it is delivering at least 7 volts to the regulator. Disconnect power and measure the resistance between the 5-volt line and ground to be sure there is no short circuit. As a last resort, try a new regulator.

Check the analog circuit next. Insert IC1 into its socket, and apply power to the circuit. Measure the voltage at pin 8 of IC1; adjust R3 for a reading of 2.5 volts. Measure the voltage at pin 14 of IC1 while rotating potentiometer R11 over its range. Make sure the range of adjustment is about 2.4 to 2.6 volts. If you don't see the correct voltages, check the wiring and components associated with IC1. Check the pressure sensor for correct orientation. Try changing IC1 as a last resort.

Disconnect power from the circuit and insert IC3 into its socket. Place the readout in its socket on the solder side of the

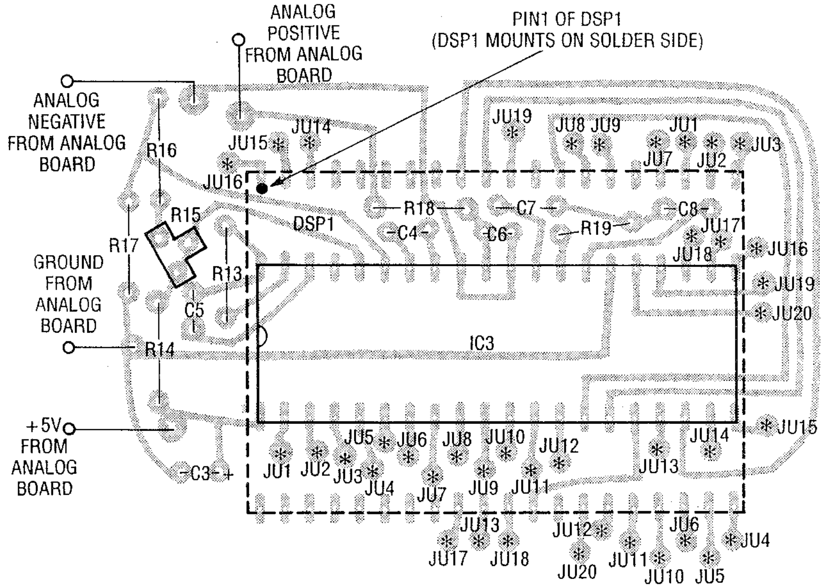


FIG. 3—PARTS-PLACEMENT DIAGRAM for the digital board. Note that the LCD module mounts on the solder side of the board after all other components are installed *and* the board is tested (see text for details). Also note the twenty pairs of pads labelled JU1–JU20. You must solder a jumper wire between each pair of pads; for example, JU1 to JU1, JU2 to JU2, and so on.

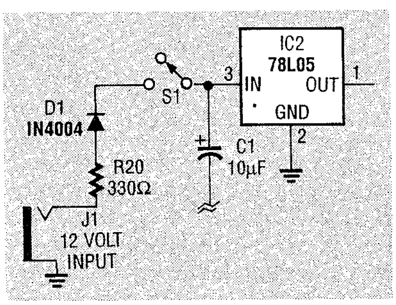


FIG. 4—WIRE THE ALTIMETER as shown here for 12-volt power exclusively.

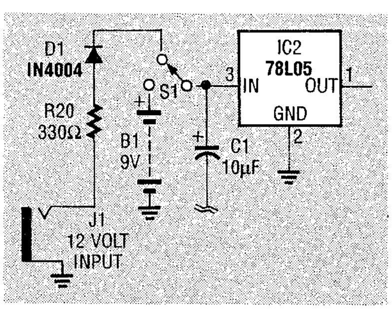


FIG. 5—THE ALTIMETER IS SHOWN wired for both 9- and 12-volt operation.

