An Infrared Thermometer Accessory

Lets any DMM measure temperatures fast—without requiring physical contact!

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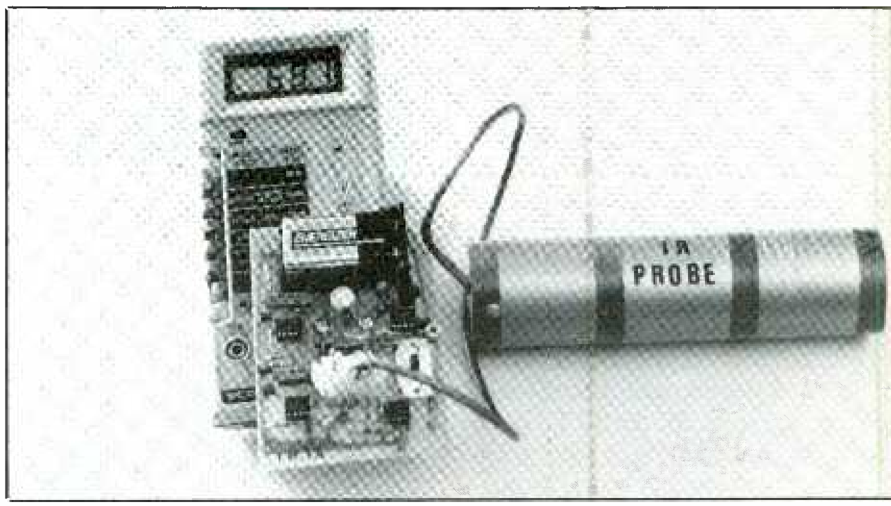


An infrared thermometer can do seemingly amazing things —measure the temperature of a cloud layer from the ground and, with a special rig, the surface temperature of the moon and Mars. More mundane uses include temperature measurement of moving objects and non-contact measurements of hazardous objects like high-voltage and radioactive equipment. The response of an IR thermometer is also fast!

An infrared thermometer is also useful in applications in which contact thermometers are traditionally used. For example, it can be used for making quick checks of building insulation and weather-stripping for estimating heating/cooling loss. Too, a non-contact infrared thermometer that accurately measures temperature in the 85° to 115°F range has obvious utility in medicine. Good as it is, though, the infrared thermometer cannot fully replace the mercury thermometer, whose advantages include greater accuracy and lower cost. But for specialized non-contact measurements, the infrared thermometer cannot be beat.

The IRTA Thermometer accessory plugs into the inputs of a handheld DVM or DMM set to dc volts; so no enclosure is required. Except for the probe assembly, all components, including switches and battery, mount on a printed-circuit board.

About the Circuit

The complete schematic diagram of the IRTA Accessory is shown in Fig. 1. The output of thermopile detector *IRS1* is connected to the noninverting (+) input of *IC1*. With a 1,000-ohm value for *R1* and 150,000-ohm value for *R2*, *IC1* amplifies the output of *IRS1* by 151 (1 + 150). This amplified output is connected to *R3*, which forms one leg of the summing amplifier. The other input to this summing amplifier comes from *IC2*, which provides the temperature-compensation voltage for the circuit.

Actual design of the temperature-compensation circuit is a bit involved mathematically and will not be presented here. The goal here is to have the thermopile detector respond only to temperature differences. Therefore, either the reference junction must be maintained at a constant temperature or the reference junction temperature must be measured and used to compensate the circuit. This instrument uses automatic temperature compensation.

Temperature measurement of the reference junction of the sensor is accomplished with LM335 temperature transducer *IC10*. This transducer attaches with a thermally-conductive cement to the TO-5 header leads of *IRS1*. According to Dexter Application Brief-2, the leads of the detector is the best place to monitor the temperature of the reference junction.

The value of *R10* is chosen to be as large as practical to minimize self-heating of *IC5*. The temperature-compensating circuit is made up of *IC2*, *R6*, *R8*, *R9* and *IC5*.

