Accurate thermometer uses single quad op amp

by Yishai Nezer
Haifa, Israel

For temperature ranges up to 150°C, a thermometer built around a single integrated circuit has not only greater linearity than a thermocouple but also far greater sensitivity—approximately 2 millivolts per degree Celsius. The sensor achieves this superior performance by exploiting the well-known voltage-to-temperature relationship of a semiconductor pn junction.

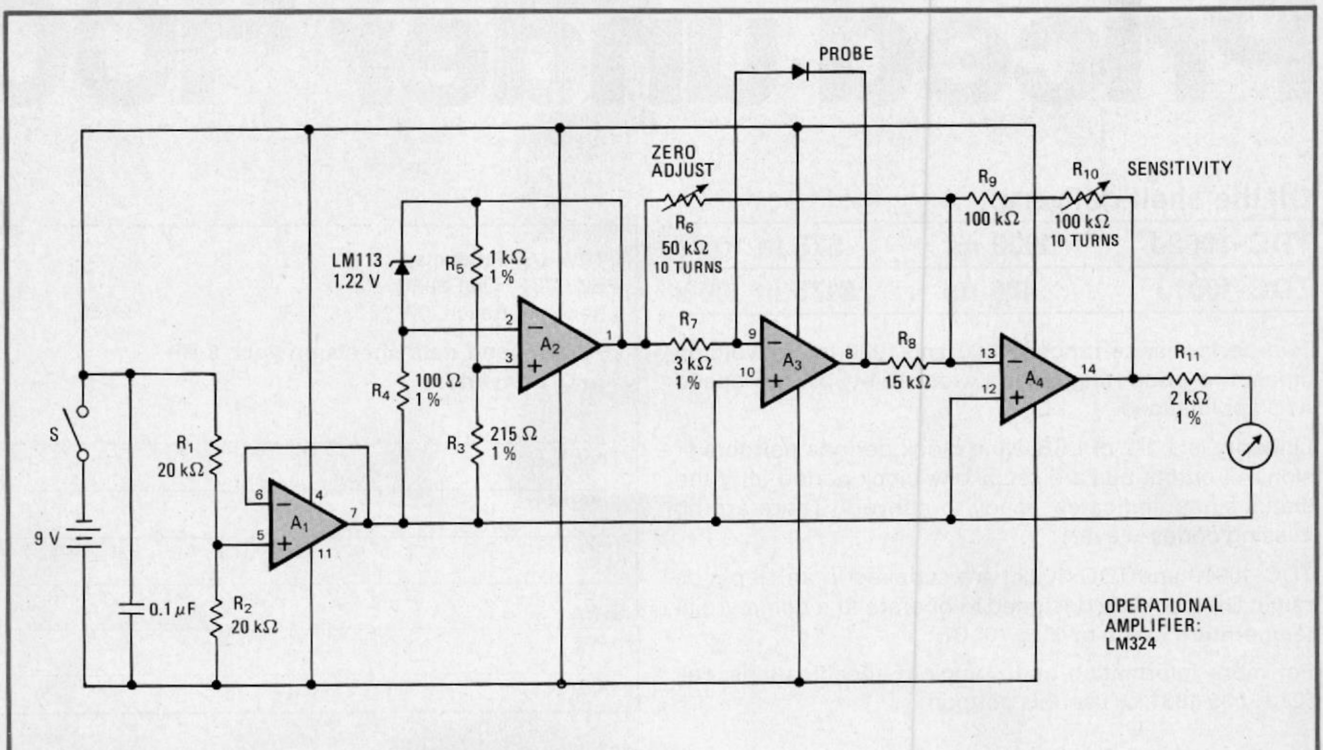
In the temperature-sensing scheme shown, the low-power LM324 quad operational amplifier and a diode probe are the central elements. The first two op amps, A_1 and A_2, have the job of keeping a constant current through the diode, to ensure that any voltage changes across the diode are a direct result of temperature changes at the probe. A_1 serves as a buffer for the input circuit divider resistors, producing an output of 4.5 volts that acts as a reference point for the other op amps and permits them to operate in their linear region. A_2, in conjunction with the LM113 reference diode, produces a constant 1.5-v output, which is practically independent of variations in battery voltage or circuit temperature and thus supplies the diode probe with a constant current of about 0.5 milliampere.

The output voltage of this diode is buffered by op amp A_3, and changes in A_3's output are reflected in the output of A_4, inserted to provide a separate point to adjust for device sensitivity and calibration.

A simple calibration procedure is necessary for proper operation. Once the range of temperatures to be measured has been determined, the zero-adjust potentiometer is set for zero output voltage at the low temperature extreme, and the sensitivity-adjust potentiometer is set for a convenient output (perhaps full-scale reading) at the upper temperature extreme. A 1-mA meter movement can be used at the output.

If a wide range of temperatures (0° – 150°C) is to be measured, a diode-connected transistor (base and collector connected) is often preferable to a diode, because its properties better approximate an ideal pn junction. But in applications where the temperature variations are small, a glass-encapsulated diode is more convenient. The probe should be isolated when the circuit's power supply is not floating with respect to the tested environment.

Precision is better than 0.1°C, provided shunt conductances are minimized at the probe. Current drawn by the circuit is typically 4 mA. Power consumption can be conserved further by use of a switch. □

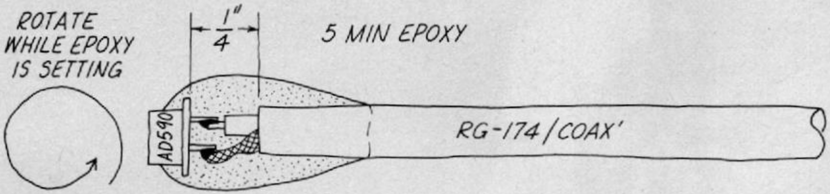


Precision thermometer. Accuracy is limited primarily by ammeter readability. Thermometer is sensitive enough for medical applications where temperature variations are small. LM113 can be replaced by two silicon diodes in series for less demanding applications.

letters

T-100 THERMOMETERS

Optoelectronics, Inc., has now assembled a number of T-100 thermometers and is satisfied with their performance, especially their accuracy. The linearity from 0°C to 100°C is typically .1° or .2°.



The company has decided to incorporate a change that will be included in all kits. It is recommended that a second 9-volt battery be added in series to boost the supply voltage to 18. This will insure that at least 4 volts is always across the sensor so that high Fahrenheit readings (>150°F) can be produced. Battery life will be more than doubled because each battery can discharge down to 5 volts rather than the single battery discharging to 7½ volts. Battery life will be typically greater than 100 hours with carbon-zinc cells, and 300 to 400 hours with alkaline cells. A second battery snap will be included in all kits along with a piece of double-stick tape. The second battery fits nicely into the case without modification.

The company also recommends that the probe should be assembled as shown (see diagram) without using the nylon shell. However, the shell will be included with all the kits that are shipped.

BILL OWEN
Optoelectronics, Inc.
Fort Lauderdale, FL

WHERE ARE THE DESIGNERS?

Before semiconductors, was the only true designer the one who designed new vacuum tubes?

As some philosophers point out, we seem to have gotten confused over the extent of design versus the intent of design. The intent hasn't changed, but advancing technology has allowed brand-new "extents" especially suitable to reliance on interchangeable parts available in mass quantity at super-low cost. The designer still designs, but he's charged with operating at a different level that today's tools and components make possible. This means that the economies of when to customize—always an expensive proposition—have changed, too, and the good designer adapts to that also, because it

continued on page 22

WINE TEMPERATURE METER

Ensure your wine is at the correct temperature with this little idea from our project team

WINE, WOMEN AND SNOG — no not another misprint but ETI's updated version of that phrase that so aptly describes that which a young man's fancy turns to in spring, or any other time of year for that matter. We at ETI can't do much about the provision of the above items but this project will at least ensure that when you get your hands on one of them it will be in perfect condition. Before going any further let's make it clear that its the wine we're talking about in this connection.

In use the wine temperature meter's sensor is clipped to the plonk of your choice and the condition of the booze, with regard to temperature, read off from the three LEDs on the meter's front panel. To set up the instrument consult our table showing the range of temperatures considered acceptable for the various types of wines. Turn RV2 fully anticlockwise and bring the sensor to a temperature that is in the middle of the desired range. Adjust RV1 until the centre LED just lights

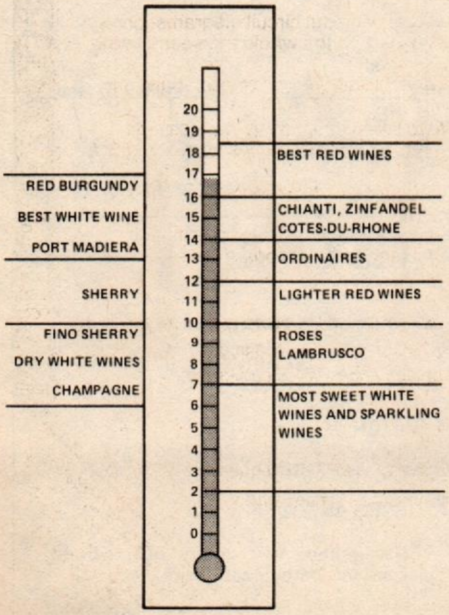
Next lower the temperature of the sensor until it is at the lower temperature limit. Adjust RV2 until the lower LED is just extinguished.

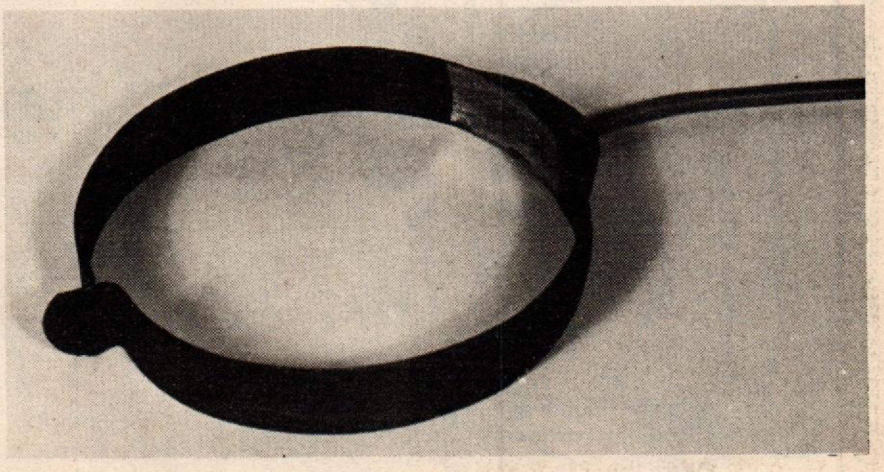
Construction of the project is quite straightforward. Assemble all the components according to the overlay shown. Space is at a premium if the case chosen for our prototype is used so keep everything tidy.

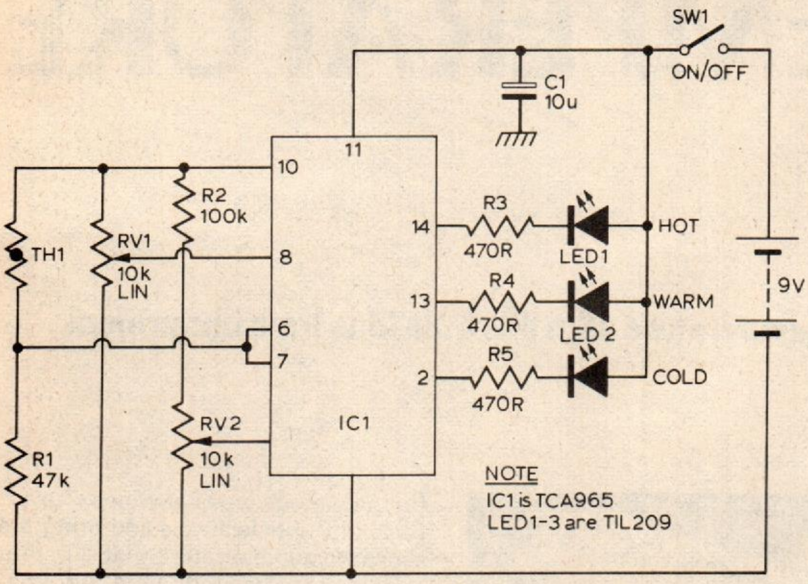
Our sensor was made from a bicycle clip. The thermistor was epoxied to the clip — we smeared a small amount of silicon grease on the clip before mounting the sensor — this provides a good thermal contact. We coated the sensor in a layer of black paint when it was complete leaving the area under the sensor as bare metal.

Insert the battery and start getting your grapes as they should be enjoyed.

Above, the complete unit while below the sensor, a bicycle clip painted black with the sensor epoxied to it.







Circuit diagram of the wine temperature meter.

HOW IT WORKS

The project is based on the TCA965 window discriminator IC. This device can be used in a number of different modes, the one selected for this application allows the potentiometers RV1 and RV2 to set up a "window height" and "window width" respectively.

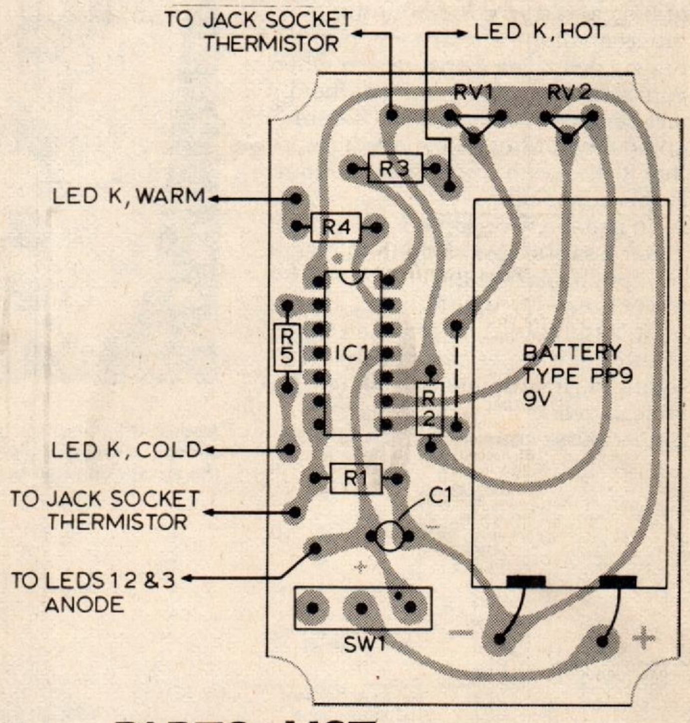
R1 and thermistor TH1 for a potential divider connected across the supply lines. The value of R1 is chosen such that at ambient temperature the voltage at the junction of these two components will be approximately half supply.

As the temperature of the sensor changes so the voltage will change and it is the temperature dependent voltage that is input to ICI.

RV1 will set the point which corresponds to the centre voltage of a windoe the width of which is set by RV2. The switching points of the IC feature a Schmitt characteristic with low hysteresis.

The outputs of IC1 indicate whether the input voltage is within the window or outside by virtue of being either too high or too low..

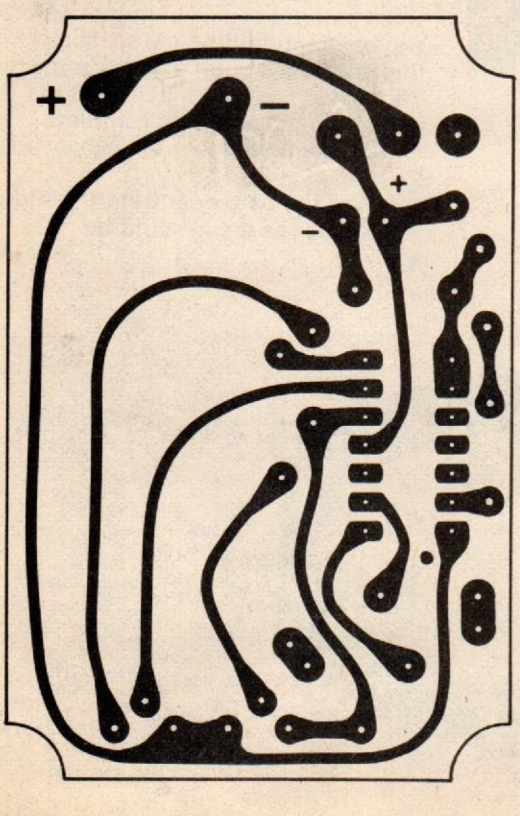
The outputs of IC1 are all open collectors capable of providing up to 50mA. In our circuit however they are only required to drive a LED via a current limiting resistor.



BUYLINES

All the components for this project should be available from most local shops — no problems.

Foil pattern of the wine temperature meter.



PARTS LIST

RESISTORS

R1	47k
R2	100k
R3, 4, 5	470R

POTENTIOMETERS

RV1, 2	10k sub. min. preset

CAPACITORS

C1	10u 10V tantalum

SEMICONDUCTORS

IC1	TCA965
LEDs1-3	TIL209

SWITCH

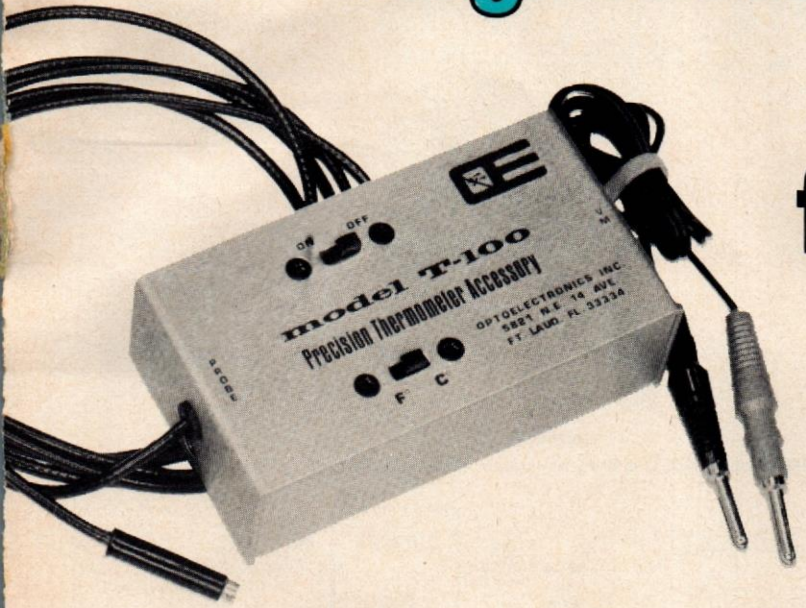
SW1	SPDT

MISCELLANEOUS

PCB as pattern, Vero potting box, 2.5mm jack socket, battery wire, wire etc.

BUILD

Digital Thermometer Add-On for your DMM



A simple, easy-to-build accessory converts your digital voltmeter into a handy thermometer for monitoring semiconductor case temperatures, photographic chemicals and numerous other uses around the lab, home and workbench.

BILL OWEN*

HOW OFTEN HAVE YOU WORRIED ABOUT a component that was running hot to the touch? The part could be safely within specifications or in danger of burning out. If you include a digital thermometer as part of your test gear then you simply measure the component's temperature and check the data book for temperature limits. The capability to reliably and accurately measure temperature can also help to get a handle on more complex temperature problems such as specifying heat sinks, crystal oscillator drift and op-amp stability.

Several major manufacturers of digital multimeters now offer a thermometer option built in or as a separate accessory. Now you can build a simple thermometer conversion circuit for your digital voltmeter that is as good as any and better than most of the commercial units and at one-third the cost.

The temperature sensor is an integrated circuit developed by Analog Devices Inc. as a precision temperature-dependent current source. Of the many advantages this sensor enjoys over others, its accuracy of 0.5° and its range of from −55° to +150°C are most impressive. Because it is a current source with only two active leads, the sensor is virtually free from noise pickup even when remoted over hundreds of feet of cable. Its tiny TO-52 metal-can transistor package allows for fast temperature response. Other features will be apparent as we use the temperature sensor to build the T-100 direct-reading thermometer.

The T-100 has a 10 mV-per-degree output that enables any digital or analog voltmeter to directly read Fahrenheit or Celsius by the flip of a switch. Resolution is to 0.1° with a 3½-digit voltmeter and to 0.01° with a 4¼-digit meter. Total current consumption is about 3 mA, giving the T-100 many hours of operation from an inexpensive 9-volt battery.

While we have mentioned only electronics, the T-100 is ideally suited for a wide variety of other applications. Simply dedicate a voltmeter to exclusive use and you have a thermometer to monitor inside, outside, aquarium, swimming pool, greenhouse, darkroom chemical, freezer, cooking, air conditioning and an almost infinite list of other temperatures.

Circuit description

Figure 1 shows the AD590K temperature transducer's linear current output of 1 μA per degree Kelvin. The Kelvin degree is the same size as a Celsius degree; however, the Kelvin temperature scale is 273.16° higher than the Celsius scale. Zero degrees Kelvin is called absolute zero because it can be shown that colder temperatures cannot exist. There is also an absolute Fahrenheit temperature scale (Rankine) that is 459.69° higher than the regular Fahrenheit scale.

Figure 2 is the schematic of the thermometer accessory. The transducer's output current is scaled by the combination of resistors R10 and R11, or by R8 and R9 depending upon the position of the CELSIUS/FAHRENHEIT switch S1. The voltage developed across scaling resistors R8 and R9 is equal to 10 mV per degree Kelvin or 10 mV per degree C + 2.73 volts. Similarly, the voltage across the R10, R11 combination is equal to 10 mV per degree F + 4.59 volts. These output voltages follow naturally from the Kelvin to Celsius and Kelvin to Fahrenheit conversion equations:

T Celsius = T Kelvin − 273.16°

T Fahrenheit = 9/5 T Kelvin − 459.67°

To read Celsius and Fahrenheit directly we must generate reference voltages of 2.73 and 4.59.

The LM334Z is a precision current source with a 2-mA output that is set by resistor R1. The current output is used to bias a LM329DZ precision 6.9-volt temperature compensated Zener reference.

This device is actually an integrated circuit with many advantages over the usual Zener diode. A big advantage is the low current level required (1 mA) for stable operation. The IC1/IC3 combination provides a very stable, low-power voltage reference for the voltage dividers. The voltage divider formed by R2, R3 and R4 generates the 2.73-volt reference and the divider formed by R5, R6 and R7 generates the 4.59-volt reference. The correct reference is selected by the switch S1 and connected to the "minus" output terminal. The thermometer's output then is the voltage difference between the + and − output terminals.

Construction

Assembly of the thermometer circuit

*Product Engineer, Optoelectronics, Inc., Ft. Lauderdale, FL board is simple and straightforward. The foil pattern for the PC board is in Fig. 3 and the components placement is shown in Fig. 4. Trimmer resistors R3, R6, R9 and R11 are mounted on the foil side of the PC board. The thermometer shown here uses a custom aluminum enclosure for the circuit board and battery. The two slide switches were installed in the cabinet top and the PC board aligned for proper fit with the cabinet bottom before soldering. Grommets were fitted in each end of the cabinet top. Small diameter coax cable was inserted in the hole labeled PROBE and zip cord in the hole labeled VM in the cabinet top. The coax center conductor and shield are soldered to the PC connections labeled SIG and SHLD, respectively, in Fig. 4. The zip cord is soldered to the holes labeled OUT with the red banana plug soldered to the "+" wire and the black banana plug to the "−" wire. The 9-volt battery snap is connected to BATT holes with the red wire soldered to "+" and the black wire to "−."

