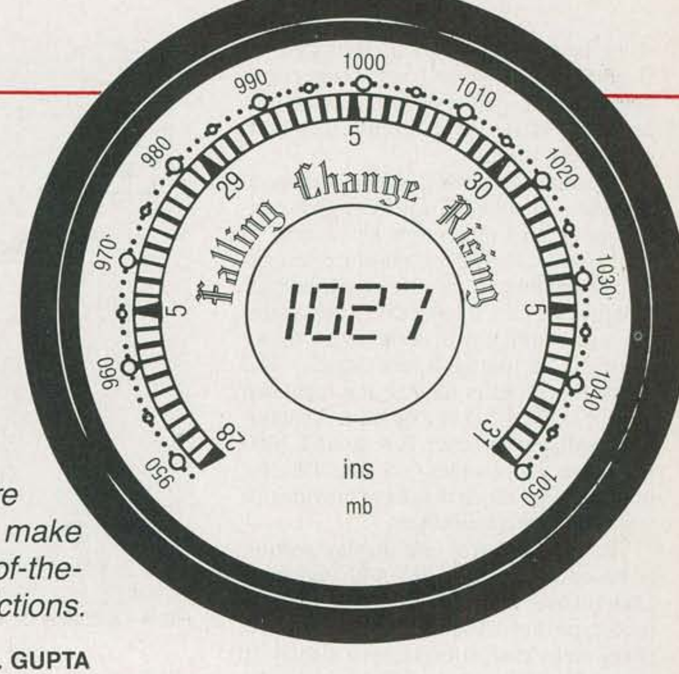
BUILD THIS

Solid State BAROMETER



Measuring and charting the atmospheric pressure has long been recognized as an effective way to make weather forecasts. Now you can build this state-of-the-art barometer and make your own weather predictions.

SUDHIR K. GUPTA

BEFORE WEATHER SATELLITES CAME INTO use, the barometer was perhaps the most useful instrument for providing information about future changes in the weather. Both mercury and aneroid barometers have long been used to measure the atmospheric pressure. But we're going to show you a new type of barometer—a barometer that uses a state-of-the-art solid-state pressure transducer and gives a digital readout of atmospheric pressure.

The barometer that we'll build can be thought of as being made up of four basic building blocks. As shown in Fig. 1, they include the pressure transducer, power supply, signal conditioner, and the measurement-and-display section. Let's look at each separately.

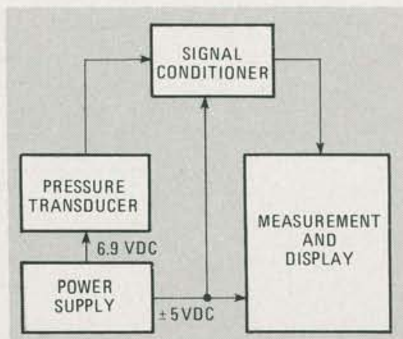


FIG. 1—THE SOLID-STATE BAROMETER can be thought of as being made up of four blocks of circuitry.

The pressure transducer

A transducer is a device which transforms one form of energy to a different form of energy. In this barometer, we'll be using a pressure transducer that converts barometric pressure into electrical signals. The transducer is made by SenSym (1255 Reamwood Ave, Sunnyvale, CA 94809) and is shown in Fig. 2. It is an absolute-pressure device. That is, it measures pressure relative to a vacuum. (Another pressure-transducer type is the *gage* type, which measures pressure relative to ambient pressure.)

FIG. 2—THE LX0503A pressure transducer is ideal for barometric applications.

