Build The Intelligent Thermometer *Part 2*

A microprocessor and a programmed EPROM are used in this sophisticated circuit to measure and analyze changes in temperatures

By Tom Fox

LAST month, we described the circuit of the Intelligent Thermometer and how it works. Here is a description of the program and instructions on construction.

EPROM Program Description. Figure 5 shows a simplified flow chart for the program.

The CPU must receive 18 identical temperature readings in a row before it can continue its program. This feature provides digital filtering, makes for a steady display, and eliminates faulty readings.

Every four minutes an internal clock causes the CPU to stop what it's doing, find the current temperature, and then proceed to the MEAN routine. Although the procedure appears simple in the flow chart in Fig. 5, it takes many instructions to calculate the different mean-temperatures and degree-days. For instance, first the hourly mean is calculated. This is done by using temperature readings taken every four minutes over a one-hour period. These temperatures are added together and divided by 15. Next, the daily mean is found by adding up 24 consecutive hourly means and dividing by 24. Finally, the mean is found by adding up the daily means and dividing by the days since the mean was last cleared.

A complete EPROM listing can be obtained free of charge by including a self-addressed stamped envelope and requesting it from the address in the Parts List.

Construction. The project should be constructed on a pc board. A double-sided board for this purpose has been designed but the foil patterns are too large to be reproduced here without reduction. Full-size copies of the foil patterns for the CPU board and the display board will be supplied with component layout diagrams when the EPROM listing is ordered from the address given in the Parts List. Note that, while the pc board is double-sided with plated-through holes, it is possible to use a one-sided board with jumpers, instead of foil, on the component side. Use wires or a cable to connect points labeled with letters on the display board to the same points on the CPU board. External elements are connected to the CPU board as shown in Fig. 6.

Battery *B1* is an optional four-cell nickel-cadmium type that has a fully charged voltage of about 5.2 V. This back-up battery will allow retention of information in its memory during a power failure. Resistor *R13* should be chosen for a proper trickle-charge rate for the battery used. As a rule of thumb this rate should be around C/50, where C is the capacity of the battery in ampere-hours. AA cells having an ampere-hour rating of about 0.5 were used in the prototype. C cells have a rating about three times as high. With AA cells you can try 470 ohms for *R13*. It is best to check *B1*'s charging rate after you have the project up and running for a day or so. Use a milliammeter placed in series with *B1*.

If you choose not to use a back-up battery, eliminate *D1, D2, R13,* and *C6* and connect pin 35 of *IC8* to the main V_{cc} (+5 V) source. You can do this on the circuit board by connecting jumper wire J to point J5 instead of point JB on the board.

Resistors *R34* through *R45* are optional. In most applications they increase the circuit's noise immunity although here their use is ques-