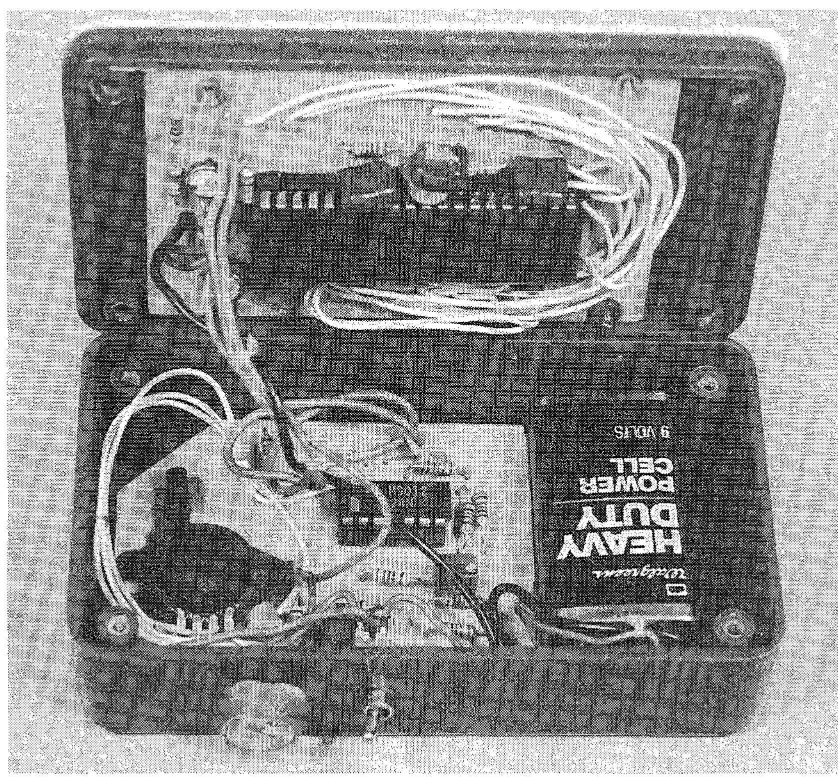


FIG. 6—HERE'S THE AUTHOR'S PROTOTYPE. Notice the four wires that connect the analog and digital boards together.

digital board in accordance with Figs. 3 and 7. If you didn't use a socket for the display, position it so that its terminals are flush with the component side of the board and solder.

With the LCD installed, set R15 to mid position, apply power, and adjust R11 over its range. The display should indicate some number that can be varied via R11 between approximately −1000 and +1000.

If the display is completely blank, check the orientation of the LCD module and IC3 to be sure that they have not been placed backwards in the circuit. If available, an oscilloscope can be used to verify the presence of the backplane signal generated by IC3 at pin 1 of the readout. A normal indication at pin 1 is a 5-volt peak-to-peak square wave with a period of about 140 microseconds.

If the readout displays digits but the numbers do not ascend and descend with adjustment of R11, the fault is most likely with the components or wiring of IC3. Check all parts to be sure they have the correct value. The reference network composed of R14–R17 can be checked by removing IC3 from its socket and measuring the voltage between pins 35 and 36 of the socket while adjusting R15 over its range. Normal indication is 15 to 35 millivolts with pin 36 positive with respect to pin 35.

Operation of IC3 can be checked by removing IC1 from its socket and temporarily shorting pins 8 and 14 of IC1 socket. That causes the differential input voltage fed to the A/D chip to be zero, and the display should read 000.

Once the display is operating properly, operation of the altimeter can be verified before final calibration. Set R15 to mid position and adjust R11 for a display of about 20 or 30 feet.

Physically move the altimeter higher and lower to observe the change in altitude reading. Hold the project horizontally or vertically as you make this test; a change from one orientation to the other can cause the readout to vary 3 or 4 feet, due to gravitational force on the extremely sensitive solid-state pressure sensor.

You should be able to detect and resolve 1 or 2 feet of vertical displacement. It is normal for the display to fluctuate 1 or 2 digits. Additionally, it should be noted that the altimeter is a pressure-sensitive device and will respond to any variation in barometric pressure, in which a change in pressure of only 0.001 inch of mercury at sea level will cause a change of 1 foot in the altitude reading.

Even though the resolution of the instrument is 1 foot, the altimeter will not have either the accuracy or stability to indicate altitude that accurately.

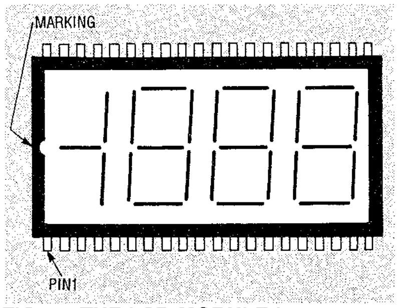


FIG. 7—THE LCD MODULE has a marking similar to that on an IC, indicating where pin 1 is. Note that the module mounts on the solder side of the digital board, so be careful where pin 1 goes.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.