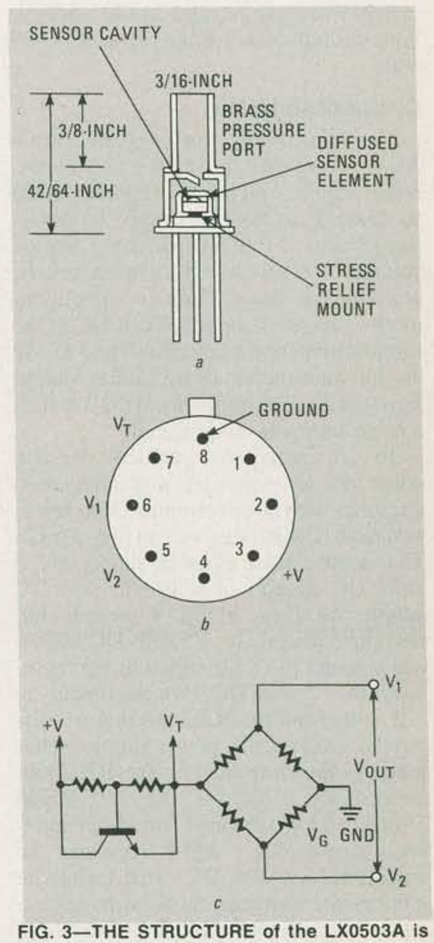


FIG. 3—THE STRUCTURE of the LX0503A is shown in *a* and its pinout is shown in *b*. The schematic of the device is shown in *c*. We will not use the V_T pin, which is normally used for temperature compensation.

The transducer's sensing circuitry is deposited on a silicon chip that has a cavity etched out to form a diaphragm. On the top of the diaphragm (the "exposed" side) is the pressure-sensing circuitry. The other side of the diaphragm is a vacuum. Figure 3 shows the structure of the device along with the transducer's pinout and its schematic.

Changes in ambient pressure affect the deflection of the sensing diaphragm. The resistance of the piezoresistive elements changes as the pressure changes, and thus the output voltage changes. The voltage on pin 6 (V_1) increases with an increase in pressure. The voltage on pin 5 (V_2) decreases (or goes negative) with increasing pressure.

The signal-conditioner section is necessary to provide zero and offset corrections for the transducer output. The signal from the transducer (about 40 millivolts) is amplified to about 1 volt. That corresponds to a display of 100 kilopascals (abbreviated kPa). We'll discuss that unit, and others, shortly.

We want the power-supply section to provide +5 volts DC for the signal-conditioning and measurement section as well as 6.9 volts DC for transducer excitation. Therefore we can use an AC adapter that provides 8 − 11 volts DC. Such adapters are readily available from many sources, including Radio Shack. The adapter's output is filtered and regulated by IC3, a 7805 5-volt regulator. A monolithic voltage converter, IC4 (an ICL7660 from Intersil) provides −5 volts DC. Finally, a Zener diode is used to provide 6.9 volts DC to the transducer.

The measurement-and-display section is based on a single-IC A/D converter from Intersil: their ICL7106. The author's prototype used Intersil's ICL7106 EV panel-meter evaluation kit for a display. It is capable of displaying 199.9 millivolts or 1.999 volts full-scale. In our application, the full-scale reading is set to 1.999 volts.

