DIGITAL PRESSURE GAUGE

Now you can take pressure readings the modern way using our electronic pressure gauge.

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MOST OF US ARE FAMILIAR WITH AN ORDINARY pressure gauge, such as that used for tires that measures pressure in *p*ounds per *s*quare *i*nch (psi). They are usually analog devices with an indicator bar or a moving needle whose movements depend on the specific pressure. However, with the advance of solid-state technology, it is possible to construct an accurate electronic pressure gauge with a resolution as low as 0.1 psi.

Our digital pressure gauge operates from a 9-volt battery, so it is completely portable. The circuit uses only 4 milliamperes, so battery life will be extremely long. A large two-digit LCD is used to display pressure readings, but we'll also show you how to build it with a 3½-digit display.

The full-scale range of the pressure gauge is determined by the selection of the pressure sensor; in this case we have used a 0–100 psi semiconductor sensor, manufactured by Sensym (1255 Reamwood Ave, Sunnyvale CA 94089). Other sensors are available in full-scale ranges of 1, 5, 15, 30, 100, and 150 psi. Using a 15-psi sensor, for example, would result in a display resolution of 0.1 psi with a two-digit readout.

Pressure is measured by connecting a flexible hose between the sensor and source of pressure. If the project is to be used for differential pressure measurements, two hoses must be connected to the sensor and the device under test. Vacuum measurements require only one hose connection.

The circuit

The sensor is a differential device, which allows two pressure connections, and it measures the difference between the two. The sensor also permits vacuum measurements when one side of the sensor is exposed to the atmosphere and vacuum applied to the other. Pressure and vacuum measurements may be taken on any non-corrosive and non-toxic media such as air, dry gases, etc. The portable nature of the unit allows it to be used almost anywhere, such as for checking tire pressure or a compressed air tank.

The heart of this project is a differential piezoresistive pressure sensor which is constructed using integrated-circuit technology. It consists of four resistors connected in a Wheatstone bridge configuration, which are deposited on a silicon diaphragm that separates two chambers of the sensor housing. Each side of the diaphragm can be exposed to a pressure source by means of "ports" called P1 and P2. Any pressure difference between port P1 and port P2 will be detected by the sensor, providing a differential pressure reading. Figure 1 shows a closeup of the sensor.

The common pressure gauge which many people are familiar with is, in reality, a differential pressure gauge, with atmospheric pressure (14.7 psi) being the reference pressure. Thus, when no pressure is applied to the sensing port of the common gauge, the reading is zero. The same goes for our gauge; pressure is applied to P2 while P1 is exposed to the atmosphere.

When the pressure sensor is at rest, there is no stress on the silicon diaphragm and the values of the resistors are essentially equal. The Wheatstone bridge is thus balanced and its output voltage is virtually zero. During a pressure measurement, any difference in pressure between the two ports of the sensor result in mechanical stress of the silicon diaphragm and a change in the values of the four resistors. Two resistors increase in value and two de-

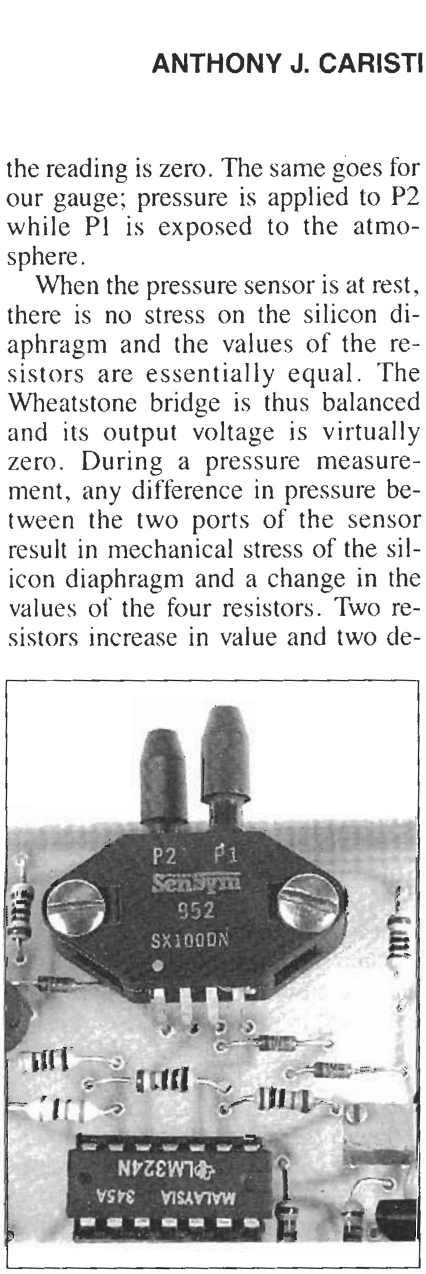

FIG. 1—HERE IS A CLOSEUP of the semiconductor pressure sensor.