R1, R4–R9—100,000 ohms, 1% metal film
R2—2210 ohms, 1% metal film
R3—5000 ohms, cermet PC-mount potentiometer
R10, R12—107,000 ohms, 1% metal film
R11—10,000 ohms, PC-mount potentiometer, screwdriver adjust
R13—100,000 ohms
R14, R17—249,000, 1% metal film
R15—2000 ohms, cermet PC-mount potentiometer
R16—1500 ohms, 1% metal film
R18—1 megohm
R19—47,000 ohms
R20—330 ohms (optional for 12-volt operation)

Capacitors

C1—10 µF, 25 volts, axial electrolytic
C2—0.1 µF, 50 volts, ceramic disc
C3—10 µF, 25 volts, radial electrolytic
C4, C7—0.47 µF, 50 volts, metal film
C5—100 pF, 50 volts, ceramic disc
C6—0.01 µF, 50 volts, ceramic disc
C8—0.22 µF, 50 volts, metal film

Semiconductors

IC1—LM324N quad op-amp
IC2—AN78L05 5-volt regulator
IC3—ICL7106CPL A/D converter (Intersil)
IC4—MPX2101AP semiconductor pressure sensor, 15 PSI absolute (Motorola)
D1—1N4004 silicon diode (optional for 12-volt operation)
DSP1—3½-digit LCD module (DigiKey LCD002)

Other components

J1—Miniature jack (optional for 12-volt operation—also requires matching plug)
S1—SPDT minature slide or toggle switch
B1—9-volt transistor battery, alkaline or heavy duty

Miscellaneous: 9-volt battery clip, IC sockets, #24 gauge stranded hookup wire, enclosure, hardware, plastic tubing, tee fitting, clamp, soda or wine bottle, food coloring, solder, etc.

Note: The following parts are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463:

- **Set of 2 etched and drilled PC boards (analog and digital)—$19.95**
- **LM324N op-amp (IC1)—$2.00**
- **AN78L05 regulator (IC2)—$1.50**
- **ICL7106CPL A/D converter (IC3)—$17.50**
- **MPX2101AP pressure sensor (IC4)—$39.50**
- **Set of 13 metal-film resistors—$4.95**

Please add $2.75 postage/handling.

Final calibration

To perform the final circuit adjustment, you will need a tape measure, three lengths of ¼-inch outside diameter clear plastic tubing, a tee for a three-way connection, and a clear plastic or glass bottle of clean drinking water. A soda or wine bottle is a good choice. Be sure that the inner diameter of the plastic tubing allows it to be stretched over the pressure port of the sensor for an air-tight seal. The suggested test setup is shown in Fig. 8.

In this procedure, the absolute pressure that represents 1900 feet of altitude will be simulated by drawing a partial vacuum to cause a column of water to rise in the straight, clear tube. This procedure uses basic laws of physics to set a desired pressure differential.

As noted earlier, absolute air pressure, under standard conditions, is 14.696 PSI at zero altitude (sea level). At 1900 feet, the pressure falls to 13.716 PSI. The pressure levels can also be specified in other units such as inches of mercury or inches of water. In this case, the desired pressure differential between zero altitude and 1900 feet, 0.98 PSI, is equivalent to 27.13 inches of water, rounded out to 27⅛ inches. Thus, to simulate the change in pressure from zero to 1900 feet, a column of water 27⅛ inches high can be used.

Set up the altimeter and apparatus as shown in Fig. 8. In this test, the water in the vertical tube is drawn up to the required height of 27⅛ inches by drawing a vacuum at the open end of the tubing.

With no vacuum applied to the open end of the plastic tube and the pressure sensor connected as shown in Fig. 8, turn on the altimeter and allow a minute for the circuit to stabilize. Adjust R11 for an altitude reading of some small positive number, such as 50 feet or so. The number selected is not significant.

Now, gently draw vacuum at the open end of the tubing so that the column of water rises 27⅛ inches above the level of