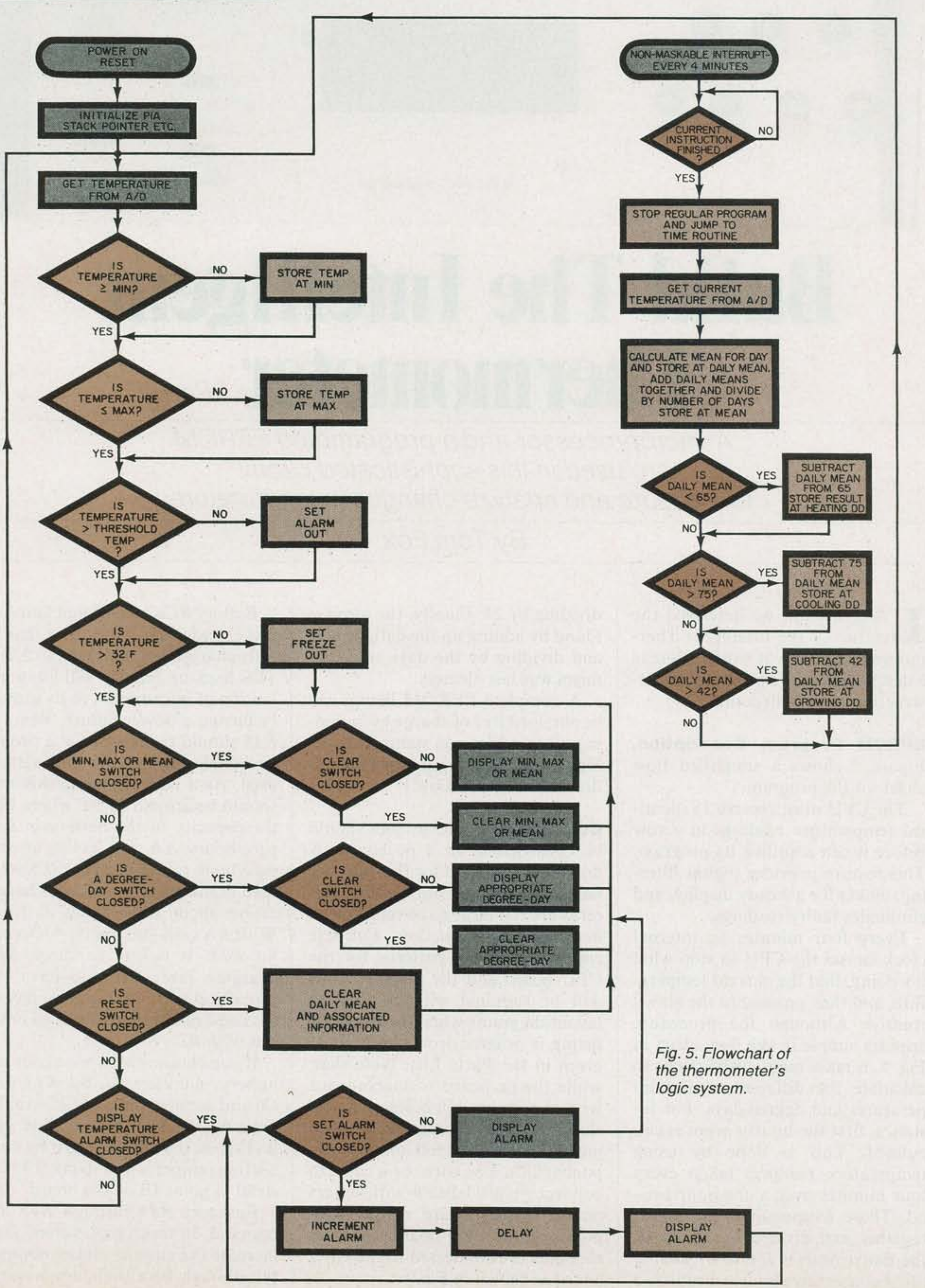


Fig. 5. Flowchart of the thermometer's logic system.

tionable. They are not shown on the pc board. If you wish, they can be easily soldered directly to the switches.

Capacitors *C7* and *C31* are needed for *IC8*'s crystal oscillator to perform properly. The 6802 is designed to be used with a 4-MHz parallel-resonant fundamental crystal.

Connect point T on the CPU circuit board to a secondary lead of the power transformer. Make sure this lead is not a ground. If you are not sure of the voltage rating of the transformer (which sometimes happens if you buy a commercial power supply) use an ac voltmeter to measure the voltage between this lead and ground. If the voltage is 6.3 V, *R7* should be about 100 kilohms. If the voltage is 12.6 V, try a 39-kilohm resistor, and if you have a 16-V transformer, a 33-kilohm resistor is close to optimum. The exact value of *R7* is not critical. Just make sure it is chosen so that the output of *IC5A* is normally high when *R9* is adjusted properly.

Notice that *R30* and *R31* are 1% precision resistors. They simplify calibration. If you wish, you can replace *R31* with a combination 22-kilohm resistor and 5-kilohm pot in series. However, this complicates calibration and can reduce long-term accuracy.

For a faster responding unit, reduce *C8* (*IC9*, pin 4) to 150 pF, but some flicker may be noticed in the display. Although they are not shown in the schematic (they *are* shown on the component layout), 0.01-μF capacitors should be connected between the supply leads (+5 V and ground) physically close to *IC5, IC10, IC13, IC17, IC18, IC20, IC22, IC24,* and *IC27.*

Figure 7 shows a typical low-cost power supply that uses a 6.3-V transformer that can be purchased from surplus electronic dealers. The transformer should be rated at least at 1.5 A. This circuit uses two voltage-doubling circuits to achieve +12 V and −5 V, in addition to the +5-V supply. Keep in mind that this is a low-cost power supply that provides the minimum power requirements. Any other power supply is suitable as long as it is well filtered, well regulated (±5%), and provides the following minimum requirements: +5 V at 500 mA, +12 V at 50 mA, and −5 V at 40 mA.

