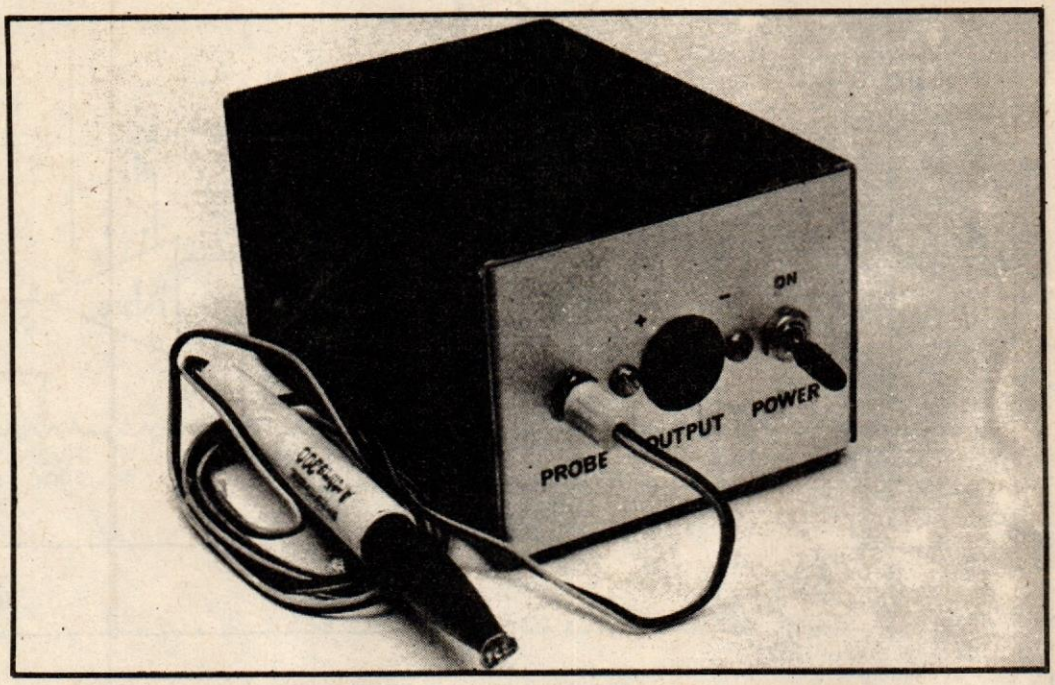
etiproject 130

TEMPERATURE METER



Converter connects to any analogue or digital meter.

OUR original design concept for this unit was as a complete instrument based on our ETI 533 digital display (October 1975 and Top Projects No.3) sensor – this generating a temperature-proportional voltage which in turn is supplied to a voltage-to-frequency converter. We planned to use a timebase to generate the necessary strobe and reset pulses. However the cost and complexity of this arrangement was such that we decided against it.

What finally emerged was a simple temperature-to-voltage converter which can be used in front of *any* analogue or digital meter. The converter provides an output of 10 mV/degree which can be either Celcius or Farenheit depending on calibration. If a dedicated digital readout is required we suggest our ETI 118 digital voltmeter (October 1975 and Top Projects No. 3).

CONSTRUCTION

Whilst a printed-circuit board is by no means essential, using one certainly makes construction easier and improves the appearance. The potentiometers as shown in our prototype are single turn presets which are quite adequate if an analogue meter is to be used for the readout. However if a digital meter is to be used the extra accuracy of the readout would warrant ten-turn presets being used for RV1 and RV2, as setting accuracy is considerably improved.

The converter quite readily fits into a small aluminium case. Two nine volt batteries are used to power the unit and battery drain is low enough to ensure a life of many months.

A 3.5 mm jack is used to connect the sensor to the unit and the output to the meter is provided via an inexpensive two-pin speaker socket.

The probe is constructed by mounting the sensor-diode into the tip of a ball-point pen casing, or similar. The method may best be understood by reference to the drawing.

CALIBRATION

To calibrate the instrument, two accurately known temperatures are required. One may be water or oil at room temperature (ice water should not be used as there the temperature may vary several degrees between different points in the solution). The high temperature is best obtained by heating oil or water and allowing it to stabilise at around 80°C. A second smaller heat conductive container filled with water is then immersed in the larger container. This simple procedure prevents errors due to circulating currents in the larger volume of water. An accurate mercury-in-glass thermometer should be used to measure temperatures during the calibration procedure as detailed below.

SPECIFICATION

RANGE	0 to 100°C 32 to 212°F
OUTPUT	10 mV/degree
ACCURACY	± 1°
RESPONSE TIME	3 seconds

TEMPERATURE METER

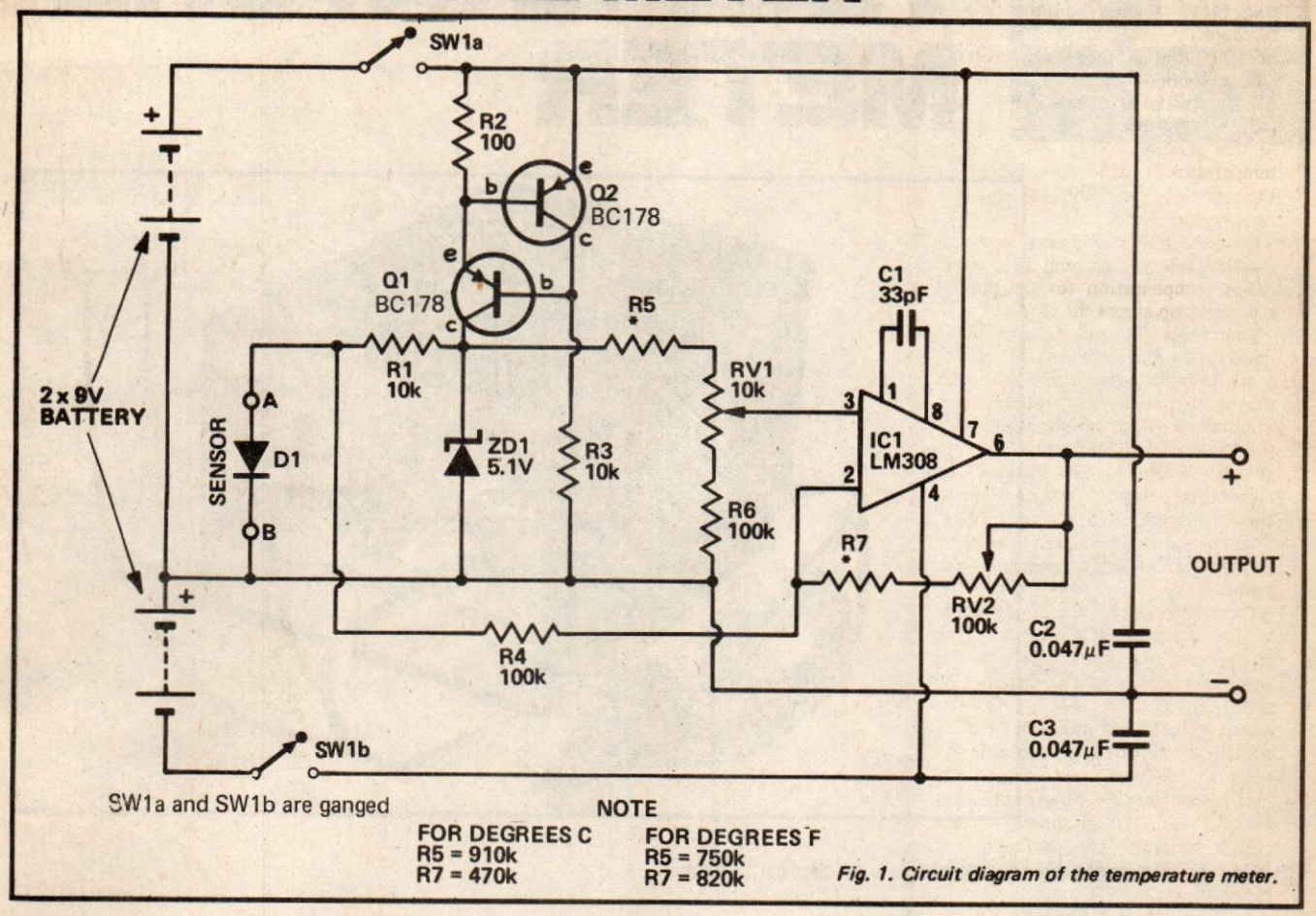


Fig. 1. Circuit diagram of the temperature meter.

1. Place the sensor and thermometer into the cool solution, allow a little time for stabilisation, and then measure the voltage from the converter and the temperature. Record these two readings.

2. Place the sensor and thermometer into the hot solution and measure the voltage and temperature as before. The voltage change between the first and second readings should be equal to the temperature change times 10 millivolts.

3. If the voltage versus temperature is not as specified in step 2 adjust RV2 and repeat steps 1 and 2 until it is. Note that varying RV2 changes the voltage at both the hot and the cold positions. It is the correct slope, or rate of change that we are after at the moment.

4. When the correct rate of change has been set as above place the sensor and thermometer into the cool solution and adjust RV1 to obtain a reading of 10 mV per degree. That is if the solution is at 25°C adjust RV1 to obtain a reading of 0.25 V.

Due to the spread of diode characteristics from one device to another the necessarily small adjustment range of RV1 and RV2 may not allow all diodes to be calibrated with the resistor values specified. If this is found to be the case it may be necessary to change the value of R5, R6 or R7.

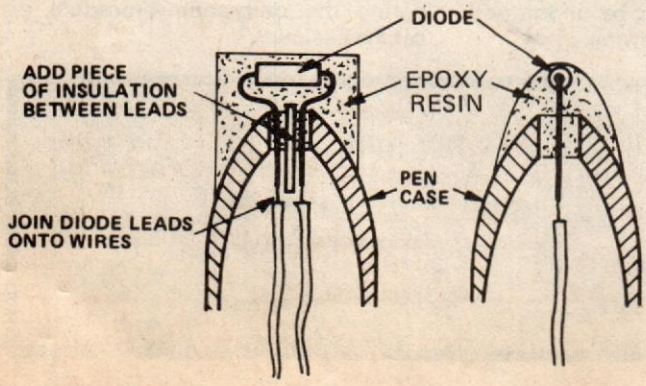


Fig. 2. This diagram shows how the sensor is mounted into a ball-point pen casing or similar.

PARTS LIST

R1,3	Resistor	10k ½W 5%
R2	"	100 ½W 5%
R4,6	"	100k ½W 5%
R5,7	"	See Fig. 1 and test.
RV1	Potentiometer	10k * trim type
RV2	"	100k * " "

*for digital readout a multiturn trim potentiometer is recommended.

C1	Capacitor	33pF ceramic
C2,3	"	0.047μF polyester
D1	Diode	1N914
ZD2	Zener Diode	5.1V, 400mW
Q1,2	Transistor	BC558, BC178
IC1	Integrated Circuit	LM308

Metal box
Two 9V batteries (PP3 etc)
Two pole toggle switch
PC board ETI 130
3.5mm plug and socket
Two pin plug and socket for output

HOW IT WORKS – ETI 130.

A forward biased diode has a temperature coefficient of about –2 mV/°C. That is the normal voltage across a silicon diode of nominally 0.6 volts will decrease by two millivolts for every degree C increase in temperature. This change with temperature is sufficiently linear over the range of 0 to 100°C to use it as a temperature sensor.

What the ETI 130 circuit does is to amplify this voltage and to provide offset compensation for the normal 0.6 volt drop across the diode.

Transistors Q1 and Q2 provide a constant-current source of about 5 mA into the zener diode ZD1 such that a very stable five volt reference is obtained which is independent of the battery supply voltage. (V supply greater than 6 V.) The forward bias current through the sensor diode is about 0.5 mA as provided by R1. This current is low enough to prevent errors due to self heating of the sensor diode.

The voltage across the sensor diode is amplified by IC1 (a very high input-impedance operational amplifier) whose gain is fixed at the ratio of (R7 + RV2)/R4. The necessary offset is provided by RV1 which is adjusted to cancel the normal 0.6 volt drop across the diode. By selecting the correct values for R5 and R7 as shown on the circuit diagram the indication of temperature in degrees C or F may be obtained.

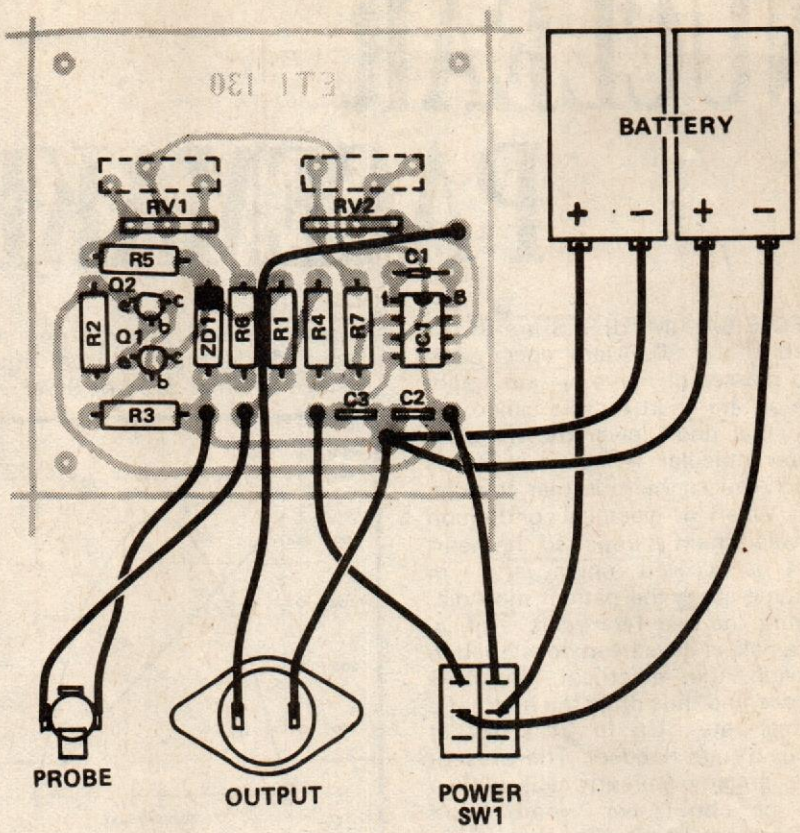


Fig. 3. Component overlay and interconnection diagram.