The AD590K sensor was prepared by cutting off the case lead and staggering the + and − leads leaving the + lead longer. Figure 5 shows a cross section of the probe assembly. The sensor leads will not short together if the coax conductor and shield are staggered to match as shown. The shield lead is connected to the sensor's + lead. The sensor is soldered on the end of the coax and the connection potted in with epoxy glue to make it waterproof. A nylon shell was used to house the coax connection and provide a seal for the sensor. The shell was slid over the free end of the coax with the larger diameter end going on the cable first.

A 5-minute setting epoxy is used to pot the sensor. A very small amount was mixed and an even coat applied to the bottom of the sensor. The sensor was then held tightly against the end of the nylon shell and kept centered until the epoxy became set.

Next, an amount of epoxy to sufficiently fill the probe was thoroughly mixed. The probe tip was held down and epoxy was applied between the shell and coax using a toothpick. The epoxy flows down

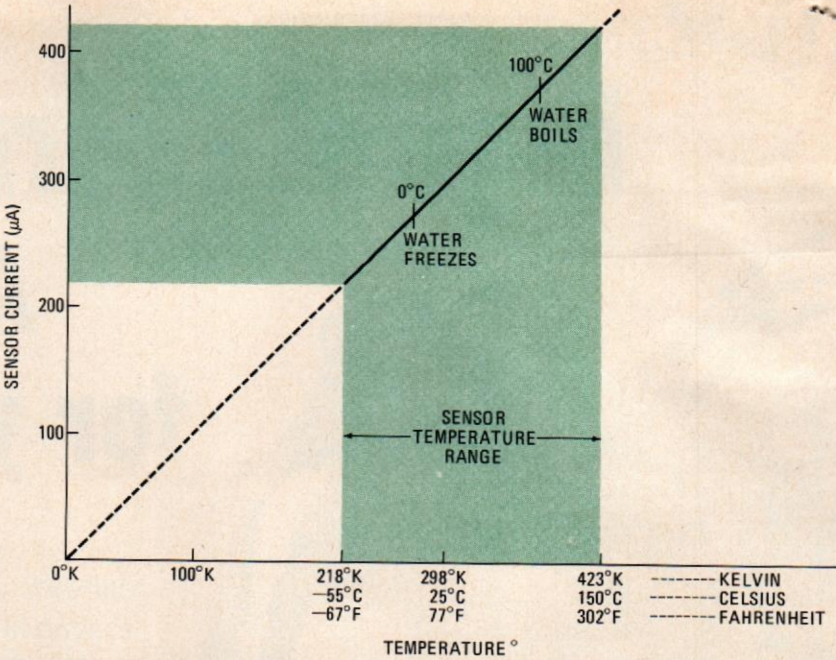


FIG. 1—CURRENT OUTPUT of the AD590 is linear at 1 μA per degree Kelvin.

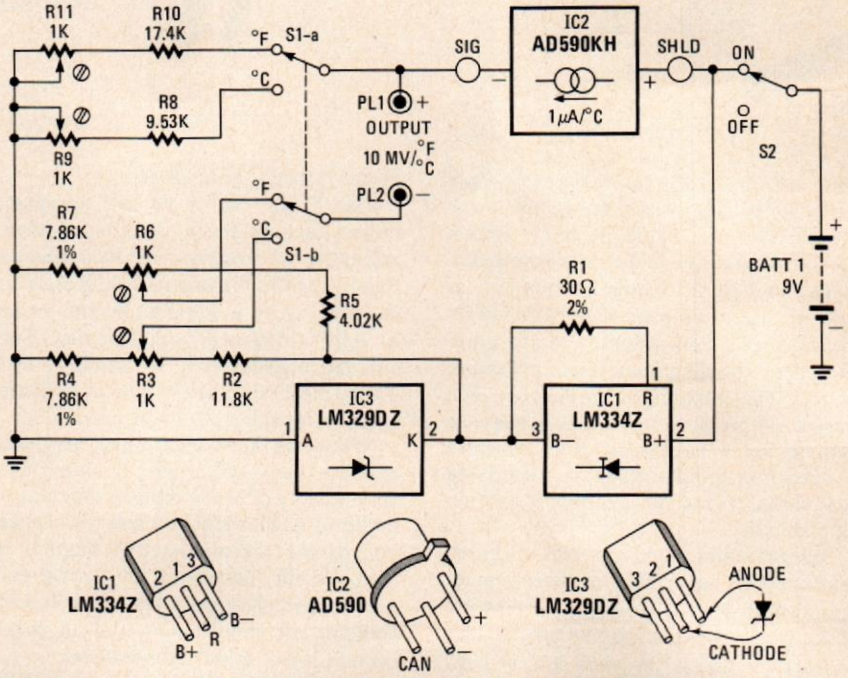


FIG. 2—SCHEMATIC OF THE T-100 thermometer accessory for a digital voltmeter. The circuit is essentially a resistive bridge with the temperature sensor as one of its legs.

PARTS LIST

- R1—30 ohms, 2%
- R2—11,800 ohms, 1%
- R3, R6, R9, R11—1000 ohms PC mount trimmer potentiometer
- R4, R7—7860 ohms, 1%
- R5—4020 ohms, 1%
- R8—9530 ohms, 1%
- R10—17,400 ohms, 1%
- IC1—LM334Z constant-current source (National)
- IC2—AD590K linear temperature-dependent current source (Analog Devices)
- IC3—LM329DZ precision temperature-compensated voltage reference (National)
- S1, S2—miniature DPDT slide switch
- BATT1—9-volt battery, transistor radio type
- PL1, PL2—banana plugs, 1 red, 1 black
- Misc: RG-174/U coax, 4 feet or as needed; 2 feet of lightweight ZIP cord, nylon probe shell (see text), PC board, case screws and assorted hardware.

The following items are available from Optoelectronics, Inc., 5821 N.E. 14th Avenue, Ft. Lauderdale, FL 33334. Phones: (305) 771-2050 and 771-2051. Epoxy (used in probe assembly) and 9-volt battery must be purchased separately.

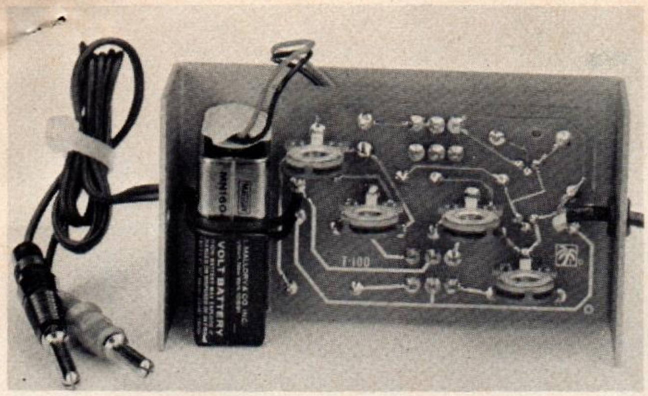
Kit T-100RE—Complete parts kit less case and switches. $30.00

Kit CAB 10S—Deluxe prepunched gold anodized and screened aluminum cabinet with switches, screws, grommets and rubber feet. $9.95.

T-100WT—Factory-wired, tested and calibrated thermometer. $59.95.

TP-100K—Additional probe kit with 6 feet of coax. $14.95.

Florida residents add state and local taxes as applicable.



DIGITAL THERMOMETER with rear cover removed shows internal layout. Note four trimmers are mounted on foil side of PC board.

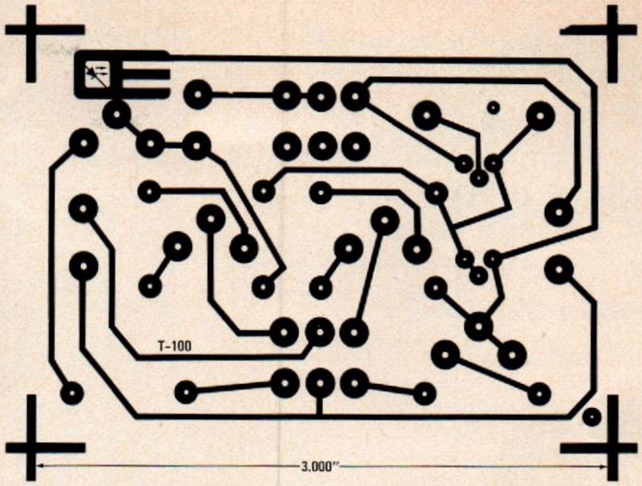


FIG. 3—PRINTED CIRCUIT PATTERN for the digital thermometer accessory.

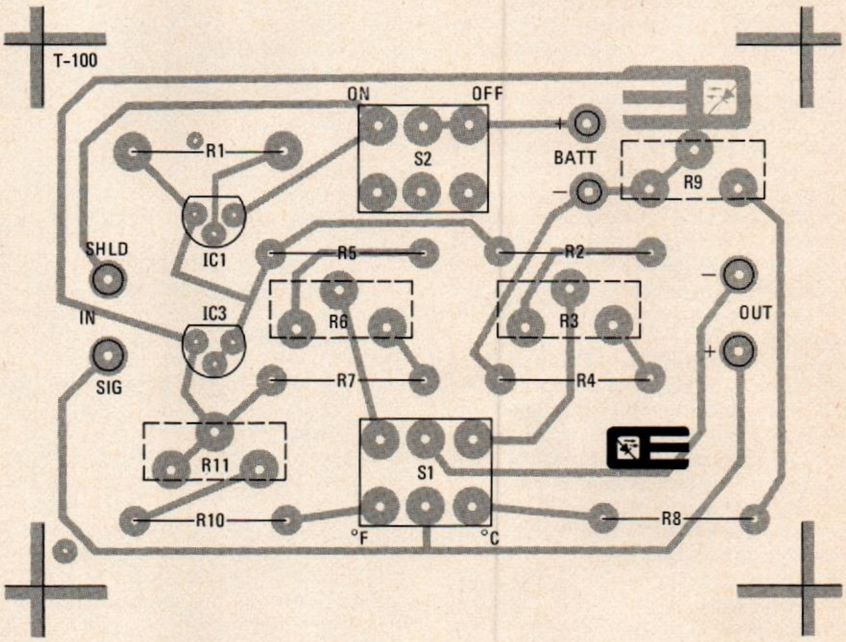


FIG. 4—THE PARTS LAYOUT is an indication of the simplicity of the device.

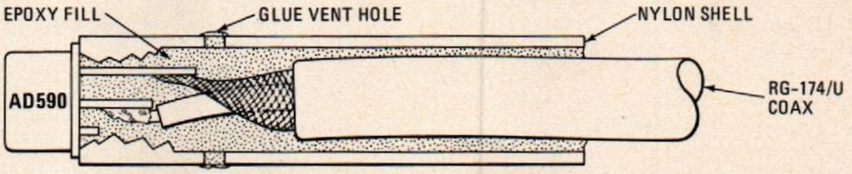


FIG. 5—DETAILS OF THE PROBE ASSEMBLY. The potting compound seals the probe against moisture and other contaminants.

the coax and into the space inside the shell. Tapping the probe tip on the table helps the epoxy flow. As the probe space fills, the epoxy seeps out of the vent holes in the sides of the shell. Any excess can be wiped away. Keep the coax centered in the end of the shell while the epoxy sets. Allow the epoxy to cure overnight before subjecting the probe to mechanical stress or excessive temperatures.

(The plastic probe shell is made from a 1-inch-long ¼-inch O.D. plastic spacer with one end counterbored to accept the outside diameter of the RG-174/U coaxial cable. (See Fig. 5.) A reasonably good substitute can be made using ¼-inch O.D. shrinkable tubing. Connect the cable to the sensor and fill the void in the tubing with the potting compound. When the compound has fully cured, apply just enough heat to shrink the tubing.—*Editor*)

Calibration

The voltage reference in the thermometer can be more stable than the internal voltage references in some digital voltmeters. Calibration should be done with the voltmeter that will be used with the T-100.

Connect the negative voltmeter lead to thermometer ground. The center lugs (wipers) on trimmers R9 and R11 are grounded as is the black (negative) battery lead. Connect the voltmeter's positive lead to the center terminal on trimmer R3 and adjust R3 to read 2.73 volts. Move the voltmeter's positive lead over to the center terminal of trimmer R6 and adjust R6 to read 4.59 volts.

The thermometer's output is linear so calibration for the entire range can be performed at one known temperature. Although the AD590K had 0.5° linearity over its entire range, we have found that it is even more accurate between 0° and 100°C. This means that to realize the accuracy potential of the device, we should have a temperature standard accurate to 0.1°C or better. Certified thermometers accurate to 0.1° are expensive and not readily available. For calibration we must then rely on some less precise methods.

Method 1. A 50% mixture of water and crushed ice that is well stirred in a styrofoam container should come to equilibrium within 0.5°C of 0.0°C in 15 to 30 minutes.

Method 2. Boiling water, containing no chemical impurities at standard atmospheric pressure (29.92 inches of mercury) should come very close to 100.0°C. Altitude and pressure corrections must be made.

Method 3. A good-quality accurate clinical thermometer can be used to compare readings within its range. Errors arise in reading the thermometer as well as from trying to have two different sensors track a changing temperature when they have differing time constants.

After calibration, the Celsius and Fahrenheit ranges on the thermometer should be reconciled using the conversion formulas:

$$T_F = 32°F + 9/5\ T_C$$

and

$$T_C = (T_F - 32)\ 5/9.$$

This completes the construction and calibration, and your thermometer accessory is ready to use. At first you'll probably have just one or two applications but as you become more familiar with it, the digital thermometer will become increasingly valuable. **R-E**

Investment Evaluation Program

FRED BLEECHMAN

HAVE YOU EVER MADE AN INVESTMENT IN stocks or metals and then wondered some time later if you would have been better off leaving the money in the bank? Or perhaps you'd like to know how much an investment must grow before it equals what you'd make leaving the money in the bank, at regular bank interest. The Investment Evaluation Program, written in TRS-8Ø Level I BASIC uses only 2464 bytes of RAM (*R*andom *A*ccess *M*emory), so it can be run on the least expensive 4K RAM TRS-8Ø.

The program is very straightforward, and has a handy subroutine for calculating the number of days between any two 20th century dates. The calculations are based on daily compounding of interest; if you want to change to monthly, quarterly or yearly compounding, you'll have to change lines 16Ø, 17Ø, 2ØØ, 25Ø and the subroutine starting at line 5ØØ.

Using the program is easy! After carefully entering and checking each line, type RUN and enter.

To illustrate, let's say that on July 20, 1974 you purchased 404 ounces of silver bullion for $2098.38, including a service charge of 60¢ per ounce and 6% sales tax. You would like to know how the value of that bullion now compares with the same amount of money if it had been left in savings at, say, 5.25% annual interest, compounded daily. The day you want to calculate up to is July 1, 1978.

Set up the program on the computer and enter your name, social security number, 2098.38 invested at 5.25 as the questions are asked. Enter Ø for the days calculation, then enter 7,20,74 for the start date and 7,1,78 for the end date. The computer will tell you the number of investment days is 1442. Enter this number and the computer will print out, after about 40 seconds, the total interest ($483.58) and the new principal of $2581.80. (Don't mind the 16¢ error in addition of the interest and new principal. As a matter of fact, even the interest calculated is slightly off, due to rounding-off during the 1442 multiplications!).

Enter 404 for the number of ounces of silver bullion and the value of silver per ounce on the calculation end date—say, 5.28. The computer now displays that your investment is worth $2133.12 and that you have now *lost* $448.676 (there's that slight inaccuracy again!) compared to having left your money in your savings account. It also tells you that silver on that date would have to be worth $6.39058 per ounce for you to just break even!

You can then press break to end the program, or perform another calculation. This same program can also be used to determine the future value of stock, bonds, gold, silver, etc., for break-even at some future date if you plan a particular investment. **R-E**