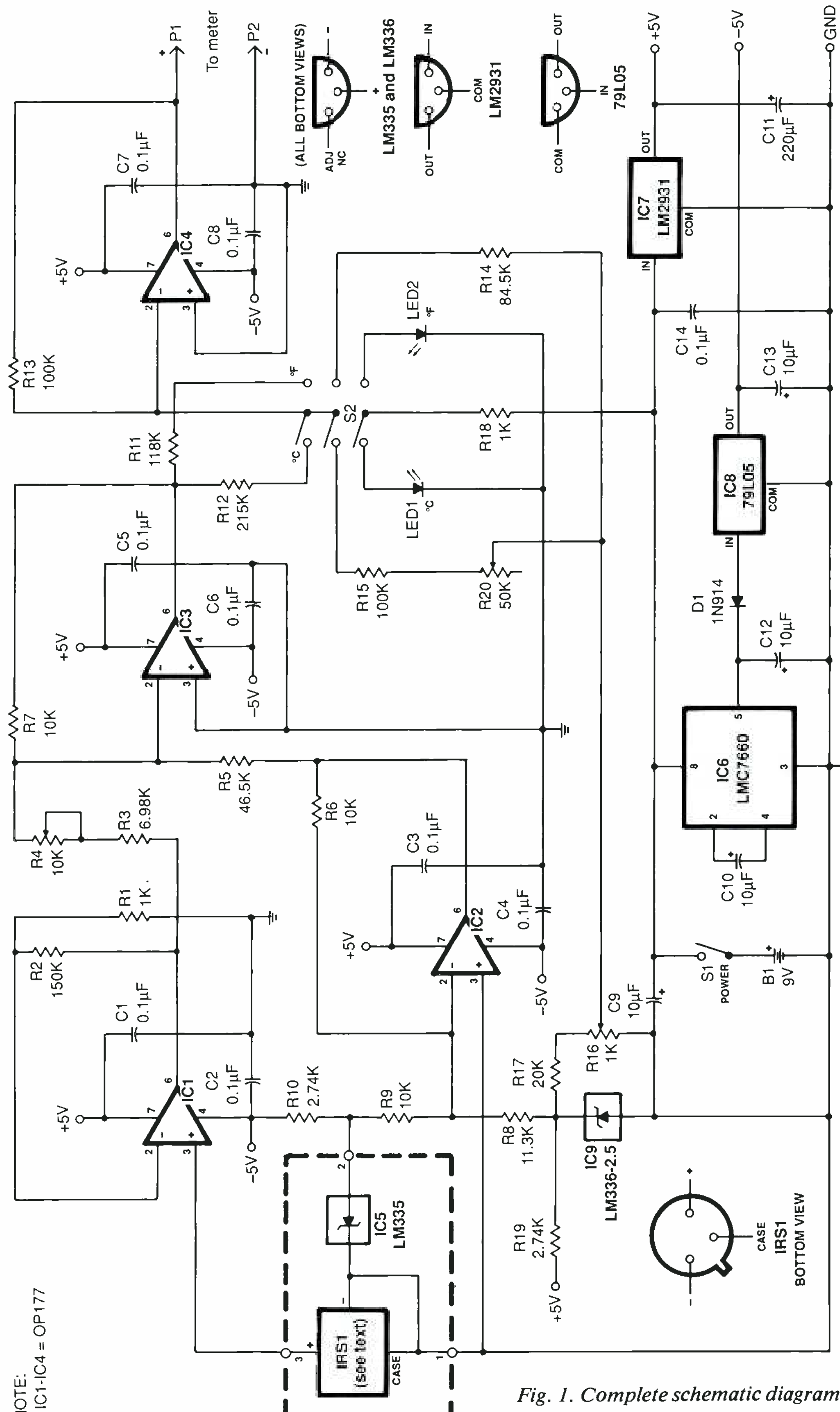


Fig. 1. Complete schematic diagram of Infrared Thermometer Accessory.