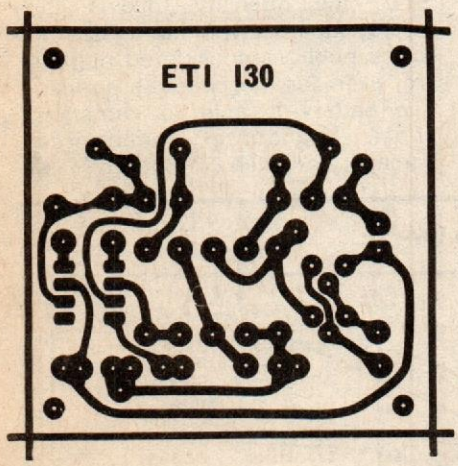
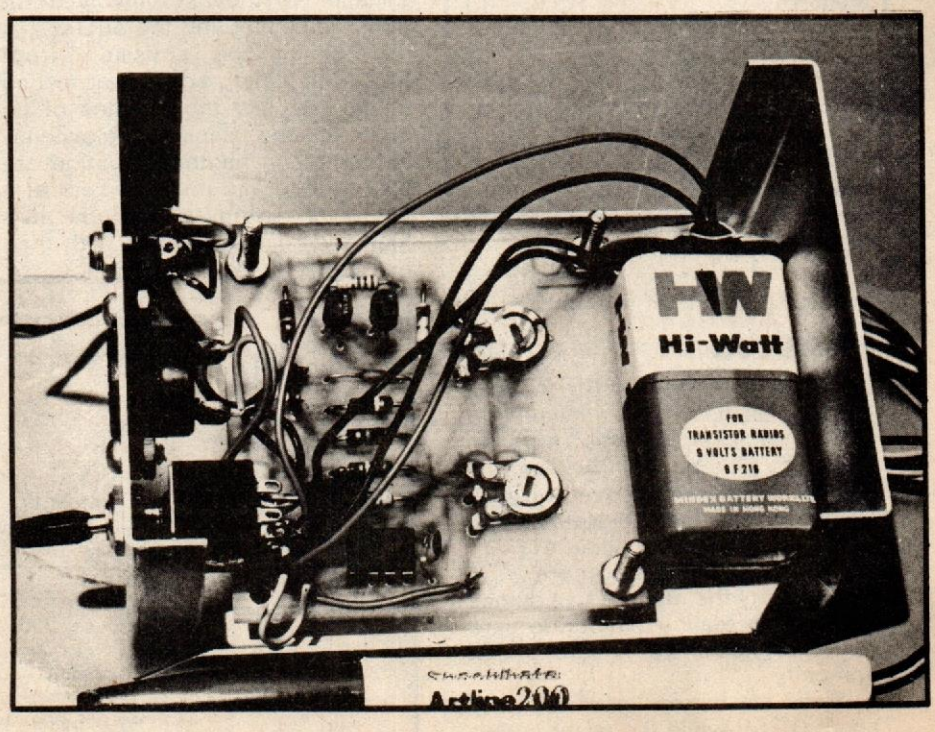


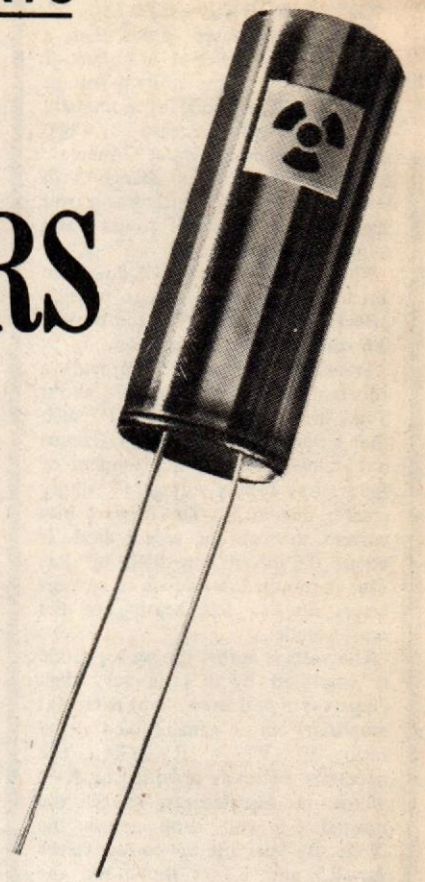
Fig. 4. Printed circuit pattern. Full size 63 x 63 mm.



Internal view of the completed temperature converter. Note also the probe at front.

A SUBJECT CLOSE TO OUR HEARTS

NUCLEAR PACEMAKERS



ELECTRICAL IMPULSES are at the heart of us all. More specifically two masses of nerves — an upper one on the heart muscle called the sinoatrial, and a lower known as the atrio-ventricular — set up impulses which causes the muscular contraction. When the electrical conduction between them is impaired the heart beat is slowed down and, in extreme cases the patient may die. During the last few years artifical pacemakers have been developed to provide the electrical impulses needed and thus drive the heart at a normal rate. (Up to 250 μW at about 5V are needed). The present units employ mercury cells with a life of about two years, and replacement involves an operation.

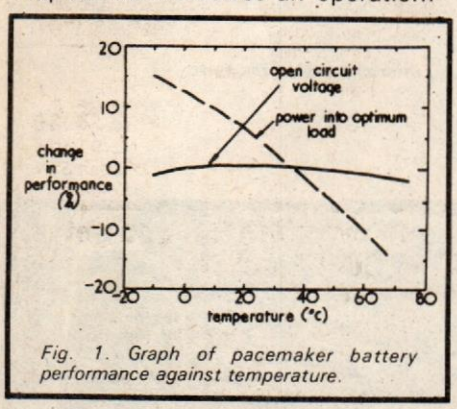


Fig. 1. Graph of pacemaker battery performance against temperature.

It would be better to reduce the number of these replacements by increasing the life of the unit.

ATOMIC FUEL

Dr J. Myatt at the AERE Harwell laboratories has in fact developed power sources for this purpose fuelled by plutonium 238, using its thermal energy and converting it to electric power by a thermoelectric module with a life expected to be of the order of ten years or more.

For safety the fuel has two stages of hermetic sealing. Elaborate care has been taken to ensure shock immunity.

Since the battery produces only about 0.25V while the pacer circuit needs 5V, a DC/DC converter is used to amplify the voltage, using Zener diodes to stabilise output voltage at either 5.5V or 6.7V.

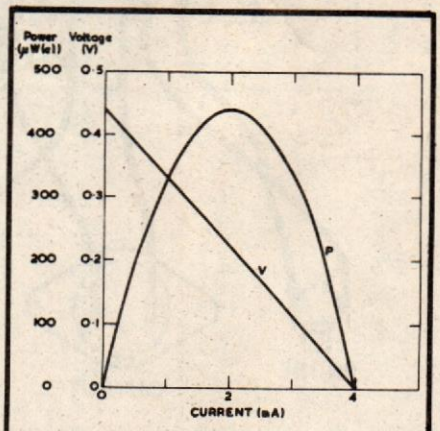


Fig. 2. Battery output characteristics at 37°C.

RISKS INVOLVED

This approach to powering the battery needs a very critical examination of the risks involved for both the patient and the public.

Most of the emission from Pu238 is alpha particles, absorbed in the first few thousandths of an inch of the capsule. However, neutrons and gamma radiation are also emitted and must be kept at a low level. Using the isotope at a high level of purity helps with this, but there are practical limits to the gamma shielding possible.

The organs most sensitive to radiation are the eyes, gonads, and bone-marrow, all of which are a good distance from the source centre and should therefore receive only a very low dose. Whether this dose is acceptable will depend on the views of the health authorities. Since the intensity follows the inverse square law, radiation danger to the public is considered negligible, even for the patient's spouse. The battery is able to withstand shock, accidental mechanical damage, and even cremation!

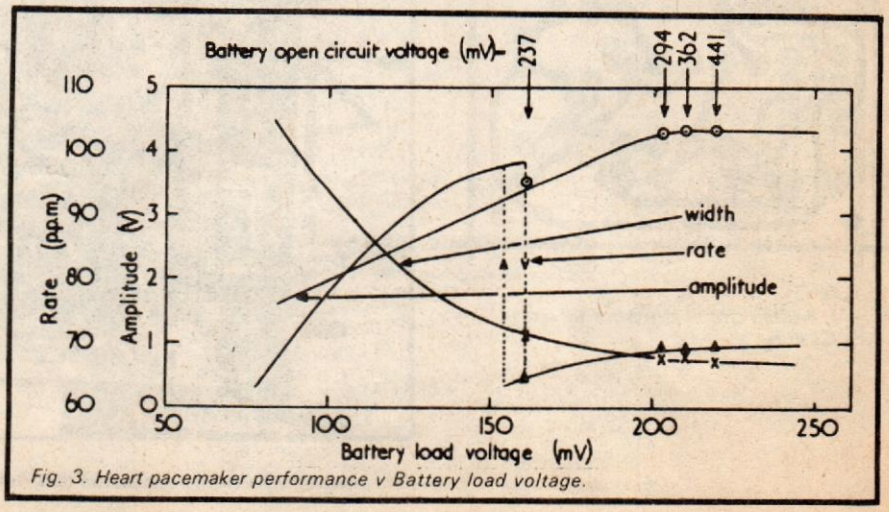
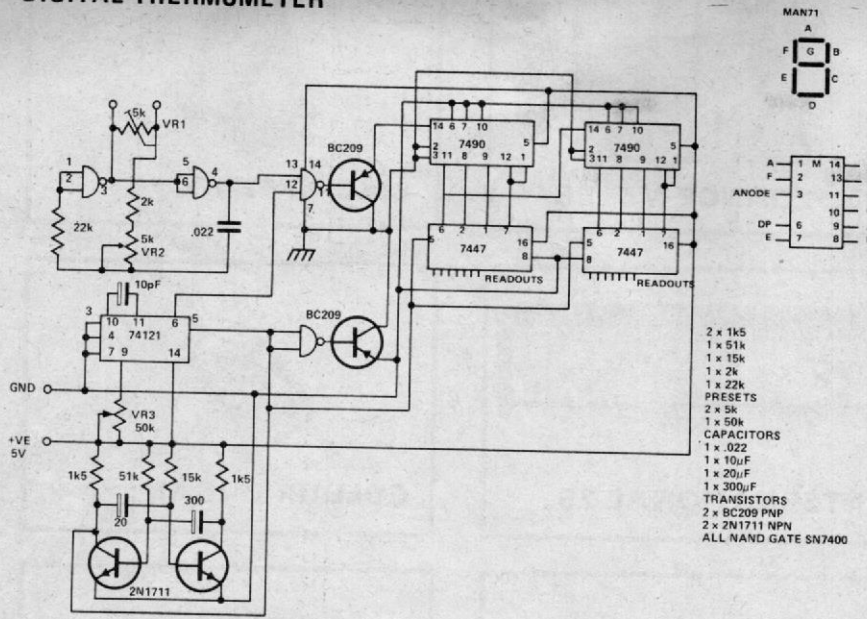
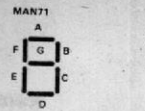
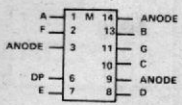


Fig. 3. Heart pacemaker performance v Battery load voltage.

DIGITAL THERMOMETER







2 x 1k5
1 x 51k
1 x 15k
1 x 2k
1 x 22k
PRESETS
2 x 5k
1 x 50k
CAPACITORS
1 x .022
1 x 10μF
1 x 20μF
1 x 300μF
TRANSISTORS
2 x BC209 PNP
2 x 2N1711 NPN
ALL NAND GATE SN7400

DESCRIPTION

The frequency of the CMOS Multivibrator depends on the resistance of the thermistor, which is determined by the ambient temperature. Thus, if the temperature increases, the frequency of the multivibrator goes up and vice versa. Trimmer pot VR1 is used to adjust linearity.

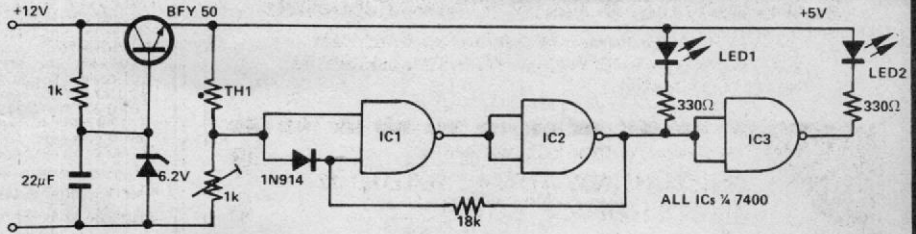
The two transistor multivibrator automatically resets the 7490 decade counters and triggers the monostable 74121. When the 74121 operates, it closes the CMOS 'NAND' gate and allows the output of the temperature dependent multivibrator to pass to the counters. The length of time that the 74121 is on, is determined by the value of C2 and the setting of trimmer VR3.

CALIBRATION

Fill a glass with ice cubes and top it up with cold water. Fill another glass with water that is as close to 90°F as possible. (Use an accurate thermometer). Place the thermistor in the ice water, adjust VR3 until display reads 32. Place the thermistor in the 90°F water, adjust VR2 until display reads 90°F. Repeat adjustment until accurate. Adjust VR1 for linearity. The digital thermometer is accurate to within 1°F between 32°F and 90°F.

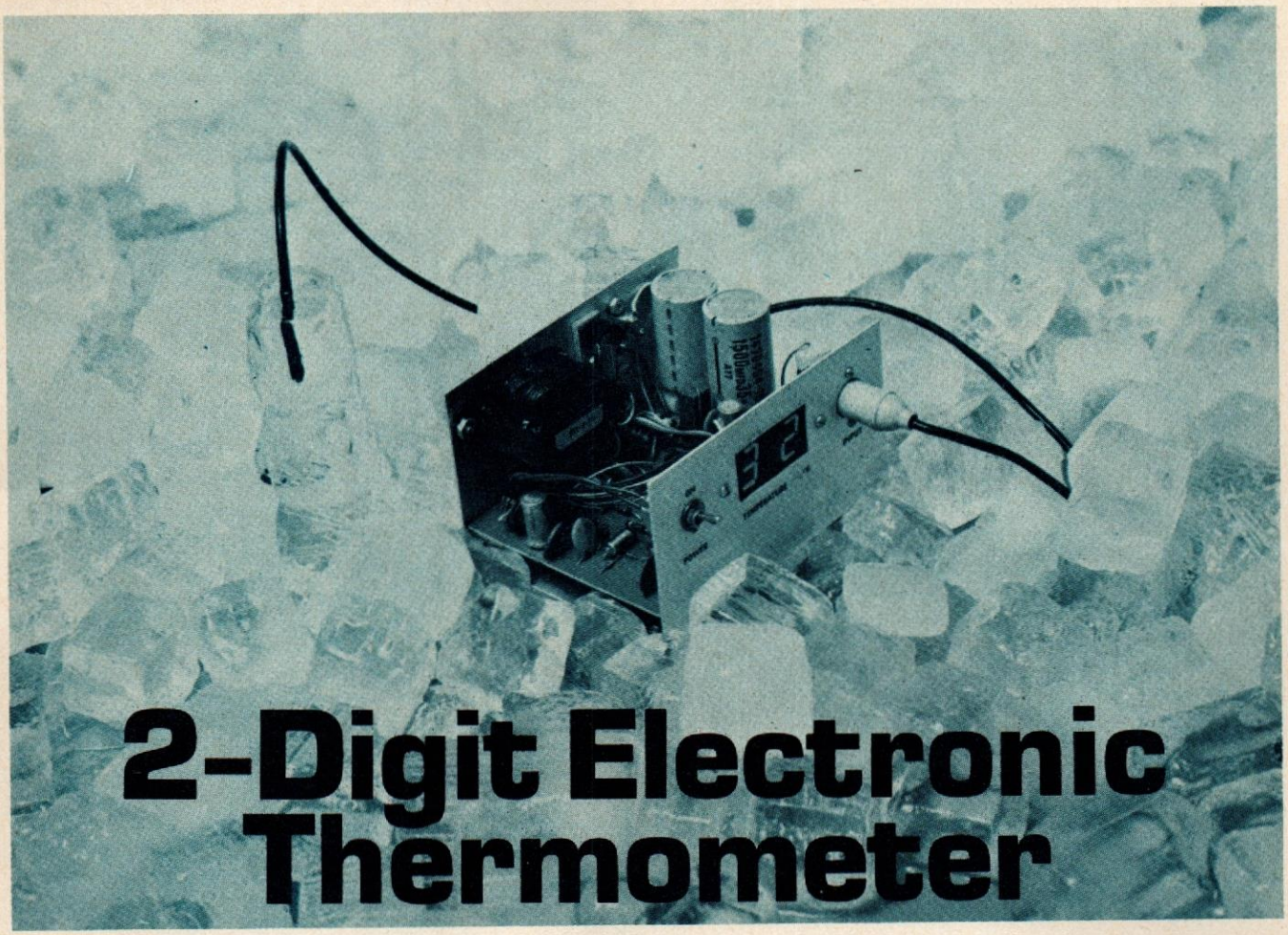
'WARMTH' INDICATOR

The sensing element used was a thermistor, attached to the outlet which is warm when the pilot light is on. A rod-type thermistor was used for cheapness, with a resistance of about 3k @ 20°C, but a bead type would work as well and with a faster response time.