PCB in VIDEO Frame Grabber.

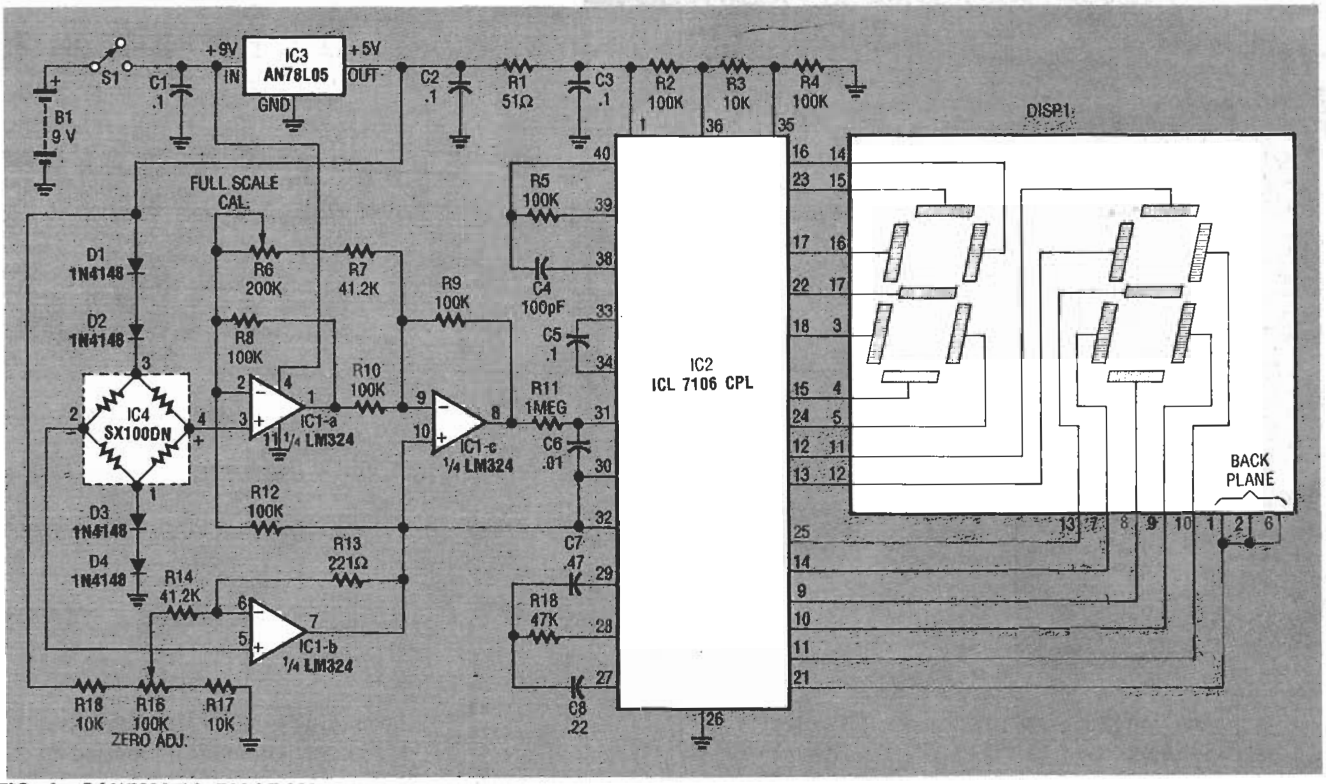

FIG. 2—SCHEMATIC DIAGRAM of the electronic pressure gauge. It uses a Sensym semiconductor pressure sensor.

crease. That causes the Wheatstone bridge to become unbalanced, producing an output voltage which is proportional to the difference in pressure between the two ports of the sensor. That voltage, which in the millivolt range, is amplified and used to provide the drive signal to the display section of the circuit.