To protect the circuit against lightning and other destructive power-line surges, it is wise to connect a surge absorber to the ac line immediately after the switch and fuse. You can use Panasonic's ZNR or GE's Varistor or any other similar device. To protect the RAM from error bits, you also might want to connect an r-f filter to the line circuit. One filter that is readily available is Radio Shack's 15-1106.

Sensor Assembly. Use a 2-conductor cable, size #26 or larger, for the sensor probe assembly. If a length of several hundred feet is desired, use #22 wire.

Refer to Fig. 8 for one way of sealing and waterproofing the probe. If you use this construction, first, color code the leads so there can be no confusion. Cut off the "Adj" lead from *D9* since it will not be used. Place sleeving on the cable's wires before making connections to the sensor. After soldering (use a heat sink between the solder and sensor), spray the assembly with several coats of a plastic insulating spray. Pull up the sleeving to cover all bare wires. Spray the assembly again. When the spray is dry, use an epoxy-type putty (E-POX-E Ribbon etc.) to encase the assembly. Use your fingers and hands to form a neat appearing probe. After the epoxy sets, spray the assembly again with plastic. If you wish to paint the probe, use a white or metallic silver paint.

Preliminary Testing. If the display doesn't show some number when first turned on, don't panic! It is possible that *R9* may have to be adjusted. Slowly turn *R9* until the display appears steady. Then turn it another $^1/_8$th of a turn in the same direction. Hold the probe in your hand. The display should show increasingly larger numbers. If everything seems to be OK so far, proceed to the Calibration section. If not, use a voltmeter or oscilliscope to measure the voltage at pin 40 of *IC8.* It should be close to 4 volts. If you cannot get pin 40's voltage up this high by adjusting *R9*, you'll have to increase *R7.* Try first increasing it by about 25%. If still no luck, increase it further.

Calibration. Use an accurate voltmeter (a DVM is preferred) to measure the voltage, with respect to ground, at pin 9 of *IC9*. Adjust *R28* so that it is exactly 2.49 V.

Note that the display shows the temperature of the probe unless one of the pushbutton switches is pressed. To measure temperatures in degrees Fahrenheit, place the "°F/°C" switch (*S10*) in the "°F" position. The "F" on the display should light. If you prefer the Celsius system, switch to "°C".

For final calibration, place the waterproof probe in the middle of a large container that has a mixture of ice and water (50% minimum ice). Stir occasionally and wait at least 10 minutes. Adjust *R26* so that 32 F or 00 C shows on the display. If you wish, you can place a drop of cement on *R26*'s wiper arm.

Operation and Use. If this sophisticated instrument is to be used to monitor the weather and local climate (its original purpose) don't

ORDERING INFORMATION

Note: The following are available from Magicland, 4380 S. Gordon, Fremont, MI 49412: complete kit of parts including pc boards, all ICs, and sensor, but not case, power supply, battery or cable, for $179.00, postpaid. Also available separately: 2708 EPROM (preprogrammed) for $25.00; ADC0801 for $8.25, LM135H for $9.50; 1% precision resistor for $1.75 each; LM324N for $1.25. On orders less than $5.00, add $1.00 for handling. Outside U.S., Canada, and Mexico, add $5.00 for shipping. Michigan residents, add 4% tax. The following are available from Danocinths Inc., PO Box 261, Westland, MI 48185: microprocessor pc board (#RW403) for $64.00; display pc board (#RW403D) for $10.85; both pc boards for $70.00; postpaid. Michigan residents, add 4% tax. The listing for programming the EPROM and the foil patterns and component layouts for the pc boards can be obtained by sending a stamped, self-addressed legal-size envelope to Dept. IT, Computers & Electronics, One Park Ave., New York, NY 10016.