Two gates of the 7400 provide a Schmitt trigger with a low hysteresis (determined by the 18k feedback resistor) and the third gate inverts that output. When the pilot light is on, the input of IC1 is high, IC3 output is logic 0 and LED2 (green) is on. If the pilot lights fails, the temperature falls, all ICs change state, LED2 goes off and LED1 (red) comes on.

The temperature at which the changeover takes place is set by the 1k preset.



2-Digit Electronic Thermometer

Measure temperature easily with this electronic thermometer. It has a 2-digit LED display and covers a 100° F. range

WALTER SIKONOWIZ

HERE'S A DIGITAL THERMOMETER THAT MEASURES FROM 0° TO 99°F and displays the temperature on a 2-digit LED display with 0.6-inch high digits. The unit is relatively simple and should cost about $50 to build. The accuracy is such that readings will off by −2° at 30°F and +2° at 70°F. Restricting the temperature range and recalibrating the unit should yield better accuracy. However, the thermometer may be best suited to remote monitoring of outdoor temperatures requiring the 0° to 99°F temperature range.

About the circuit

The thermometer circuit combines two functional modules: The first module is a thermistor/resistor network whose output voltage is a nearly linear function of temperature over the 0° to 99°F range; the second module is a two-decade A/D converter. The maximum output of the temperature-sensing network is 2.2 volts, which is slightly less than the maximum voltage that the A/D converter will accept.

The block diagram (Fig. 1) and timing waveforms (Fig. 2) show how the circuit operates. During the display interval, when the output of monostable IC4 is high, the converter is inactive while the last conversion is being displayed. In this inactive state, the output of oscillator IC1 is inhibited, staircase generator IC2 is reset to zero and the displays are visible. The output of IC4 remains high for about 1 second, then drops for the duration of the conversion interval. When the output of IC4 goes low, it generates a negative pulse that clears the counters.

During the conversion interval, which can last a maximum of 10 milliseconds, the display is blanked. This rapid blanking cannot be seen and the rapid display changes that would occur during clocking of the counters remain invisible.

There is a delay of about 100 μs before the first clocking edge (negative) appears at the output of IC1. This delay permits the negative pulse to clear the counters. Each clocking edge from IC1 increments the counters and causes the staircase to increase by one step.

Comparator IC3 monitors the output voltage of the temperature-sensing network as well as the staircase-generator output. As soon as the staircase output exceeds the output of the

temperature-sensing circuitry, IC3's output drops low and triggers IC4. Before another clocking edge can arrive, the oscillator is inhibited and the staircase generator is reset. The displays are also unblanked and show the count accumulated in the counters. When IC4's output again drops low, the whole process is repeated.

The schematic diagram is shown in Fig. 3. A 10-kHz multivibrator is formed by IC1, R2, R3, R4 and C10. When base drive is present, Q1 shorts out C10 and inhibits the multivibrator output. This method of inhibiting has another effect: The oscillator cannot operate until 100 μs after base drive is removed from Q1. The reason is that C10 must charge to its operating potential through R4. This allows time for the counters to be cleared.

Operational amplifier IC2 generates the positive-going staircase. Resetting the staircase generator is performed by FET Q2 which shorts out capacitor C14. If you cannot obtain the 2N4393 FET specified for Q2, you can substitute another, but test it to be sure it has a pinch-off voltage of less than 4.5 volts.

The output of IC2 couples to pin 3 of comparator IC3, while pin 2 receives the output signal of the temperature-sensing network. Capacitor C16 filters out any noise that might be picked up by the thermistor and its input leads. The comparator's output signal (at pin 7) couples to monostable IC4, whose own output is available at pin 3.

As can be seen in Fig. 3, IC4's output drives Q1's base, Q2's gate, the blanking terminals of display drivers IC7 and IC8 (pin 4), as well as a differentiator composed of R19, C19 and D9. The output spike from the differentiator clears counters IC5 and IC6. The output of oscillator IC1 goes to inverter Q4, which drives the clock input of the first counter. The four outputs of each counter go to a decoder/driver IC (either IC7 or IC8). Then R23 through R36 couple the driver outputs to the display digits. Finally, feedback from IC4's output to pin 6 of

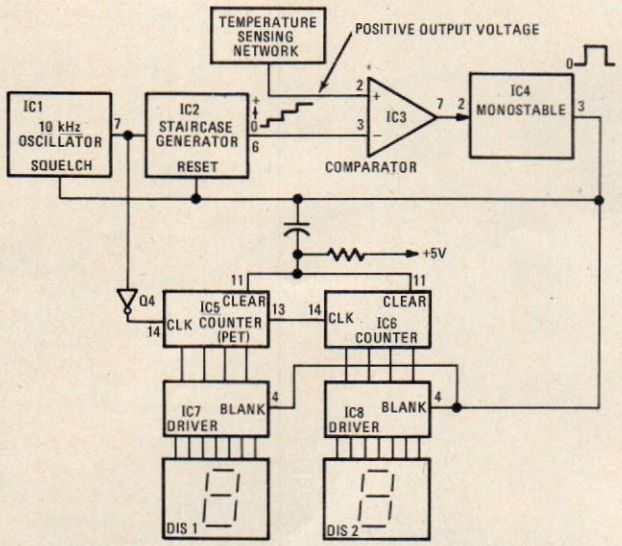


FIG. 1—DIGITAL THERMOMETER uses simple 2-digit A/D converter.

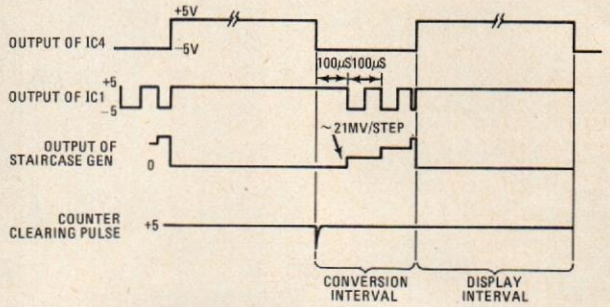


FIG. 2—TIMING WAVEFORMS of the thermometer circuit.

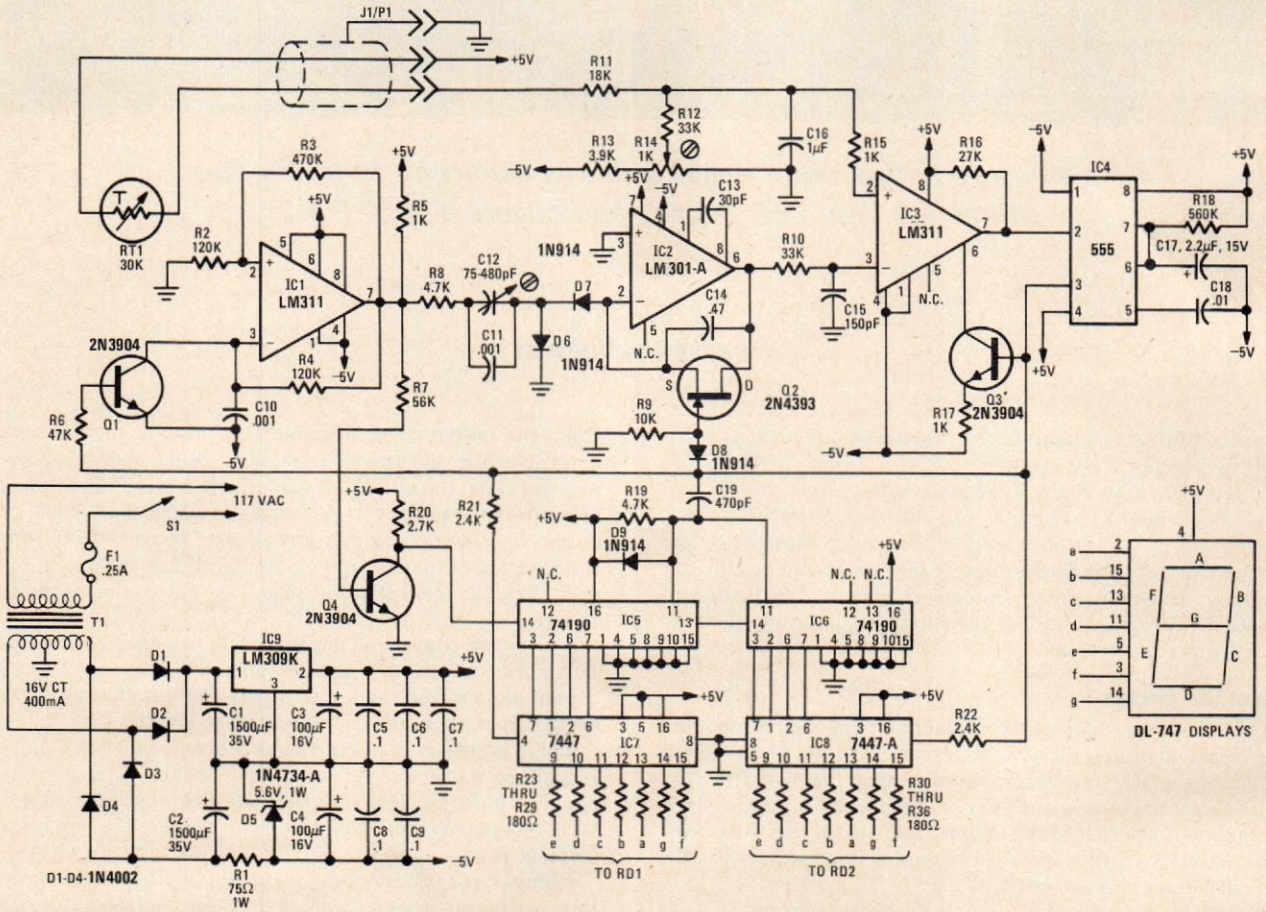


FIG. 3—COMPLETE SCHEMATIC. Power is supplied by IC regulator.

IC3, by way of Q3, eliminates an undesirable condition that results when pin 2 of IC3 is at a potential of 0 volts or less.

Construction

When constructing the thermometer be sure to include ceramic bypass capacitors for the power supply. The case should be made of metal and connected to the system ground. If the voltage regulator, IC9, is bolted directly to the chassis, with only a layer of silicone grease intervening, it will eliminate the need for a heatsink. Due to the many IC's used, it will probably be most convenient to use a PC board. The foil pattern is shown in Fig. 4 and the component overlay is shown in Fig. 5.

Two-conductor shielded cable, such as Belden No. 9452, is used to connect the thermistor to the rest of the circuitry. The shield should be connected to ground, while the two central conductors connect the thermistor to the positive supply and to R11. Use a 3- or 5-prong DIN plug-and-socket set with the shielded cable. Do not substitute for RT1, a 30K Fenwal UUT43JI precision thermistor. Use 5% resistors for R11 and R12; these two resistors, along with R13 and R14, were chosen especially to complement the thermistor. The combination provides the most linear voltage-vs.-temperature response over the 0°-to-99°F range, as shown in Fig. 6.

The thermistor assembly should be weatherproofed against environmental extremes. First insulate the exposed thermistor leads with heat-shrinkable tubing, then use Epoxy cement to seal any remaining areas where water could seep in. Since the thermistor is only 0.1-inch in diameter and thus relatively fragile, it should be mounted safely. For example, it could be put into a small plastic pill bottle, in which numerous large air holes have been punched. When mounting the thermistor outdoors, place it where summer sun and winter ice cannot damage it.

The power transformer for the thermometer is a 16-volt center-tapped 400 mA unit. If you cannot find a similar transformer, you can order one directly from the company listed in the parts list. Capacitors C11 and C14 should be polystyrene types to assure low leakage, high stability and precise capacitance values. Finally, the display pinouts are for Litronix DL-747's; others can be used, but the pin connections may be different.

PARTS LIST

All resistors ¼ watt, 5% unless noted.

R1—75 ohms, 1 watt
R2, R4—120,000 ohms
R3—470,000 ohms
R5, R15, R17—1000 ohms
R6—47,000 ohms
R8, R19—4700 ohms
R9—10,000 ohms
R10, R12—33,000 ohms
R11—18,000 ohms
R13—3900 ohms
R14—1000-ohm multiturn trimmer
R16—27,000 ohms
R18—560,000 ohms
R20—2700 ohms
R21, R22—2400 ohms
R23-R36—180 ohms
RT1—30,000 ohms precision thermistor (Fenwal UUT43J1. Write to: Customer Service, Fenwal Electronics, Framingham, MA 01701, for name and address of their distributor in your area.)
C1, C2—1500 μF, 35 volt, electrolytic
C3, C4—100 μF, 16 volt, electrolytic
C5-C9—0.1 μF, ceramic
C10, C11—1000 pF, polystyrene
C12—75-480 pF trimmer (Arco 466)
C13—30 pF, polystyrene
C14—0.47 μF, polystyrene
C15—150 pF, polystyrene
C16—1 μF, paper
C17—2.2 μF, 15 volt, tantalum
C18—.01 μF, ceramic
C19—470 pF, ceramic
D1-D4—IN4002
D5—IN4734A, 5.6 volt, 1 watt
D6-D9—IN914
IC1, IC3—LM311 voltage comparator
IC2—LM301A op-amp
IC4—555 timer
IC5, IC6—74190 synchronous up/down counter with mode control
IC7, IC8—7447A BCD-to-seven segment decoder/driver
IC9—LM309K voltage regulator, 5 volt
F1—¼ amp
J1—3-pin DIN jack
P1—DIN plug
Q1, Q3, Q4—2N3904
Q2—2N4393
S1—SPST toggle
T1—16 volt, center-tapped, 400 mA (Signal No. 241-4-16. Available from Signal Transformer, 1 Junius St., Brooklyn, NY 11212. $3.70 each, plus postage.)
DIS 1, DIS 2—DL-747 (Litronix seven-segment display.)
Misc.—Case, 2-conductor shielded cable (Belden No. 9452 or equal), miscellaneous hardware.

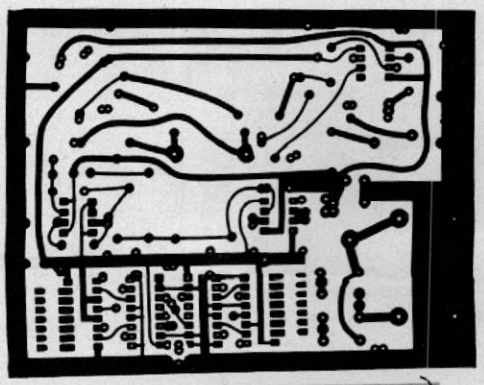


FIG. 4—FOIL PATTERN, shown half size.