PARTS LIST

Semiconductors
D1—1N914 or similar silicon diode
IC1 thru IC4—OP-177 precision operational amplifier (see text)
IC5—LM335Z temperature transducer
IC6—LMC7660 voltage converter
IC7—LM2931 fixed +5-volt regulator
IC8—79L05 low-power fixed −5-volt regulator
IC9—LM336-2.5 2.5-volt precision voltage reference
LED1—Low-power, high-efficiency red light-emitting diode
LED2—Low-power, high-efficiency green or yellow light-emitting diode
Capacitors
C1 thru C8,C14—0.1-μF, 50-volt ceramic monolithic
C9,C10,C12,C13—10-μF, 25-volt electrolytic
C11—220-μF, 25-volt electrolytic
Resistors (¼-watt, 1% tolerance)
R1—1,000 ohms
R2—150,000 ohms
R3—6,980 ohms
R5—46,400 ohms
R6,R7,R9—10,000 ohms
R8—11,300 ohms
R10,R19—2,740 ohms
R11—118,000 ohms
R12—215,000 ohms
R13,R15—100,000 ohms
R14—84,500 ohms
R17—20,000 ohms
R18—1,000 ohms (5% tolerance, ¼-watt)
R4—10,000-ohm, 15-turn pc-mount trimmer potentiometer
R16—1,000-ohm, 15-turn pc-mount trimmer potentiometer
R20—50-ohm, pc-mount trimmer potentiometer

Miscellaneous
B1—9-volt alkaline battery
P1,P2—Banana plug
IRS1—1M thermopile detector with argon gas and 6.5-to-15.5-micron LWP filter (specify argon gas and LWP filter; $50 + $2 P&H from Dexter Research Center, Inc., 7300 Huron River Dr., Dexter, MI 48103; 313-426-3291)
S1—Spst pc-mount slide switch (Digi-Key Cat. No. SW100-ND)
S2—3pdt miniature pc-mount slide switch (Digi-Key Cat. No. SW121-ND)
Main printed-circuit board or perforated board with holes on 0.1" centers and suitable Wire Wrap or soldering hardware and enclosure (see text); detector pc board; sockets for all DIP ICs; 3-contact plug/socket pair (Digi-Key Cat. No. A1493/A1436; optional —see text); 9-volt battery snap connector and holder; three-conductor cable with red-, green- and black-insulated conductors; 1½"L × ½"ID yellow CPVC pipe; 1⅝"L × 1½"ID white PVC pipe; 5"L × 1½"ID white PVC pipe; epoxy cement; cable tie; insulation; duct tape; aluminum paint; solder; etc.

Note: The following items are available from Magicland, 4380 S. Gordon, Fremont, MI 49412: Complete kit of parts, including all ICs, main and probe pc boards and all other components (pipes, cables, etc.) but *not* including IRS1, battery and optional items, Kit. No. IRTA-MAG1, $49.50; OP-177 op amps, each $2.50.
Digi-Key is located at 701 Brooks Ave. S., P.O. Box 677, Thief River Falls, MN 56701-0677; tel. 1-800-344-4539.

The output of the temperature-compensating circuit is applied via *R5* to summing amplifier *IC3*, which sums this voltage with the amplified thermopile voltage. The output of *IC3* goes to a degree circuit made up of *S2*, *IC4* and related components. The primary purpose of this degree circuit is to modify the voltage to make it (in millivolts) correspond to either Celsius or Fahrenheit degrees, depending upon the setting of *S2*.

With *S2* set to °F, 50 millivolts yields a meter reading of 50 °F. Similarly, in the °C position, 50 millivolts yields a reading of 50 °C. Switch *S2* also controls two light-emitting diodes: red °F *LED2* and green °C *LED1*.

Calibration for this circuit is accomplished with *R16* and *R4*. Potentiometer *R4* is used to adjust the gain of the amplified thermopile voltage and *R16* provides a small offset voltage to the degree calibration circuit. Potentiometer *R20* is used to adjust the Celsius circuit.

Since the IRTA Thermometer accessory uses a single 9-volt battery (*B1*) and the circuitry requires both +5 and −5 volts for proper operation, some type of voltage conversion is required. This is accomplished with LMC7660 voltage converter *IC6*, which converts the +9 volts from *B1* to the −9 volts required by the summing amplifiers.

The −9 volts that exits at pin 5 of *IC6* is unregulated. It is passed through *IC8*, which outputs a tightly regulated −5 volts. The +9-volt source from *B1* also goes to *IC7*, which outputs a tightly regulated +5 volts. Thus, all voltage requirements of the circuitry are satisfied by the relatively simple *IC6/IC7/IC8* power supply arrangement.

Bear in mind that the values of several resistors used in this accessory depend on the geometry and material of the thermopile probe. For instance, the value of *R2* depends upon the internal diameter and length of the pipe in the probe assembly. So keep in mind that the values given in Fig. 1 and specified in the Parts List were selected for the prototype probe described later.