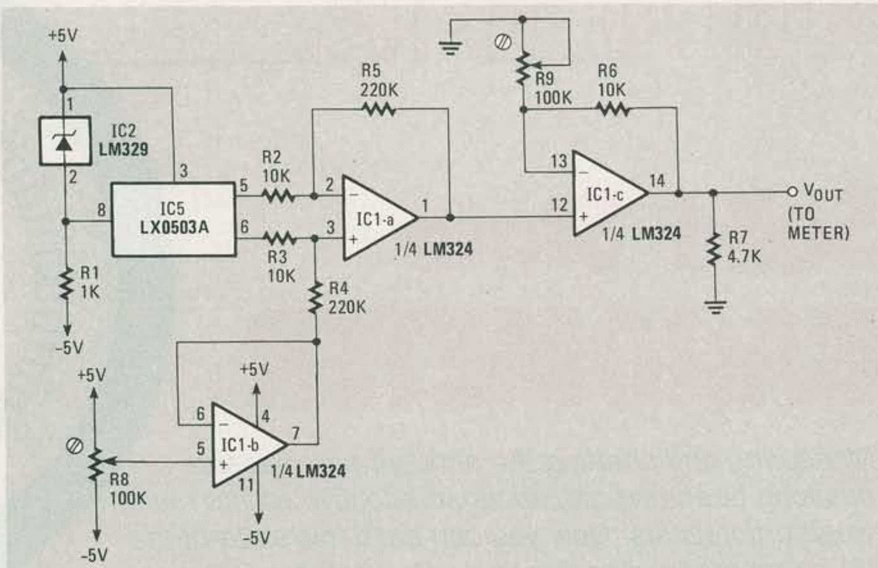


FIG. 4—A ZENER DIODE is used to regulate the transducer's input voltage to 6.9 volts.

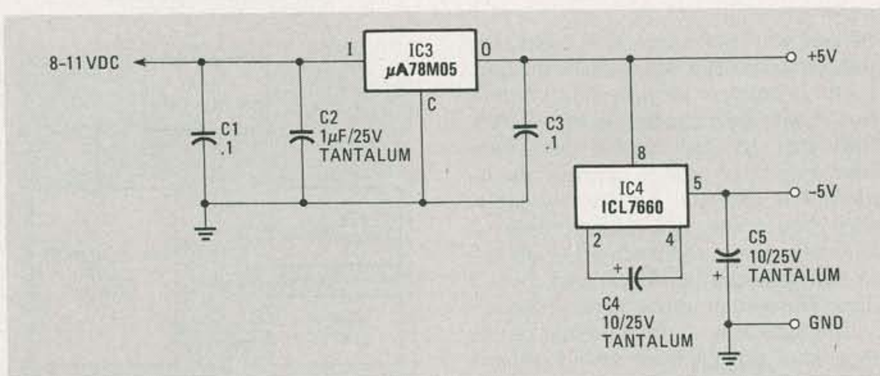


FIG. 5—THE POSITIVE 5-volt supply is easily converted to a bipolar supply by using the ICL7660 voltage converter.

Circuit description

Conventionally, the pressure transducer is powered by a 10 − 15-volt DC power supply, and a 6.9-volt Zener diode is shunted across the supply terminals (pins 3 and 8). That provides an excitation voltage of 6.9 volts DC. Unfortunately, when that is done, there is a common-mode voltage of about 1.8 volt DC at the signal-output terminals (pins 5 and 6). We do not want the small transducer output signal of 30 − 40 millivolts to ride on such a large common-mode signal.

To get around that problem, we can either use an expensive instrumentation amplifier with large common-mode rejection ratio (CMRR), or we can play a trick. That is, we can use a bipolar supply of ±5 volts DC instead of a 10 − 15 volt DC supply. As shown in Fig. 4, we can connect pin 3 directly to +5 volts DC and we can connect pin 8 through a dropping resistor to −5 volts DC. (We can obtain the −5 volts from the ICL7660 that we discussed earlier; the power-supply schematic is shown in Fig. 5. The ICL7660, incidentally, is listed in this year's Radio Shack catalog.) A precision Zener reference across pins 3 and 8 regulates the voltage to 6.9 volts DC. That technique reduces the common-mode voltage to a mere 100 millivolts. Now it is feasible to use a conventional op-amp (like the LM324) as a differential amplifier.

One quarter of that quad op-amp (IC1-a) is used as a differential amplifier. It amplifies the input signal by a factor of about 22. We use IC1-b, another section of the LM324 quad op-amp to introduce the offset that will be required to calibrate the barometer. The signal is further amplified by IC1-c to about 1 volt. That gives us a scaling factor of 10 millivolts per kilopascal.