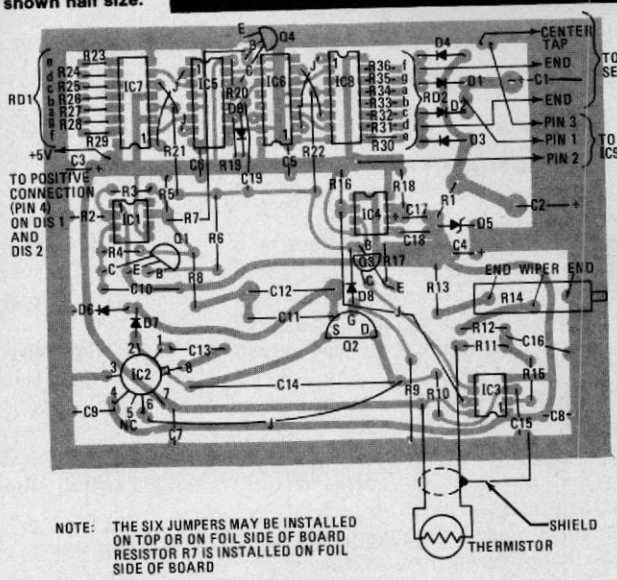


FIG. 5—COMPONENT PLACEMENT diagram.

Calibration

After construction, only the circuit calibration remains to be done. To adjust R14, use a 287K 1% metal-film resistor. Thermistor resistance at 0°F is theoretically 288K ±1.5%; the precision resistor is a very close match. By using the precision resistor, you can obtain an accurate 0°F temperature reference for the calibration. Connect the precision resistor into the circuit at the point where RT1 would normally be inserted. Apply power to the thermometer, and connect a high-imped-

continued on page 99

Precision Digital Thermometer

BILL OWEN*

THE PRECISION DIGITAL THERMOMETER described in this article uses large-scale integrated circuitry and laser-trimmed temperature transducers to achieve state-of-the-art temperature-sensing capabilities. The two switch-selectable probes can be connected through hundreds of feet of cable to provide accurate temperature sensing in remote areas. Celsius or Fahrenheit measurement is switch-selectable with 0.1° resolution, with an accuracy better than ±0.5 °C (1.2 °F) over a −50° to +150°C range (−60° to 200 °F). Table 1 shows the digital thermometer specifications.

The digital thermometer can operate from a 117-volt to 9-volt plug transformer, 12-volt automotive or marine battery systems or from internal rechargeable NiCad batteries for portable operation.

This thermometer has the range, flexibity and accuracy necessary for many useful applications, including

- A weather station with indoor/outdoor monitoring capability
- In a ham installation to report local temperature
- Medical or veterinary use
- Troubleshooting air conditioning and heating systems
- Aquarium monitoring
- Hothouse/greenhouse monitoring
- Monitoring solar-energy collectors
- Monitoring incubators
- Fresh and salt water fishing
- On the electronics bench to check semiconductor case temperature; measure crystal oven temperature; etc.
- Glass-fiber mixing
- General laboratory use, setting water baths, ovens, etc.
- Photographic and darkroom use

There are many more applications where this digital thermometer can replace mechanical thermometers and provide better resolution, accuracy and readability.

The heart of the thermometer is the AD590K temperature sensor. This sensor is an IC that, when connected to a voltage source, produces an output current proportional to temperature. The output current is equal to I μA per-degree-Kelvin. The Kelvin degree is equal in size to the Celsius degree; however, the Kelvin temperature scale is offset 273.2° higher than the Celsius scale, with 0°K (−273.2°C) called absolute zero. Absolute zero is the coldest possible temperature where molecular motion is at a minimum. The relationship between the Kelvin, Celsius and Fahrenheit scales is as follows:

$T°C = T°K - 273.2°$

$T°F = {}^{9}/_{5}\,(T°C) + 32°$

$T°F = {}^{9}/_{5}\,(T°K - 273.2) + 32°$

There is also a little-used Rankine temperature scale that starts at absolute zero with Fahrenheit-size degrees and is offset 459.7° from the Fahrenheit scale. Rankine-to-Fahrenheit conversion is as follows:

$T°F = T°R - 459.7°$

When the output current of the AD590K is passed through the appropriate value-scaling resistor, the resulting output voltage is proportional to the Kelvin or Rankine temperature, as shown in Fig. 1. The scaling resistors can be combined as shown in Fig. 2 so that °K or °R can be switch-selectable and read from a voltmeter. To generate an output voltage that is proportional to the more common Celsius and Fahrenheit scales, we need to subtract 2.732 volts from the °K output

TABLE 1—DIGITAL THERMOMETER SPECIFICATIONS

Range	−50°—+150°Celsius −60°—+200°Fahrenheit
Resolution	0.1°C 0.1°F
Sensor Linearity	±0.5°C, from −55° to +150°C
Meter Error	±1 count = ±0.1°C or F
Accuracy	Linearity error + calibration error + meter error
Probe Inputs	Two, switch-selectable
Sensor Probe	Number: 2 Type: temperature-dependent current source Response time: 3.4 seconds to reach 63.2% of step change in temperature in stirred liquid bath Voltage standoff: ±200V from sensor case to either active lead Cable length: 10 feet (can be extended to several hundred feet) Connector type: RCA phono plug
Meter Operating Temperature Range	0°—50°C
Display	3½, 0.43-inch-high, high-intensity red LED digits
Size	1¾ H × 4¼ W × 5¼ inches D
Weight	14 oz. (20 oz. with batteries and charger)
Input Power	9-14 volts AC or DC, 175 mA, 1.7 watts

*Product Engineer, Optoelectronics, Inc.

tion voltage. It will be used later in other circuits.

The video FM and the delayed video FM signals are both applied to a demodulator module, as shown in Fig. 6. The video demodulator I module receives the undelayed video FM signal and applies it to the FM demodulator stage at pin 15. The composite video output of the demodulator appears at a test point on pin 1 and is applied to the video amplifier. This amplifier has a frequency response extending to 4.2 MHz.

The amplifier's gain is controlled by R3013. The output from pin 4 is applied through DL3, a 540-ns delay line, to pin 4 of the video demodulator II module. Here the composite video signal is applied to point A of the electronic dropout switch.

The 64-μs delayed video FM signal is applied through pin 17 to the FM demodulator stage on the video demodulator II module. Its composite video output appears at a test point on pin 1 and applied to the video amplifier. The frequency response of this amplifier is rolled off at 2.6 MHz because the 64-μs delay line cannot pass signals above that frequency. As a result, dropout corrections are in black and white. The effect is not noticeable on the screen however.

Resistor R3013 controls the gain of the video amplifier. The video output is applied to point B of the electronic dropout

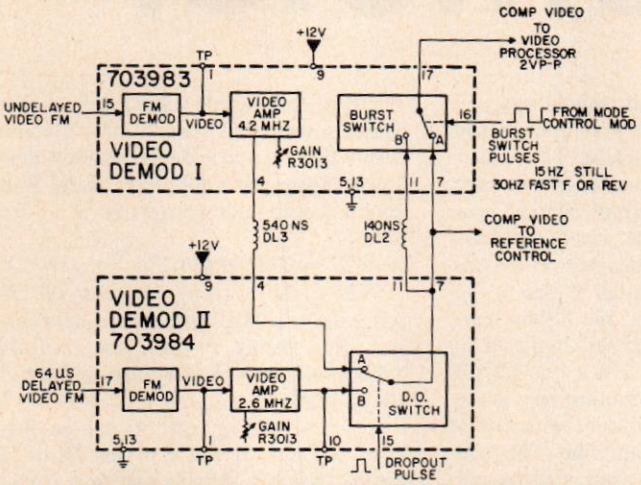


FIG. 6—VIDEO FM SIGNAL PROCESSING CIRCUIT is made up of two separate video demodulator circuit modules.

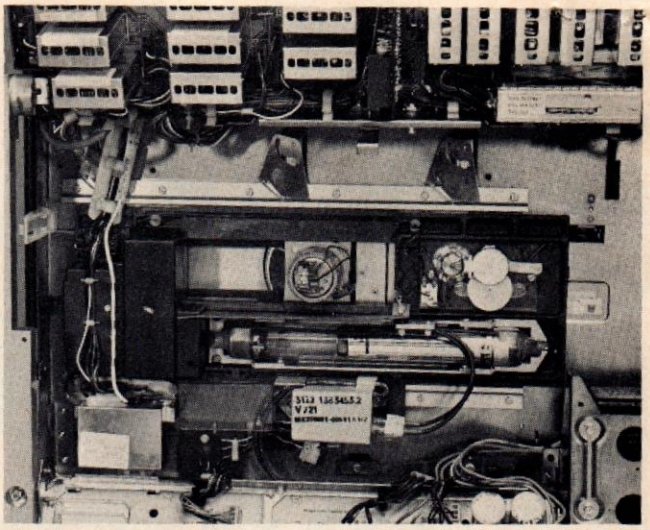
switch and can be monitored at the test point on pin 10.

The electronic dropout switch receives 540-ns delayed video on point A and one line delayed (64 μs) composite video on point B. The voltage at pin 15 determines which of these signals is applied to the electronic burst switch. The voltage at pin 15 is the high-frequency identification voltage from the dropout detector module. When a dropout occurs, the voltage goes high and creates a dropout pulse for the duration of the dropout. The dropout switch is normally in position A and receives the undelayed video (540 ns). However, when a dropout pulse is present, the dropout switch moves to position B and receives the delayed video (64 μs). The selected signal leaves at pins 7 and 11.

The 540-ns delay line compensates for the dropout response time. About 540 ns is required for the dropout circuitry to respond to the actual dropout. Thus, the "undelayed" video is actually delayed by 540 ns. When a dropout occurs the undelayed video remains present at position A of the dropout switch for 540 ns and gives the dropout circuit time to switch in the delayed video. The actual time difference between the two video signals is 64 μs minus 540 ns. This equals about 63.5 μs.

The electronic burst switch on the video demodulator II module is used to maintain the 180° phase difference in the 3.58-MHz chroma signal from frame to frame during special modes of operation, such as still picture, reverse, fast forward and slow motion. The chroma signal is normally 180° out of phase from track to track on the videodisc. This chroma relationship is also true from frame to frame on normal TV broadcasts since it is standard NTSC format. The purpose is to cancel 3.58-MHz interference in the picture.

However, when the same track (frame) is being played over



INSIDE THE VIDEODISC PLAYER. The laser tube is visible in the center of the photo. At the top are some of the many plug-in modules.

and over, such as during still-picture operation, the chroma signal would not be 180° out of phase from frame to frame. To introduce this phase difference, the signal is delayed by 140 ns every other revolution during still picture. The 140-ns delay line, DL2, is equivalent to ½ of a 3.58-MHz period.

The electronic burst switches delay line DL2 in or out depending on the burst switch pulses at pin 16. These pulses come from the mode control module. During normal play, no pulses are present, the burst switch remains in position A, and the 140-ns delay line is not in the circuit. During still picture, the burst switch pulses are at a 15-Hz rate. As a result, the burst switch is in position B for 1/30th of a second (one frame) and in position A for 1/30th of a second. During reverse play and fast forward, the burst switch pulses are at 30 Hz because only one half of each track is read at a time. The burst switch is then in position B for ½ revolution (1/60th of a second) and position A for the other half revolution.

The resultant composite video signal is coupled out of the module at pin 17 where it is sent to the video processor module. The composite video at pin 7 is identical to the signal at pin 17 except it lacks the burst switch correction. This signal is sent to the reference control module.

The video signal from the electronic burst switch is coupled to the first video amplifier in the video processor module at pin 17, as shown in Fig. 7. The video blanking input at pin 16 blanks the video signal during the return of the light beam to the inside of the videodisc and also during initial turn-on. The video signal from the amplifier is processed by the DC clamp circuit. It clamps the video signal to the correct DC level. The clamp adjust control, R3029, can vary this DC level. The DC clamp is driven by a horizontal rate clamp-gate pulse at pin 15. The DC level is corrected during each horizontal blanking interval.

Composite video is clipped in the reference control module by the amp/clipper stage. The resultant clipped video contains the digital code that represents the picture number. This code is applied to a decoder on the mode control module. The video generator actually creates the video signal for the picture number. A video signal is also generated that provides the grey background behind the picture numbers on the screen.

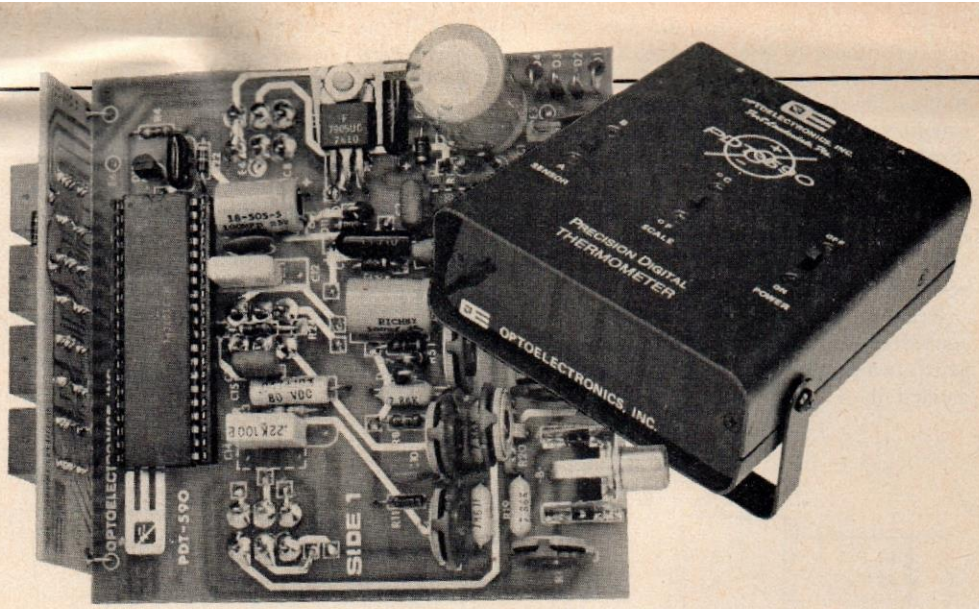
These video signals are applied to the second video amplifer and then to the VHF modulator. The composite video signal is also applied to the rear-panel monitor jack.

The VHF modulator, Fig. 8, receives the composite video signal and the audio signal. These signals modulate the RF carrier in the RF modulator stage. The RF modulator is an oscillator that delivers an RF signal on VHF TV channel 3 or 4. If the channel selector switch connects to ground, channel 3 is generated. If the switch connects to 12V, channel 4 is generated.

A simplified diagram of the antenna switch box is shown in

continued on page 89

This easy-to-build electronic thermometer provides a resolution of 0.1 degree with unusually rapid response time. Two switch selectable sensor probes can be used for accurate measurements from remote areas.



and 4.597 volts from the °R output, as shown in Fig. 2. This is accomplished by having the voltmeter measure the difference between the scaled output voltage and the appropriate reference voltage.

The reference voltages must be very stable, so a 6.9-volt-precision, integrated-circuit Zener (IC7, LM329DZ) is used with appropriate resistor dividers. Figure 3 shows the complete temperature-to-voltage circuit with Celsius-to-Fahrenheit and sensor switches. Trimmer resistors are used to calibrate the temperature sensors and to precisely adjust the reference voltages.

The selected temperature sensor's Celsius or Fahrenheit output voltage is measured by a 3½-digit digital voltmeter (DVM). The DVM has a −1,999-volt to +1.999-volt range, and so when the scaled output voltage falls below the reference voltage, a negative temperature is indicated. Because the input voltage is 10 mV-per-degree Celsius or Fahrenheit, the decimal point is placed between the 1-mV and 10-mV digits to obtain a degree C or degree F readout.

The complete schematic is shown in Fig. 4. The DVM is built around Intersil's 7107 analog-to-digital (A/D) converter IC. The 7107 uses the dual-slope integration method of conversion, and has autozero and a true differential input (it measures the net difference between voltages applied to its input-high and input-low terminals).