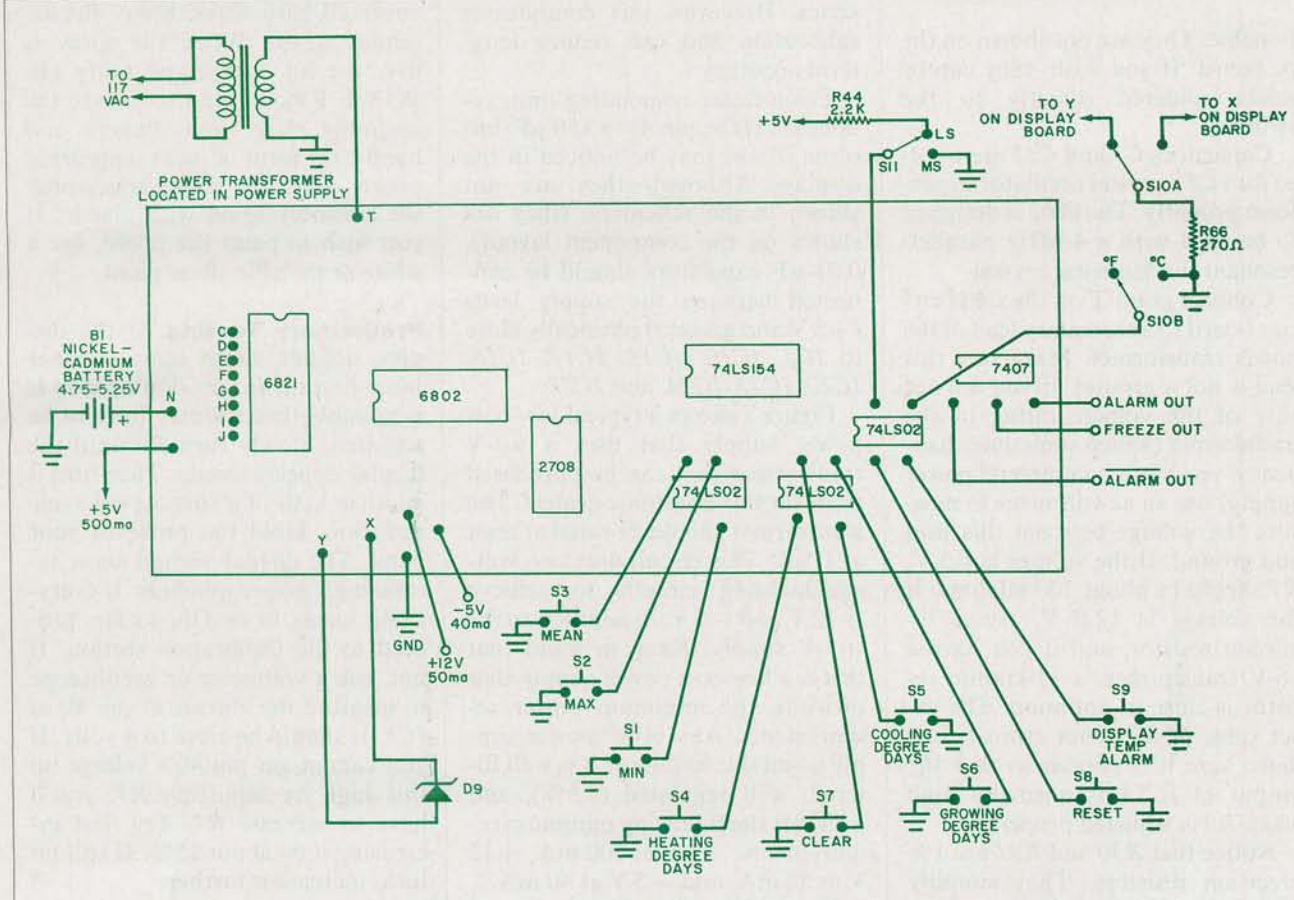


Fig. 6. External connections to the main pc board.

simply stick the probe out a window! Even a north window isn't good enough. No matter how accurate an instrument is, the readings it takes can only be correct if the probe is placed in a suitable location. The reason for this is that only *air* temperature readings are pertinent for most applications. Your primary aim in locating the probe is to avoid letting the sensor receive heat from a source that is at a different temperature from that of the air. You may already have taken the first step by painting the probe white or metallic silver. Placing the probe at the 5-foot level in a large screened porch where it gets plenty of air circulation and is away from a heated building is close to being the ideal location for the sensor.