The schematic diagram is shown in Fig. 2. In order to preserve the accuracy of the pressure measurement with respect to variations in battery terminal voltage, IC3, a fixed 5-volt regulator, maintains a constant power source which feeds the sensor bridge. A set of four silicon diodes, D1 through D4, has been placed in the circuit to temperature compensate the bridge. That eliminates changes in calibration of the circuit due to ambient temperature effects.

Three sections of IC1, an LM324N quad op-amp, amplify the millivolt output of the bridge to a useful level for the analog-to-digital (A/D) converter circuit that follows.

When there is no pressure applied to the sensor, the voltage between terminals 2 and 4 of the sensor is essentially zero; however, there may be a small output voltage, called zero offset. To compensate for that error, potentiometer R16 allows a small DC voltage to be fed to the amplifier circuit which negates the offset voltage of the sensor.

When the sensor is exposed to 100 psi, the output of the bridge circuit will generate approximately 34 millivolts. However, there may be variations in output voltage of as much as 30% between different sensors. To compensate for any given sensor, the amplifier gain is adjustable by means of potentiometer R6.

The display section consists IC2, which is a combination A/D converter/7-segment decoder/display driver, capable of driving a 3½-digit LCD (we've used only a two-digit display, DSP1). It is driven by the voltage between pins 7 and 8 of op-amp IC1. The sensitivity of the A/D converter is set by the reference voltage applied between pins 35 and 36. The reference voltage, which is about 238 millivolts, is set by the divider composed of R2, R3, and R4.

In this project only two digits are required since the resolution of the project is 1 psi and full scale is 100 psi. However, note that if you measure exactly 100 psi, the readout will display 00, since the hundreds digit is not present.

Note that for readings greater than 99 psi, or for 0.1 psi resolution, the circuit can modified to use the most significant and least significant digits of the A to D chip. In this case you'd need to use a 3½-digit readout, and its decimal place would be illuminated as required. If you wish to use a 3½-digit LCD, Fig. 3 shows the additional connections to the A/D converter that are required. However, note that the 3½-digit display is a 40-pin device that won't fit on the provided PC board. You must either hardwire it or design your own board.

Because of the characteristics of the pressure sensor, the display will read up-scale regardless of which port of the sensor is pressurized. However, you should use the same port for which the project was calibrated. If the project is to be used for vacuum or differential pressure measurements, the display will indicate the pressure difference in psi, with no polarity indication. The A to D converter used in this circuit does have an output terminal to indicate polarity, but it is not used.

Construction

The project is constructed on a single-sided PC board. A foil pattern is provided in PC Service. The circuit can also be hard wired on a perforated construction board if you wish. The parts-placement diagram is shown in Fig. 4. Note that the LCD readout is mounted on the copper side of the

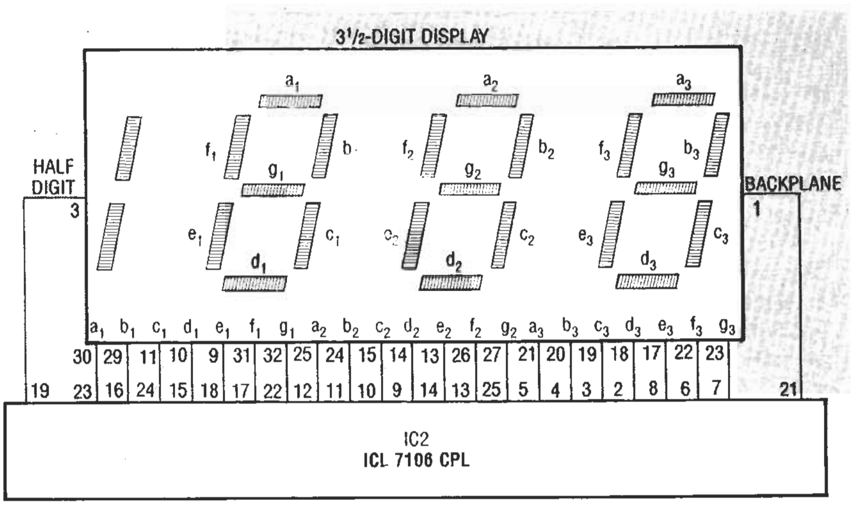

FIG. 3—HERE ARE THE ADDITIONAL CONNECTIONS to the A/D converter that are required for a 3½-digit display. Note that the 40-pin display won't fit on the PC board—you'll have to hardwire it or design your own board.