The A/D converter contains amplifiers, buffers, analog switches, a comparator, a clock oscillator, counters, latches and LED segment drivers. In the first part of a measurement cycle, the A/D converter internally shorts the inputs and charges autozero capacitor C15 to compensate for the amplifier and integrator offset voltages. In the next phase, the integrator output voltage increases at a rate that is proportional to the unknown input voltage for a fixed number of clock pulses. In the final phase, the integrator

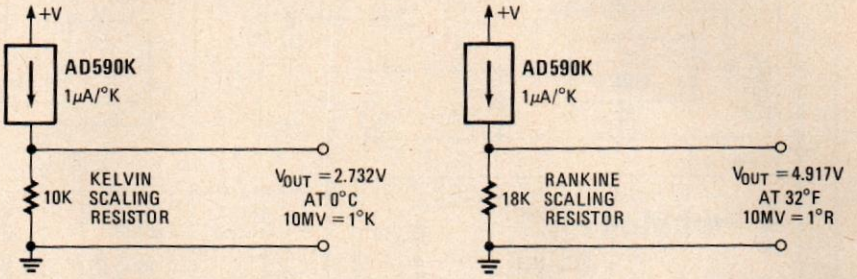


FIG. 1—TEMPERATURE-DERIVED CURRENT flows through scaling resistors to develop voltages proportional to Rankine and Kelvin temperatures.

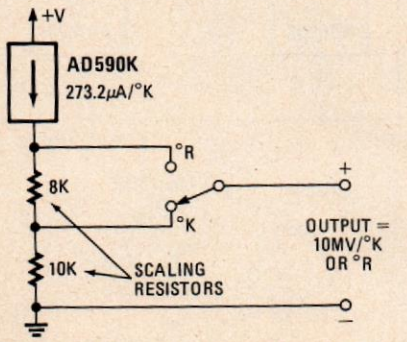


FIG. 2—SCALING RESISTOR adjusted to give Kelvin- and Rankine-proportional voltages.

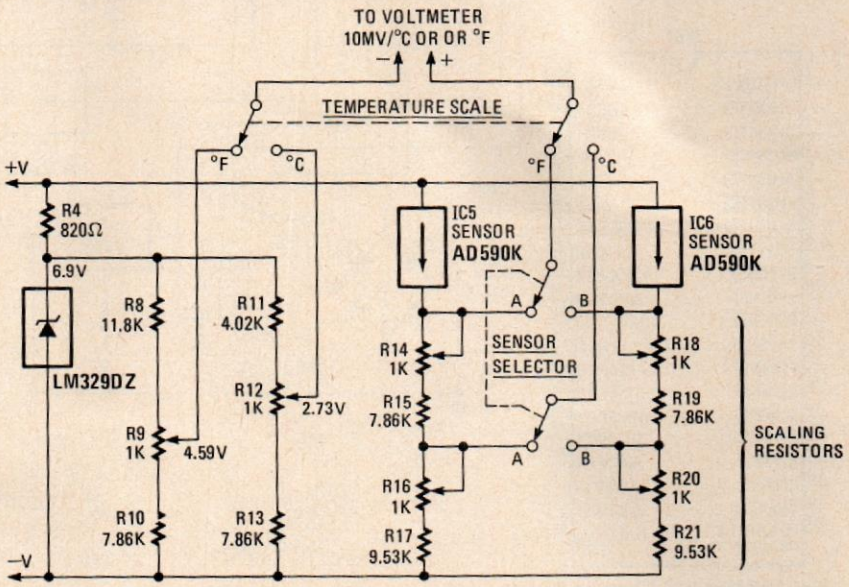


FIG. 3—REFERENCE VOLTAGES, derived from a 6.9-volt precision source, are used to produce temperature-dependent voltages corresponding to Centigrade and Fahrenheit scales.

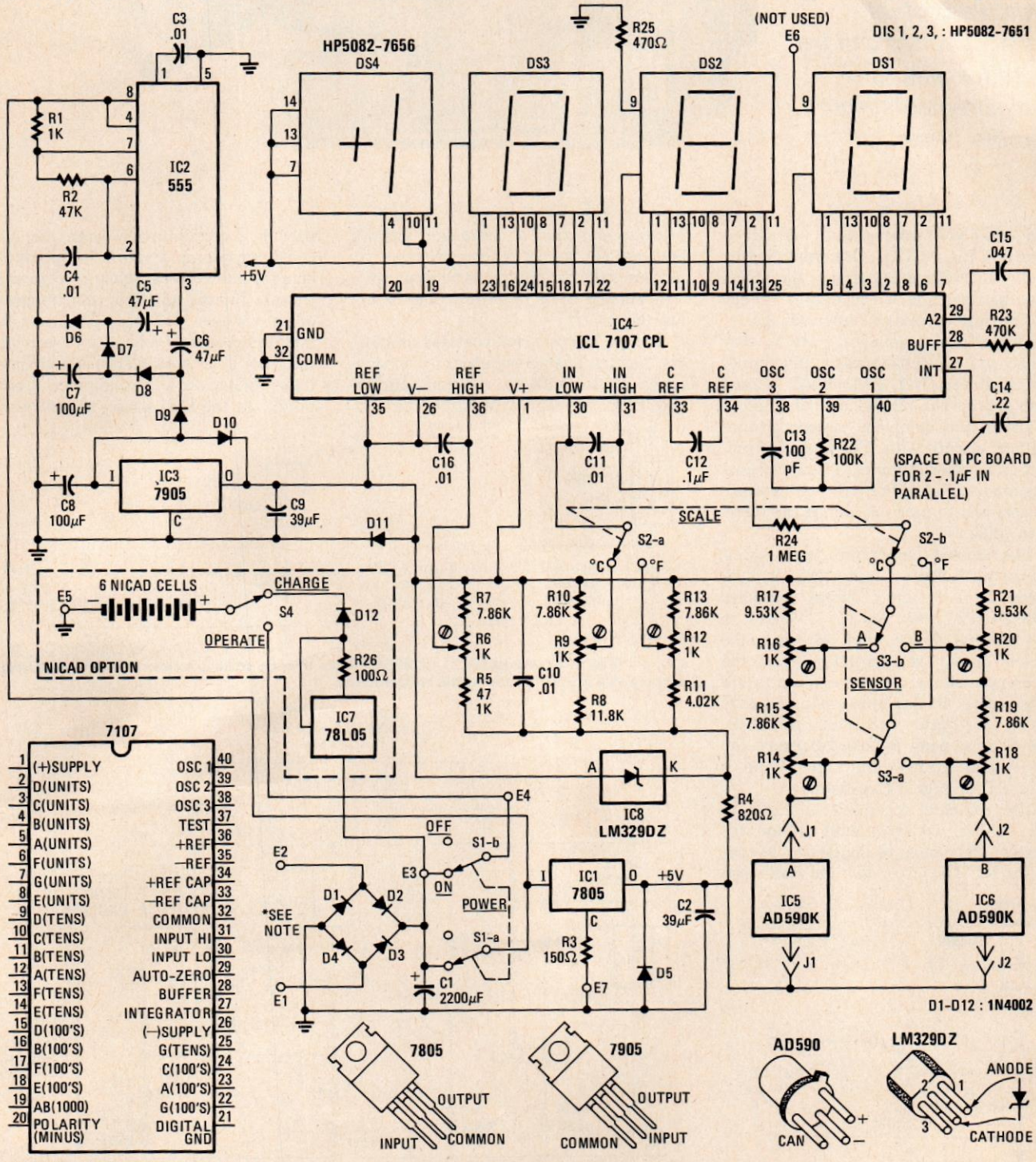
output voltage is decreased at a rate that is proportional to the reference voltage stored on reference capacitor C12. The number of clock pulses required for the integrator to reach 0 volt is counted and displayed. If the unknown voltage is integrated for 1000 counts, and if it requires 1000 counts during the final phase to reach 0 (using a 1-volt reference), then 1000 is displayed corresponding to 1.000 volt.

Resistor R22 and capacitor C13 are connected to the internal oscillator to generate a frequency of 48 kHz, which is divided by 4 before being used. Maximum 60-Hz rejection is achieved by having the integration period be an integral multiple of the line frequency. Three conversions-per-second are performed with the 48-kHz clock frequency.

Accuracy with the dual-slope A/D converter is achieved without using precision resistors or capacitors. Integration capacitor C14, autozero capacitor C15 and reference capacitor C12 must have low leakage characteristics as well as low dielectric adsorption. Polypropylene film, Mylar and polycarbonate capacitors are recommended for their excellent dielectric properties.

Although the A/D converter has an on-chip voltage reference, the LM329DZ reference voltage is more stable because it is not subject to internal heating caused by the LED segment drivers. The 1-volt reference is externally supplied from a resistive divider across the LM329DZ precision Zener.

The circuit requires a +5.6- as well as a −5-volt power supply. The 9 to 14 volts AC or DC input supply is rectified and filtered by D1–D4 and C1. The 7805 voltage regulator supplies the +5 volts. The 555 timer (IC2) operates the astable mode and generates a 2-kHz squarewave



*9VDC OR 12VAC AT 300mA VIA J3

FIG. 4—THE DIGITAL THERMOMETER is designed around a 3½-digit A/D converter. The 555 timer IC generates a pulse train that is voltage-doubled and rectified for the negative supply.

that is voltage-doubled and clamped to produce the negative supply voltage that is regulated by 7905 regulator IC3.

Construction

Assembly is simple and straightforward; the PC foil patterns are shown in Figs. 5, 6 and 7, and parts placement is shown in Figs. 8, 9 and 10. Insert and solder all components referring to the parts list and Fig. 8. Start with the resistors and diodes, working your way up to the larger items. Note that some components are installed on the side of the main PC board opposite the other components, as in Fig. 9. Many components are top-soldered or soldered on both sides of the PC board wherever the PC foil surrounds a component lead. There are several feed-through locations (indicated by a □ in the parts layout) where a short piece of wire clipped from a component lead is inserted through a hole and soldered to the PC foil on both sides of the board.

The 7905 voltage regulator is installed on side 1 of the main PC board, and the 7805 voltage regulator is installed on side 2, using mica insulators and an insulating *nylon machine screw*. The three 7805 leads must be bent straight down about ¼ inch away from the regulator body, and soldered and clipped before the 7905 leads are soldered. Clip the excess 7805 leads close to the PC board so that they do not touch the 7905 leads.

The LED digits are soldered to the display board as shown in Fig. 10. After completing the PC boards, place a ¾-inch piece of excess resistor lead in main PC board locations b and e, and solder them in place so that one-half the lead length extends from each side of the board. Bend these wires forward and insert the ends of wire b into locations a and c, and insert wire e into locations d and f on the display board. Solder the wires after carefully aligning the two PC boards so that they are at right angles, with all foil fingers exactly matching. There are two sets of foil semicircles that can be used as indicators to check the alignment. After rechecking alignment, solder the 26 mating foil fingers together.

Secure the three slide switches to the cabinet top with small flat-head screws. Put the main PC board on the switch lugs and check the positioning with the rear panel, front panel and cabinet top in place. Solder the 18 slide-switch lugs to the main PC board.

Power-input jack J3 is mounted on the rear panel using shoulder washers and nylon spacers. Check to make sure that there is no continuity between the power jack and the rear panel. Use stranded hookup wire to connect the power-jack bracket and center pin to PC board locations E1 and E2.

Probe construction

Remove the case leads from the AD590K temperature sensors. Cut the

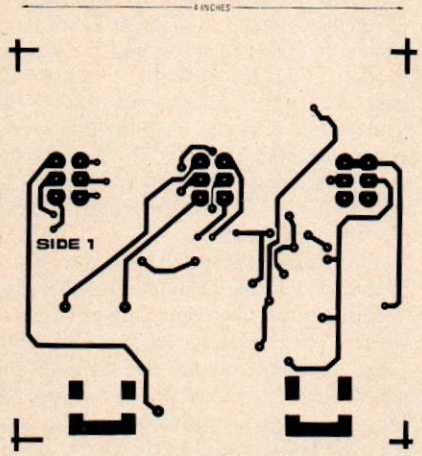


FIG. 5—FOIL PATTERN for the components side of the PC board. Approximately half size.

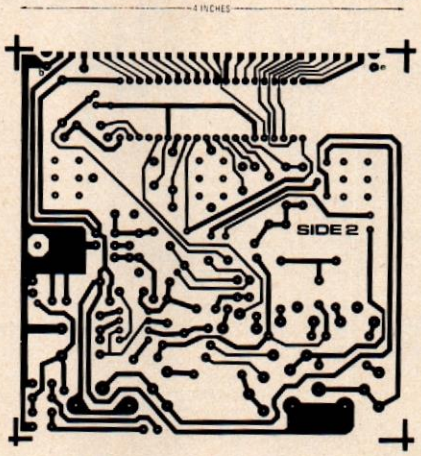


FIG. 6—PATTERN for side-2 of the board. Only a few parts are mounted on this side.

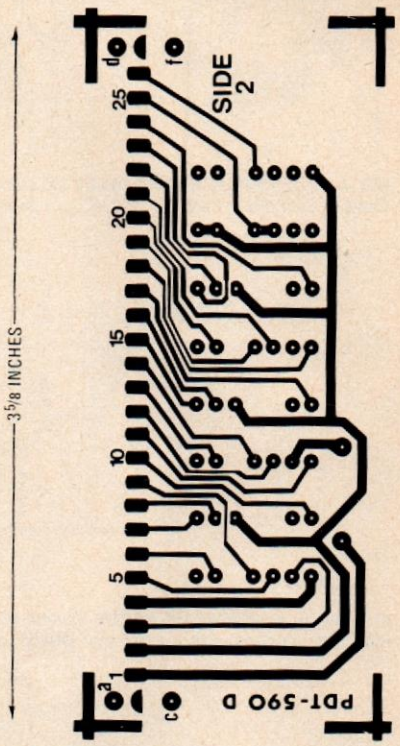


FIG. 7—DISPLAY BOARD uses this pattern with edge pads to mate with those on main board.

PARTS LIST

Resistors, ¼ Watt, 5% unless otherwise noted
R1—1000 ohms
R2, R5—47,000 ohms
R3—150 ohms
R4—820 ohms
R6, R9, R12, R14, R16, R18, R20—1000 ohms, vertical-mount, trimmer potentiometer
R7, R10, R13, R15, R19—7860 ohms, 1%
R8—11,800 ohms, 1%
R11—4020 ohms, 1%
R17, R21—9530 ohms, 1%
R22—100,000 ohms
R23—470,000 ohms
R24—1 megohm
R25—470 ohms
R26—100 ohms

Capacitors
C1—2200 μF, 16 volts, electrolytic
C2, C9—39 μF, 10 volts, tantalum
C3, C10, C16—.01 μF, ceramic disc
C4, C11—.01 μF polyester
C5, C6—47 μF, 16 volts, electrolytic
C7, C8— 100μF, 25 volts, electrolytic
C12—0.1 μF, Mylar
C13—100 pF, dipped mica
C14—0.22 μF, polyester
C15—.047 μF, polypropylene

Semiconductors
D1-D13—1N4002
DIS1-DIS3—HP5082-7651, 7-segment LED display, common anode, right-hand decimal point, high-efficiency RED
DIS4—HP5082-7656 universal overflow display, ± 1, right-hand decimal point
IC1—7805, +5-volt regulator
IC2—NE555 timer
IC3—7905,—5-volt regulator
IC4—ICL7107CPL, 3½-digit CMOS A/D converter (Intersil)
IC5, IC6—AD590K, temperature sensor (Analog Devices)
IC7—LM329DZ precision Zener, 6.9 volts

Miscellaneous
S1-S3—miniature slide switch, DPDT
S4—miniature toggle switch, SPDT
Power transformer, 9 volts AC, 300 mA, plug-type with molded plug
Socket, 40 pins, DIP
Socket, 8 pins, DIP
J1, J2—phono jacks, PC mount
J3—pin-type power receptacle to match power transformer
Case, assorted hardware

The following kits for the digital thermometer are available from Optoelectronics, Inc., 5821 N.E. 14th Ave., Ft. Lauderdale, FL 33334:

The complete kit for the PDT-590 digital thermometer (includes cabinet, power supply, two probes and all parts except optional NiCad battery and charger) $99.95. The PDT-590/WT, wired and tested $159.95.