Ultra-precision OP-177 devices are recommended for all operational (summing) amplifiers. Specifications of the new OP-177 are significantly better than those for the famed OP-07—at about the same price. For optimum operation, *IC1* requires the tightest possible specifications, which means that an OP-177 or its equal should be used here. For *IC2*, *IC3* and *IC4*, the specifications are not as critical; so you can use less-expensive op amps—even a 741—to economize.

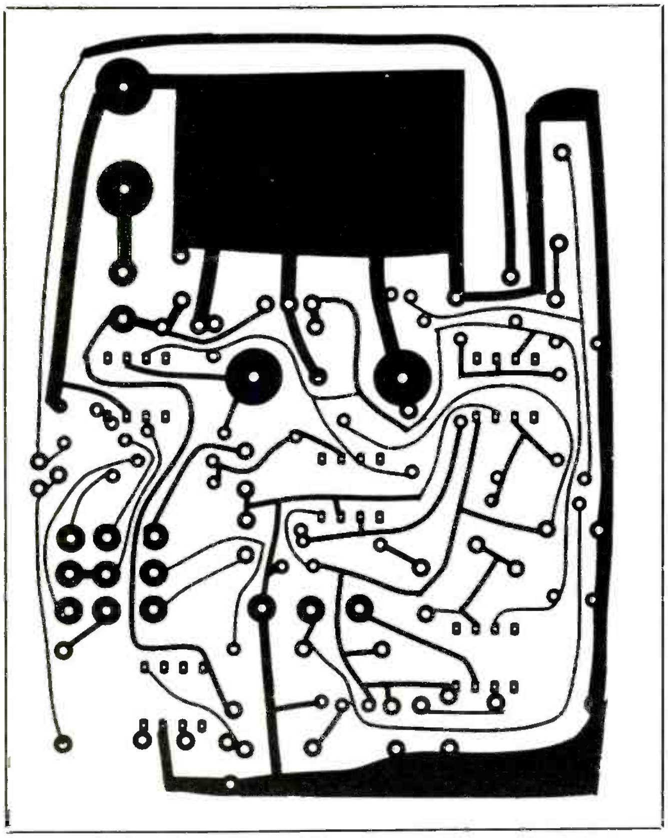
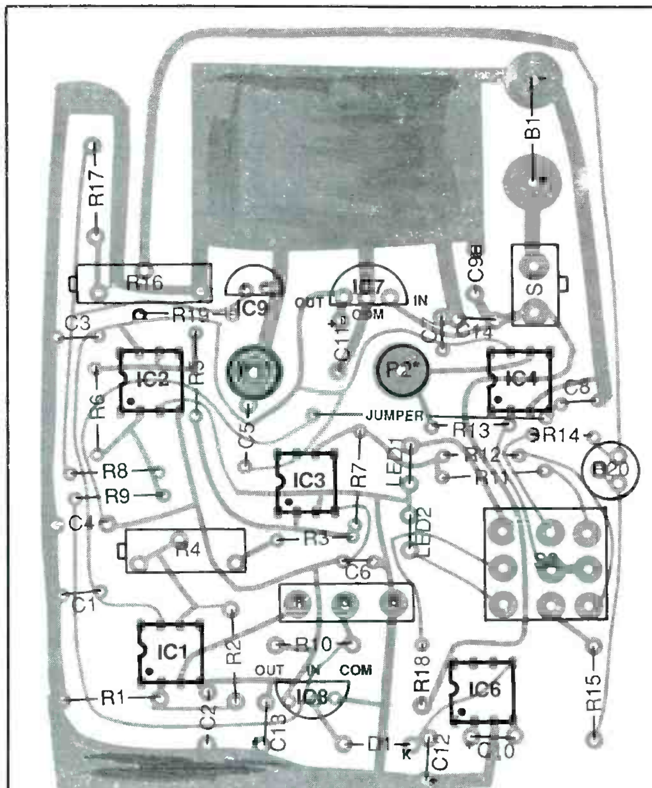


Fig. 2. Actual-size etching-and-drilling guide for main printed-circuit board.



NOTE:
*P1 and P2 mount on trace side of board.

Fig. 3. Wiring guide for main pc board.