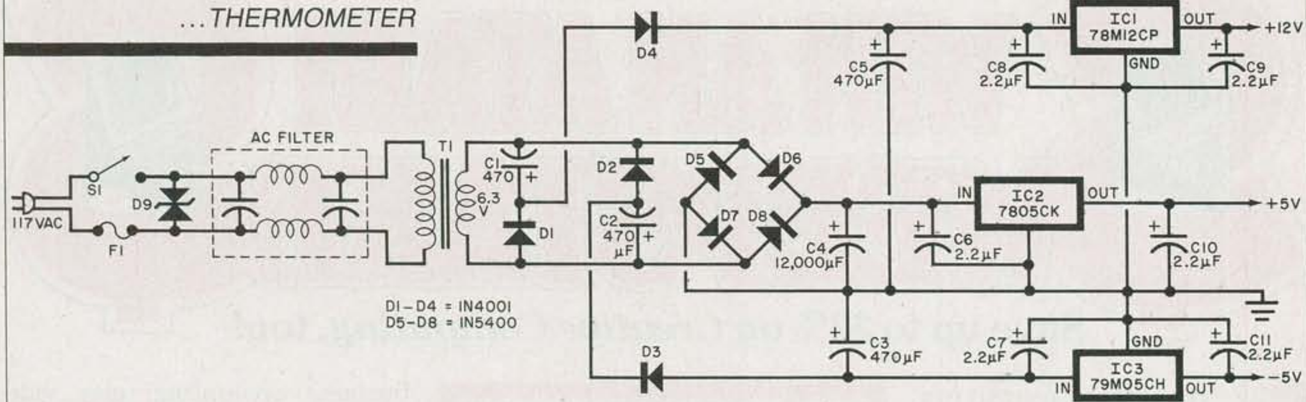
On the other hand, a simple shelter can be made from a wood box that has no bottom and a back consisting of a fine meshed plastic or aluminum screen. A second large roof on top of the box can be added for even better results. Paint the shelter and roof white and suspend the sensor in the middle of the box about 5 feet from ground level. Place the shelter in a location that gets plenty of air circulation and orient it so that the screened back is pointing north.

After turning the unit on, press the RESET switch (*S8*). This is necessary to clear internal registers in the memory. The RESET switch can also be used whenever you want the precise mean temperature or degree-days from a particular time. If you simply clear the MEAN memory registers (by pressing the MEAN and CLEAR switches at the same time), without pressing the RESET switch, the mean temperature shown by the display can be off a bit. Practically speaking, however, if you plan to find the mean-temperature or degree-days for a period longer than a week, it is not necessary to reset the circuit (except when you first turn it on).

To clear the minimum, maximum, mean, heating degree-days, cooling degree-days or growing degree-days memory registers, press clear switch *S7* at the same time you press the switch that pertains to the register you want cleared.

When the minimum or maximum memory registers are cleared, the present temperature is stored in the registers. When the mean register is cleared, −56°F (−49°C) is stored in the mean memory register. When any degree-day registers are cleared, 0 is stored in the respective register.

When operating any of the pushbutton switches, keep the switch depressed until the display



PARTS LIST (Power Supply)

C1,C5—470-µF, 25-V electrolytic
C2,C3—470-µF, 15-V electrolytic
C4—12,000-µF, 15-V electrolytic
C6 through C11—2.2-µF tantalum capacitor
D1 through D4-1N4001 diode (or similar)
D6 through D8-1N5400 diode (or similar)
D9-Varistor (Panasonic ZNR or similar)
F1—½-A slow-blow fuse
IC1—78M12CP, 12-V voltage regulator
IC2—7805CK, 5-V voltage regulator
IC3—79MO5CH, —5-V voltage regulator
S1—125-V, 3-A spst switch
T1—6.3-V, 1.5-A transformer
Misc.—AC filter (Archer 15-1106 or similar), wire, hardware, etc.

Fig. 7. Schematic for a suitable power supply.

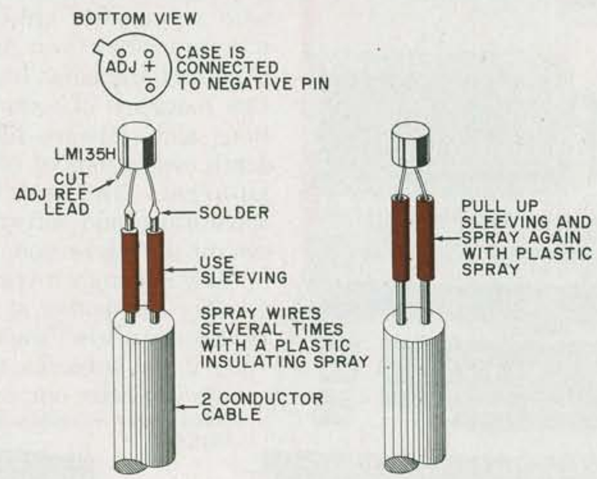


Fig. 8. How to make the sensor assembly.