Rechargeable battery option NI-CAD-590 includes batteries, holder, mounting hardware, switch and charging circuit (used in kit and factory-wired models) $25.00. Set of PC boards and switches PCB-590 $19.95. Extra probe kit P-590K $12.00; extra assembled probe P-590 $15.00.

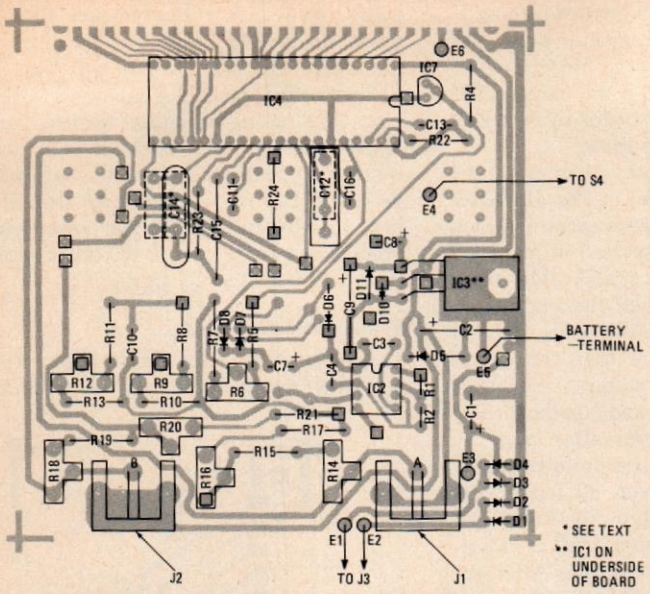


FIG. 8—PARTS PLACEMENT DIAGRAM showing locations of most of the components. Note that IC3 and IC1 are back-to-back.

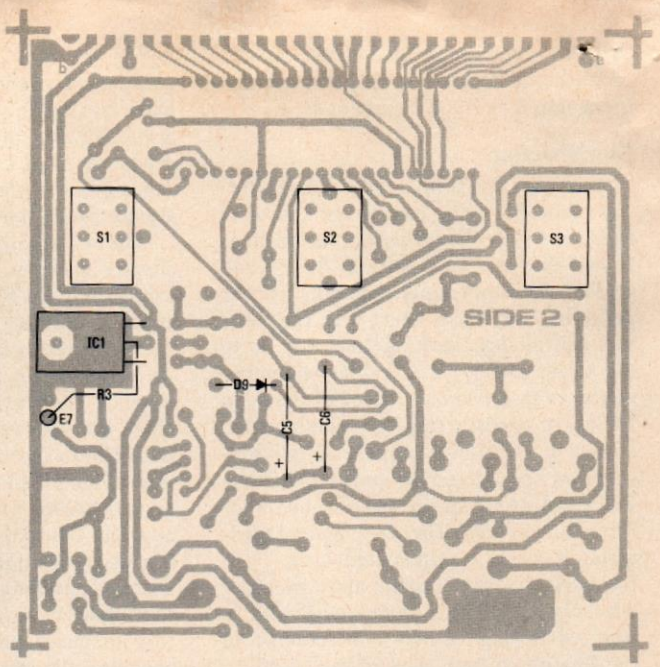


FIG. 9—SLIDE SWITCHES and a few other parts are mounted on side-2 of the main PC board.

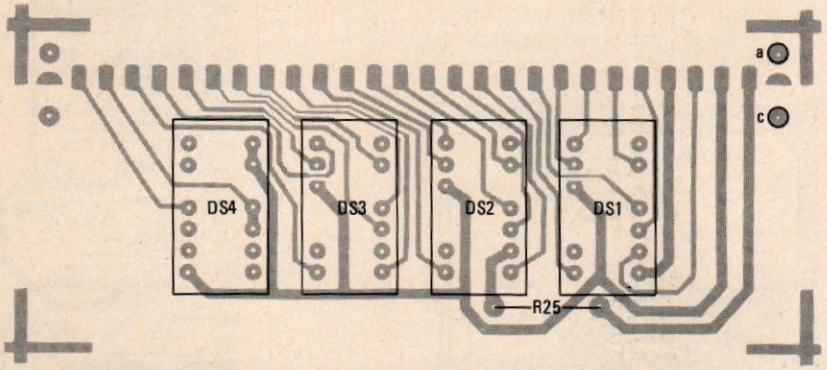


FIG. 10—PLACEMENT OF SEVEN-SEGMENT READOUTS on the display PC board. Be sure that the readouts are right-side up and that DS4 is in correct position.

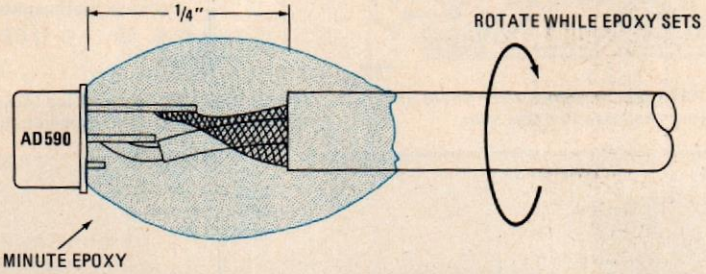


FIG. 11—HOW TEMPERATURE PROBES ARE CONSTRUCTED. Note that clear quick-setting epoxy cement is used to insulate and seal the sensor connections.

positive and negative leads back to 1/4 inch in length and tin them. Remove 1/4 inch of insulation from the end of the probe cable, and twist and tin the shield and the center conductor wires. Solder the shield to the sensor's positive lead and the center conductor to its negative lead.

Clear-drying five-minute epoxy cement should be used to waterproof the sensors. Thoroughly mix some epoxy and apply it around the solder connections on the sensor while rotating the cable (see Fig. 11) while the epoxy sets.

Calibration

After completing the sensor probes, plug them into the instrument and apply power to the circuit. Even without calibration the display count should increase as the sensor responds to the heat from your hand. Label one probe "Sensor A" and the other "Sensor B," and do not unplug or interchange them during calibration.

Calibration requires a DVM to set the reference voltages. Connect the negative DVM lead to pin 2 of the 7905 voltage regulator (IC3) and the positive lead to ground, and then check for 5 volts ±0.25 volt. Next, connect the positive DVM lead to pin 2 of the 7805 regulator and check for 10.6 volts to 11 volts. If the voltage is below 10.6 then increase R3 to 180 ohms or 200 ohms to raise the positive supply voltage.

With the negative DVM lead on pin 2 of the 7905 voltage regulator, connect the positive lead to the center lug of trimmer resistor R6 and adjust R6 for 1.000 volt. Next, connect the positive lead to the center lug of trimmer R9 and adjust R9 for a 2.73-volt measurement. Then, connect the positive lead to the center lug of R12, and adjust R12 for 4.59 volts.

The sensor probes are easily calibrated using the boiling point and freezing point of water for reference. To achieve ±0.6°C accuracy (or better), the sensor probes should be calibrated at both points and the error should be evenly split between them. For instance, if the meter is adjusted to read 0.0°C at the freezing point of water and 101.0° at the boiling point of water, then the error will be +1°C. The error would be ±0.5°C if the meter were readjusted to read −0.5°C at the freezing point and 100.5°C at the

continued on page 83

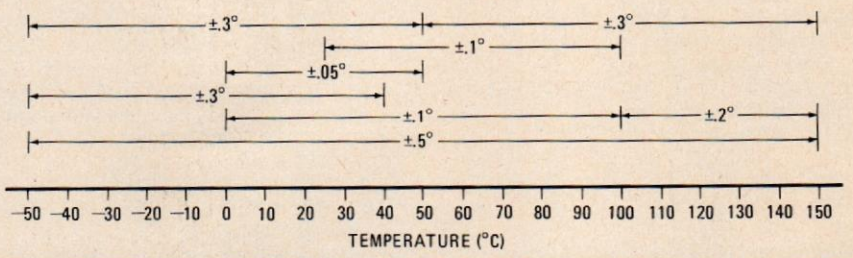


FIG. 12—SENSOR NONLINEARITY of the PDT-590 digital thermometer improves over reduced temperature ranges. Note that linearity is as good as ±0.05° between 0° and 50° C.

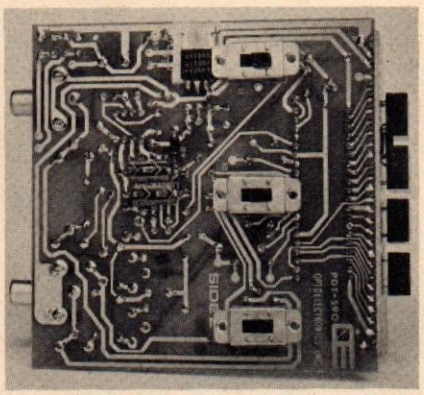
DIGITAL THERMOMETER

Continued from page 46

boiling point. This method of equalizing the error over the temperature range is sometimes referred to as "splitting the rock."

Place both sensors in a pot of mineral-free water (distilled if necessary), and after it is freely boiling, adjust R16 for Sensor A and R20 for Sensor B for 100.0°C. (R14 and R18 should be set at mid-range.) If you are very far above sea level, then it may be necessary to make an altitude correction.

For the freezing point of water, mix crushed ice with an equal amount of cold water. Stir the mixture for several minutes; you should observe the temperature reach a low point and stabilize for several minutes when equilibrium is reached. If it measures right on 0.0°C, then you are finished with calibration. If the temperature is below 0.0°C, then adjust trimmers R16 and R20 until the amount of error is reduced by a half—"splitting the rock."



SWITCHES are mounted on Side 2 of the PC board and protrude through top of the case.

Next, place the sensors in tap water and allow them to come to equilibrium at room temperature. Use the conversion equations and calculate the Fahrenheit temperature from the indicated Celsius temperature. Adjust R14 and R18 for the correct Fahrenheit temperature.

Figure 12 shows the sensor linearity error over several different temperature spans. In order to achieve these accuracies over reduced spans, an accurate thermometer with 0.1°C resolution must be used to calibrate the sensors at each end of the selected span. An accurate clinical thermometer can be used over the clinical range; however, note that it tends to integrate the temperature from the tissue with which it is in contact along its length, while the AD590K measures the temperature of the point it contacts.

Accurate glass thermometers with 0.1° resolution are available from most laboratory supply distributors for under $25; however, they are very fragile and require that a specific length of thermometer be immersed for accurate measurements. The glass thermometer should be used in a well-stirred water bath in order to calibrate the sensor probes. **R-E**

Write and run programs—the very first night—even if you've never used a computer before!

You're up and running with video graphics for just $99.95 — then use low cost add-ons to create your own personal system that rivals home computers sold for 5-times ELF II's low price!

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Own a powerful home computer system, starting for just $99.95—a price that gets you up and running the very first night . . . with your own TV for a video display. $99.95 ELF II includes RCA 1802 8-bit microprocessor addressable to 64k bytes with DMA, interrupt, 16 registers, ALU, 256 byte RAM, full hex keyboard, two digit hex output display, stable crystal clock for timing purposes, RCA 1861 video IC to display your programs on any video monitor or TV screen *and 5-slot plug-in expansion bus (less connectors) to expand ELF II into a giant!*

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Soon to be introduced: ELF II special application kits that give you the hardware and software you need to use ELF II for specialized purposes such as a telephone dialer . . . industrial controller . . . home photography . . . security system . . . police alert . . . motor controller . . . station output monitor on a conveyor belt assembly line . . . and some new, super-fantastic games!

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Regardless of how minimal your computer background is now, you can learn to program an ELF II in almost no time at all. Our *Short Course On Microprocessor & Computer Programming*—written in non-technical language—guides you through each of the RCA COSMAC 1802's capabilities, so you'll understand *everything* ELF II can do . . . *and how to get ELF II to do it!* Don't worry if you've been stumped by computer books before. The *Short Course* represents a major advance in literary clarity in the computer field. You don't have to be a computer engineer in order to understand it. Keyed to ELF II, it's loaded with "hands on" illustrations. When you're finished with the *Short Course*, neither ELF II nor the RCA 1802 will hold any mysteries for you.

In fact, not only will you now be able to use a personal computer creatively, you'll also be able to read magazines such as BYTE . . . INTERFACE AGE . . . POPULAR ELECTRONICS and PERSONAL COMPUTING and fully *understand* the articles. And, you'll understand how to expand ELF II to give you the exact capabilities you need!

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$99.95 ELF II includes all the hardware and software you need to start writing and running programs at home, displaying video graphics on your TV screen and designing circuits using a microprocessor—the very first night—even if you've never used a computer before.

ELF II connects directly to the video input of your TV set, without any additional hardware. Or, with an $8.95 RF modulator (see coupon below), you can connect ELF II to your TV's antenna terminals instead.

ELF II has been designed to play all the video games you want, including a fascinating new target/missile gun game that was developed specifically for ELF II. But games are only the icing on the cake. The real value of ELF II is that it gives you a chance to write machine language programs—and machine language is the fundamental language of all computers. Of course, machine language is only a starting point. You can also program ELF II with assembly language and tiny BASIC. But ELF II's machine language capability gives you a chance to develop a working knowledge of computers that you can't get from running only pre-recorded tape cassettes.

ELF II Gives You The Power To Make Things Happen!

Expanded, ELF II can give you more power to make things happen in the real world than heavily advertised home computers that sell for a lot more money. Thanks to an ongoing commitment to develop the RCA 1802 for home computer use, the ELF II products—being introduced by Netronics—keep you right on the outer fringe of today's small computer technology. It's a perfect computer for engineering, business, industrial, scientific and personal applications.

Plug in the **GIANT BOARD** to record and play back programs, edit and debug programs, communicate with remote devices and make things happen in the outside world. Add **Kluge** (prototyping) **Board** and you can use ELF II to solve special problems such as operating a complex alarm system or controlling a printing press. Add **4k RAM Boards** to write longer programs, store more information and solve more sophisticated problems.

ELF II add-ons already include the **ELF II Light Pen** and the amazing **ELF-BUG Monitor**—two extremely recent breakthroughs that have not yet been duplicated by any other manufacturer.

The ELF-BUG Monitor lets you debug programs with lightening speed because the key to debugging is to know what's inside the registers of the microprocessor. And, with the ELF-BUG Monitor, instead of single stepping through your programs, you can now display the entire contents of the registers on your TV screen. You find out immediately what's going on and can make any necessary changes.

The incredible ELF II Light Pen lets you write or draw anything you want on a TV screen with just a wave of the "magic wand." Netronics has also introduced the ELF II Color Graphics & Music System—more breakthroughs that ELF II owners were the first to enjoy!

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Ultimately, ELF II understands only machine language—the fundamental coding required by all computers. But, to simplify your relationship with ELF II, we've introduced an **ELF II Tiny BASIC** that makes communicating with ELF II a breeze.