R-E will publish reader letters telling how to adopt this program to run on other hobby computers. Let us hear from you

```
100 CLS:P.
105 REM * COPYRIGHT 1978 FRED BLECHMAN * FOR TRS-80 I-4K *
110 P."          INVESTMENT EVALUATION":P.:P.
112 P."THIS PROGRAM COMPARES AN INVESTMENT WITH PUTTING THE"
113 P."SAME AMOUNT OF MONEY IN A SAVINGS ACCOUNT WHERE IT EARNS"
114 P."DAILY INTEREST. IF YOU WISH TO CHANGE THE PERIOD TO"
115 P."MONTHLY OR YEARLY, CHANGE LINES 160,170,200 & 250. . . ."
116 P.". . . . .AND THE SUBROUTINE STARTING AT LINE 500."
120 P.:P.
125 IN."WHAT IS YOUR FIRST NAME";A$
126 IN."WHAT IS YOUR SOCIAL SECURITY NUMBER";B$
130 A=0:B=0:C=0:D=0:E=0:F=0:G=0:H=0:I=0
131 J=0:K=0:L=0:M=0:N=0:O=0:P=0:Q=0:R=0
132 S=0:T=0:U=0:V=0:W=0:X=0:Y=0:Z=0
140 IN."WHAT IS THE DOLLAR AMOUNT INVESTED";P
150 IN."WHAT IS YOUR REGULAR SAVINGS INTEREST RATE(%)";R
155 P.
160 P."HOW MANY DAYS ARE INVOLVED? IF YOU WANT THE NUMBER"
170 P."OF DAYS CALCULATED (20TH CENTURY ONLY) ENTER 0";D
180 IF D=0 GOSUB 500
185 IF D=0 GOTO 155
186 P.
190 P.". . . . . . .PATIENCE! . . .I'M CALCULATING THE ANSWER. . . ."
195 P."             (TAKES ME ABOUT 10 SECONDS FOR 365 DAYS)"
200 S=R/36500:V=P
205 REM * CALCULATE INTEREST AND ADD TO PRINCIPAL *
210 FOR X=1 TO D
220 I=V*S:V=V+I:T=T+I
230 NEXT X
235 P.
240 P."          THE TOTAL INTEREST IS";T
250 P."THE VALUE OF $";P;"AFTER";D;"DAYS AT";R;"% IS";V
255 P.
256 REM *COMPARE PRESENT VALUE OF INVESTMENT TO SAVINGS *
260 P."HOW MANY SHARES,BARS,OUNCES,ETC.,DO YOU OWN?"
265 IN."  (TO RECALCULATE INVESTED AMOUNT,ENTER 0)";H
270 IF H=0 GOTO 130
275 P.
280 IN."WHAT IS THE PRESENT VALUE OF EACH SHARE,BAR,ETC.";M
290 Q=H*M
295 P.
300 P."YOUR INVESTMENT IS NOW WORTH $";Q;",";A$;"."
310 Z=V-Q
315 P.
320 IF Z>0 P.A$;"-";B$;",YOU HAVE LOST $";Z;"COMPARED TO SAVING!"
330 IF Z<0 P.A$;"-";B$;",YOU HAVE EARNED $";-Z;"MORE THAN SAVINGS!"
335 P.:P."THE 'BREAK-EVEN' POINT IS $";V/H;"SHARES,BARS,ETC."
340 P.:P."PRESS BREAK TO END PROGRAM. . . . . ."
350 GOTO 130
360 END
500 REM * SUBROUTINE FOR CALCULATING DAYS *
510 DATA 0,31,28,31,30,31,30,31,31,30,31,30,31
520 REM * DETERMINE NUMBER OF DAYS FROM 0 TO START *
525 P.
530 IN."WHAT IS THE INVESTMENT START DATE(M,D,Y)";A,B,C
540 E=A
550 GOSUB 1000
560 F=F+B
570 G=F+C*365
580 REM * DETERMINE NUMBER OF DAYS FROM 0 TO END *
590 IN."WHAT IS THE INVESTMENT END DATE(M,D,Y)";J,K,L
600 E=J
610 GOSUB 1000
620 F=F+K
630 N=F+L*365
640 REM * CALCULATE AND ADD LEAP YEARS *
650 O=INT((L-1900)/4):U=INT((C-1900)/4):W=O-U
660 X=(N-G)+W
665 P.
670 P."THE NUMBER OF INVESTMENT DAYS IS";X
680 RETURN
1000 F=0
1010 FOR X=1 TO E
1020 READ Y
1030 IF Y=28 THEN IF (L/4)-INT(L/4)=0 THEN Y=29
1040 F=F+Y
1050 NEXT X
1060 RESTORE
1070 RETURN
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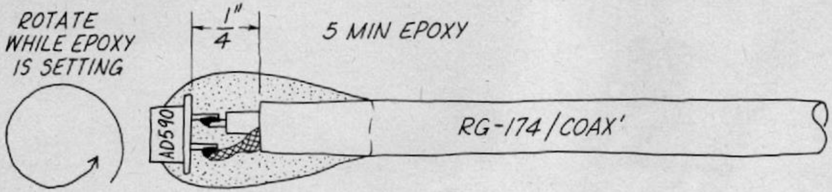
letters

T-100 THERMOMETERS

Optoelectronics, Inc., has now assembled a number of T-100 thermometers and is satisfied with their performance, especially their accuracy. The linearity from 0°C to 100°C is typically .1° or .2°.



The company has decided to incorporate a change that will be included in all kits. It is recommended that a second 9-volt battery be added in series to boost the supply voltage to 18. This will insure that at least 4 volts is always across the sensor so that high Fahrenheit readings (>150°F) can be produced. Battery life will be more than doubled because each battery can discharge down to 5 volts rather than the single battery discharging to 7½ volts. Battery life will be typically greater than 100 hours with carbon-zinc cells, and 300 to 400 hours with alkaline cells. A second battery snap will be included in all kits along with a piece of double-stick tape. The second battery fits nicely into the case without modification.

The company also recommends that the probe should be assembled as shown (see diagram) without using the nylon shell. However, the shell will be included with all the kits that are shipped.

BILL OWEN
Optoelectronics, Inc.
Fort Lauderdale, FL

THERMOCOUPLE THERMOMETER

The circuit illustrated was devised to provide a low-cost, sensitive thermometer for measuring temperature differences. The transducer used is a thermocouple consisting of two wires of the same metal, often copper, joined at the two points A and B by a wire of different metal. This thermocouple pair generates a small voltage difference across the points A and B when a temperature difference exists between the junctions a and b . This voltage varies almost linearly with temperature for differences up to about 100°C, although this assumption should not be made in calibrating the thermometer for accurate measurement.

A 741 is used (IC1) for amplifying the small voltage difference between the points a and b enabling a rugged voltmeter to be used to display the temperature difference. The potentiometer is used to set the meter to zero; values of 1kΩ makes setting easy when measuring small temperature differences. However, it may prove necessary to adjust the value of R1 or R2 if zero setting cannot be obtained. If fairly large temperature differences are being measured, VR1 could be increased to 1kΩ.

The sensitivity of the circuit is controlled by the full scale deflection of the voltmeter chosen, on the setting of VR2 (the voltage gain is the ratio VR2/R3), and on the choice of metals in the thermocouple. If the

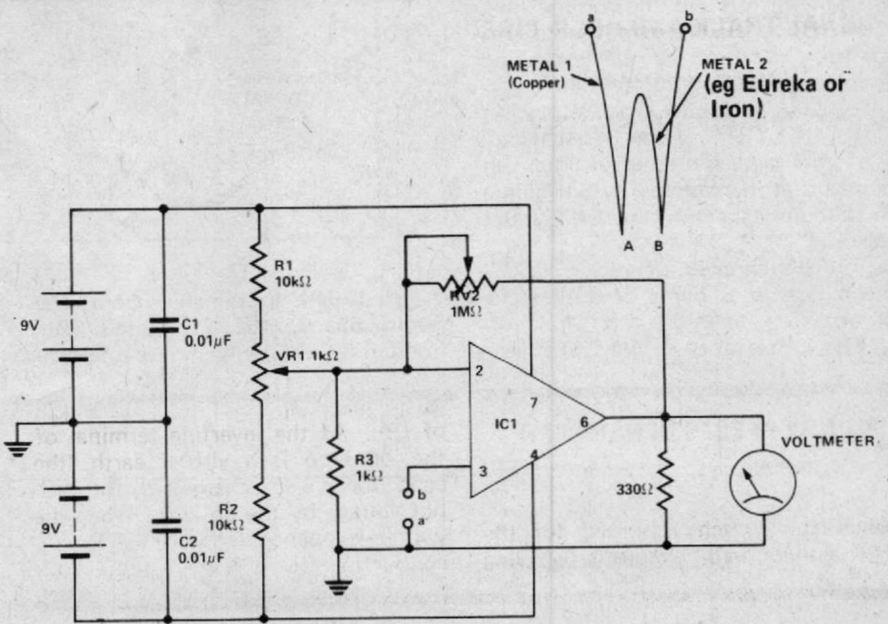
Tech-Tips is an ideas forum and is not aimed at the beginner. We regret we cannot answer queries on these items.

ETI is prepared to consider circuits or ideas submitted by readers for this page. All items used will be paid for. Drawings should be as clear as possible and the text should preferably be typed. Circuits must not be subject to copyright. Items for consideration should be sent to the Editor, Electronics Today International, 36 Ebury Street, London SW1W 0LW.

gain of the circuit is set high (at 1,000), electrical noise pick-up and drift become serious problems and it is advisable to assemble the circuit in a metal, earthed box and to ensure the unit is kept at constant temperature.

For best results, the power supplies should be stabilised and balanced Capacitors C1 and C2 filter out any electrical noise on the power supply leads; if the thermocouple leads are long, a similar value capacitor across a and b should be used for the same reason.

Calibration and use of the thermometer is carried out by immersing one junction in a liquid at a reference temperature, say melting ice, and using the other junction to monitor the changing temperature.



Connections to IC1 are for 8 pin DIL version of '741'

tech-tips

A DUMMY LOAD FOR HIGH POWER AMPLIFIERS

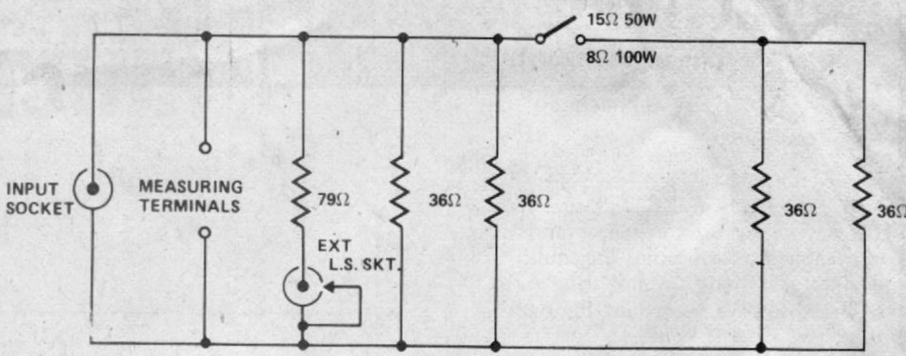
This dummy load will replace the normal big loudspeaker system needed when testing amplifiers of up to 100W rating. The power is absorbed as heat in large resistors and this power can be measured by putting a multimeter (set tp 100V a.c.) across the measuring terminals and using the formula

$$\text{R.M.S. Power} = \frac{(\text{R.M.S. Voltage})^2}{\text{Load Resistance}}$$

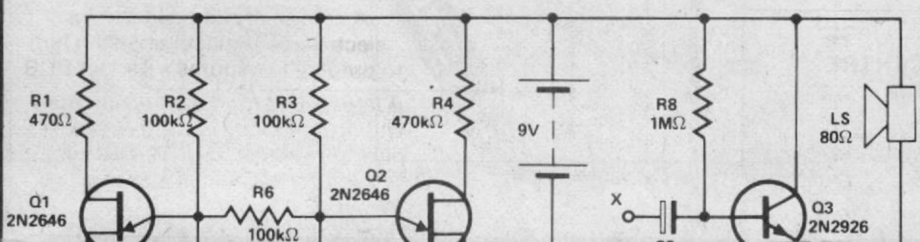
At the same time the amplifier can be heard at low volume by plugging a small loudspeaker into the 'EXT. L.S.' socket.

The switch gives a choice of 100W dissipation at 8 ohms or 50W at 15 ohms.

The resistors are Labgear YJ PL11040 (obtainable from The Radio Shack, 161 St. John's Hill, London S.W.11.) which have one section of 36 ohms at 25W and one section of 79 ohms at 9W. They should be mounted in a well ventilated box.

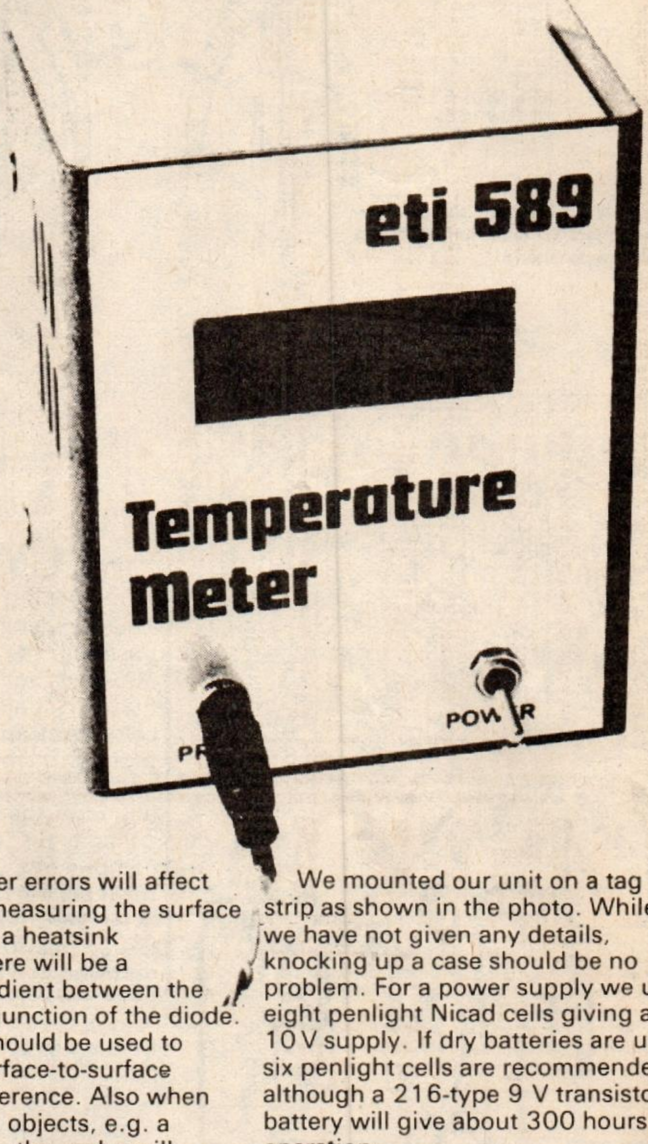


SOUND EFFECTS GENERATOR



C1 and C2 begin to charge via resistors R2 and R3, respectively. Owing to the smaller time constant of the R3/C2 combination, UJT Q2 discharges before Q1, the pulse being fed to the speaker via C3 and the Darlington-pair amplifier consisting of Q3 and Q4. Meanwhile C1 is much more slowly charging so that the next time that C2 begins to charge there is small

TEMPERATURE METER



A simple yet accurate temperature meter based on the LCD panel meter published in our March issue.

THE RELIABILITY of electronic circuits in the days of valves was, to say the least, poor by today's standards. The introduction of transistors and integrated circuits increased reliability dramatically. One of the main reasons for this is the reduction of power dissipation and the resultant lowering of temperature. Devices and circuits are now designed to minimise power dissipation as this allows a higher component density while increasing reliability. However, some circuits by their nature must dissipate high power and the semiconductor devices used must be kept within their temperature limits.

This temperature meter will allow transistor temperatures to be measured and the appropriate heatsink chosen. It is just as useful outside the electronic scene measuring liquid or gas temperature especially where the readout needs to be physically separate from the sensor.

Use and Accuracy

The accuracy of the unit depends on the calibration; provided it has been calibrated around the temperature at which it will be used, accuracy of 0.1 degree should be possible. We could not accurately check linearity but it appeared to be within 1° from 0° to 100° C.

However, other errors will affect this reading. If measuring the surface temperature i.e. a heatsink temperature, there will be a temperature gradient between the surface and the junction of the diode. Silicon grease should be used to minimise the surface-to-surface temperature difference. Also when measuring small objects, e.g. a TO-18 transistor, the probe will actually cool the device slightly. At high temperatures these effects could give an error of up to 5% (the reading is always less than the true value). If the probe is in a fluid (eg water) or air this problem does not occur.

Construction

Assemble the panel meter as previously described but omitting the zener diodes and R6 and R7. The value of R1 has also been changed. The decimal point drive should be connected to the righthand decimal point. The additional components can be assembled on a tag strip as shown.

We mounted our unit on a tag strip as shown in the photo. While we have not given any details, knocking up a case should be no problem. For a power supply we used eight penlight Nicad cells giving a 10 V supply. If dry batteries are used six penlight cells are recommended although a 216-type 9 V transistor battery will give about 300 hours of operation.

The sensor should be mounted in a probe as shown in Fig. 1 if other than air temperature will be measured. This provides the electrical insulation needed for working in liquids etc. It should be noted however that the quick dry epoxies are not normally good near or above 100° C and if higher temperatures than this are expected one of the slow dry epoxies should be used.

Calibration

To calibrate this unit two accurately known temperatures are required, one of which is preferably zero degrees and the second in the area ▶

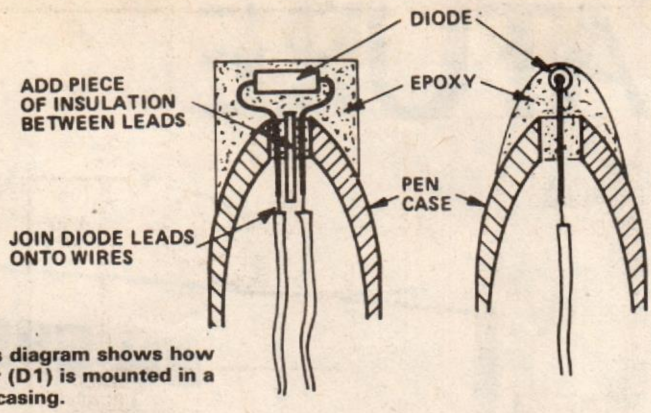


Fig.1. This diagram shows how the sensor (D1) is mounted in a ball-point casing.

HOW IT WORKS

While the voltage across a silicon diode is nominally about 600 mV it is dependent upon the ambient temperature and current in the device. The temperature coefficient is negative, i.e. the voltage falls with increasing temperature but fortunately is linear in the region of interest. The actual value varies with current and from device to device, but is typically —2.2 mV/° at 250μA.

By measuring the voltage across the diode with a suitable offset voltage to balance the voltage at zero degrees an accurate temperature meter results. The digital panel meter described in October has a stable reference voltage avaliable (between pins 1 and 32) of about 2.9 V; with the 10k resistor R11 this provides a constant current for D1 (the sensor). The offset voltage is also derived from this reference voltage by R12, RV2 and RV3. The panel meter is used as a differential voltmeter and measures the potential difference between the offset voltage and the diode. We have used two trimpots in series in the offset adjustment to give better resolution. If desired a 10-turn trimpot can be used (2k2). Adjustment of the three potentiometers allows the meter to be calibrated in either °C or °F with the upper limit of 199.9°F due to the panel meter over-ranging.