Construction

If you prefer not to fabricate a pc board, you can assemble the circuitry on perforated board that has holes on 0.1-inch centers, using suitable Wire Wrap or soldering hardware. If you go this route, make the connections to the meter via short cables terminated in banana plugs and house the assembly in a small enclosure.)

Fabricate the pc board using the actual-size etching-and-drilling guide shown in Fig. 2. If you do use this guide, be sure to use the recommended battery holder and switches. Begin populating the board by installing and soldering into place sockets in all DIP IC locations. Do not plug the ICs into their respective sockets until after you have conducted initial voltage checks and are satisfied that the circuit is properly wired. Next, mount the banana plugs in their respective locations on the copper-trace side of the board. After they are physically mounted, spot solder the banana plugs to the copper pads surrounding them to assure good electrical connections.

Now install and solder into place the resistors, trimmer controls, capacitors, diode and LEDs in their respective locations. Make sure the electrolytic capacitors, diode and LEDs are properly oriented before soldering their leads into place.

Continue populating the board by installing and soldering into place *IC7*, *IC8* and *IC9*, making sure you follow the basing diagrams given in Fig. 1. Trim the leads of a 9-volt battery snap connector to a convenient length and strip ¼ inch of insulation from each. Tightly twist together the exposed fine wires and sparingly tin them with solder. Plug the black-insulated lead into the hole labeled B1– and solder it into place. Similarly, plug the red-insulated lead into the hole labeled B1+ and solder it into place. Mount a 9-volt battery clip holder in the space reserved for it at the top of the circuit-board assembly with 4-40 machine hardware. Finally, mount the switches in their respective locations. If you wish, you can mount a cable connector in the area just above *R10* (see Parts List).

Carefully examine the circuit-board assembly to make certain that all components are installed in the proper locations and that those that require polarization and special basing are properly installed. Turn over the circuit-board assembly and carefully check your soldering. Solder any connections you may have missed, reflow the solder on any suspicious connections and remove solder bridges, especially around the closely spaced IC socket pads, with a va-

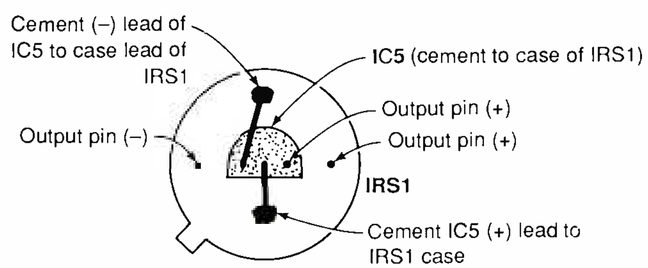


*Fig. 4. Epoxy cement top of LM335 (*IC5*) to bottom of thermopile detector (*IRS1*) case and connect together leads as illustrated.*

cuum-type desoldering tool or desoldering braid. Then temporarily set aside the circuit-board assembly.

Though the design of the basic circuitry is fairly straightforward, if you use an ultra-precision op amp like the OP-177 for *IC1*, probe design is simple but not trivial. As shown in Fig. 4, begin fabrication of the probe by cementing, with fast-setting epoxy cement, the top of the case of *IC5* to the bottom of the case of *IRS1*. Position the two devices as shown.

When the cement has fully set, loosely twist together the positive (+) lead of *IC5* and the case lead of *IRS1* and solder the connection. This assures that *IC5* measures the reference-junction temperature of *IRS1*.

You should use a printed-circuit board on which to mount the *IRS1/IC5* combination and wire to it the cable that connects the probe assembly to the main circuit. Fabricate this board with the aid of the actual-size etching-and-drilling guide shown in Fig. 5(A). Once the board is ready, mount the *IRS1/IC5* assembly on it, as shown in Fig. 5(B).

Now remove 1 inch of outer plastic jacket from both ends of a 24- to 36-inch length of three conductor cable, preferably with insulation color coded red, green and black. Twist together the exposed fine wires in all conductors at both ends of the cable and sparingly tin with solder. Plug the conductors at one end into the holes specified in Fig. 5(B) and solder them into place. Note that the cable conductors plug into the *copper-trace* side of the board.