Scaling the display

Barometric pressure is expressed in a variety of units, including pounds-per-square-inch (psi), bars, millibars, pascals, inches of mercury, atmospheres, torr, etc. Table 1 is a conversion chart to help you convert from one unit to another. To use that chart, look across the top for the unit you want to convert *from* then look down the side for the unit you want to convert *to*. Multiply the units you have by the conversion factor indicated by the table, and your answer will be in the units you want.

Because we are using a 3½-digit display, the maximum resolution is obtained when the pressure is displayed in kilopascals (millibar/10) or millibars. A barometric scale of 95 kilopascal (28 inches of mercury) to 105 kilopascal (31 inches of mercury) more than covers the useful barometric pressure range. You may think that using the unit of pascal (a unit that you've probably never heard of) is not a good idea. However, that's not necessarily so. The pascal is the standard unit for pressure or stress in the International System of Units (SI). ANSI (the *A*merican *N*ational *S*tandards *I*nstitute) has adopted the pascal as its standard pressure unit. It is equal to one newton per square meter (N/m^2). Weather reports often give barometric readings in millibars as well as in inches of mercury just as they give temperature readings in both Fahrenheit and Celsius. Conversion from kilopascals to millibars is simply a matter of multiplying by a factor of 10.

Construction

The project is built in two parts; the transducer/power-supply board, and the display board. A suggested layout for a printed-circuit transducer board is shown in Fig. 6. A parts-placement diagram is shown in Fig. 7. However, it's not really necessary to use a PC board. It is just as well to use perforated construction board and point-to-point wiring. We do, however, recommend that you use IC sockets for all IC's.

As we mentioned before, the display

PARTS LIST

All resitors 1/4 watt, 5% unless otherwise noted
R1—1000 ohms
R2,R3,R6—10,000 ohms
R4,R5—220,000 ohms
R7—4700 ohms
R8,R9—100,000 ohms, multiturn trimmer potentiometer

Capacitors
C1,C3—0.1 µF, ceramic disc.
C2—1 µF, 25 volts, tantalum
C4,C5—10 µF, 25 volts, tantalum

Semiconductors
IC1—LM324 quad op-amp.
IC2—LM329 6.9-volt precision voltage reference
IC3—µA78M05 5-volt regulator (Fairchild) or similar
IC4—ICL7660 voltage converter (Intersil)
IC5—LX0503A pressure transducer (SenSym)

Miscellaneous: IC sockets PC or perforated construction board, Intersil evaluation board ICL 7106 EV kit or any meter with a 2-volt range, AC adapter, 8 – 11 volts DC