The power supply is simply a 9 V battery, and so the zener diodes and dropping resistors described in the panel meter article should be omitted.

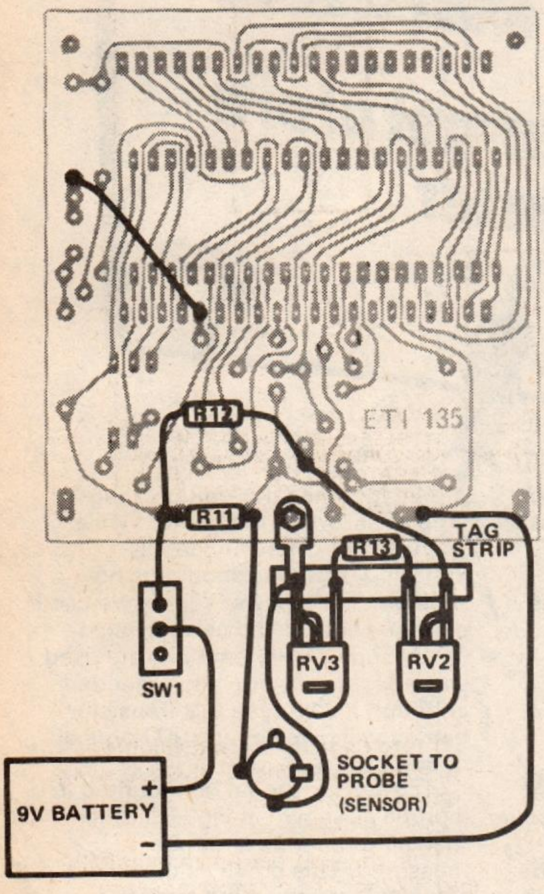
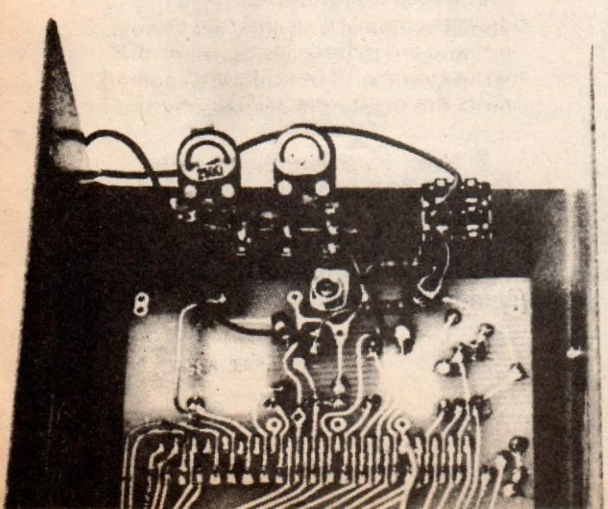


Fig.2. The external components associated with the panel meter to form the thermometer. For full details of the panel meter (foil pattern etc.) see the March 78 issue of ETI.

BUYLINES

The original LCD meter was based on the Intersil evaluation kit but since then a number of advertisers have put together kits for our project. Such a kit is probably the best place to start although the ICL7106 and suitable displays, the only components likely to prove difficult to find, are now available from most of the larger mail order firms advertising in ETI.



The photograph (left) shows the external components, detailed in Fig.2, in position.

PARTS LIST

RESISTORS

R1, 11	10k
R2	47k
R3, 9	100k
R4	not used
R5	1M
R6, 7	not used
R8, 10	4M7
R12	27k
R13	5k6

POTENTIOMETERS

RV1	1k 10 turn trim
RV2	2k preset
RV3	200R preset

CAPACITORS

C1	100n polyester
C2	470n polyester
C3	220n polyester
C4	100p ceramic
C5, 6	10n polyester

SEMICONDUCTORS

IC1	ICL7106
Q1	BC549
D1	1N914

MISCELLANEOUS

PCB as LCD Panel Meter (March 78 *ETI*), tag strip, LCD display, socket for display, box, switch and 9 V battery.

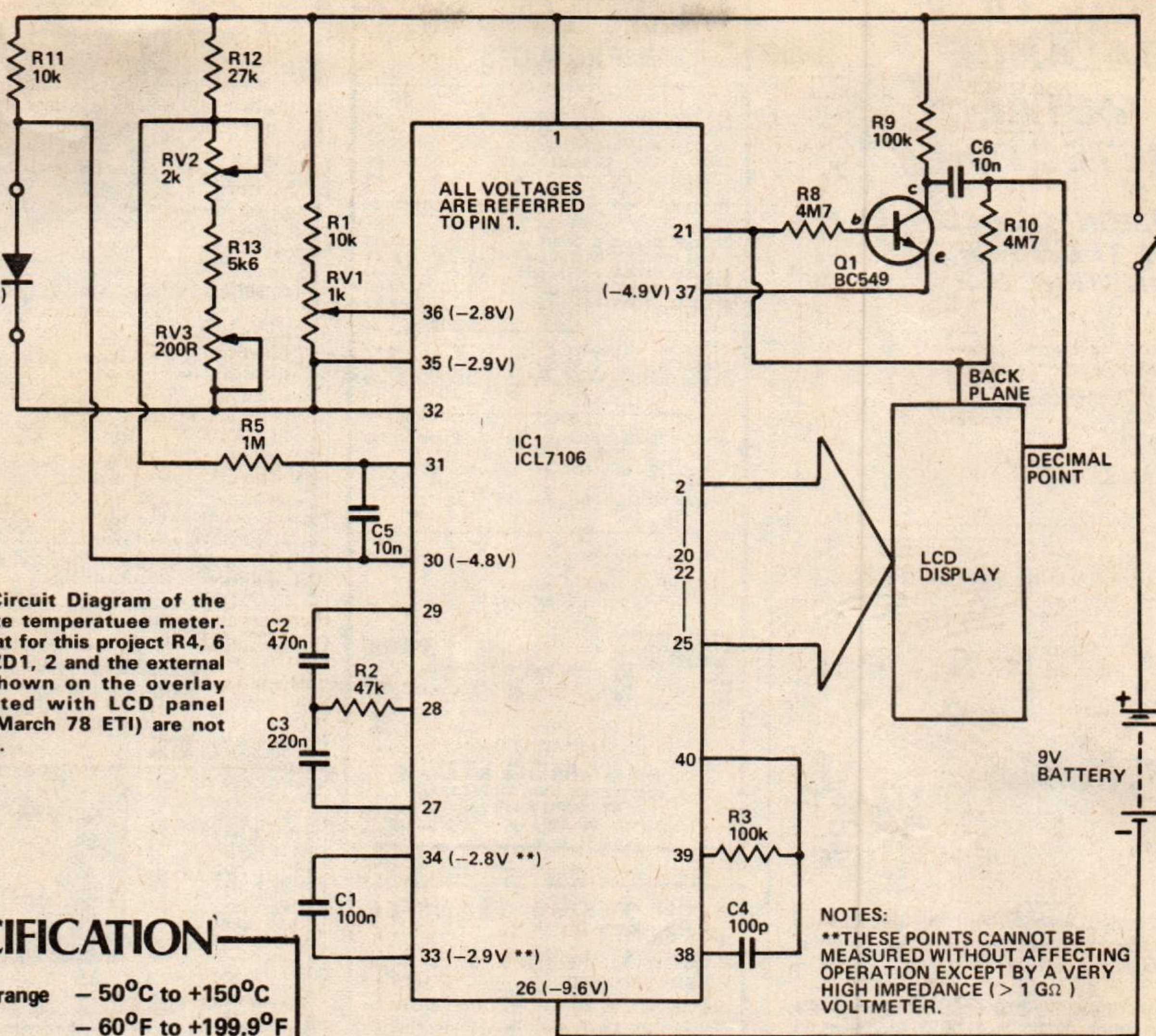


Fig.3. Circuit Diagram of the complete temperatuee meter. Note that for this project R4, 6 and 7; ZD1, 2 and the external leads shown on the overlay associated with LCD panel meter (March 78 ETI) are not required.

SPECIFICATION

Temperature range	**− 50°C to +150°C** **− 60°F to +199.9°F**
Resolution	**0.1°C or F**
Sensor	**silicon diode**
Power consumption	**1.5mA @ 9 V dc**

where the meter will normally be used and highest accuracy is required. For a general-purpose unit 100°C is suitable. The easiest way of obtaining these references is by heating or cooling a container of distilled water. However temperature gradients can cause problems, especially at zero degrees.

One method of obtaining water at exactly zero degrees is to use a test tube of distilled water in a flask of iced water and allowing it to cool to near zero. Now by adding salt to the iced water its temperature can be lowered to below zero. If you are very careful, the test tube water will also drop below zero without freezing (you should be able to get to about −2°C). However, the slightest disturbance at this temperature will instantly cause some of the water to freeze and the remaining water to rise to exactly zero, providing an ideal reference.

For a hot reference the boiling point of distilled water is very close to 100°C especially if the container has a solid base and is evenly heated e.g. on an electric hotplate.

The actual calibration is done as follows:

1. In the 0°C reference adjust RV2 and RV3 until the unit reads zero.
2. In the hot reference adjust RV1 to give the correct reading.

This should be all the adjustment required.

If zero degrees is not available, e.g. if setting up for °F, the following method can be used:

1. In the cold reference use RV2 and RV3 to adjust reading to zero.

2. In the hot reference use RV1 to adjust the reading to indicate the temperature difference between the two standards. If freezing and boiling points are used, this will be 180°F.

3. Now, back in the cold bath, adjust RV2 and RV3 to give the correct reading.

No further adjustment should be required. ETI

Digital thermometer circumvents drift

by Henry Wurzburg and Mike Hadley
Motorola Semiconductor Products Inc., Phoenix, Ariz.

A direct-reading thermometer that measures temperature digitally can be built from a diode sensor and an analog-to-digital converter, without any buffers or operational amplifiers. The temperature-drift errors associated with amplifiers are therefore eliminated, so that, unlike its analog counterpart, the circuit remains calibrated over a wide temperature range—from −199° to 199° in either the Fahrenheit or Celsius scales. The circuit resolution of 0.1° is primarily limited by the 3½-digit a-d converter.

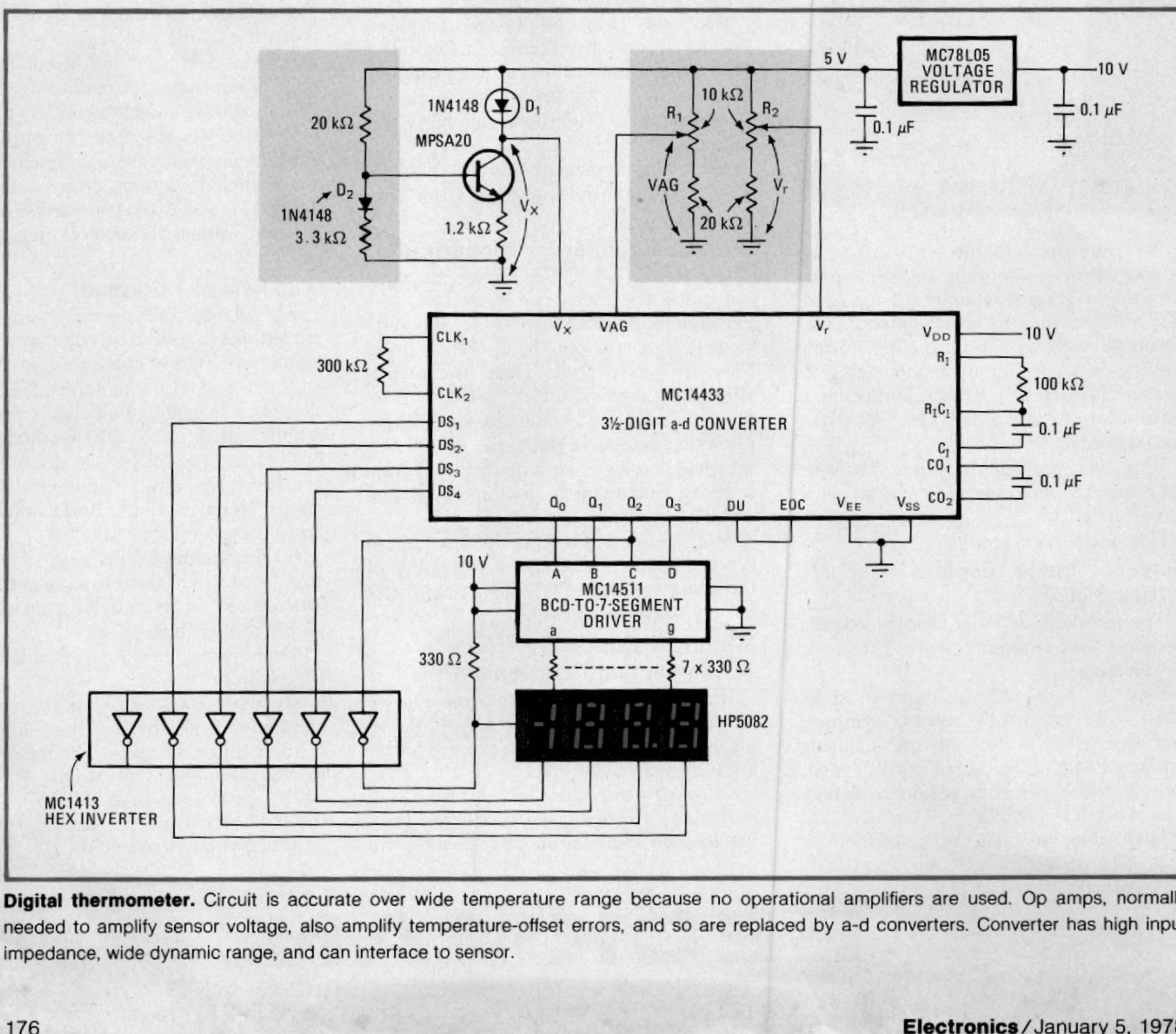
The figure shows the MC14133 converter chip changing the output voltage of D_1, a 1N4148 silicon temperature sensor, into a binary-coded-decimal number. The auto-zero and auto-polarity features of the chip ensure that its operation is virtually unaffected by temperature changes. More important, its high-impedance differential input circuit, with its wide, 200-millivolt-to-2-volt range of full-scale input voltages, allows the chip to be directly connected to the diode sensor, despite the latter's low output voltage, so that there is no need for intervening buffers or amplifiers that would amplify temperature-offset errors.

The MPSA20 transistor and associated network supply a suitable operating bias to D_1. The effect of temperature on the bias network, and thus output current, is extremely low.

Output count of the converter (see figure) is:

$$C = [(V_x - VAG)/(V_r - VAG)] \times 2{,}000$$

This number is displayed by the HP5082 displays with the aid of the MC14511 BCD-to-seven-segment decoder



Digital thermometer. Circuit is accurate over wide temperature range because no operational amplifiers are used. Op amps, normally needed to amplify sensor voltage, also amplify temperature-offset errors, and so are replaced by a-d converters. Converter has high input impedance, wide dynamic range, and can interface to sensor.

drivers and one MC1413 hexadecimal inverter.

To calibrate the circuit, the sensor temperature should be kept at 0°C or 0°F while R_1 is adjusted until the display reads 0. The sensor is then brought to a temperature of 199° (or to a lower temperature if decreased accuracy is acceptable), and R_2 is adjusted until the display matches the sensor temperature. V_r must be greater than VAG during all phases of the calibration in order for the converter to function properly.

Using a standard diode sensor limits the error of the system to no greater than 1.0°. However, diode sensors with an error of less than 0.6°C are available from Motorola on a special-order basis. □

Engineer's notebook is a regular feature in *Electronics*. We invite readers to submit original design shortcuts, calculation aids, measurement and test techniques, and other ideas for saving engineering time or cost. We'll pay $50 for each item published.

PROM converts weather data for wind-chill index display

by Vernon R. Clark
Applied Automation Inc., Bartlesville, Okla.

A programmable read-only memory and four arithmetic/logic units can convert air-temperature and wind-speed data in real time into wind-chill temperature, which is displayed on a direct numerical readout.

The wind-chill equation adopted by the National Weather Service is:

$$H = (100w^{1/2} + 10.45 - w)(33 - T_a)$$

where H is the heat loss in kilogram-calories per square meters per hour, w is the wind speed in meters per second, and T_a is the actual air temperature in °C. A modified form of this equation is the basis for the well-known wind-chill temperature chart issued by the service. In this circuit, the PROM is programmed so that, in combination with the arithmetic/logic units, it will generate output values identical to those in the chart for a wide range of air temperatures and wind speeds.

Basically, the circuit determines from the incoming data the apparent temperature change (T_c) caused by the wind. Then, it adds or subtracts T_c from T_a to find the equivalent temperature (T_e).

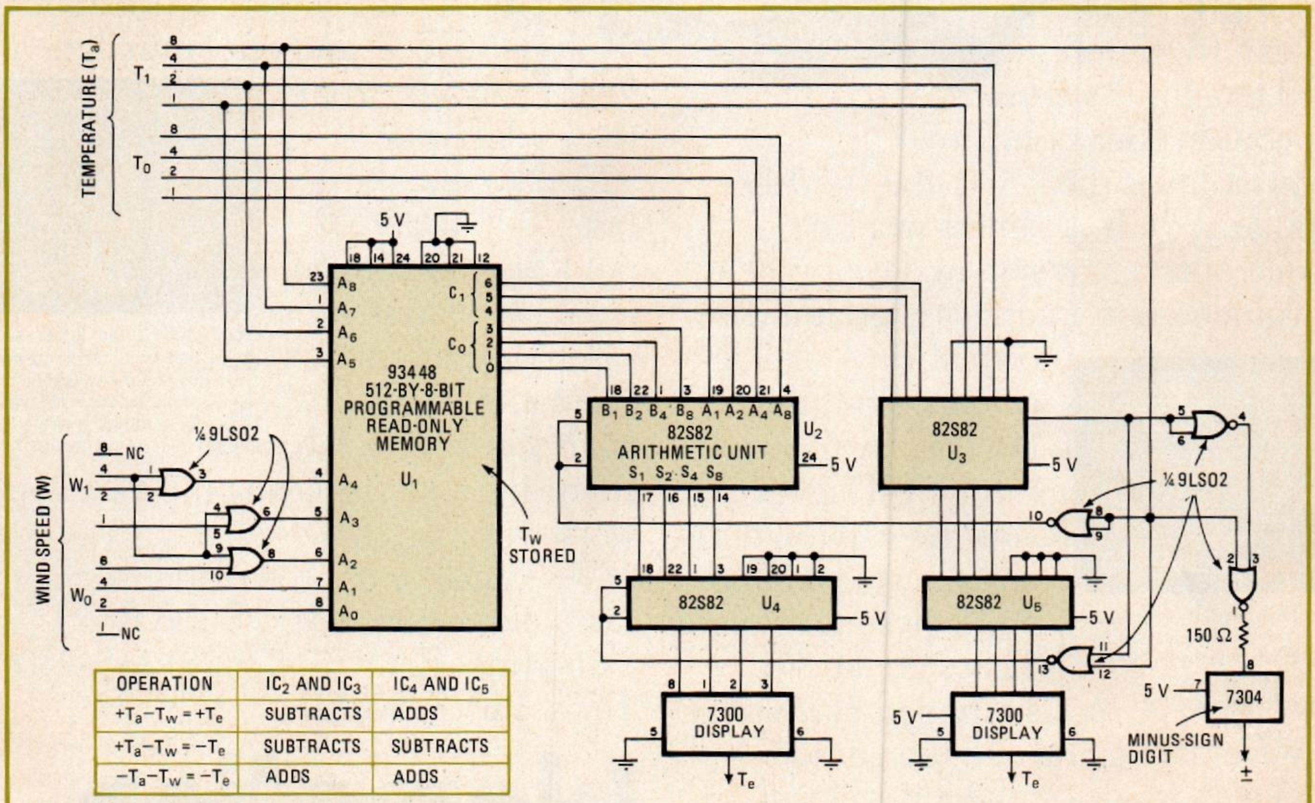
The T_c values are programmed into the PROM for all combinations of air temperature and wind speed over the range:

$$-60F \leq T_a \leq 50F \text{ (10 increments)}$$
$$0 \leq w \leq 46 \text{ miles per hour (2 mph increments).}$$

The circuit must relate each T_a and w to each T_c to find the equivalent temperature.

As shown in the figure, each T_c may be accessed by introducing air-temperature and wind data, in binary-coded-decimal form, to the PROM (U_1) address lines. The actual values of T_c programmed in the PROM are shown in the table.

The value of T_c appearing at the output, for a given T_a and w, is introduced to two ALUs, U_2 and U_3. Also driving U_2 and U_3 is the T_a data. The ALUs compute the magnitude and sign of T_e by adding T_a and T_c. U_4 and U_5 perform a 10's complement operation in order to drive the 7300 displays properly. The operation of all four ALUs is summarized in the figure.



OPERATION	IC_2 AND IC_3	IC_4 AND IC_5
$+T_a - T_W = +T_e$	SUBTRACTS	ADDS
$+T_a - T_W = -T_e$	SUBTRACTS	SUBTRACTS
$-T_a - T_W = -T_e$	ADDS	ADDS

Cold solution. Circuit determines and displays wind-chill temperature (T_e). Air temperature (T_a) and wind-speed data (w) address PROM lines to access apparent temperature change (T_c) brought about by given w at T_a. Arithmetic/logic units U_2 and U_3 add T_a and T_c to find T_e. U_4 and U_5 perform a 10's complement operation for the digital display units, for which they serve as an interface.

PROM CONTENTS — WIND-CHILL INDICATOR

LOC		LOC		LOC		LOC		LOC	
0000R	0002	0070R	2628	00E0R	0000	0150R	4750	01C0R	0004
0002R	0409	0072R	3030	00E2R	0000	0152R	5355	01C2R	0714
0004R	1500	0074R	3100	00E4R	0000	0154R	5700	01C4R	2500
0006R	0000	0076R	0000	00E6R	0000	0156R	0000	01C6R	0000
0008R	2125	0078R	3233	00E8R	0000	0158R	5960	01C8R	3543
000AR	2933	007AR	3434	00EAR	0000	015AR	6162	01CAR	5055
000CR	3700	007CR	3637	00ECR	0000	015CR	6365	01CCR	6000
000ER	0000	007ER	3738	00EER	0000	015ER	6667	01CER	0000
0010R	3941	0080R	0001	00F0R	0000	0160R	0003	01D0R	6468
0012R	4344	0082R	0205	00F2R	0000	0162R	0511	01D2R	7275
0014R	4600	0084R	0900	00F4R	0000	0164R	2000	01D4R	7800
0016R	0000	0086R	0000	00F6R	0000	0166R	0000	01D6R	0000
0018R	4849	0088R	1215	00F8R	0000	0168R	2834	01D8R	8082
001AR	5051	008AR	1719	00FAR	0000	016AR	4044	01DAR	8485
001CR	5354	008CR	2100	00FCR	0000	016CR	4800	01DCR	8890
001ER	5556	008ER	0000	00FER	0000	016ER	0000	01DER	9294
0020R	0002	0090R	2223	0100R	0002	0170R	5255	01E0R	0000
0022R	0407	0092R	2425	0102R	0409	0172R	5759	01E2R	0000
0024R	1300	0094R	2600	0104R	1500	0174R	6200	01E4R	0000
0026R	0000	0096R	0000	0106R	0000	0176R	0000	01E6R	0000
0028R	1923	0098R	2728	0108R	2125	0178R	6466	01E8R	0000
002AR	2730	009AR	2929	010AR	2933	017AR	6768	01EAR	0000
002CR	3300	009CR	3031	010CR	3700	017CR	7071	01ECR	0000
002ER	0000	009ER	3132	010ER	0000	017ER	7273	01EER	0000
0030R	3537	00A0R	0000	0110R	3941	0180R	0004	01F0R	0000
0032R	3840	00A2R	0203	0112R	4344	0182R	0612	01F2R	0000
0034R	4200	00A4R	0700	0114R	4600	0184R	2200	01F4R	0000
0036R	0000	00A6R	0000	0116R	0000	0186R	0000	01F6R	0000
0038R	4343	00A8R	1012	0118R	4849	0188R	3036	01F8R	0000
003AR	4445	00AAR	1415	011AR	5051	018AR	4247	01FAR	0000
003CR	4749	00ACR	1700	011CR	5354	018CR	5200	01FCR	0000
003ER	5051	00AER	0000	011ER	5556	018ER	0000	01FER	0000
0040R	0002	00B0R	1818	0120R	0002	0190R	5660	0200R	
0042R	0407	00B2R	1920	0122R	0409	0192R	6365		
0044R	1200	00B4R	2100	0124R	1700	0194R	6700		
0046R	0000	00B6R	0000	0126R	0000	0196R	0000		
0048R	1620	00B8R	2222	0128R	2329	0198R	6971		
004AR	2426	00BAR	2323	012AR	3337	019AR	7374		
004CR	2800	00BCR	2425	012CR	4100	019CR	7677		
004ER	0000	00BER	2526	012ER	0000	019ER	7879		
0050R	3032	00C0R	0000	0130R	4346	01A0R	0004		
0052R	3436	00C2R	0000	0132R	4850	01A2R	0613		
0054R	3700	00C4R	0000	0134R	5200	01A4R	2300		
0056R	0000	00C6R	0000	0136R	0000	01A6R	0000		
0058R	3839	00C8R	0000	0138R	5354	01A8R	3340		
005AR	4040	00CAR	0000	013AR	5657	01AAR	4652		
005CR	4142	00CCR	0000	013CR	5960	01ACR	5600		
005ER	4243	00CER	0000	013ER	6162	01AER	0000		
0060R	0002	00D0R	0000	0140R	0002	01B0R	6064		
0062R	0306	00D2R	0000	0142R	0510	01B2R	6770		
0064R	1000	00D4R	0000	0144R	1800	01B4R	7300		
0066R	0000	00D6R	0000	0146R	0000	01B6R	0000		
0068R	1418	00D8R	0000	0148R	2632	01B8R	7577		
006AR	2022	00DAR	0000	014AR	3640	01BAR	7980		
006CR	2400	00DCR	0000	014CR	4400	01BCR	8283		
006ER	0000	00DER	0000	014ER	0000	01BER	8485		

Wind speed frequently varies over a wide range in a short time. This may cause rapid flickering of the display and make it hard to determine the average wind-chill temperature. One answer to this problem is to sample the input data periodically. Another is to use average-value sensor circuits for smoothing the data. □

Build a
Diode Temperature Probe

Low-cost sensor gives temperature reading on a DMM

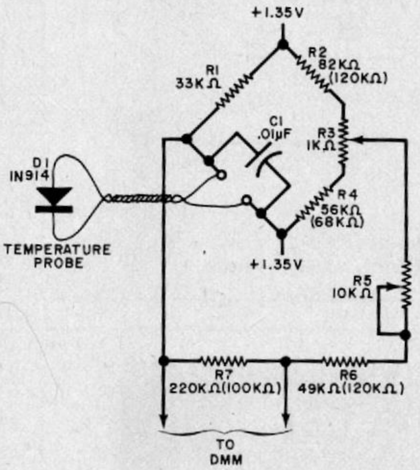


Fig. 1. Diode is one leg of a Wheatstone bridge connected to DMM.