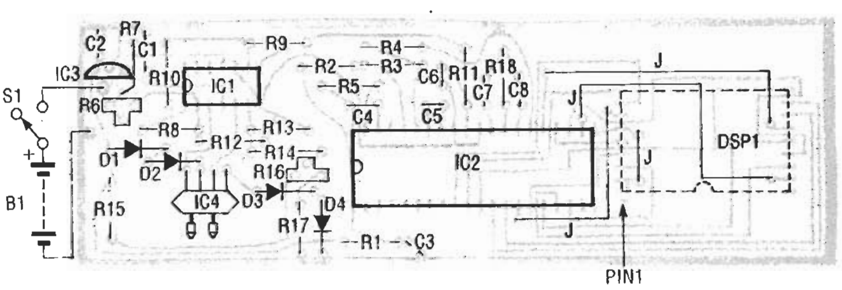

FIG. 4—PARTS-PLACEMENT DIAGRAM. Note that the LCD readout is mounted on the copper side of the board.

board. That allows the relatively flat side of the PC board to be mounted next to the side of a suitable enclosure containing a cutout or window to expose the readout for viewing.

You should use sockets for both of the IC's. Especially for IC2, which is a 40-pin chip and not inexpensive. The cost of a socket is minor compared to the IC itself, and you can never predict when an IC will have to be removed from a PC board. Once the sockets are in place, continue installing components, but do not insert the IC's yet.

The 5-volt regulator, IC3, looks like a small transistor; simply solder it directly to the board, and be sure to watch its orientation. Also be sure that the diodes are properly oriented.

The circuit requires four jumpers; the short jumper wire between pins 2 and 6 of the LCD can be a piece of bare wire, but the other three should be insulated to avoid shorts.

Many of the resistors specified in the parts list are metal-film types which exhibit excellent temperature stability. Since we want the project's calibration to remain stable with varying temperature, you should not substitute other types of resistors.

The LCD and the pressure sensor are fragile and must be handled carefully to avoid breakage. It is suggested that the readout be mounted to the board last. You may wish to use a socket for the readout, and you can make one by taking an ordinary 18-pin DIP socket and cutting it in half lengthwise. Remember, the socket (and readout) will be placed on the copper side of the board, so you must allow some space between the plastic of the socket and the board itself to allow room for soldering.

Before mounting the LCD, take note of where pin 1 is. If you look at Fig. 5, the black border around it has a marking on one side. Looking at that marking, pin 1 is where you'd normally see it on any ordinary IC.

The pressure sensor may be fastened to the board using two #4 machine screws and nuts, but be very careful not to over-tighten them; it could result in a cracked plastic assembly. Note that one of the terminals of the sensor is marked with a small dot. That is pin 1, so be sure to mount it as shown in Fig. 4. The four terminals of the sensor are very fragile, and must be carefully bent into position using a needle-nose pliers to support the leads next to the body of the part. If you attempt to bend the leads with-

PARTS LIST

All resistors are ¼-watt, 5%, carbon, unless otherwise indicated.
- R1—51 ohms
- R2, R4, R8–R10, R12—100,000 ohms, 1% metal film
- R3, R15, R17—10,000 ohms, 1% metal film
- R5—100,000 ohms
- R6—200,000 ohms, PC-mount potentiometer
- R7, R14—41,200 ohms, 1% metal film
- R11—1 megohm
- R13—221 ohms, 1% metal film
- R16—100,000 ohms, PC-mount potentiometer
- R18—47,000 ohms

Capacitors
- C1–C3, C5—0.1 µF, ceramic disc
- C4—100 pF, ceramic disc
- C6—0.01 µF, ceramic disc
- C7—0.47 µF, ceramic disc
- C8—0.22 µF, ceramic disc

Semiconductors
- IC1—LM324N quad op-amp
- IC2—ICL7106CPL 3½-digit A/D converter (Intersil)
- IC3—AN78L05 5-volt regulator
- IC4—differential semiconductor pressure sensor,
  - SX01DN for 1 psi full scale
  - SX05DN for 5 psi full scale
  - SX15DN for 15 psi full scale
  - SX30DN for 30 psi full scale
  - SX100DN for 100 psi full scale
  - SX150DN for 150 psi full scale
  - (Sensym, 1255 Reamwood Ave, Sunnyvale CA 94089)
- D1–D4—1N4148 silicon diode
- DSP1—two-digit LCD module (DigiKey LCD001)
- Optional—3½-digit module (Digikey LCD002)

Other components
- S1—SPST toggle or slide switch, N.O.
- B1—9-volt battery

Miscellaneous: battery clip, enclosure, IC sockets, hose w/fitting, clamps, wire, solder, etc.