The internal structure of the probe assembly consists of a 1½-inch length of a ½-inch inner-diameter CPVC plastic pipe and the small pc board used to mount the detector/transducer assembly, as shown in Fig. 6. Common CPVC plastic water pipe is a good choice for the housing of the probe assembly. The ideal material is a tube that absorbs infrared energy in the 6.5-to-15.5-micron wavelength region but does not emit infrared in this wavelength band. CPVC may have at least a slight tendency to this ideal characteristic.

The excellent directional characteristics of the probe assembly indicates that CPVC absorbs most infrared energy in the 6.5-to-15.5-micron region. The main circuit compensates somewhat for the potential error caused by the IR emissions from the tube striking the thermopile detector. The primary error here arises if the tube is at a significantly greater or lesser temperature than the transducer. This can occur if one holds onto the sensing end of the probe assembly or if the probe is used in an environment where the temperature is rapidly changing.

In addition to being the electrical heart of the probe, the ½-inch inner-

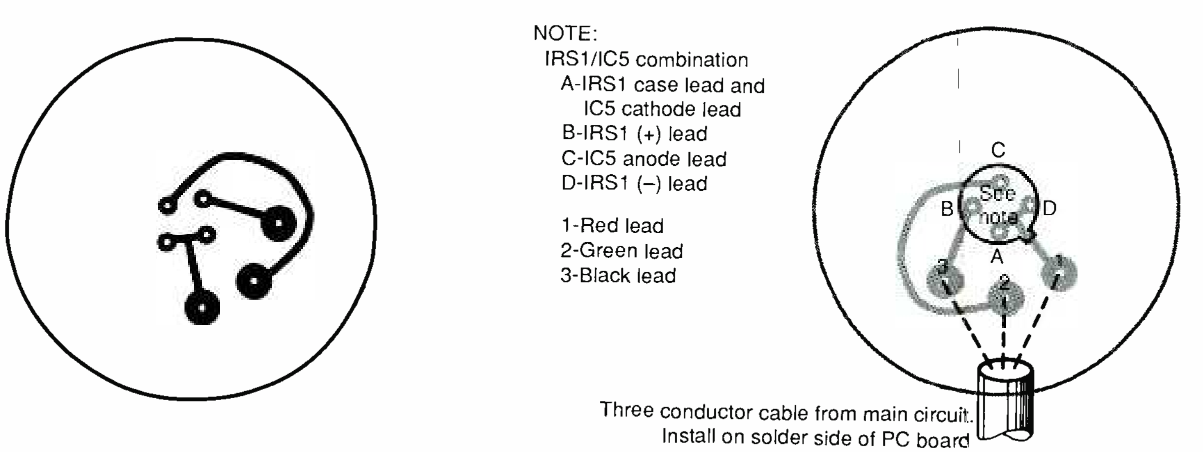


Fig. 5. Actual-size etching-and-drilling guide (A) for probe pc board and wiring guide (B) for same.