IF YOU own a digital multimeter (DMM), it can be made to give temperature readings for a small expenditure in parts and effort. When a small forward bias is applied to a conventional silicon diode, the voltage drop across the diode junction changes at a rate of about 1.25-mV/°F (2.24-mV/°C). Thus, a low-cost and readily available diode such as the 1N914 can be used as a temperature probe.

The bridge circuit shown in Fig.1 works in conjunction with the sensor diode and a DMM on the 200-mV (low temperature) or 2-volt (high-temperature dc voltage ranges.The displayed digits are the temperature. Note that in Fig. 1, two values are shown for *R2*, *R4*, *R6*, and *R7*. The values in parenthesis are for Celsius operation, while the others are for Fahrenheit. Capacitor *C1* is used to bypass stray signals that may be picked up on the leads.

Construction. The circuit can be assembled on a small printed-circuit or perforated board. The small circles at *C1* indicate the need for a pc pad, or WireWrap pin to make the connections to the remote diode.

To make the temperature probe safe for liquid immersion, the arrangement shown in Fig. 2 is used. Preform a short length of vinyl tubing, fill it with epoxy, and "thread" it up the diode leads to make contact with the diode body. Allow the epoxy to thoroughly cure. If desired, a length of heat-shrink tubing may be used. In either case, leave a short length of diode lead exposed for soldering to the flexible cable.

Slide a short length of heat-shrink tubing over the covered diode leads, solder each diode lead to the flexible cable, and then fit the tubing over the solder joint. Shrink the tubing to make a tight fit.

PARTS LIST

C1—0.01-μF disc capacitor
D1—1N914 silicon diode
R1—33 kΩ, ½-W resistor
R2—82 kΩ (F) or 12 kΩ (C) ½-W resistor
R3—1-kΩ pc-mount potentiometer
R4—56 kΩ (F) or 68 kΩ (C) ½-W resistor
R5—10 kΩ pc-mount potentiometer
R6—49 kΩ (F) or 120 kΩ (C) ½-W resistor
Misc.—1.35-volt battery and holder, vinyl or heat-shrink tubing, flexible two-conductor cable, epoxy, solder, etc.

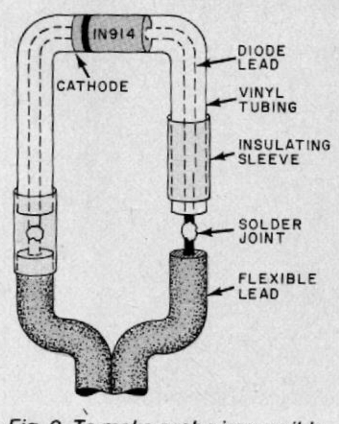


Fig. 2. To make probe immersible, vinyl tubing is added around leads.

Calibration. The resistance values for *R2-R4* and *R6-R7* are not critical, but their *ratios* are. Perform the following calibration tests before changing any resistance value.

Potentiometer *R3* balances the bridge to indicate 32°F (0°C) at this temperature. Potentiometer *R5* is used to reduce the 1.25 (2.24) mV/degree to exactly 1 mV/degree and is also used to set the upper range point.

With *R3* and *R5* at their center of rotation, immerse the diode probe in a container of finely shaved or crushed ice. Adjust *R3* to produce a DMM indication of 32 (°F) or 0 (°C). Place the DMM in the 2-volt dc range, immerse the probe in a container of boiling water, and adjust *R5* for a DMM indication of 212 (°F) or 100 (°C).

If you find that *R3* is at one end of its rotation, add a parallel resistor in the megohm range across either *R2* or *R4*, depending on the location of the wiper of *R3*. If *R5* is at one end of its rotation, add a parallel resistor (also in the megohm range) across *R6* or *R7*. If desired, a 10-turn trimmer potentiometer can be used for each of the fixed resistors and preset for the correct ratios.

Since the DMM will also indicate negative voltages, it will similarly indicate temperatures below those at which it is calibrated. Also, the diode can operate at temperatures above 212°F, which is about the limit for the plastic insulation used for the diode leads, so a plastic with a higher temperature rating can be used to liquid-proof the sensor. Or, without such protection, the sensor can be used for dry, or contact, temperature measurements. ◇

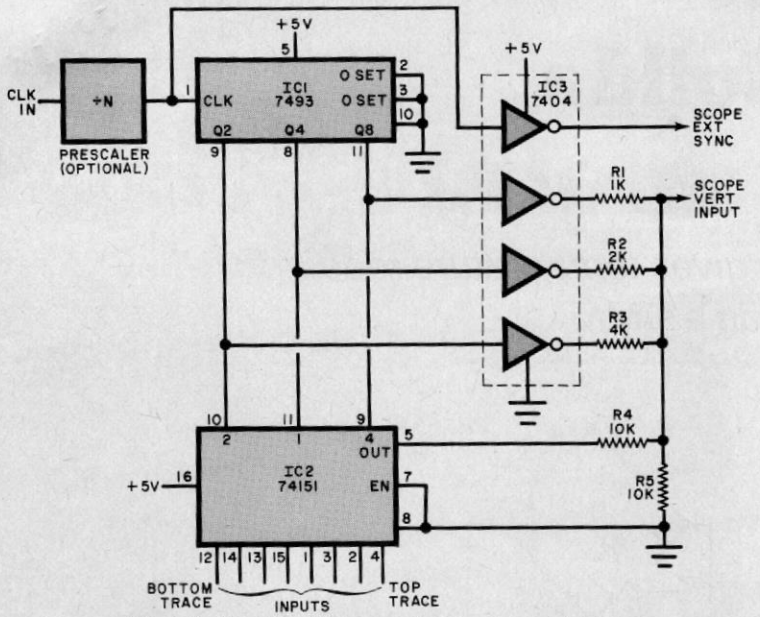
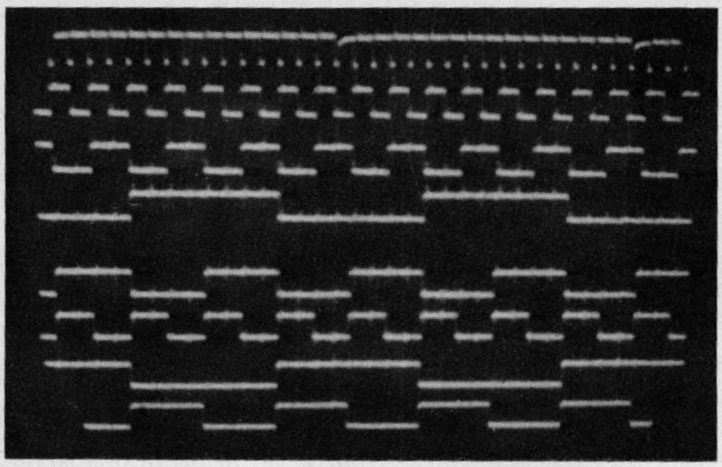


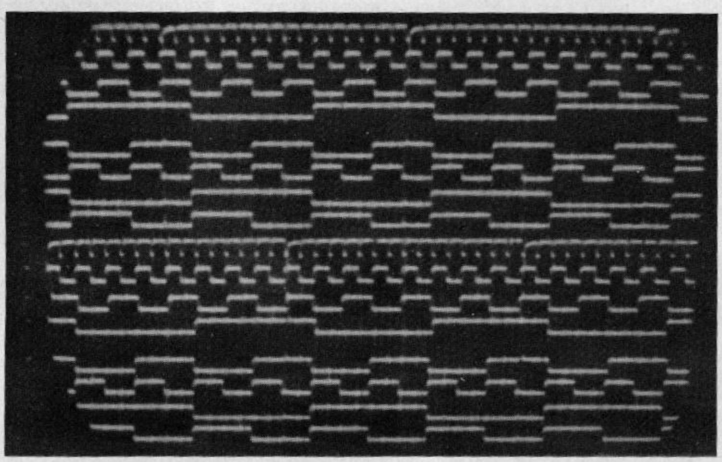
Fig. 1. Rudimentary D/A converter creates an eight-step wavefrom. Scope sweep adjustment produces eight traces.

PARTS LIST

IC1—7493 divide-by-16 counter
IC2—741511-of-8 data selector
IC3—7404 hex inverter
R1—1-kΩ, ½-W resistor
R2—2.2-KΩ, ½-W resistor (see text)
R3—4.7-KΩ, ½-W resistor (see text)
R4,R5—10-kΩ, ½-W resistor
Misc.—Optional prescalers, scope connectors, 8-lead ribbon cable (color coded), grommets, suitable enclosure, miniature test clips (Radio Shack 270-372, Calectro F2-916, or similar), 14- or 08 16-pin IC clamp on, mounting hardware, etc.



Display of eight traces from a typical counter.



Sixteen-trace synthethis using a dual trace scope.

Construction. The simple circuit can be assembled on a small perforated (or a home-made pc) board, leaving room for two or three optional ICs. The basic circuit consists of IC1, IC2, IC3 and the five resistors.

Once assembled, the board can be mounted in a small enclosure; and, if desired, a low-power 5-volt supply can be added. Since the basic circuit requires about 72 mA, the analyzer can be powered from the circuit under test.

The scope sync and vertical input connectors can be mounted anywhere on the enclosure, while the 8-lead ribbon cable (one lead for each data selector input) exits via a grommetted hole. The +5-volt, ground, and clock leads exit via their own protected hole.

The 11 leads can be terminated as desired. The prototype used miniature test clips (Radio Shack 270-372, Calectro F2-916, or similar) to make the closely spaced IC pin connections. To examine a single IC, a 14- or 16-pin IC clamp-on may be used. When using such a clamp-on, the +5 volts and ground can be taken from the IC. Some form of identification must be used on each of the eight data leads.

Use. Connect the status analyzer to the +5 volts, ground, and clock of the circuit under test. Connect the analyzer ground and output to the scope ground and vertical input, and the sync to the scope external sync input. With operating power applied, adjust the scope sweep for eight discrete traces.

Any or all of the eight analyzer inputs can be connected to the logic under test. Adjust the scope sweep and sync for a stable display. Once this is done, the value of *R4* can be selected for the desired signal height on the traces. To avoid confusion, make sure that the signals do not overlap. Resistor *R5* can be selected for a convenient signal level input for the scope.

Although this circuit is realized with TTL chips, a resourceful experimenter could build one using CMOS logic, following the same approach. ◇

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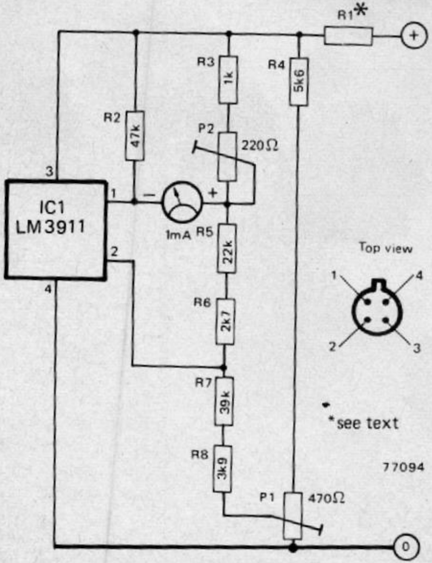
room thermometer

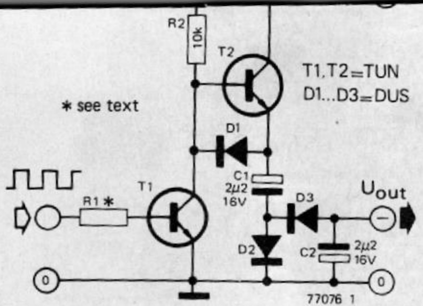
Using a National LM3911 IC, a 1 mA meter and a few resistors it is a simple matter to construct a thermometer to measure over the temperature range −20° to +50°C, which should be adequate for all but polar climates! As the circuit is intended as a room thermometer the entire circuit operates at the temperature which is being measured, so the resistors used should be low-temperature coefficient types to maintain the accuracy of the circuit.
To calibrate the thermometer the meter scale must first be marked out linearly from zero = −20° to full-scale = +50°. With P2 set to its mid-position the circuit should be placed in a freezer or the freezing compartment of a refrigerator set to −20°C and P1 should be adjusted until the meter reads −20. The circuit should then be placed in a temperature of +50°C and P2 adjusted until the meter reads 50. Of course it is also possible to mark out the scale from 0°F to 120°F and calibrate zero and full-scale accordingly.
P1 and P2 interact to a small extent, so it may be necessary to repeat the procedure several times until both the −20 and +50 readings are accurate.
As the IC contains its own stabiliser the

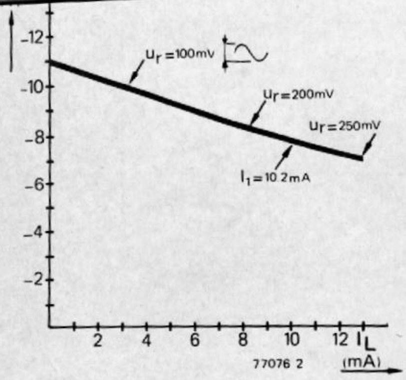


supply voltage is not critical provided the value of R1 is chosen so that about 3 mA flows through it. The value of R1 is given by

$$R1 = \frac{V_b - 6}{3}\ (k\Omega).$$

negative supply from positive supply





It is sometimes necessary to provide a negative supply voltage in a circuit that otherwise uses all positive supply voltages, for example to provide a symmetrical supply for an op-amp in a circuit that is otherwise all logic ICs. Providing such a supply can be a problem, especially in battery operated equipment.

In the circuit shown here T1 is turned on and off by a squarewave signal of 50% duty-cycle at approximately 10 kHz. In logic circuits it is quite conceivable that such a signal may already be available as clock pulses. Otherwise an oscillator using two NAND gates may be constructed to provide it.

When T1 is turned off, T2 is turned on and C1 charges through T2 and D2 to about 11 V. When T1 turns on, T2 turns off and the positive end of C1 is pulled down to about +0.8 V via D1. The negative end of C1 is now about 10.2 V negative so C1 discharges through D3 into C2, thus charging it. If no current is drawn from C2 it will eventually charge to around −10 V. Of course, if a significant amount of current is drawn, the voltage across C2 will drop as shown in the graph and a 10 kHz ripple will appear on the output.

BY THOMAS R. FOX

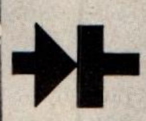
SOME LIKE IT HOT...

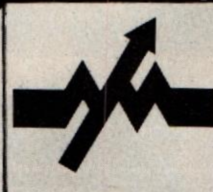
But which ones?
Test your knowledge of how circuit components respond to temperature.

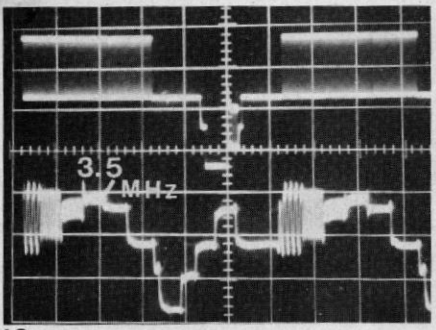
SOME electronic components, especially semiconductors, are extremely sensitive to temperature changes. Even passive components (resistors and capacitors, for example), which are normally insensitive to temperature variations, can undergo parameter changes that are sometimes sufficient to influence circuit behavior.

Here is a quiz that will check your knowledge of how the parameters of some common electrical components (as well as a few rare ones) change with temperature. The quiz gives you the common name and electrical symbol or pictorial representation of the components and the parameters of interest under temperature change (resistance, voltage, etc.).

Your task is to answer the following questions about each component: (A) Does the parameter of interest increase or decrease as the component's temperature increases from 68°F (20°C) to 95°F (35°C)? (B) Is the component frequently used in temperature measuring, control, or compensation circuits? As an example, for component No. 1, the thermistor, the answers are: (A) Decrease; (B) Yes. Answers for the rest are on the third page of the quiz. If you get 35 correct answers out of the total 50, you have done very well indeed.

Component	Symbol	Parameter of interest
1 Thermistor		Resistance
2 Silicon diode		Forward voltage drop
3 Silicon photovoltaic cell (Solar cell)		Power output
4 Copper wire		Resistance

Component	Symbol	Parameter of interest
5 Platinum wire		Resistance
6 Electrolytic capacitor (A1)		Capacitance
7 Polystyrene capacitor		Capacitance
8 NPO-type capacitor		Capacitance



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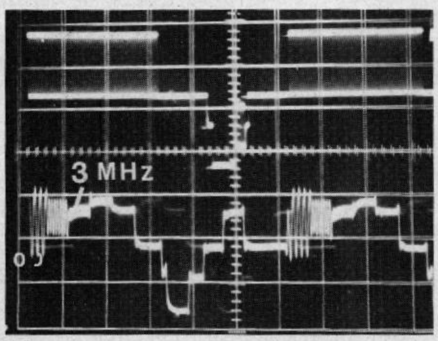

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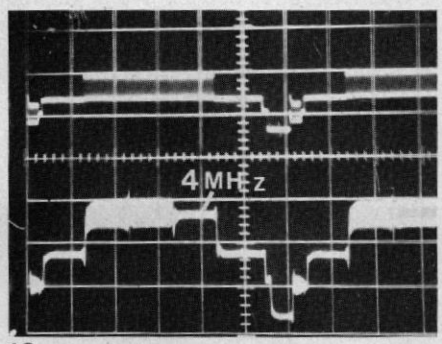

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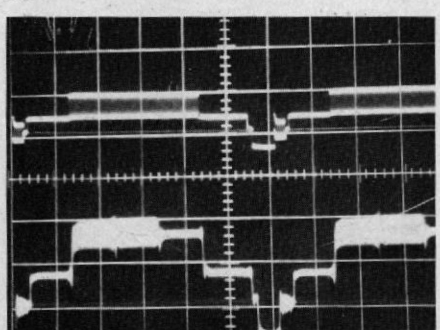

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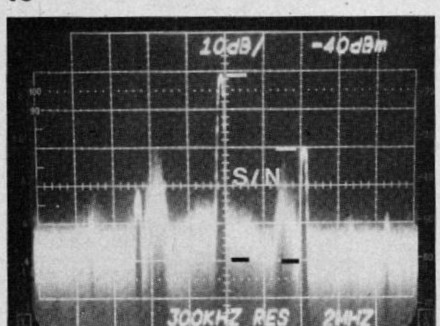

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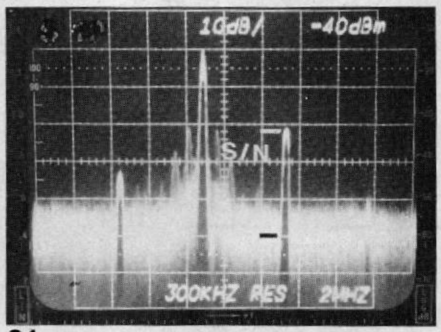

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Figures 1 through 9 on the opposite page are performance characteristics for the Zenith/Beta system. Figure 1 is multiburst response during record; Fig. 2 still during record is swept chroma. Multiburst baseband response during playback for Beta II and Beta III are in Figs. 3 and 4; with similar chroma playback baseband in Fig. 5 (Beta II) and Fig. 6 (Beta III). Beta II/Beta III multiburst playback through the modulator is shown in Fig. 7 with swept chroma response in Fig. 8. Figure 9 is a spectrum analyzer display of the Beta's audio and video carriers at antenna terminals. Figures 10 through 21 are for the Pansonic PV-1750. Figures 10 and 11 are responses in luminance and chroma in record mode and SP. Baseband for SP and SLP are in Figs. 12 and 13, with swept chroma in Figs. 14 and 15. Figures 16 and 17 are responses through the r-f modulator for SP and SLP, while Figs. 18 and 19 are the same for swept chroma. Figures 20 and 21 are spectrum analyzer displays for the SP and SLP modes.