Note: A PC board is available for $14.95 and a pressure sensor for $35.00 from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463. Add $2.50 postage and handling per order.

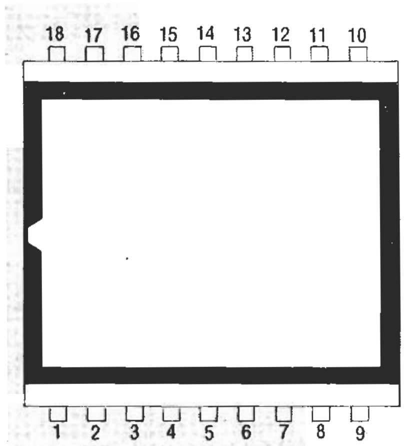

FIG. 5—THE BLACK BORDER around the display has a marking on one side. Using the marking as a reference, pin 1 is where you'd normally see it on any ordinary IC.

out such support, you risk breaking the wires.

A suitable pressure hose must be connected to port P2 of the sensor, and secured with a small metal clamp that has been designed to handle high pressures. Such clamps can be obtained from automotive supply outlets. It cannot be over-stressed that pressures greater than 10 psi are substantial, and the hose and clamp must be able to withstand such force.

If you want to use the project to measure tire pressure, you need a hose from a bicycle shop with a fitting at the end that depresses the valve stem during a pressure measurement. You might be able to take an old tire pressure gauge and modify it for use with our digital pressure gauge. As with the pressure-sensor connection, you will need to clamp the valve fitting to the hose.

You may wish to use a normally open pushbutton switch for your project. That will prevent accidentally leaving the power on and depleting the battery.

Be sure to use a connector clip for the battery to ease replacement when necessary. The battery should be securely mounted in the project's enclosure so that it does not rattle around and break anything.

When you have completed assembly, examine the circuit board very carefully for bad solder connections and inadvertent short circuits, especially between adjacent IC terminals. Bad solder joints often are dull, rough blobs of solder. Correct any problems that you find. Figure 6 shows both sides of the completed unit.

Checkout

To check out the project you will need a DC voltmeter, as well as a source of air pressure such as a portable air tank. Be sure tank pressure is not over 100 psi. For the preliminary checkout it is not necessary to know the precise pressure of the source, but it should be in the range near the maximum measurement capability of the project.

Before putting IC1 and IC2 in their sockets, set the calibration potentiometers to mid-position. Connect a 9-volt battery, and turn on power.

Measure the voltage across C2; you should obtain a reading between 4.8 and 5.2 volts DC. If you do not obtain the correct reading, do not proceed with the checkout until you troubleshoot the problem. Check IC3 for proper orientation. Check the terminal voltage of the battery to verify that it is delivering at least 7 volts. Disconnect the battery and measure the resistance across C2 to verify that you do not have a short circuit between the 5-volt bus and ground.

When you are satisfied that the 5-volt regulator is operating properly, disconnect the battery from the project and insert the IC's into their sockets. Be sure to follow the orientation as indicated in Fig. 4.

Reconnect the battery to the project and turn the power switch on. No pressure is to be applied to the sensor at this time. The display should indicate a two digit reading, and adjustment of R16 should allow you to set the reading to 00.

If you don't get any display, check that the LCD is properly mounted on the copper side of the board. Check IC2 to be sure that it is properly oriented in its socket. Check the 5-volt regulator to verify that power is being applied the circuit. If your meter is capable of measuring DC current, you can check the current draw from the battery to determine if it is approximately 4 milliamperes, which is the normal current draw of the project.

If you obtain a display but the illuminated segments of the digits are not entirely correct, the most likely cause is open or short circuits at the output connections of IC2 which drive the readout. Disconnect IC2 and the battery from the project and locate the fault using an ohmmeter.

Note that the display may, on occasion, indicate 01 instead of 00. This is not to be construed as a defect in the circuit; it merely means that your zero adjustment is not centered exactly.