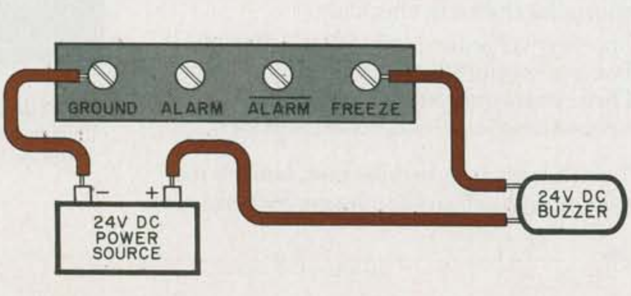


Fig. 9. Connecting to the terminals on the back panel.

changes. The CPU must receive 18 identical temperature readings in a row before continuing the program. If the temperature is exactly between two numbers (which occurs infrequently) this "digital filtering" can cause a second or so delay in switch action.

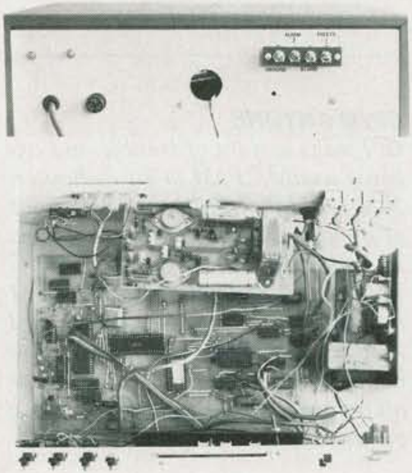
The operation of the MINIMUM and MAXIMUM switches is rather obvious. When you press either of these switches, the display shows the minimum or maximum temperature, respectively, measured since last memory clearance. When the MEAN switch is pressed, the display shows the accumulated mean temperature over a period of days (255 maximum) since the MEAN register was last cleared.

To display degree-days, place the LS/MS switch (*S11*) in the MS position. Also determine if you want Fahrenheit degree-days or Celsius degree-days and place the °F/°C switch (*S10*) in the appropriate position. (Note: Celsius degree-days are automatically rounded off to the nearest hundred and the LS display will always show 00.) When you press the particular DEGREE-DAY switch you are interested in, the display will show the number of degree-days in hundreds (e.g. 34 stands for 3400). Finally, switch the LS/MS switch to the LS position to find the units. (If the display shows 34 in the MS position and 53 in the LS position the number of degree-days is 3453.)

To display the threshold temperature stored in the alarm memory register, press the DISPLAY TEMPERATURE ALARM (DTA) switch. To change this threshold temperature, momentarily switch on the SET ALARM TEMPERATURE switch while pressing the DTA switch. Continue pressing the DTA switch until the desired temperature shows up on the display and then release it.

Up to 30 V and up to 40 mA dc can be controlled with the FREEZE and ALARM outputs (Fig. 9). The "FREEZE" output sinks current when the temperature drops to 32°F (0°C) or lower. The "ALARM" output sinks current when the temperature drops to or below the "threshold temperature" stored in the ALARM memory register. The $\overline{\text{ALARM}}$ output is complementary to the ALARM output since it responds to temperatures above the threshold.

Applications. The practical uses for this thermometer to measure the current temperature, and record the maximum and minimum temperatures over a period are obvious.



Photos of the rear and interior of the author's prototype.

The interested builder should consult library references covering heating/cooling degree days as they pertain to gas or oil heating and air conditioning, and growing/cooling degree days as they pertain to plant and crop growing.

The FREEZE output is connected to an alarm that will sound off when the measured temperature drops below freezing. The ALARM output is set to the "threshold" temperature; and, when an alarm is connected to this output, it will sound off at the preset temperature. The threshold temperature can be set (another example) to −20°F to sound an alarm that the water pipes are frozen!

By connecting the ALARM output to one relay, and the $\overline{\text{ALARM}}$ output to another relay, you can create a digital heating/cooling thermostat. It is possible to re-write the EPROM program to use the built-in clock and make a very sophisticated thermostat that is activated by time and temperature. ◊