2-MHz per horizontal division and 10-dB per vertical division, and −40+ (+5.72) dBm down, you see the video carrier and its two sidebands and the unmodulated audio carrier on the right. With the noise center as reference, the video carrier has a S/N ratio of 49 dB, while the audio carrier shows 36 dB.

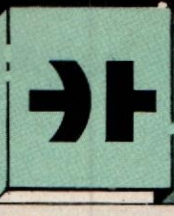
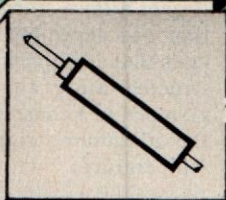
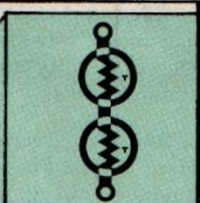
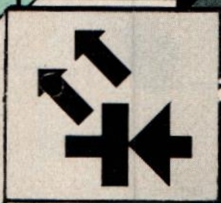
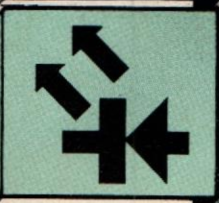
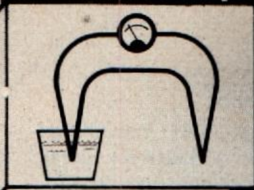
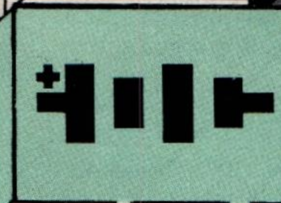
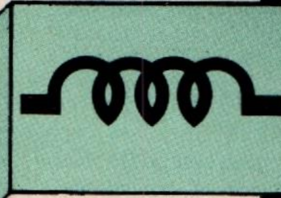
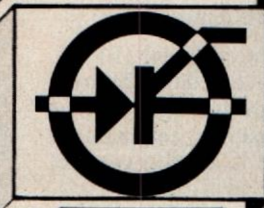
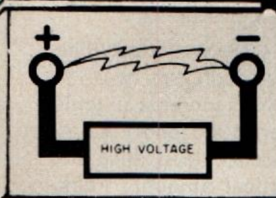
The Panasonic PV-1750 waveforms, Figs. 10 through 16, precisely match those for Beta. However, since there are some additional differences between SP and SLP that require illustrating, the Panasonic group continues to Fig. 21.

Figures 10 and 11 show good responses in luminance and chroma out to 4 MHz with the player in record mode in the SP position. As you can see, most of these are exceptional. Figures 12 and 13 are SP and SLP, respectively, with 3.5 MHz plainly visible in SP, and only about 3 MHz in SLP at baseband via camera and video input/output. Figures 14 and 15 show relatively little difference in swept chroma, except that the 4.08 MHz seems to be down a bit more. In Figs. 16 and 17, responses through the r-f modulator into the TV receiver are exceptional for a VCR, as are the other parameters, including a slightly distorted (rounding) staircase. Figures 18 and 19 show swept chroma passing through the modulator, with the 4-MHz portion, well down, as is to be expected. Figures 20 and 21 are spectrum-analyzer displays for the SP and SLP modes. Observe that the S/N ratio is 49 dB for SP video and 30 dB for audio. In SLP, video drops to about 45 dB, and audio drops to 28 dB.

Conclusions. Both units represent an improvement over their respective predecessors. Images are more distinct, noise is reduced, control flexibility and range are enhanced, and record/play times are considerably longer than they were a few years ago.

But between the formats there are real differences. Beta has an audio S/N ratio about 5 or 6 dB better than VHS, and a frequency response extending to about 10 kHz. VHS, on the other hand, has a wider video bandpass, a video S/N ratio comparable with that of Beta, more program selections, and many more remote-control functions. VHS also plays an hour longer in extended play and has a lighted moisture (dew) sensor. Of course, if your receiver bandpass is too limited, the extra bandwidth of the Panasonic VHS player is of no practical consequence.

The absolute contest between the two systems would be a hookup with your own TV. Both units tested here are of superior quality. The decision as to which type of player is more suitable for you is yours alone. ◇

Component	Symbol	Parameter of interest
9 Class I ceramic capacitor		Capacitance
10 Carbon composition resistor		Resistance
11 Positive temp. coef. silicon resistor		Resistance
12 Insulated test lead		Insulation resistance
13 Thermistor (TC= −1000 ppm/°C) Sensitor TC= +1000 ppm/°C) (Pos. temp. coef.)		Resistance between points A and B (Assume perfect linearity)
14 NPN silicon transistor		DC Beta (current gain)
15 Germanium diode		Reverse leakage current
16 Red LED		Radiant power (light output)
17 Red LED		Wavelength of light (Red = long wave Violet = short wave)
18 Copper-iron thermocouple		Current when temp. of test junction rises
19 Lead-acid storage battery		Capacity
20 Typical primary battery (Zn/C, for example)		Storage life
21 Inductor		Inductance
22 Silicon controlled rectifier		Minimum trigger voltage
23 Passivated alloy silicon diode		Reference voltage
24 7400 TTL gate		Threshold voltage
25 CMOS gate		Transfer voltage
26 Spark gap		Minimum spark voltage

QUIZ ANSWERS

1. See introduction.

2. (A) Decrease; (B) Yes. **Note:** The silicon diode has a relatively linear forward voltage vs. temperature characteristic. It is also low-cost and readily available. However, it is comparatively insensitive.

3. (A) Decrease; (B) No. **Note:** Keeping the cell cool raises efficiency.

4. (A) Increase; (B) No. **Note:** Except possibly at high temperatures, copper's variation of resistance is seldom taken into account in designs.

5. (A) Increase; (B) Yes. **Note:** Platinum makes probably the best of the metallic type of temperature probe. Its advantages are: it can be highly refined; it resists contamination; it is electrically and chemically stable; its resistance characteristic is quite linear; and its drift and error with age are negligible.

6. (A) Increase; (B) No. **Note:** Seldom used in critical circuits.

7. (A) Slight decrease; (B) No. **Note:** The capacitance of polystyrene units varies little with temperature.

8. (A) Almost no change; (B) No. **Note:** NPO (Negative-Positive-Zero) is a temperature compensating dielectric that has an ultrastable temperature characteristic. Used in certain types of ceramic capacitors.

9. (A) Most decrease (B) Yes. **Note:** Some types of Class I ceramic capacitors, which are usually made of titanium dioxide, are frequently used in compensation circuits.

10. (A) Increase; (B) No. **Note:** This workhorse of the resistor world has quite a high temperature coefficient and thus isn't used frequently in critical circuits that must be temperature stable. Carbon-film, metal-film, or wire-wound resistors are better choices for application in critical circuits.

11. (A) Increase; (B) Yes. **Note:** Because of its fairly linear resistance/temperature characteristic (especially with a properly chosen fixed resistor in parallel) this component has possible use in simple digital thermometers.

12. (A) Decrease; (B) No. **Note:** Keep this in mind when testing high-voltage circuits.

13. (A) None; (B) No. **Note:** The thermistor resistance decreases by 0.1% for every degree Celsius increase in temperature (remember, 1000 ppm/°C = 0.1%) and the Sensitor resistance increases by an identical amount. Thus, the overall effect is zero.

14. (A) Increase; (B) Yes. **Note:** This effect has been used in inexpensive electronic thermometers. Also, it must be compensated for when designing a transistor circuit so that the transistor's operating point doesn't change significantly with temperature.

15. (A) Increase; (B) Yes. **Note:** A simple electronic thermometer can be constructed from a reverse-connected germanium diode, a battery, and a microammeter. The relatively high, temperature-dependent reverse leakage currents of germanium diodes make the silicon diode, whose leakage is far smaller, preferable in some applications.

16. (A) Decrease; (B) No. **Note:** Keep LEDs cool for increased brightness.

17. (A) Increase; (B) No.

18. (A) Decrease; (B) Yes. **Note:** Does this surprise you? Well, this is sort of a trick question. One normally thinks of a thermocouple's output as increasing with an increase in temperature. The fact is, a thermocouple's output increases with an increase in the *difference* in temperature between its standard junction and the test junction. Since the standard junction shown is at a constant 120°F, the thermocouple's output *decreases* until the test junction reaches 120°F, at which point the output is zero. For test junction temperatures above 120°F, the output increases with further increase in temperature. Since we are limited to a maximum temperature of 95°F, the output is said to *decrease* with increasing temperature.

19. (A) Increase; (B) No. **Note:** This answer is obvious to anyone who had no trouble starting his car on a relatively mild winter afternoon, but early the following morning, when it was bitter cold, had to jumper the battery to start the car. (Of course, thickening oil exacerbates the problem.)

20. (A) Decrease; (B) No. **Note:** This effect is more important than most people realize. One answer is to store batteries in as cool an area as possible. A standard battery will retain nearly all its original capacity for as long as two years if stored at 32°F. This same battery, if stored at 160°F (say in an attic), will have only about 15% of its original capacity after only 1 month of storage!

21. (A) Increase; (B) No.

22. (A) Decrease; (B) No. **Note:** A substantial increase in temperature can trigger a false alarm. (Although the author has never seen it done, he speculates that a simple fire alarm can be constructed using an SCR with its gate clamped to a constant voltage just below the minimum trigger point (at room temperature).

23. (A) Almost none; (B) No. **Note:** This diode provides a reference voltage whose stability compares with that of standard cells.

24. (A) Decrease; (B) No. **Note:** Here is one reason why commercial-quality TTLs should be used only between 0°C and 70°C.

25. (A) Slight decrease; (B) No. **Note:** CMOS devices are less sensitive to temperature than TTLs. Plastic-cased CMOS are guaranteed to operate satisfactorily from −40°F to 185°F (−40°C to 85°C).

26. (A) Decrease; (B) No. **Note:** Spark gaps are frequently used to measure extremely high voltages. While this method may seem crude, it is accurate.◇

"I said, I think maybe the ghosts seem sharper now!"

Diode pair senses differential temperature

by Don DeKold
Dekolabs, Gainesville, Fla.

Normally, a germanium diode functioning as a temperature sensor relies on the linear variation of its forward voltage with temperature. But a pair of germanium diodes can be made to serve as a differential-temperature comparator if the circuit exploits a much less used temperature-dependent diode property–the logarithmic variation with temperature of the reverse saturation current. The resulting circuit is useful for industrial-control applications.

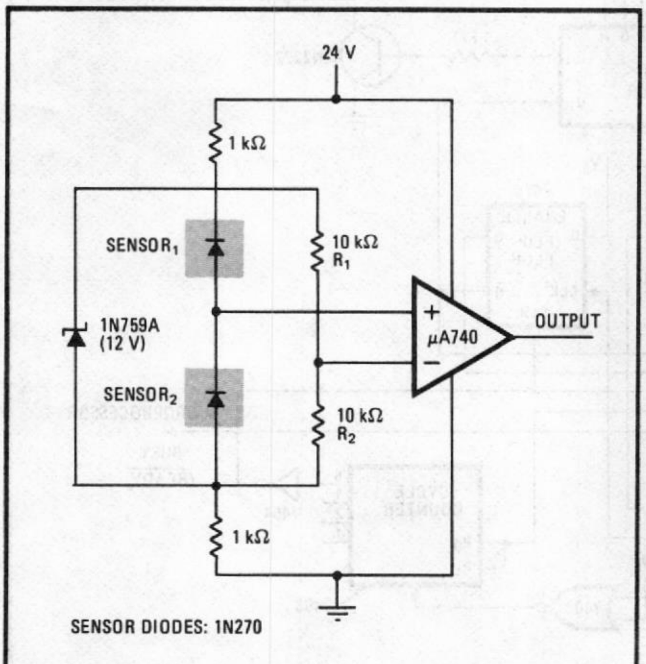
When one diode (SENSOR$_1$) is at temperature T_1 and the other diode (SENSOR$_2$) is at temperature T_2, the circuit output will change state as the temperature differential (T_1–T_2) approaches and crosses a differential threshold, $\Delta T_{1,2}$. For the circuit shown here, $\Delta T_{1,2}$ is 13°C–when (T_1–T_2) is less than 13°C, the circuit's output is low; and when (T_1–T_2) is greater than 13°C, the output goes high. The circuit has a fairly wide and useful temperature range of 20°C to 120°C.

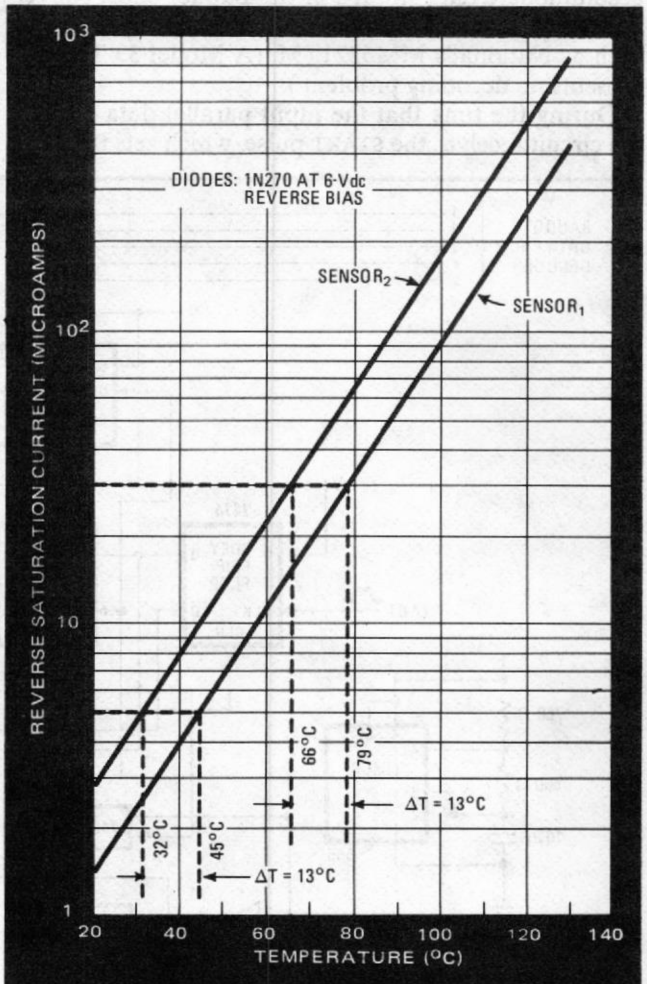
The two diodes, along with resistors R_1 and R_2, form a resistance bridge. The right-hand side of the bridge consists of equal resistances that divide the bridge voltage in half, establishing a reference voltage at the inverting terminal of the FET-input operational amplifier. The noninverting op-amp terminal receives the temperature-dependent voltage, which is derived from the division of the bridge voltage across the diode temperature sensors.

In general, the reverse saturation currents of two unmatched diodes are different at a single temperature. However, when plotted as a function of temperature on semilog paper, the two reverse-current characteristics will be parallel to each other. That is, a diode's reverse current may vary from one unit to the next at a single temperature, but it will increase in an identically proportional manner from one unit to the next as a function of temperature.

For instance, for the type 1N270 germanium diodes used here, the current doubles every 13°C. The doubling is highly regular, producing a nearly linear semilog plot over a fairly wide temperature range, as shown by the graph of reverse saturation current versus temperature for two type IN270 diodes.

Now, when a diode is reverse-biased, it in effect becomes a temperature-dependent current source with a reverse saturation current that is only negligibly influenced by the actual magnitude of the reverse voltage. But as the reverse voltage approaches zero, the reverse current decreases. When two diodes are connected in series, therefore, the voltage across them will divide equally only when their currents are the same, a condition that occurs at a fixed temperature difference between the two. This equal-current temperature differ-





Temperature comparator. Unmatched germanium diodes have different reverse saturation currents at the same temperature. But this difference remains proportionate with changing temperature so that the temperature differential between the two currents stays the same, as shown by the graph. A differential-temperature comparator can be built by connecting two unmatched diodes in a bridge configuration.