When you are satisfied that the zero adjustment of the display is correct, you may apply full pressure to the P2 port of the sensor. When that is done, the readout will indicate some number. Adjust R6 for a display equal to the pressure of the source, if known.

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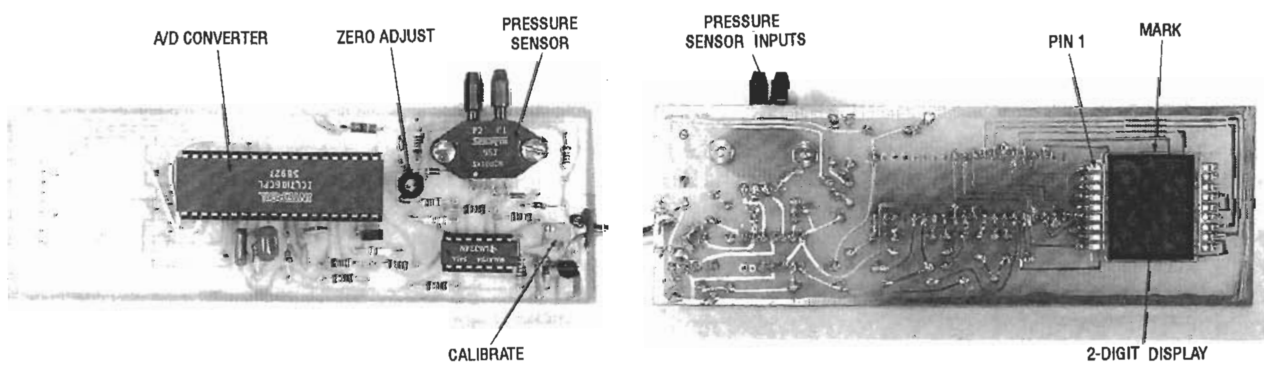

FIG. 6—HERE ARE BOTH SIDES of the completed unit. notice how the display goes on the foil side.

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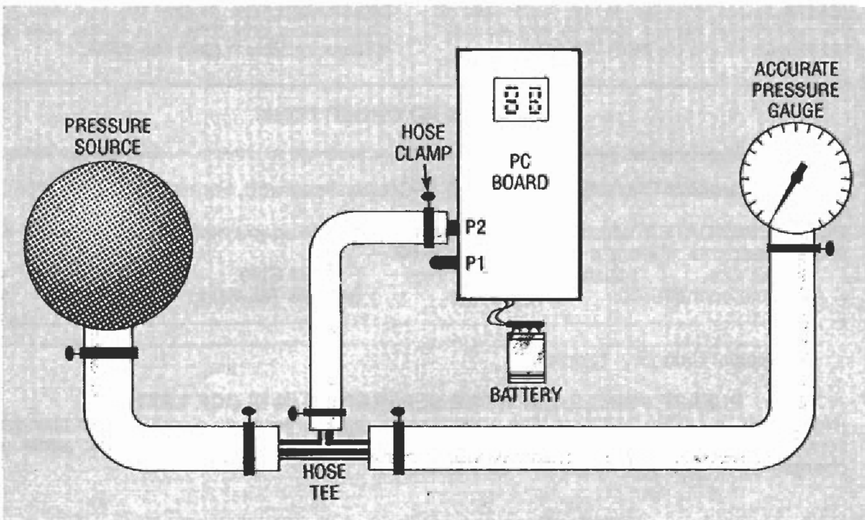

FIG. 7—TO CALIBRATE THE GAUGE, use this setup. Remember that all hose connections must be securely clamped.

Final calibration

The best way to calibrate your pressure gauge is to compare it to the reading of a known, accurate gauge. Additionally, if you plan to use the gauge to measure pressure which is normally less than full-scale capability, it would be prudent to calibrate it at this pressure level rather than at full scale. Use the setup in Fig. 7, remembering that all hose connections must be securely clamped. The setup allows the pressure source to be applied simultaneously to both gauges.

Adjust R6 so that the digital readout agrees with the reference gauge. After adjustment of R6, remove the pressure from the sensor and check the display, which should read zero. If there is some offset from zero, repeat the adjustment for R16 and R6.

Battery life should be as long as 1 or 2 years if the project is used intermittently. The display will change in appearance when the battery needs to be replaced, and it will disappear altogether when the battery is totally exhausted. **R-E**