Tiny BASIC saves you the time of having to code your individual instructions in machine language for ELF II. Instead, you simply type instructions on a keyboard—PRINT, RUN, LOAD, ETC. Your Tiny BASIC program automatically translates them into machine language for ELF II. Then it translates ELF II's output back into simple words and symbols for you.

Now Available! Text Editor, Assembler, Disassembler And A New Video Display Board!

The Text Editor gives you word processing ability and the ability to edit programs or text while it is displayed on your video monitor. Lines and characters may be quickly inserted, deleted or changed. Add a printer and ELF II can type letters for you—error free—plus print names and addresses from your mailing list!

ELF II's **Assembler** translates assembly language programs into hexidecimal machine code for ELF II use. The Assembler features mnemonic abbreviations rather than numerics so that the instructions on your programs are easier to read—this is a big help in catching errors.

ELF II's **Disassembler** takes machine code programs and produces assembly language source listings. This helps you understand the programs you are working with . . . and improve them when required.

The new **ELF II Video Display Board** lets you generate a sharp, professional 32 or 64 character by 16 line upper and lower case display on your TV screen or video monitor—dramatically improving your unexpanded $99.95 ELF II. When you get into longer programs, the Video Display Board is a real blessing!

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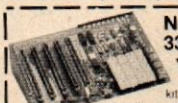
Don't be trapped into buying an expensive dinosaur, simply because you can afford it. ELF II is more advanced and more fun to use than big name computers that cost a lot more money. With ELF II you learn to write and run your own programs. You're not just a keypunch operator. No matter what your interests are, ELF II is the fastest way to get into computers. ***Order from the coupon below!***



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Yes! I want my own computer! Please rush me—

☐ RCA COSMAC ELF II kit at $99.95 plus $3 postage and handling (requires 6.3 to 8 volt AC power supply)

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☐ Tom Pittman's **Short Course On Microprocessor & Computer Programming** teaches you just about everything there is to know about ELF II or any RCA 1802 computer. Written in non-technical language, it's a learning breakthrough for engineers and laymen alike. $5 postpaid

☐ Deluxe Metal Cabinet with plexiglas dust cover for ELF II. $29.95 plus $2.50 p&h

☐ I am also enclosing payment (including postage & handling) for the items checked below!

☐ **I want my ELF II wired and tested with power supply, RCA 1802 User's Manual and Short Course—all for just $149.95 plus $3 p&h.**

Total Enclosed $ _____
(Conn. res. add tax)

CHARGE IT! Exp. Date ____
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ALSO AVAILABLE FOR ELF II

☐ **GIANT BOARD™** kit with cassette I/O, RS-232 C/TTY I/O, 8-bit P I/O, decoders for 14 separate I/O instructions and a system monitor/editor. **$39.95** plus $2 p&h

☐ **Kluge** (Prototype) **Board** accepts up to 36 IC's. **$17.00** plus $1 p&h

☐ **4k Static RAM kit.** Addressable to any 4k page to 64k. **$89.95** plus $3 p&h

☐ Gold plated **86-pin connectors** (one required for each plug in board). **$5.70** ea., postpaid

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☐ **ELF II Tiny BASIC** on cassette tape. Commands include SAVE, LOAD, ± × ÷ ( ) 26 variables A-Z, LET, IF/THEN, INPUT, PRINT, GOTO, GOSUB, RETURN, END, REM, CLEAR, LIST, RUN, PLOT, PEEK, POKE. Comes fully documented and includes alphanumeric generator required to display alphanumeric characters directly on your tv screen without additional hardware. Also plays tick-tack-toe plus a drawing game that uses ELF II's hex keyboard as a joystick. 4k memory required. **$14.95** postpaid

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☐ **Assembler** on cassette tape translates assembly language programs into hexidecimal machine code for ELF II use. Mnemonic abbreviations for instructions (rather than numerics) make programs easier to read and help prevent errors. **$19.95** postpaid

☐ **Disassembler** on cassette tape takes machine code programs and produces assembly language source listings to help you understand and improve your programs. **$19.95** on cassette tape.

SAVE $9.90—Text Editor, Assembler & Disassembler purchased together, only **$49.95!** (Require Video Display Board plus 4k memory.)

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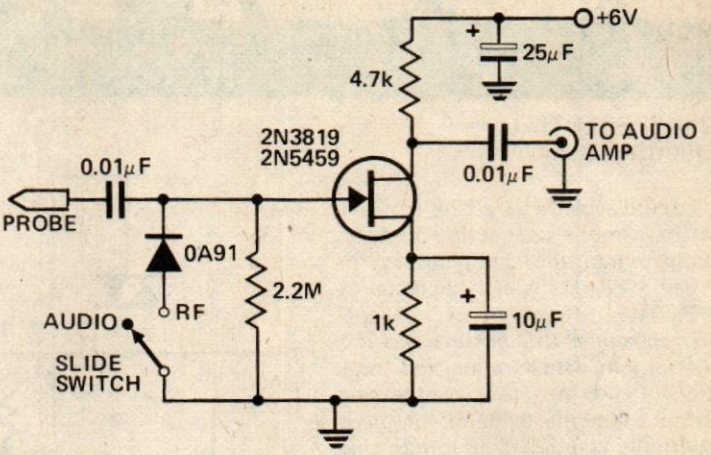
tech-tips

AUDIO-RF SIGNAL TRACER PRE-AMP

This economical signal tracer is very useful for servicing and alignment work in receivers and low power transmitters. It is easily constructed on a small piece of matrix board which can be mounted inside a commercially-available probe case or homemade probe. The slide switch can be mounted on the probe housing. A miniature toggle switch could be used as a substitute.

When switched to RF, the modulation on any signal is detected by the diode and amplified by the FET. A twin-core shielded lead can be used to connect it to an amplifier and to feed 6 volts to it.

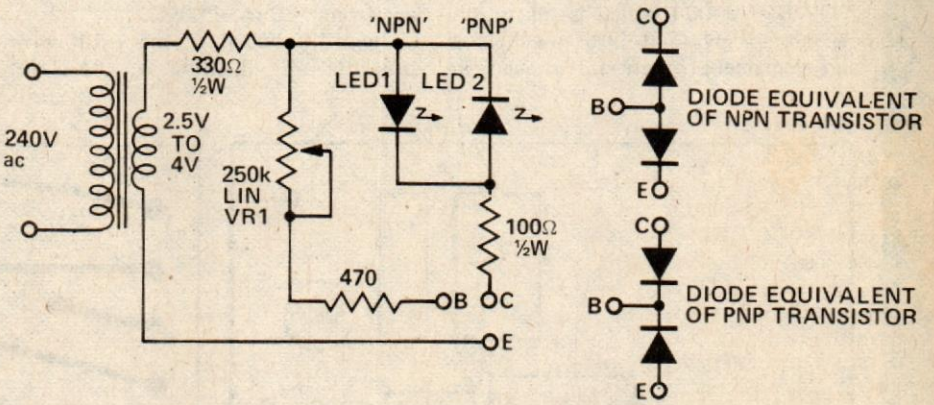


GO/NO-GO DIODE/TRANSISTOR CHECKER

A diode can be checked by connecting it between C and E. If LED 1 lights the diode is OK and its anode is connected to C. If LED 2 lights its cathode is connected to C. If both light it is a short circuit suitable only as a link!

To check transistors with known pin connections, set VR1 at maximum resistance and connect the transistor. Advance VR1 until one LED lights. If LED 1 lights it is NPN, PNP if LED 2 lights. If both light you have a three-legged link. If neither light you have a three-legged fuse!

To check transistor connections, if unknown, short two of its leads together and check as for a diode making note of which lead/leads respond as anodes. Short two other leads together and do it again. Refer to diagrams above.



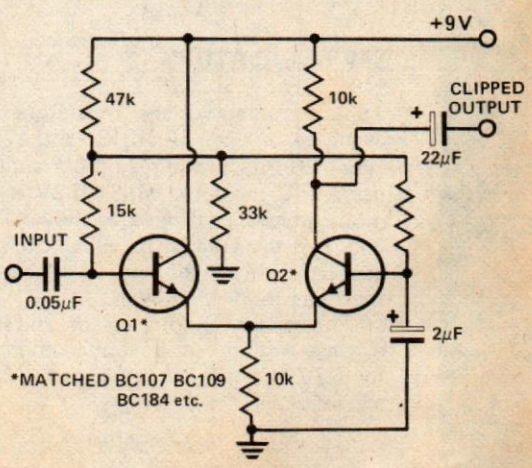
TINNING WITH SOLDER WICK

Do not discard the lengths of solder saturated solder wick. Further use can be made of them to plate printed-circuit boards by pre-tinning the joints, prior to inserting components and soldering.

The simple operation is as follows – place the saturated solder wick on the printed board and apply a heated soldering iron to melt the solder in the wick. At the same time, move the wick and iron along sections or joints requiring tinner. A neat plated copper print will result.

PRECISE AUDIO CLIPPER

A differential amplifier makes an excellent audio clipper and can provide precise, symmetrical clipping. The circuit shown commences clipping at an input of 100 mV. The output commences clipping at ±3 V. Matching Q7 and Q2 is necessary for good symmetrical clipping, however, if some asymmetry can be tolerated this need not be done.



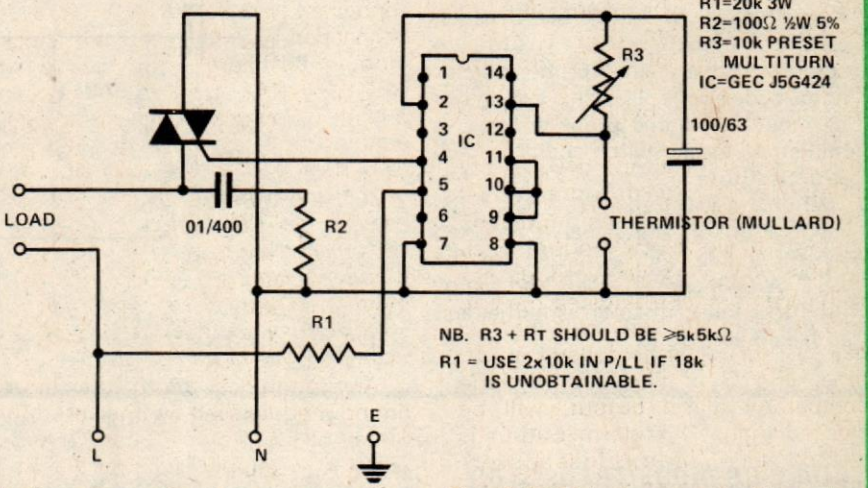
tech-tips

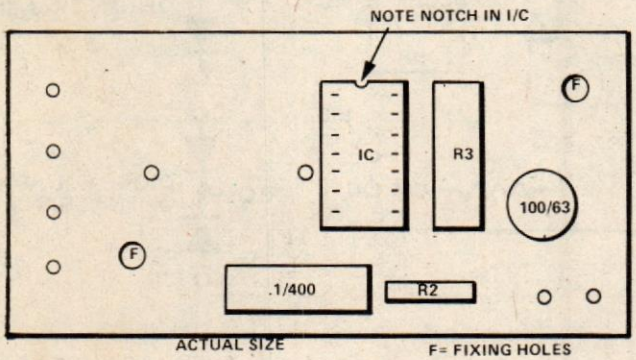
LOW DIFFERENTIAL THERMOSTAT

This circuit evolved as a result of the need for a more satisfactory method of controlling the temperature in our paint heaters which operate at 170°F. The differential of conventional mechanical thermostats was too wide, both in actual rating and in % accuracy, so that severe overheating occurred when the demand for paint momentarily lapsed. The result was poor finish and in a number of cases the destruction of the thermometer (at approx £10 a time).

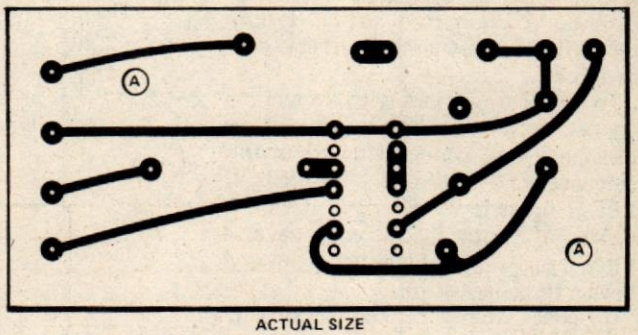
The introduction of the new thermostat completely eliminated the problem. The circuit consists of a GEC J5G424 Zero Voltage Switch in IC form together with a Mullard 2322 640 90004 which is plastic encapsulated, giving it both mechanical and electrical protection. It is available in four sizes with a temperature coverage from −30 to +200°C.

The RC network, 0.1mF + 100ohms, prevents self latching of the Triac. The J5G424 is, by nature of its design free of RFI. The type of Triac employed will depend on the loading. We were using 6 and 15 amp loads.





ACTUAL SIZE F= FIXING HOLES



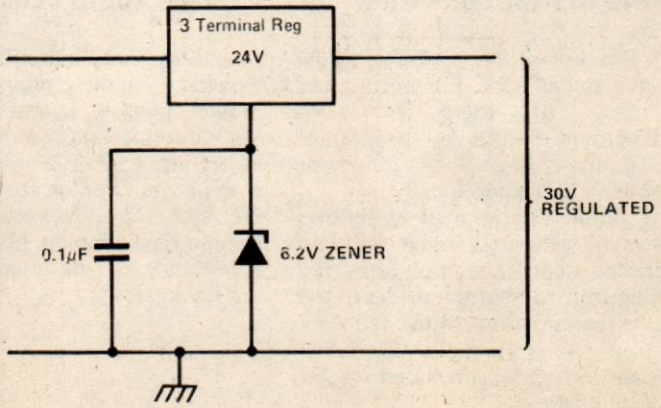
ACTUAL SIZE

This pcb is available from Ramar or Crofton (see Ad. Index) for 76p including VAT & P and P.

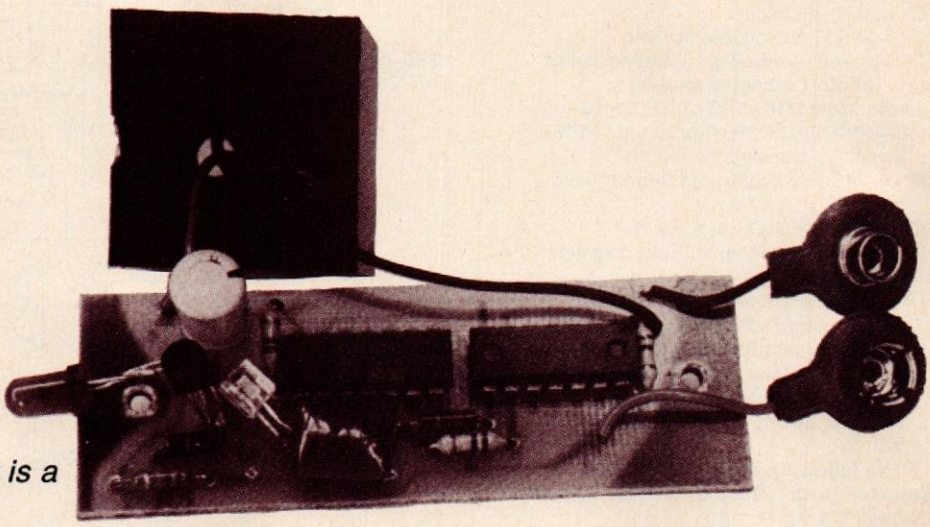
30V REGULATORS

Three-terminal voltage regulators are available in 5,9,12,15,18 and 24V types. If you require a 30V supply use a 24V regulator with a 6.2V zener diode in the earth lead as shown. This increases the volatge to 30V. A 0.1μF capacitor should be connected across the zener diode as shown.