Interfacing a teletypewriter with an IC microprocessor

by Steven K. Roberts
Cybertronic Systems, Louisville, Ky.

The lengthy software service routine generally required to interface a teletypewriter and an IC microprocessor, such as the Intel 8008, can be eliminated by the circuit shown here. A shift register and some control logic are all that it takes, bringing total component cost to only about $6.50.

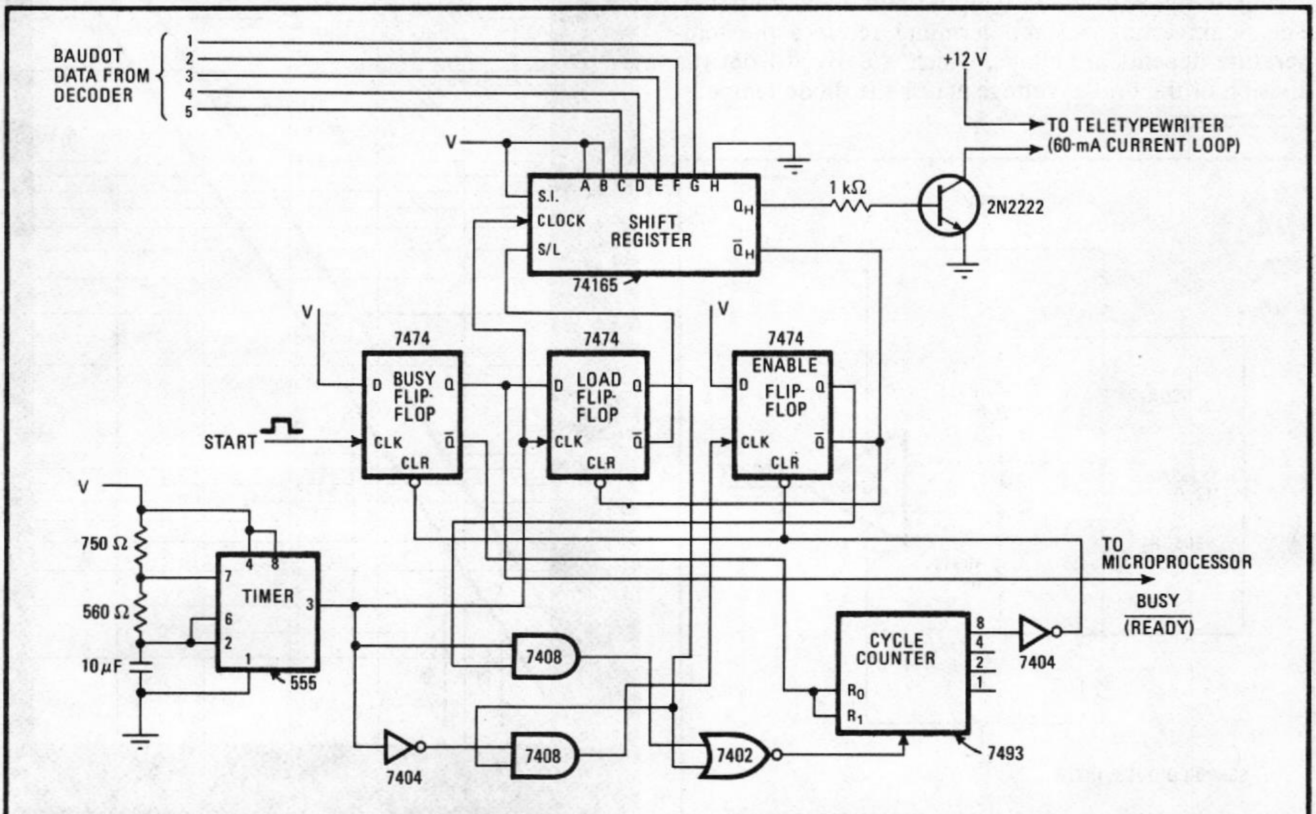
In the 8008 system, synchronization with the central-processing unit is accomplished through this microprocessor's READY line, making modification of the teletypewriter itself unnecessary. The hardware configuration given in the figure is designed for a 10-character-per-second Model 28 Teletype, which uses the five-level Baudot code. If the intended application will not easily accommodate data storage in the Baudot code, conversion may be accomplished with a read-only memory, such as National's MM5221TM. (A Model 33 Teletype presents no decoding problem.)

During the time that the input parallel data is valid, the circuit receives the START pulse, which sets the BUSY flip-flop and takes the READY line low. The BUSY flip-flop also removes the reset from the cycle counter and enables the LOAD flip-flop, which is set on the next clock pulse. This action loads the data at the input to the shift register and increments the cycle counter once.

On the succeeding clock pulse, the ENABLE flip-flop is set, and the data in the register begins to shift to the right. For each shift pulse, the cycle counter is incremented by one until it reaches a binary count of 8. Then, the BUSY and ENABLE flip-flops are both reset, and the READY signal is restored to the microprocessor so that the central-processing unit can resume operation.

In the data character presented to the shift register, bit H, which is constantly held low, corresponds to the teletypewriter START pulse. Similarly, the register's A and B bits are tied high, corresponding to the teletypewriter STOP pulse. Since the STOP signal must be applied to the teletypewriter for approximately 1.5 times longer than the other pulses, the BUSY flip-flop is reset on the falling edge of the clock, during the time that bit A is present at the register's Q_H output. The serial output of the register switches the 60-milliampere teletypewriter current loop through the transistor.

The clock signal for the circuit is derived from the IC timer that is free-running at approximately 75 hertz. For teletypewriters that operate at 6 characters per second, the clock frequency should be about 45.5 Hz. □



Software bypass. Digital interface circuit provides synchronization between a teletypewriter and a microprocessor chip through the latter device's READY line. Normally, a long software routine is needed to make the interface. The input data is in the parallel Baudot code, and the output is for a 10-character-per-second teletypewriter. A free-running IC timer is used to produce the clock signal.

Electronic Thermometer

Convert your meter to read temperature with this simple add-on unit.

USING THIS CIRCUIT you can convert any voltmeter capable of reading 0-1V to a 0-100°C temperature probe. The device that makes this possible is National Semiconductor's LM335. This is a temperature-sensing integrated circuit housed in a T0-92 transistor type package which acts as a shunt regulator giving an output voltage of 10 mV per degree. The chip gives a 0V output, not at 0°C as you might expect but at absolute zero, minus 273°C. This means that an output voltage of 2.73 V is obtained at freezing point. To get a 0 V output from the circuit at 0°C, all we need to do is compare the output of the chip with a reference voltage of 2.73 V, which we obtain from a second integrated circuit, the TL430C.

Construction

Begin by mounting resistors R1,2,3,4,5, integrated circuit IC1 and variable resistor RV1 into the printed circuit board (PCB), as shown in Fig. 2. As IC1 and IC2 look alike make sure you've picked up the right device, the TL430C. Check its orientation against the overlay diagram.

Now connect a voltmeter with its negative lead to 0 V and its positive lead to the junction of R4 and R5. With the unit connected to a 9V battery you should be able to adjust RV1 to obtain disconnect the meter and battery and a reading of 2.73 V. If all is well, solder R6, RV2 and IC2 into the PCB, taking care with IC2's orientation.

Reapply power and connect the meter this time with its negative lead to the junction of R4 and R5, and its positive lead to the junction of R6, IC2 and RV2.

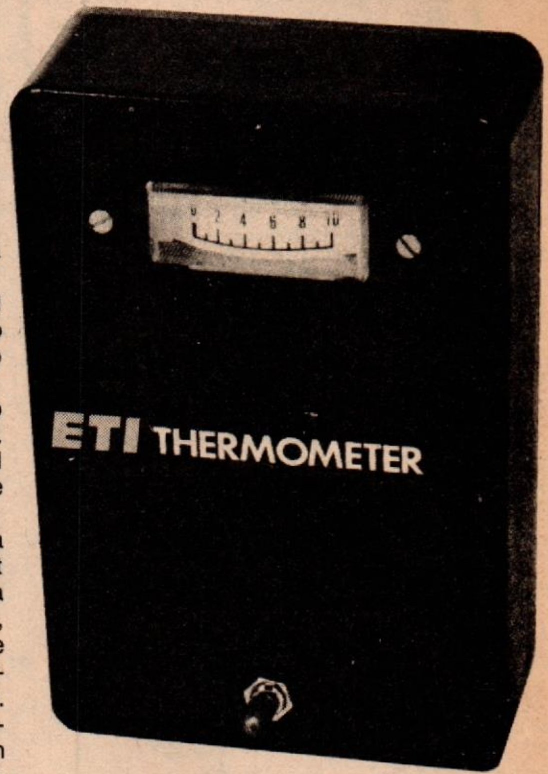
By adjusting RV2 you should obtain a reading corresponding to the ambient temperature. If the temperature is 25°C adjust RV2 for a reading of 0.25 V.

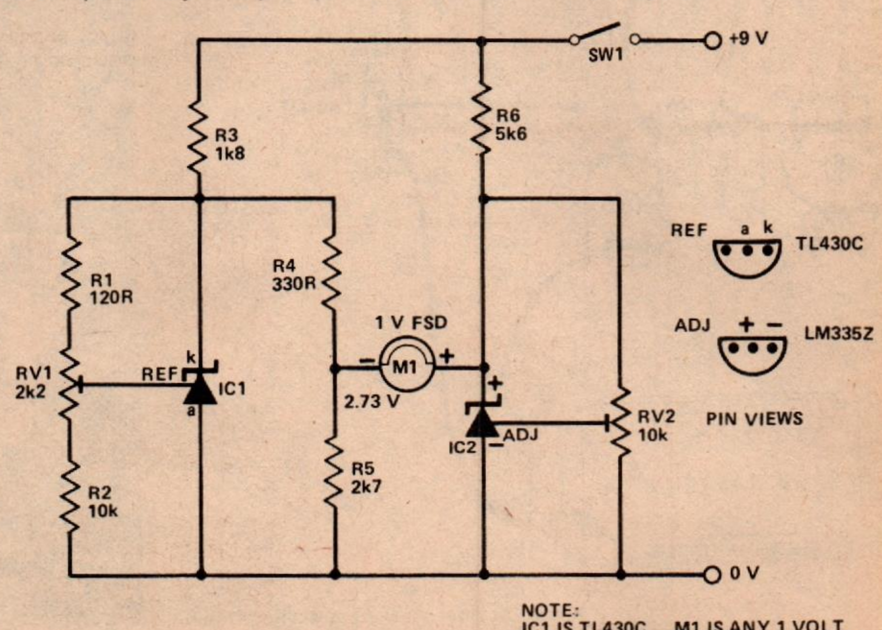
Only one calibration is needed as this sets the chip accurate to within 1°C over a range of -10°C to -100°C.

Now, mark and drill the case to fit the panel meter and on/off switch. Mount the PCB, battery, switch and meter into the case and wire up the project as shown in Fig. 2.

If you wish to make a temperature probe, you can mount IC2 remotely from the PCB. Choose a mounting to suit your application, taking care that the leads cannot be bridged or short-circuited if measuring water temperature, for example. In fact, it is a good idea to encapsulate the complete IC in epoxy resin or similar, if you intend to use the probe to measure water temperature.

And there you have it. With just two comparatively cheap chips and a handful of components, you have a complete linear temperature measurement system.





NOTE:
IC1 IS TL430C
IC2 IS LM335Z
M1 IS ANY 1 VOLT FULL SCALE METER

Fig. 1. Circuit of the ETI Thermometer.

PARTS LIST

RESISTORS (All ¼ W, 5%)

R1	120R
R2	10k
R3	1k8
R4	330R
R5	2k7
R6	5k6

POTENTIOMETERS

RV1	2k2 miniature horizontal preset
RV2	10k miniature horizontal preset

SEMICONDUCTORS

IC1	TL430C adjustable zener
IC2	LM335Z temperature sensor

MISCELLANEOUS

M1	any meter capable of indicating 0-1 V (for 0-100 °C measurement range)

Case to suit.

HOW IT WORKS

The heart of the circuit is the LM 335Z solid state temperature sensor. When a current of 400 uA to 5 mA is passed through this device, a voltage of 10 mV per degree is developed across it. At 25 °C (room temperature) a voltage of 2.98 V will be produced, not the 0.25 V (0.01 x 25) that you might expect. This is because the output is proportional to absolute temperature and 0°C is 273K so 25 °C is (273 + 25 ÷ 100) V, ie, 2.98 V. So that the meter will read zero for 0 °C, we generate a reference voltage of 2.73 V corresponding to 0 °C, 273 K (the 'K' is for Kelvin — Lord Kelvin, a physicist).

The reference voltage is produced using a special integrated circuit, the TL430C. This chip is connected just like the LM335Z and has a terminal which monitors the output voltage via potential divider R1, RV1, R2. The TL430C will regulate the voltage at its output until a voltage of about 2.7V appears at its reference input. This occurs for an output voltage of about 3V. Unlike the LM335Z whose output will change with temperature, the TL430C is designed to be temperature independent and its output will drift by less than 50 parts per million, per degree Centigrade (ie, not more than 150 uV/ °C). The required reference voltage of 2.73 V is obtained from the 3V output via potential divider R4, 5. This network is required because the reference voltage (and so the minimum output voltage) may range between 2.5V and 3V for different samples of the device. Preset RV1 accommodates this variation, enabling a 3 V output to be obtained from any sample. To obtain a temperature measurement, a 1V FSD meter is simply connected between the reference voltage from IC1 and the output of IC2.

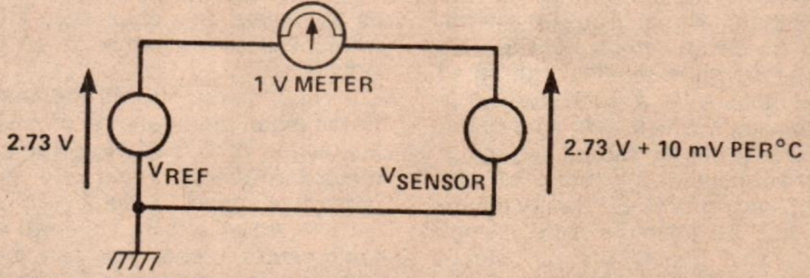
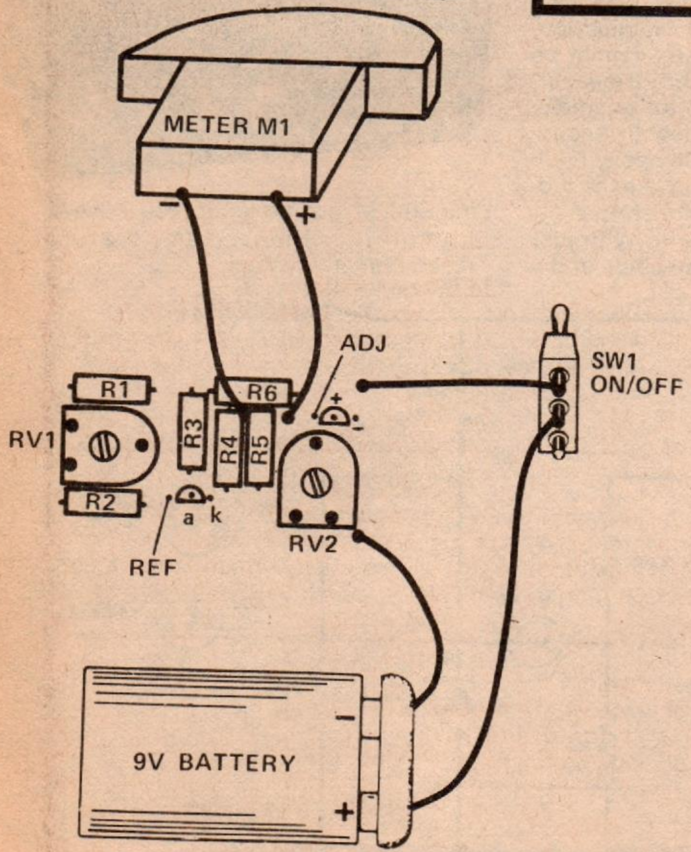


Fig. 2. Printed circuit board overlay of the Thermometer and connection details. Make sure you don't confuse IC1 with IC2 as they are similar both in size and shape.



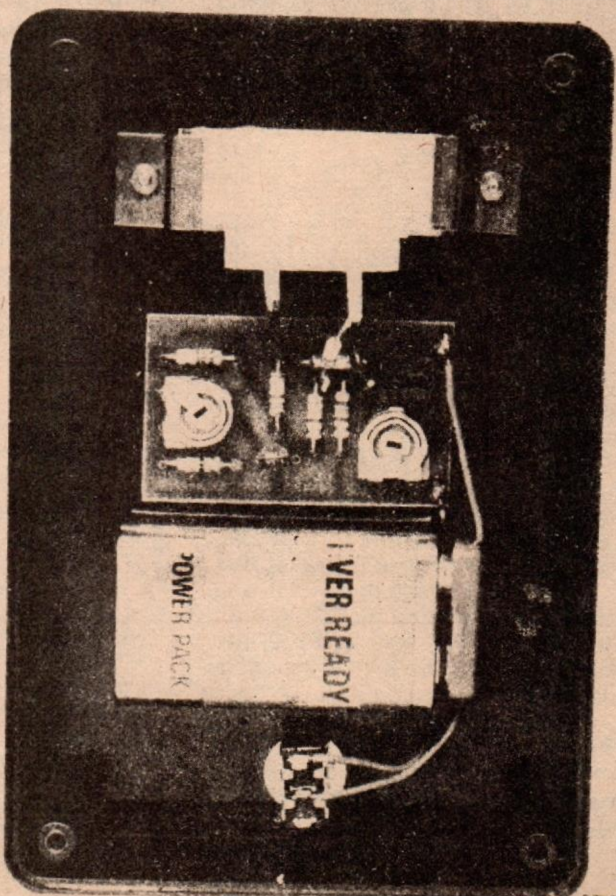
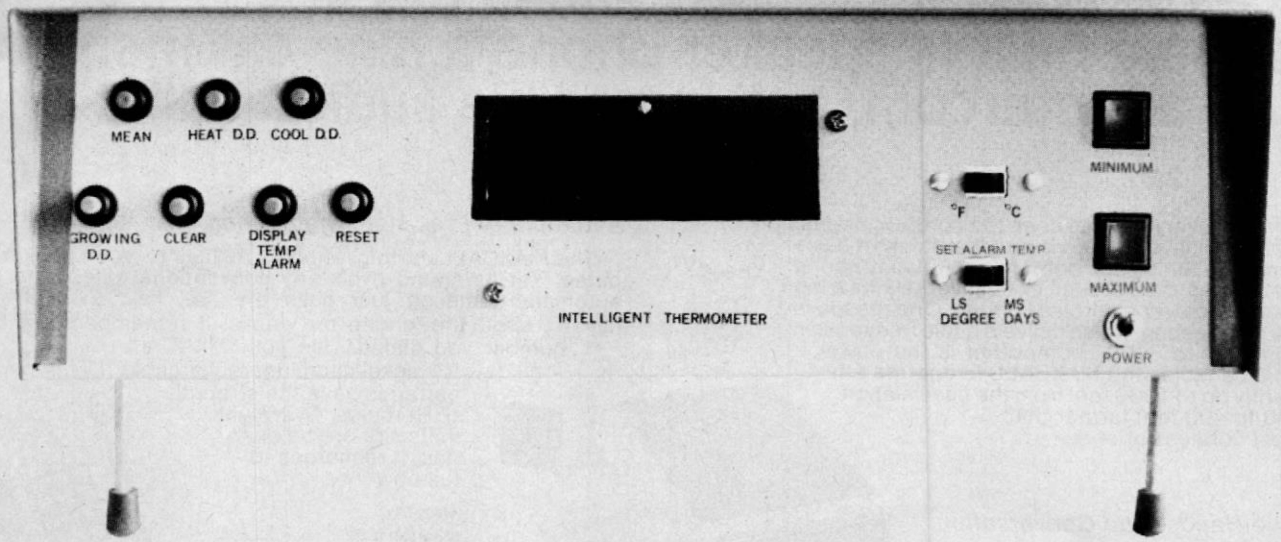


Fig.3. Internal view of the Thermometer. Keep all leads short and neat.

ETI



Build The Intelligent Thermometer

Part 1

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

By Tom Fox

MOST people associate the word "microprocessor" with computers. However, there are many sophisticated devices besides computers that use microprocessors. One such device is the Intelligent Thermometer described here. It is called "intelligent" because the particular program in its memory allows many uses besides simple temperature measurements.

For instance, the Intelligent Thermometer analyzes the temperature data and stores the results in its semi-permanent memory. It measures temperatures between −56°F and +199°F (−49°C and 93°C) and does it with an accuracy better than ±1°F over its entire range. It stores the minimum and maximum temperatures, and calculates and stores the mean temperature up to a 255-day interval with an accuracy better than that of the U.S. Weather Service. The Intelligent Thermometer also calculates and stores heating degree-days (base 65°F), cooling degree-days (base 75°F) and growing degree-days (base 42°F). Up to 9999 degree-days can be stored in each of its degree-day registers.

The analyzing portion of the thermometer has three outputs that can be used to activate a relay or buzzer. The first signals a temperature of 32°F or below, while the other two signals indicate a temperature either above or below a preset threshold of the user's choice.

The temperatures and degree-days can be displayed in either Fahrenheit or Celsius depending on the setting of a switch. (Celsius degree-days are rounded off to the nearest 100.) An optional battery allows memory retention during power failures.

The versatility of the thermometer is further enlarged by the user's ability to erase and re-program the EPROM—or plug a new EPROM into the socket. For instance, the thermometer could be transformed into an energy-saving digital thermostat by changing the EPROM and adding two relays.

About the Circuit. A block diagram of the thermometer is shown in Fig. 1. Its memory map is given in Fig. 2. The 6802 CPU is basically the same as a 6800 with the added features of an internal clock oscillator and driver, plus 128 bytes of RAM. The first 32 bytes of RAM can be retained in the low-power

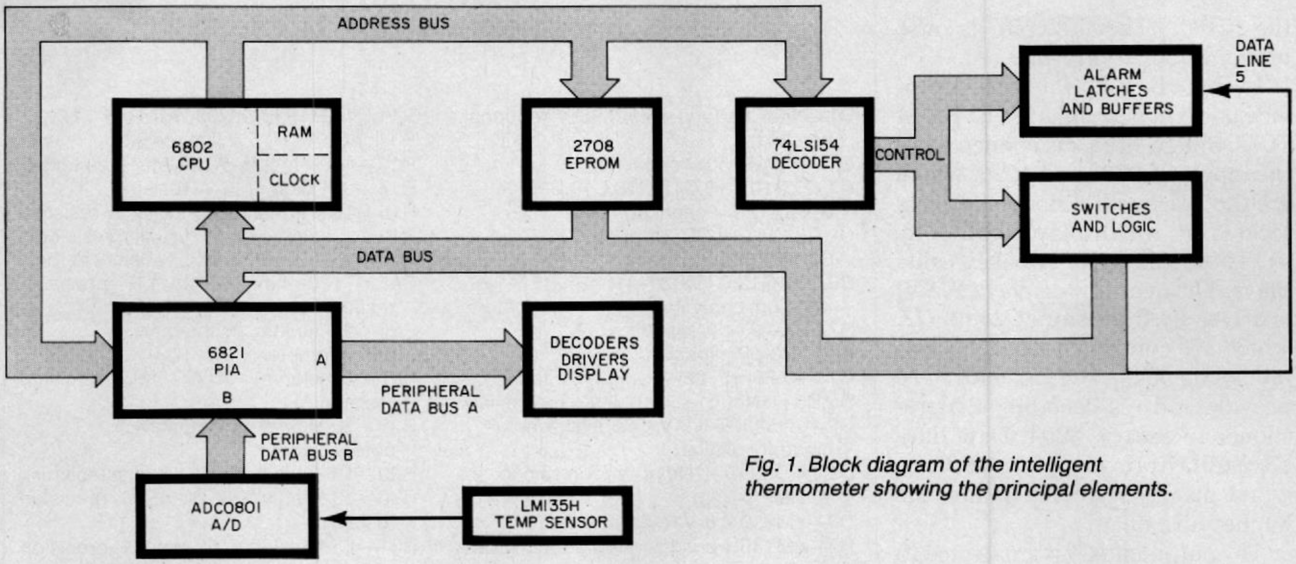


Fig. 1. Block diagram of the intelligent thermometer showing the principal elements.

mode, thus allowing memory retention in the event of power failure.

The entire program is stored within EPROM *IC12* and uses approximately 850 bytes of the 1024-byte capability.

The temperature is sensed by *D9*, a precision temperature sensor having a nearly linear response and a low dynamic impedance that allows remote sensing. The voltage reference is *D8*. The amplified (via *IC11*) temperature signal is applied to *IC9*, an A/D converter that converts the data into one byte of digital information. Each bit of the A/D converter is equivalent to 1°F. Byte 00000000 equals −56°F while byte 11111111 equals 199°F.

Side A of peripheral interface adapter *IC7* is programmed as the output with its data bus connected to *IC28* and *IC29*, a pair of 7-segment decoder/drivers. Side B is programmed as the input and is connected to the *IC9* (A/D converter) data bus.

Four-line to 16-line decoder *IC21* provides address decoding for the switches and output latches.

As shown in Fig. 3A the CPU, *IC8*, has its *reset* (pin 40) connected both to its own *read enable* (pin 36) and *IC7's reset* (pin 34). When the 6802's *reset* is brought high after being low for at least 20 ms, the CPU reset sequence starts. The 6802 first checks what 2-byte address is stored at locations FFFE and FFFF (each location contains 1 byte of the address) and then goes to this address which is the start of the program.