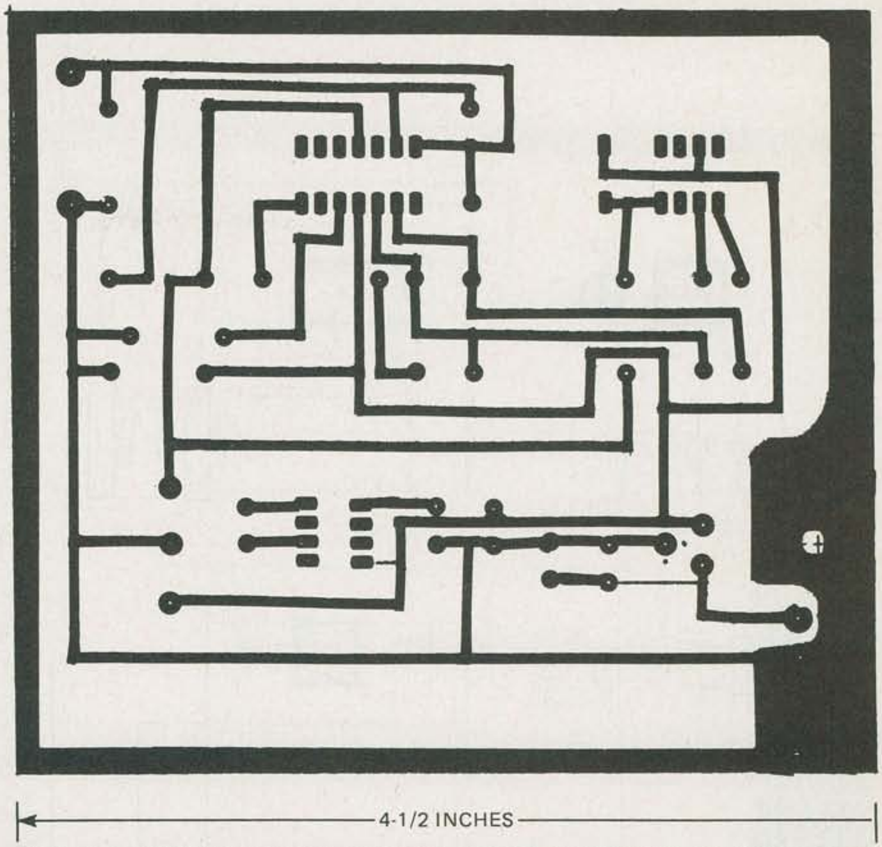


FIG. 6—FOIL PATTERN for the barometer is shown full-size above. The layout is not critical, and point-to-point wiring can be used—but be sure to use a socket for the transducer.

section of the author's prototype is based upon an evaluation board from Intersil—their ICL 7106 EV kit. That was used as a dedicated display. If you want to avoid the expense of that kit (about $35), you can use an ordinary digital voltmeter or even an analog meter with a full-scale range of 2 volts DC.

If you do use the Intersil evaluation board, follow the instructions that are supplied with it to set the full-scale display to 2.000 volts. Keep in mind that there is no need to use a battery to power the ICL7106 EV—the transducer/power-supply board generates ±5 volts that can be used for powering the display board. Connect +5 volts to the V+ input on the evaluation board and −5 volts to the V− input. We should note here that the current drain from the +5-volt supply should be limited to a few milliamps. Otherwise, degradation of −5-volt supply will result. You should, however, have no problem powering the display.

As we mentioned before, the use of IC sockets is strongly recommended. The pressure transducer can be installed in an eight-pin socket. But don't install it—or any IC's—yet. First install all resistors, capacitors, potentiometers, and IC sockets. Check for solder bridges and clean all of the flux off the board. If you used point-to-point wiring, be especially careful of cold-solder joints. When you have double-checked your work, you can install all the IC's except the transducer.

Apply 8 − 11 volts DC to the transducer/power-supply board and check for ±5 volts DC at the output indicated in the parts-placement diagram of Fig. 7. Also check for 6.9 volts DC at the transducer socket. Bend the transducer pins, recheck the orientation, turn off the power, and install it in the socket. If you wish, you may install the transducer remotely and connect it to the transducer board through a four-wire shielded cable.

You can mount the unit in just about any cabinet, but you should keep the transducer outside the cabinet, or make

TABLE 1—CONVERSION FACTORS

	PSI	PASCAL	kPa	MILLIBAR	in.Hg	mm Hg	ATM	TORR
PSI	1	1.4504×10^{-4}	0.1450	1.4504×10^{-2}	0.49118	1.9337×10^{-2}	14.696	1.9337×10^{-2}
PASCAL	6.8946×10^{3}	1	1000	.100	3.3865×10^{3}	133.32	1.0132×10^{5}	133.32
kPa	6.8946	1×10^{3}	1	10	3.3865	0.13332	1.0132×10^{2}	0.13332
MILLIBAR	68.946	1×10^{-2}	10	1	33.865	1.3332	1.0132×10^{3}	1.3332
in.Hg	2.0359	2.9529×10^{-4}	0.2953	2.9529×10^{-2}	1	3.9368×10^{-2}	29.920	3.9368×10^{-2}
mm Hg	51.714	7.5006×10^{-3}	7.5006	0.75006	25.401	1	760.00	1
ATM	6.8045×10^{-2}	9.8692×10^{-6}	9.8692×10^{-3}	9.8692×10^{-4}	3.3422×10^{-2}	1.3158×10^{-3}	1	1.3158×10^{-3}
TORR	51.714	7.5006×10^{-3}	7.5006	0.75006	24.401	1	760	1