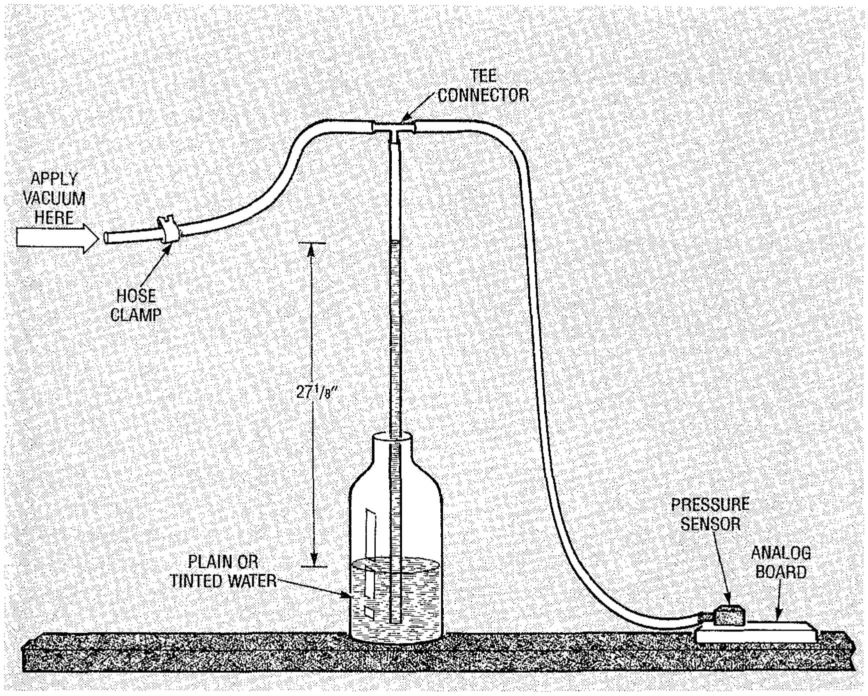
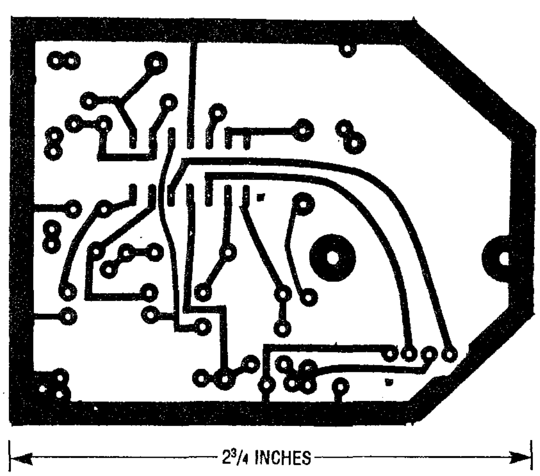


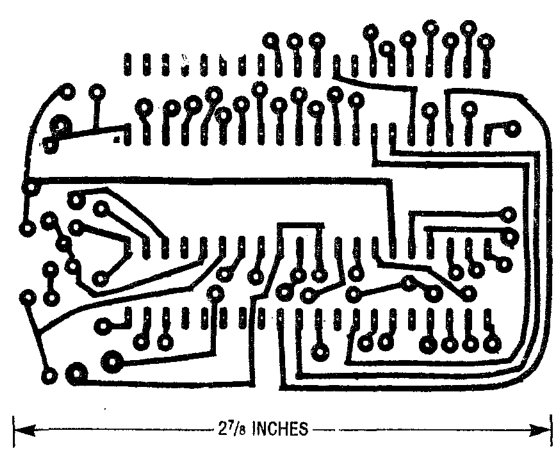
FIG. 8—CALIBRATION SETUP. You will need a tape measure, clear plastic tubing, a tee connector, and a clear bottle with water in it. Food coloring will make the water easier to see. See text for details.

water in the bottle. You can clamp the hose to maintain the required vacuum. Make sure you have a solid column of water with no air bubbles in it. Allow the display to reach a stable level and note the reading. Adjust R15 so that the display indicates 1900 feet more than the original reading (50 feet) set previously.

Repeat the above test as necessary until you are satisfied that the change in altimeter reading is as close to 1900 feet as possible when the water column is drawn up 27⅛ inches. This completes calibration.



FOIL PATTERN for the analog board.



FOIL PATTERN for the digital board.

Using the altimeter

Since the altimeter is subject to the variations of barometric readings, the instrument must always be corrected for the current barometric pressure before starting out on an excursion. You do not have to know the actual barometric reading to do this. Simply turn the unit on, allow a minute for the circuit to stabilize, and set R11 to obtain a display that represents the known existing altitude at your location.

Learning the true altitude of your home can be done by taking the altimeter to a location such as an airport where the altitude is documented, setting the altimeter to reflect the correct altitude, and then returning home immediately. The reading of the altimeter at your home will then be your reference altitude. For best accuracy, do this during a period of steady barometric pressure conditions.

For future use, before leaving home with the altimeter, simply turn it on and allow a minute or so for the display to stabilize. Then set R11 so that the reading is equal to the reference altitude at your home.

Once set, do not readjust R11 since you will have no reference against which to adjust it. At a later time, if you travel to another location with a known altitude, R11 can be readjusted to reflect a more accurate altitude if the barometric reading has changed since the original setting of R11.

When taking an altitude reading, turn the unit on and allow about a minute for the circuit to stabilize. Remember, if there is a sudden change in air pressure such as might occur with a changing weather, the reading can fluctuate. Wait for the display to settle down.

Be sure to turn off your battery-powered altimeter when not taking altitude readings. That will conserve power and provide extremely long battery life, which should be about 10 or 15 hours of altimeter operating time when using an alkaline battery. **R-E**