The circuit consisting of *IC6A*, *IC5A*, and associated components has a twofold purpose—it resets *IC7* and *IC8* during power-up, and provides a *read enable* (RE) signal for the CPU. The RE signal is arranged so that it goes low before V_{cc} drops below 4.75 V. This is necessary to keep erroneous information from being stored during a power failure. Pin 3 of *IC6A* monitor's the V_{cc} supply (+5 V). Potentiometer *R9* is set so that the voltage at pin 3 is slightly below that at pin 2, which monitors the rectified and partly filtered voltage produced by *D5*, *C14*, and *R14*. This circuit responds quickly to any power-down, or brown-out condition. When the power-line voltage starts to drop, the voltage at pin 2 drops below that at pin 3 and the *IC6A* output jumps to near 5 V. Schmitt trigger, *IC5A*, senses that *IC6A*'s output is starting to rise and produces a low output when this voltage exceeds about 3 V. Thus RE drops low several microseconds after V_{cc} drops more than about 2%—in time to ensure that the contents of the RAM are unchanged.

As mentioned earlier, this circuit also provides the "power-up" reset signal for the CPU and peripheral interface adapter (PIA). When the line voltage rises rapidly (for instance, when first turned on), *C5* instantly raises the voltage at pin 3 of *IC6A*. Pin 3's potential is now above that at pin 2, and the reset pin's potential is brought low. The voltage at pin 3 declines exponentially to a steady-state or "normal" voltage about a half second after power-up. When the voltage at *IC6A* pin 3 falls below that at pin 2, the reset pin jumps high and starts

RAM IN 6802 RETAINABLE IN LOW-POWER STANDBY MODE	0000-001F
RAM IN 6802	0020-007F
NOT USED	0080-7FFF
PIA	8000-8003
DIS 4 (−1)	8004
NOT USED	8005-87FF
SWITCHES	8800-880D
OUTPUTS	880E, 880F
NOT USED	8810-FBFF
INTELLIGENT THERMOMETER'S EPROM PROGRAM	FC00-FFFF

Fig. 2. Memory map of the system.

the CPU. The RE pin is also brought high at this time.

In Fig. 3B, *IC15A* and *IC13* provide address decoding for EPROM *IC12*. Side A of *IC7* is connected to the inputs of *IC28* and *IC29*, which are the 7-segment decoders/drivers located on the display board (Fig. 4). These ICs drive two LED displays. The overflow display (*DIS 4*) is driven by transistors *Q1* and *Q2*, which are controlled by *IC18*, a 4-bit latch. *IC14, IC15B*, and *IC16* provide address decoding that responds to address 8004. Data lines D6 and D7 provide information on which display segments (if any) the latches turn on.

The output of *IC9* is connected to *IC7's* peripheral data bus on side B. The ADC0801 (*IC9*) 8-bit A/D converter has a total adjusted error of less than ±¼ LSB (±¼°F). The LM135H precision temperature sensor, *D9*, behaves as a low-power zener diode with a breakdown voltage proportional to absolute temperature at +10 mV/°K. Thus at 77°F (25°C or 298.15°K) the LM135H theoretically breaks down at 2.9815 V. The LM135H operates over a −55°C to +150°C temperature range (−67°F to +302°F), and its extremely low dynamic impedance (less than 1 ohm) allows it to be used at remote locations. This sensor is almost perfectly linear (±0.3°C) over its entire range, which makes it simple to use with A/Ds, and it doesn't require a special linearizing program.

The LM336 2.5-V reference diode, *D8*, provides an unusually stable reference voltage for *IC9* as well as for the calibration circuit Although the LM336 is an integrated circuit, it acts as a low-power zener diode with an exceptionally small temperature coefficient. Diodes *D3* and *D4* and resistor *R28* trim *D8* for a minimum temperature coefficient of 1.8 mV over a 0°C to 70°C temperature range.

A calibration circuit (*IC11A, IC11B* and associated components) manipulates *D9*'s output voltage so that the thermometer is able to measure the full range of

(Continued on page 80)

PARTS LIST
(For Fig. 3. See pages 77, 78, 79)

B1—NiCd battery, 4.75-5.25 V (optional, see text)
C1—0.1-μF, 50-V capacitor
C4,C5,C10,C16,C17,C18,C19,C20—0.1-μF, 25-V capacitor
C2,C3,C9,C13,C22 through C30—0.01-μF, 25-V capacitor
C6,C11,C12,C15,C21—10-μF, 25-V tantalum capacitor
C7,C31—27-pF capacitor
C8—330-pF capacitor
C14—0.68-μF, 25-V tantalum capacitor
D1,D5—1N4001 silicon diode (or similar)
D2—1N5232B 5.6-V, 500-mW zener diode (or similar)
D3,D4,D6,D7—1N914 silicon diode (or similar)
D8—LM336 2.5-V reference diode
D9—LM135H precision temperature sensor (see note)
DIS1,DIS2,DIS3—7-segment common-anode LED display (MAN 72 or similar)
DIS4—Overflow common-anode LED display (MAN 73 or similar)
IC1—4020 14-stage binary ripple counter
IC2—4584 hex Schmitt trigger inverter
IC3—4082 dual 4-input AND
IC4—555 timer
IC5—74LS13 dual 4-input NAND Schmitt trigger
IC6,IC11—LM324N low-power quad op amp
IC7—6821 peripheral interface adapter
IC8—6802 microprocessor
IC9—ADC0801 8-bit A/D converter
IC10—74LS541 tristate octal buffer
IC12—2708 1K-byte EPROM (see note)
IC13—74LS30 8-input NAND
IC14,IC22,IC23,IC24—74LS02 quad 2-input NOR
IC15,IC16—74LS21 dual 4-input AND
IC17—74LS00 quad 2-input NAND
IC18,IC19—74LS75 4-bit latch
IC20—7407 hex buffer
IC21—74LS154 decoder
IC25—7404 hex inverter
IC26,IC27—7405 hex inverter
IC28,IC29—7447 decoder/driver
Q1,Q2—2N2222 npn transistor (or similar)
R1,R2,R8,R21,R22,R23,R24—100-kilohm, ¼-W, 5% film resistor
R3,R4—470-kilohm, ¼-W, 5% film resistor
R5,R6—1-megohm, ¼-W, 5% film resistor
R7—(see text)
R9—500-kilohm, pc trimmer potentiometer
R10—2.2-kilohm, ¼-W resistor (see text)
R11,R12,R18,R32,R33,R67,R68—1-kilohm, ¼-W, 5% film resistor
R13—470-ohm, ½-W resistor (see text)
R14—47-kilohm, ¼-W resistor
R15,R16,R17—3.3-kilohm, ¼-W resistor
R19—10-kilohm, ¼-W, 5% film resistor
R20—15-kilohm, ¼-W, 5% film resistor
R25—1120-ohm, ¼-W, 1% precision resistor
R26—2.5-kilohm, pc trimmer potentiometer
R27—20-kilohm, ¼-W, 1% precision resistor
R28—10-kilohm, pc trimmer potentiometer
R29—1.5-kilohm, ¼-W, 5% film resistor
R30—10-kilohm, ¼-W, 1% precision resistor
R31—25.16-kilohm, ¼-W, 1% precision resistor (see note)
R34 through R45—2.2-kilohm, ¼-W resistor (optional, see text)
R46,R47,R48—100-ohm, ¼-W resistor
R49 through R62—220-ohm, ¼-W resistor
R63,R64,R65,R66—270-ohm, ¼-W resistor
S1 through S9—Spst momentary-contact pushbutton switch
S10—Dpdt slide switch
S11—Spst slide switch
XTAL—4.0-MHz crystal
Misc.—IC sockets, power supply (see text), circuit boards, 2-conductor cable, case, hardware, wire, solder, etc.

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 (programmed) for $25.00; ADC0801 for $16.50; LM135H for $9.50; 1% precision resistors 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., P.O. 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 listings for programming the EPROM can be obtained free by sending a stamped, self-addressed envelope to Magicland, at the address above.

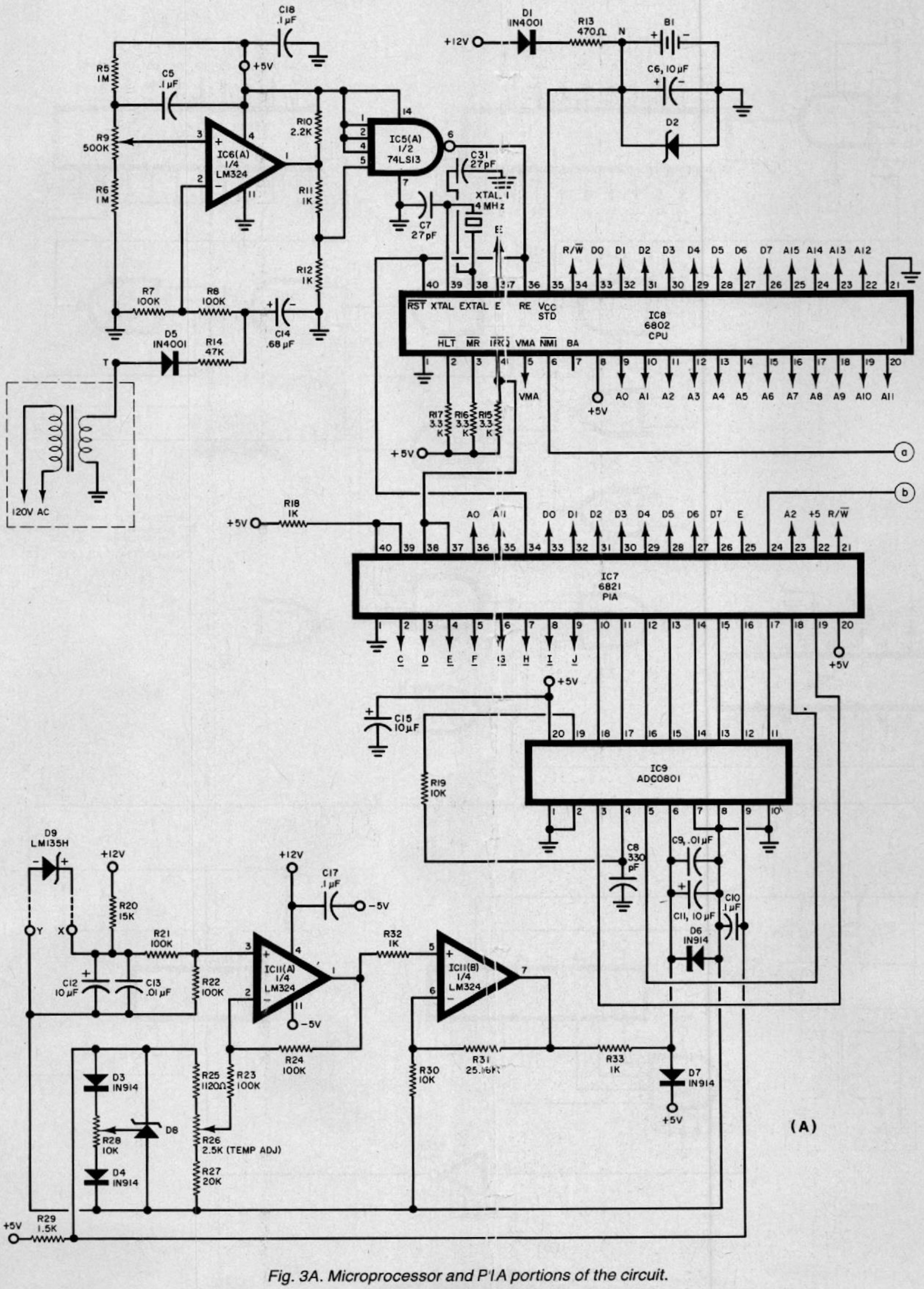
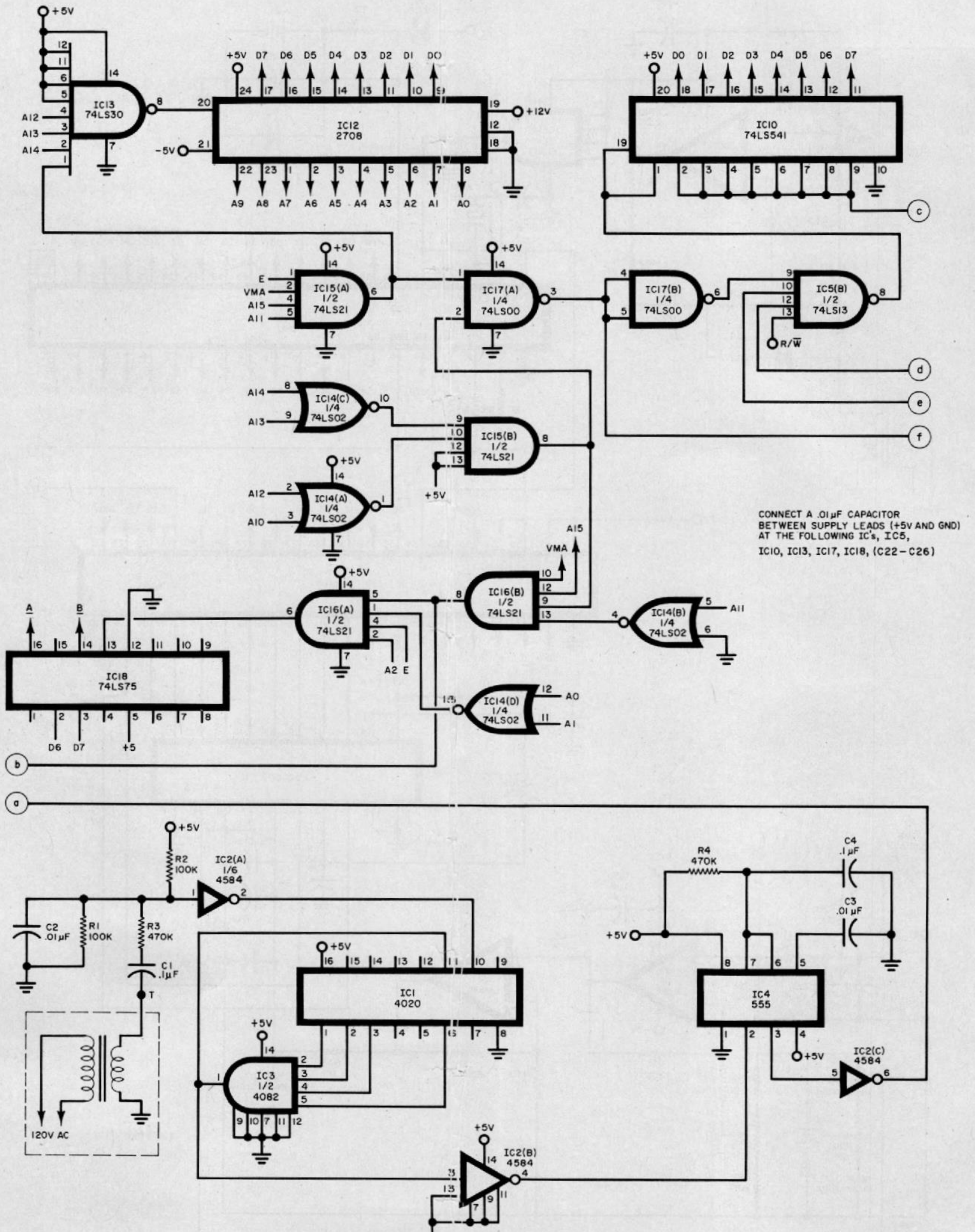


Fig. 3A. Microprocessor and PIA portions of the circuit.



(B)

Fig. 3B. EPROM and logic circuits.

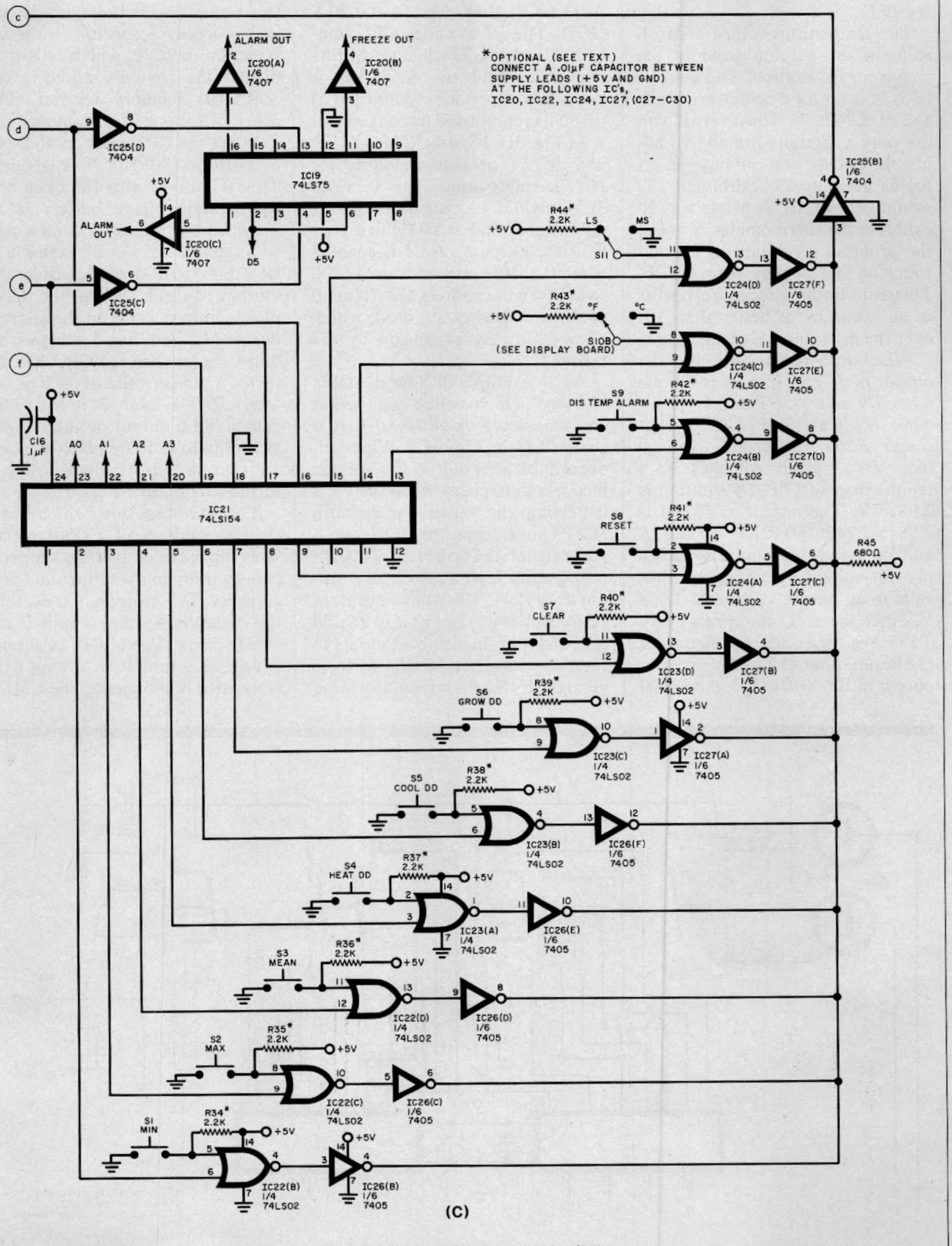


Fig. 3C. Indicating and output circuits.

temperatures between −56°F and +199°F.

The temperature-adjust control, *R26*, in this circuit provides the means for calibration. Theoretically, *R26* is set for a center-arm voltage of 2.2426 V. However, if you use only a digital voltmeter to adjust the circuit, you can have an error as great as 3°C (although 1°C would be typical). A better way to calibrate the thermometer is to put the probe in a mixture of ice and water so the display shows 32°F. This calibration procedure results in an accuracy of better than 1°F over the instrument's entire range.

When *R26* is set correctly, the output of *IC11A* (pin 1) is 0 volts when *D9* is at −56°F and 1.4167 V when *D9* is at 199°F. (*IC11A* subtracts *R26*'s center-arm voltage from *D9*'s output voltage.) At a temperature of 77°F, *D9*'s output is 2.9815 V. The output at *IC11A* is 2.9815-2.2426=0.7389 V. *IC11B* and its associated circuitry multiply this voltage by 3.516 which results in an output voltage of 2.598 V. Since the A/D interprets every .0195 V as one *least significant bit* (LSB), an input of 2.598 V gives an output of 10000101 (133 in decimal notation). Note that 133-56 = 77, which just happens to be the temperature!

The byte of information from the A/D (*IC9*) then goes to the PIA (*IC7*). The PIA, under CPU control, tells the A/D when to start its conversion and the A/D lets it know (via its $\overline{\text{INTR}}$ output at pin 5) that it has completed its conversion.

In Fig. 3B, *IC14A, IC14C, IC15,* and *IC17A* provide decoding for *IC21*'s enable input. This IC (Fig. 3C) provides address decoding for all switches and *IC19* (which controls the outputs). *IC21* is enabled when the CPU puts addresses 8800 to 880F on the address bus. (Not all of these addresses are used, which allows for easy expansion by the reader.)

As an example of how the CPU "knows" which switch is closed at any time, lets look at the MINIMUM switch (*S1* in Fig. 3C). When address 8801 goes out on the address bus (which happens when the CPU is testing the MINIMUM switch), *IC21*'s pin 2 drops low. If the MINIMUM switch is also closed, *IC22B*'s output goes high and *IC26B*'s output drops low. When any outputs of *IC26* drop low, the input to *IC25B* also drops low causing all inputs to the three-state octal buffer *IC10* to go high. If there is a read operation taking place and addresses 880E and 880F are not on the address bus, all the CPU's data lines will go high. Thus the CPU realizes that the MINIMUM switch was closed and proceeds according to the instruction in *IC12*, which tells it to display the contents stored in the MINIMUM memory register. The other switches perform similarly.

When the CPU calls up addresses 880E or 880F, *IC19* is enabled. This IC, along with the open-collector high-voltage buffer, *IC20*, provides the FREEZE, ALARM and $\overline{\text{ALARM}}$ outputs. For an example of how this circuit works, consider the FREEZE output. When the CPU places address 880F on the address bus *and* its data line 5 is high (this only occurs when the CPU has detected a temperature of 32°F or below), *IC19*'s latch 3 is set. This causes the $\overline{Q}$ output of latch 3 (pin 11) to go low. Buffer *IC20B*'s output (FREEZE) drops low allowing it to sink current.

The MEAN routine (which has a starting address of FD80) calculates the mean or average temperature by using temperature data taken every four minutes. To do this, the circuit must have a built-in accurate clock. The 60-Hz ac supply is used as a time base. Along with associated components, the CMOS

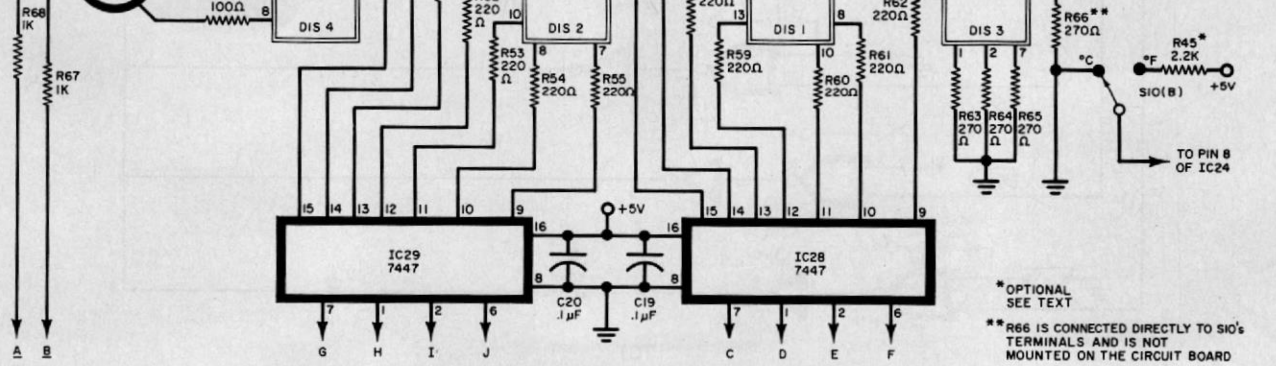


Fig. 4. Schematic of the display circuit.

Schmitt-trigger inverter, *IC2A*, shapes the 60-Hz sine wave into a CMOS compatible signal. These 60-pulses-per-second then go to the clock input of *IC1*, a 14-stage binary ripple counter. Then *IC1*, along with *IC3A*, forms a divide by 14,400 circuit, which results in one pulse every four minutes at its pin 1 output. This short pulse is inverted by *IC2B* and lengthened by *IC4*.

After leaving *IC4*, the pulse is about 50 ms long and is again inverted by *IC2C* before it is applied to the non-maskable interrupt ($\overline{\text{NMI}}$) input of the CPU (pin 6). When this pin goes from high to low, the CPU completes its present instruction and then jumps to a new set of instructions which tell it to find the present temperature and then calculate the mean temperature and degree-days.

This article will be continued next month with instructions for construction, calibration and applications. ◊

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-

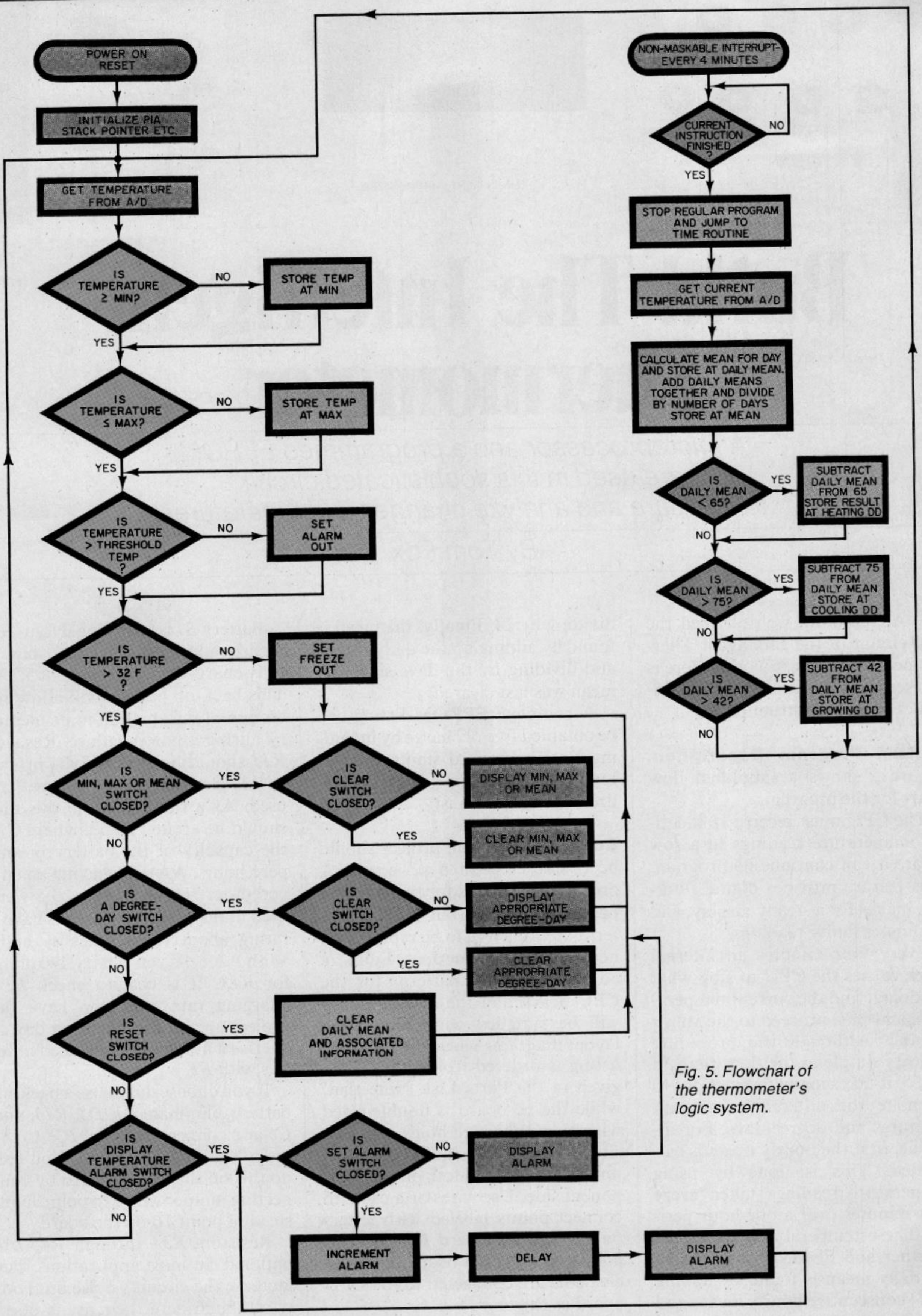


Fig. 5. Flowchart of the thermometer's logic system.

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 ⅛th 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.

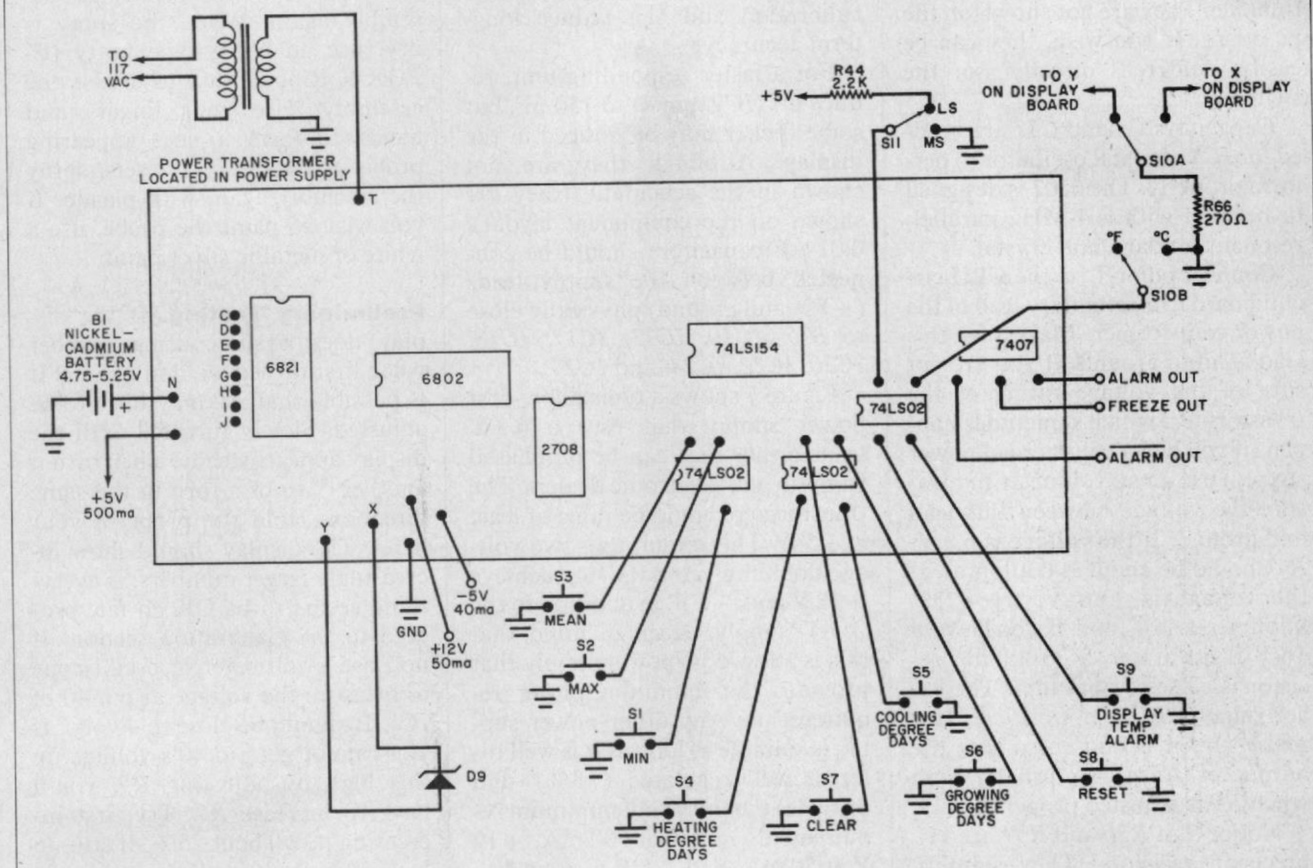


Fig. 6. External connections to the main pc board.

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 [illegible] 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

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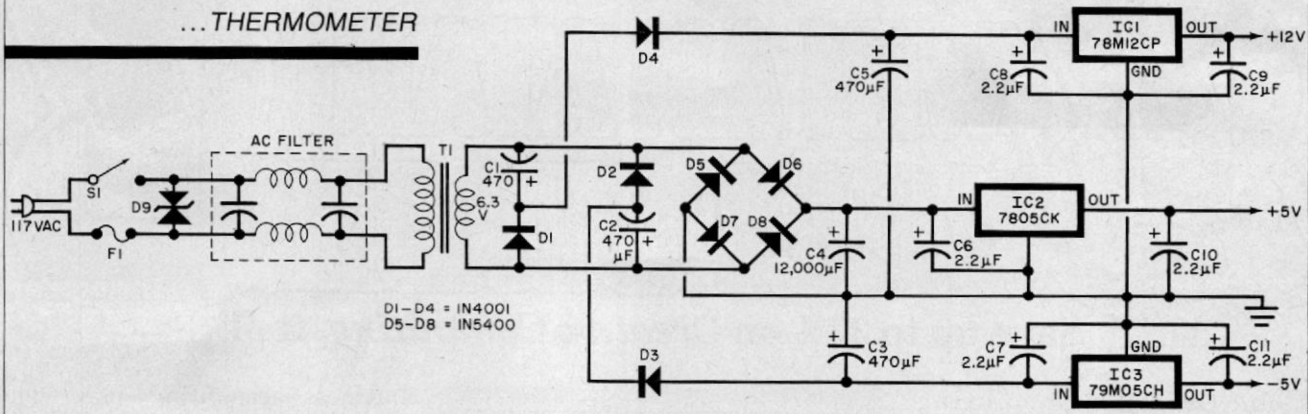


PARTS LIST (Power Supply)

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.

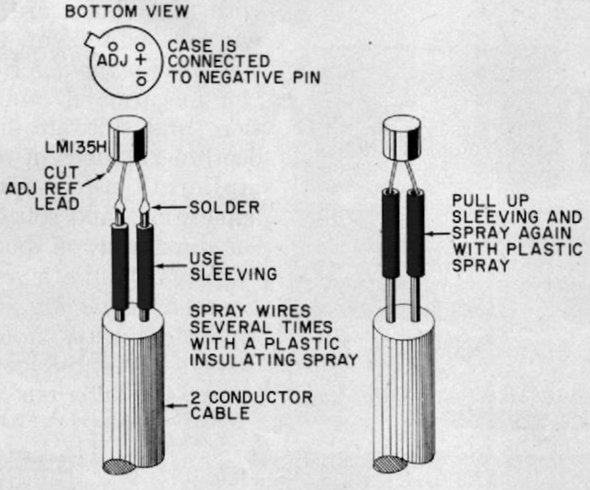


Fig. 8. How to make the sensor assembly.

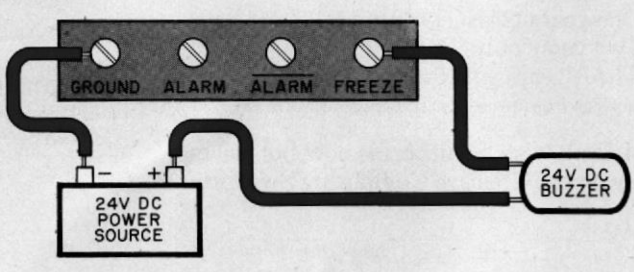


Fig. 9. Connecting to the terminals on the back panel.

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.

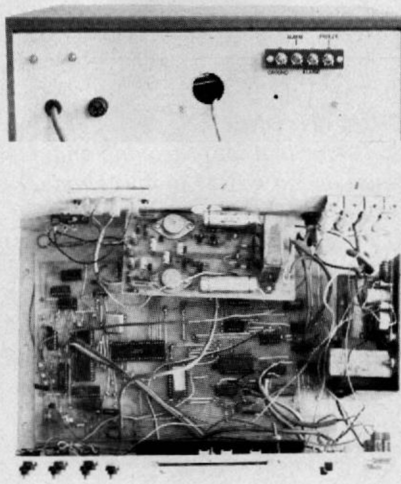
The operation of the MINIMUM and MAXIMUM switches is rather obvious. When you press either of these switches, the display shows the minimum or maximum temperature, respectively, measured since last memory clearance. When the MEAN switch is pressed, the display shows the accumulated mean temperature over 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. ◊