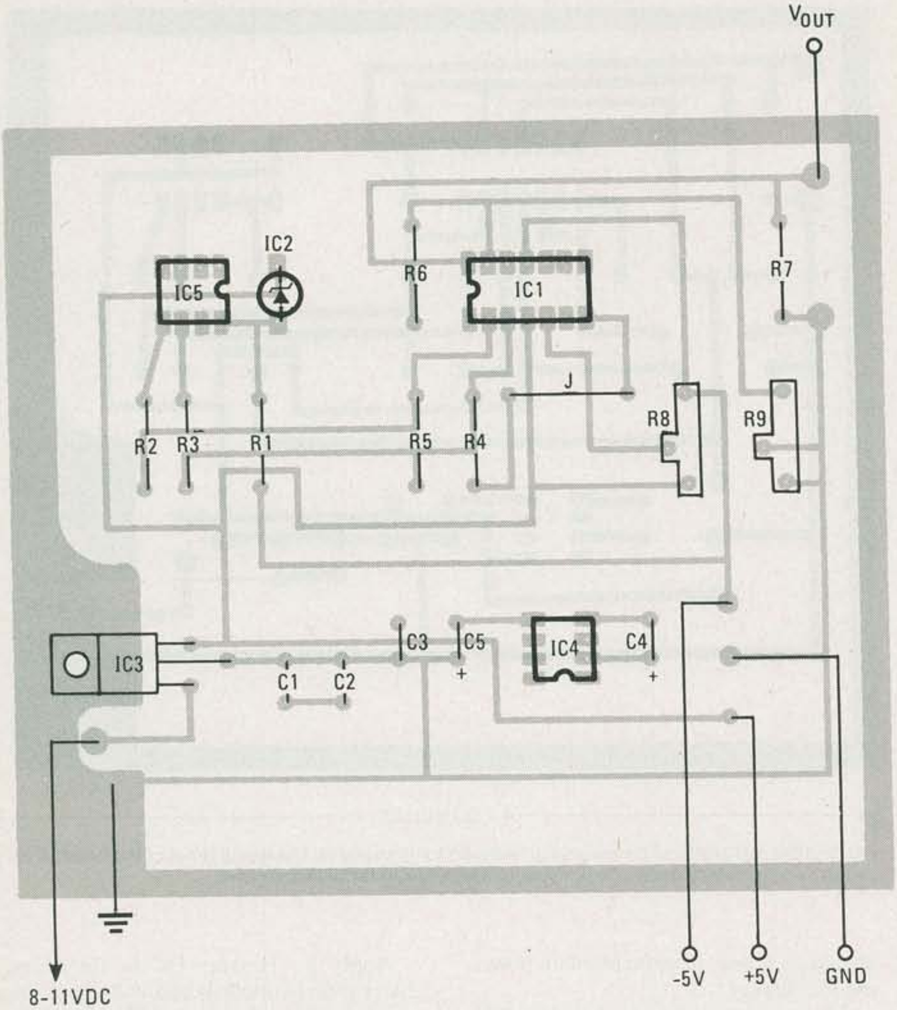


FIG. 7—THE PARTS-PLACEMENT diagram for the foil pattern shown in Fig. 6.

How to use your barometer to predict the weather.

Although some of you will build this barometer simply because you enjoy building electronic projects, many more will actually want to use it to predict the weather. So that you can do that, here's a crash course on what barometric-pressure changes usually mean.

High-pressure cells generally bring fair weather. In the northern hemisphere, the air circulation is clockwise and winds are usually light. The temperature can be warm or cold, but will remain constant for relatively long periods of time.