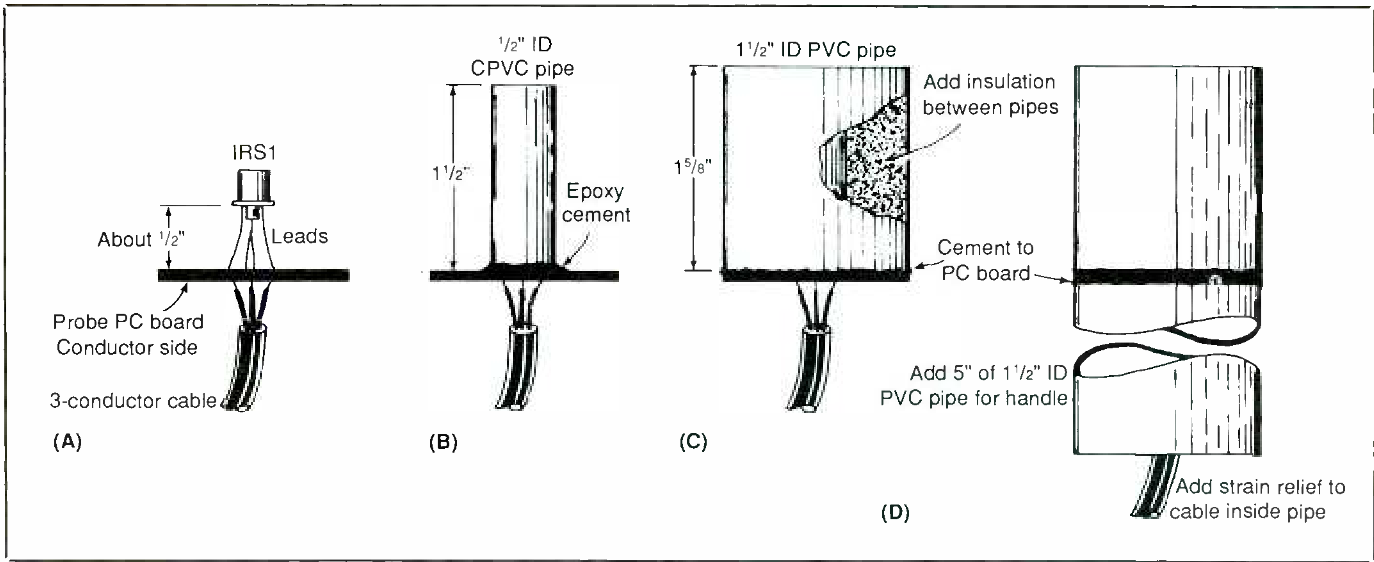


Fig. 6. Fabrication details for probe-assembly housing.

diameter main detector tube and accessory 1½-inch inner-diameter pipe cement to this pc board. Use a good-quality epoxy cement to secure the tube and pipes to the board. While not essential, you should place an insulating material between the detector tube and outside pipe.

As shown in Fig. 6(D), cement a 5-inch length of 1½-inch inner-diameter PVC pipe to the copper-trace side of the circuit-board assembly to use as a handle for the probe. Pass the cable out the open end of the pipe. Attach a strain relief to this cable inside the pipe. This can be a plastic cable tie secured in place to the wall of the pipe with hardware.

Terminate the free end of the cable in a connector compatible with the one you used on the main circuit-board assembly. Wrap the outside of the 1½-inch pipe with gray duct tape or coat the pipe with a good aluminum paint, such as Dow's XP-310.

Checkout & Calibration

Connect the common lead of a dc voltmeter or multimeter set to the dc-volts function to a convenient circuit-ground point. Snap a fresh 9-volt alkaline battery into its holder and set *S1* to "on." Touch the "hot" probe of the meter to the OUT pins of *IC7* and *IC8* in turn. You should obtain readings of +5 and −5 volts, respectively. If not, touch the "hot" probe to pin 8 of *IC6* and note if you obtain a reading of +9 volts.

Assuming the outputs of *IC7* and *IC8* are correct, touch the "hot" probe of the meter to pin 7 of the *IC1*, *IC2* and *IC3* sockets. In all three cases, you should obtain a reading of +5 volts. You should also obtain a reading of −5 volts at pin 4 of all three sockets. If you fail to obtain the proper reading at any point, power down the circuit and rectify the problem before proceeding.

Once you obtain the proper readings at all points mentioned, power down the circuit and plug the DIP ICs into their respective sockets. Make sure each is properly oriented and that no pins overhang the sockets or fold under between ICs and sockets.

On power-up, one of the LEDs should light, the specific one that does depending upon the position to which *S2* is set. Set your meter to its 200-millivolt full-scale range. Connect the common lead of the meter to circuit ground and the "hot" probe to the wiper contact of *R16* and adjust this trimmer control for a meter reading of 65 millivolts. This done, turn off the adapter and set *R4* and *R20* to about center of rotation.

Plug the adapter into the banana jacks on your meter and set the meter to its 200-millivolt full-scale range. Plug the cable from the probe assembly into its connector on the main circuit-board assembly, and switch on project and meter. Setting *S2* to °F should cause the red °F LED to light.

For preliminary calibration, use a thermometer to determine ambient room temperature. Assuming the room is at 72° F, point the probe at an inside wall (for optimum accuracy, tape the sensing area of a good-quality contact thermometer to the wall). Adjust *R16* so that 72 millivolts is displayed by the meter. For many purposes, this is the only calibration required.

Now close your fist for a minute and then point the tip of the probe at your opened hand, positioning it within an inch of but not touching your skin. The meter should indicate a temperature between 89° and 96° F, with 93° F being typical. If the temperature is outside this range, additional calibration is warranted.

(Continued on page 77)