Low-pressure cells generally bring cloudy weather, with rain or snow. In the northern hemisphere, the air circulation is counter clockwise, and winds are usually strong. Tropical lows are warm, but other lows are cold, or change to cold.

A steady barometer usually indicates unchanging weather for one or two days.

Any rapid fall usually indicates that rain or unsettled weather is on it's way. (A rapid rise or fall in barometric pressure is generally considered to be 0.05 to 0.09 inches (0.16–0.30 kPa) over 3 hours.) The lower the pressure before the rapid change, the sooner the rain will approach. For example, if the pressure is 29.8 inches (100.9 kPa) and falling rapidly, a severe storm wll pass within a few hours. A rapid rise signals that the storm is ending, and clear and colder weather is on its way.

A suggestion to make the barometer more useful is to inteface it with a computer (such as the control computer that concludes with Part 3 in this month's issue). Then you could automatically chart the changes in pressure and record the highs and lows that occur. We'd like to hear about your successes (and failures).

sure that your cabinet is not-tight fitting. The best place to mount the unit is in an old aneroid barometer. Then you not only have an interesting conversation piece, but you can also use the old barometer's pressure scale as a conversion scale!

Transducer calibration

A typical transducer requires a two-point calibration to correct for offset and gain over the entire operating range. In the case of this barometer, the actual operating range is limited to $\pm 5\%$ of the top of the scale (95 – 105 kPa). Therefore, a single-point calibration performed at the middle of the range (100 kPa) may be acceptable. So that we can please everyone, we'll discuss both methods.

Before doing any calibration, switch the unit on and let it warm up for about an hour. Set potentiometer R8 to its middle position. Obtain the barometric pressure (using the local weather forcast or a barometer that you know to be accurate). Using Table 1, convert the barometer's reading to kilopascals or millibars. (The closer the reading is to 100 kilopascals, the better.) All that is to be done for single-point calibration is to adjust potentiometer R9 until the meter displays the barometric pressure.

If you can, it is best to use two-point calibration. That's because a typical transducer requires an offset correction as well as slope correction.

As a first step, perform the single-point calibration that we just discussed and leave the unit operating over a period of a few days. Try to obtain two readings: one at the low end of the scale (around 98 kPa) and the other at the high end of the scale (around 102 – 104 kPa). On both those days, note the actual barometric pressure as well as the corresponding meter readings. We'll use a little mathematics to arrive at the calibration values. Following are some sample calibrations.

Let the old barometric pressure, P_1 = 98 kPa and the corresponding meter reading, M_1 = 972 mV.

Let the present barometric pressure, P_2 = 102.5 kPa and the present meter reading, M_2 = 1030 mV.

The change in barometric pressure is $P_2 - P_1 = 102.5 - 98$ kPa = 4.5 kPa

The change in the meter reading is, of course, $M_2 - M_1 = 1030 - 972$ mV = 58 mV.

The generated slope is $\Delta M/\Delta P$ or $(M_2 - M_1)/(P_2 - P_1) = 58/4.5$ mV/kPa or 12.88 mV/kPa.

The slope that we require is 10 mv/kPa. Therefore, the change in the gain required is 10/12.88 = 0.776.

What we are going to do is to reduce the gain generated by the op-amp by a factor of 0.776. An example of how to do that follows.

Measure the voltage at the output of IC1-a. We'll call it V_i. Presume that V_i = 755 millivolts. Then the gain of IC1-c = M_2/V_i = 1030/755. The required gain, however, is 1030/755 × 0.776 = 1.059. So the required output at IC1-c is 1.059 × V_i = 1.059 × 755 = 799 mV.

Adjust the gain potentiometer, R9, until the meter reads 799. Now adjust the offset potentiometer, R8 until the meter reads 1025 millivolts, corresponding to the present barometric pressure. That completes the calibration. Now you can substitute your own values in the calculations and perform the calibration on your digital barometer. **R-E**