The zener should be of suitable wattage rating. In a similar manner for 27V use a 3.3V zener or for 33V a 9.1V zener.



Flue Bug



An open fireplace damper is a constant source loss of air-conditioned or furnace-warmed air in your home. This low-cost electronic device warns you to close the damper as soon as the fire is out.

FRED BLECHMAN, K6UGT

IF YOU OWN A FIREPLACE, THERE CERTAINly have been times when you've forgotten to close the damper after the fire went out. Prior to the energy crisis this was not a terribly serious omission. Now, however, with energy conservation and the escalating cost of utilities, it has become much more important to close the damper to reduce the cost of heating or cooling your home. A 48-inch-perimeter open fireplace flue can allow 8% of air-conditioned or furnace-warmed air to escape your house! So, to save money and help conserve energy, you can build the Flue-Bug, available in kit form for under $10.

You may wonder, why such a strange name? Well, this gadget simply "bugs" you until you close the fireplace-flue damper. The unit winks and blinks after the fire has gone out—and it keeps blinking for days until you notice it and shut it off. It does *not* itself close the damper, it simply reminds *you* to close it.

How it works

The circuit, shown in Fig. 1, uses two standard CMOS (*C*omplementary-*S*ymmetry *M*etal-*O*xide *S*emiconductor) integrated circuits: IC1 is a quad 2-input NAND gate, and IC2 is a hex inverter. In other words, IC1 has four separate NAND gates, each with two inputs, and IC2 contains six separate inverters. Figure 2 shows the logic symbols of the two types of IC's used in this design. Figure 2-a shows a 2-input NAND gate, in which output pin 3 is LO (near ground) only when *both* inputs are HI. All other inputs result in a HI output. Figure 2-b shows an inverter that simply changes a HI to a LO, or a LO to a HI. With these facts firmly in mind you'll be able to follow the circuit explanation. For such a seemingly simple task, the circuit is quite complex.

A photo-Darlington transistor is used to sense light and radiated energy from the fireplace. Small holes in the heat shield, case and PC board allow light and heat, from the desired direction only, to impinge on the phototransistor. This biases the junctions and allows the current to flow from collector to emitter. Therefore, when you aim the Flue-Bug at the fireplace from about 5 feet away, the phototransistor senses when a fire has been lighted and when it has gone out. When the fire is out, then the Flue-Bug will start blinking.

The circuit explanation that follows is almost a minicourse in digital logic. You don't have to understand it to use the Flue-Bug, but it does illustrate some basic digital design, and by following this detailed description you can analyze many other circuits. Figure 3 shows how to follow the changes in logic states during reset, standby, fire on and fire out.

Assume that the phototransistor does *not* sense a fire. Pressing the reset pushbutton pulls pin 1 of IC1 LO, thus making pin 3 HI, regardless of the state of pin 2. Pin 4 is therefore HI. Since the phototransistor does not sense a fire and its dark-resistance is therefore quite high, input pin 5 of inverter IC2-c is LO, making output pin 6 HI. Since both inputs to NAND gate IC1-b (pins 4 and 5) are HI, output pin 6 goes LO, bringing pins 2 and 13 LO. This keeps pin 3 HI, and the circuit is stable. Since output pin 11 of NAND gate IC1-d is HI (because pin 13 is LO), output pin 2 of inverter IC2-a is LO, keeping NAND gate IC1-c output pin 8 HI. This keeps output pins 4, 8 and 10 of inverters IC2-b, IC2-d and IC2-e LO. Transistor Q2 does *not* conduct in this state, so the light-emitting diode (LED1) does not light up.

When the RESET button is released, IC1-a pin 1 is pulled HI by the positive voltage through resistor R2, but nothing else in the circuit changes.

Now, light the fireplace and the phototransistor "sees" the fire. This drastically lowers its collector-emitter resistance, and the input of inverter IC2-c goes HI, so its output goes LO. This pulls IC1 pins 5 and 12 LO. Output pin 6 of NAND gate IC1-b goes HI, making pins 2 and 13 HI. Since pins 1 and 2 are now both HI, the output of NAND gate IC1-a goes LO,

PARTS LIST

All resistors ¼ watt, 5% carbon.

R1–R3—100,000 ohms
R4—16 megohms
R5—22,000 ohms
R6—5100 ohms
C1—.047 μF, mica
C2—22 μF, 10 volt, electrolytic
LED1—red, jumbo light-emitting diode
Q1—photo-Darlington transistor (Motorola MRD-14B or GE L14H)
Q2—2N2222, 2N3904 (or equiv.) NPN switching transistor
IC1—74C00 CMOS quad 2-input NAND gate
IC2—74C04 CMOS hex inverter
S1—normally open pushbutton switch, miniature
Misc.—Battery snaps; plastic case (2⅛-in.-square × 3⅛-in. long, sprayed with silver paint); heat shield (3½ × 4¼ × .03-inch-thick aluminum); two No. 4-40 × ¾-inch screws; 2½-inch-long spacers; solder (2U6 or equiv.); 9-volt battery.

The following items are available from Interfab Corp., 27963 Cabot Rd., Laguna Niguel, CA 92677:

Kit FB-2: Complete parts kit, including PC board, all holes predrilled, battery not included; instructions, $9.50 postpaid. Assembled and tested, $12 postpaid.

California residents add state and local taxes as applicable.

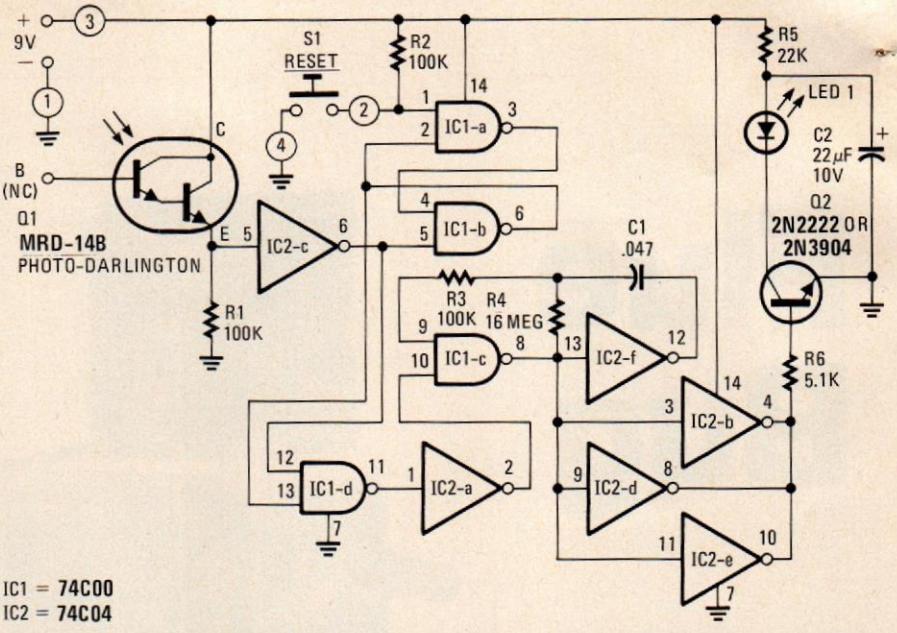


FIG. 1—FLUE-BUG is built using 2 CMOS IC's. Light-sensitive photo-Darlington transistor is used as sensor.

pulling pin 4 LO, making the output of NAND gate IC1-b HI, thus latching this part of the circuit. (NAND gates IC1-a and IC1-b are wired as a flip-flop.)

Note that output pin 8 of NAND gate IC1-c is still HI (pin 13 went HI, but pin 12 went LO), therefore, the LED is still not on. However, when the fire goes out, the phototransistor resistance increases and, at some point, forces pin 5 of inverter IC2-c LO. This makes the output of this inverter HI, pulling IC1 pin 12 HI. Since pin 13 is already HI, NAND gate IC1-d changes state, and its output (pin 11) goes LO. This is inverted by IC2-a, whose output goes HI, thus making pin 10 of NAND gate IC1-c HI. Pin 9, the other input to NAND gate IC1-c, is already HI, through resistors R3 and R4 from pin 8. Since both inputs of IC1-c are now HI, pin 8 goes LO, causing several things to happen. Inverters IC2-b, -d and -e (operating in parallel for greater current capability) change state to a HI output and forward-bias transistor Q2. This allows LED1 to flash on, powered by the charge from capacitor C2.

Meanwhile, note what happens back at NAND gate IC1-c. (See Fig. 4.) When pin 8 went LO, inverter IC2-f changed state to a HI output, releasing a charge into capacitor C1, which then discharged through R4 to the LO at pin 8. The voltage at point A drops until pin 9 (through resistor R3) is brought below the threshold voltage, and NAND gate IC1-c changes to a HI output. This cuts off the LED, and causes inverter IC2-f to change to a LO output state. Now capacitor C1 charges through R4 until point A rises to the transfer voltage. Fed through resistor R3, this transfer voltage is seen by pin 9 of NAND gate IC1-c as a HI, therefore, its output goes LO and the LED starts blinking. This circuit is a gated astable oscillator, and as long as pin 10 is held HI, the LED will flash at a slow rate (determined by C1 and R4). When the RESET button is pressed, or the phototransistor again senses light, gate IC1-c pin 10 is pulled LO and the oscillator stops in the LED-off condition.

Note that during the time that inverters IC2-b, -d and -e have a LO output and the LED is off, capacitor C2 is being charged through resistor R5. When Q2 is biased-on (inverters IC2-b, -d and -e HI output), the capacitor C2 charge flows

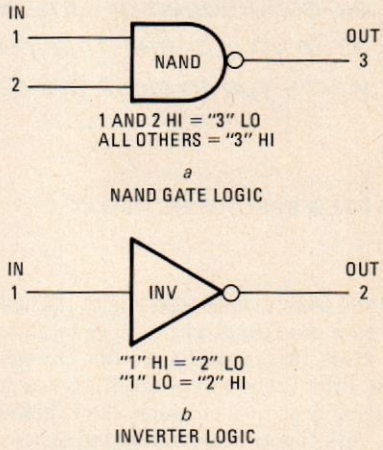


FIG. 2—POSITIVE INPUT LOGIC. NAND gate is shown in *a* and inverter is shown in *b*.

PIN #	74C00 (IC1)				74C04 (IC2)			
	RESET	STANDBY	FIRE ON	FIRE OUT	RESET	STANDBY	FIRE ON	FIRE OUT
1	L	H	H	H	H	H	H	L
2	L	L	H	H	L	L	L	H
3	H	H	L	L	H	H	H	⎍
4	H	H	L	L	L	L	L	⎍
5	H	H	L	H	L	L	H	L
6	L	L	H	H	H	H	L	H
7	L	L	L	L	L	L	L	L
8	H	H	H	⎍	L	L	L	⎍
9	H*	H*	H*	∧*	H	H	H	⎍
10	L	L	L	H	L	L	L	⎍
11	H	H	H	L	H	H	H	⎍
12	H	H	L	H	L	L	L	⎍
13	L	L	H	H	H	H	H	⎍
14	H	H	H	H	H	H	H	H

NOTE:
*MEASUREMENT REQUIRES VERY HIGH IMPEDANCE INSTRUMENT (ABOVE 50 MEGOHMS) OR CIRCUIT ACTION IS AFFECTED.

FIG. 3—TRUTH TABLE shows logic state of IC pins during normal operation.

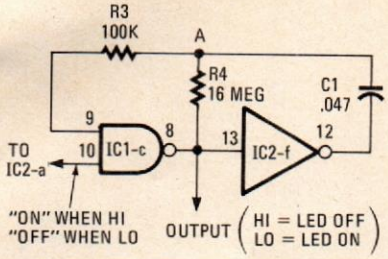


FIG. 4—GATED ASTABLE OSCILLATOR as used in the circuit shown in Fig. 1.

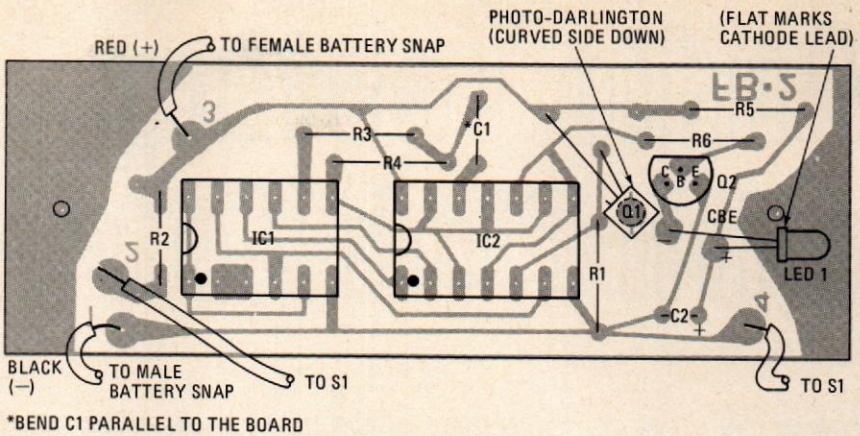


FIG. 6—COMPONENT PLACEMENT diagram.

through the LED to provide a bright "blink" of short duration. Thus, battery power is conserved, yet the flashing LED is visible in brightly lighted surroundings. The battery drain is only 5 μA during reset or standby, 80 μA when the fire is lighted and an average of approximately 2 μA when the LED is blinking. This means that a standard zinc-carbon battery will last about a year in normal use, or about 10 days' blinking.

Construction

Constructing the Flue-Bug is much easier than understanding the circuit operation. Be sure to use small-diameter rosin-core solder, a low-wattage soldering iron and a magnifying glass to check your soldering. (The kit contains detailed step-by-step instructions that should be followed closely.)

The PC board pattern is in Fig. 5; and the parts layout is shown in Fig. 6. Be sure to properly orient the IC's, electrolytic capacitor C2, LED1 and transistors Q1 and Q2. The red-lead female battery snap goes to the PC board positive trace, and the black-lead male snap goes to ground. Position the phototransistor over the small hole in the PC board, with the curved face toward the hole. Bend capacitor C1 down, after soldering it to the PC board to allow room for the battery inside the case. Mount the LED, as shown in Fig. 6, with the lead that is closest to the "flat" on the base of the LED going to the connection near phototransistor Q1. Mount pushbutton switch S1 in the cover corner hole, with two wires going to the PC board.

Connect a standard 9-volt transistor radio battery to the snaps and test the unit before the case and heat shield are installed. With the battery connected, shield phototransistor Q1 from the light and press the RESET button. If the LED was blinking before you pressed the button, it should now stop. Next, expose the phototransistor to the light—nothing should happen. Cover phototransistor Q1 again, and the LED should start blinking immediately, thus demonstrating the surprising light sensitivity of the Flue-Bug.

If the device doesn't work properly, the most likely causes are wrong parts placement or orientation, or poor solder joints or solder bridges. Figure 3 shows the states of all pins on both IC's under all conditions. You can check these states with a multimeter having a sensitivity of 20,000 ohms-per-volt or better.

Before assembling the PC board and battery into the case, pretap the holes at each end of the PC board by twisting a mounting screw into each hole to form threads. Figure 7 shows the complete assembly. Carefully slide the battery-PC board assembly into the case, making sure the phototransistor is opposite the case hole. Place the cap on the case so that the LED projects through the upper hole. Using screws and spacers, attach the heat shield so that the unit stands upright. Make sure that the bare metal side of the heat shield faces outward (to reflect heat from the plastic case) and that the black-painted side faces the unit (to prevent reflected ambient room light from falsely triggering the phototransistor). **R-E**

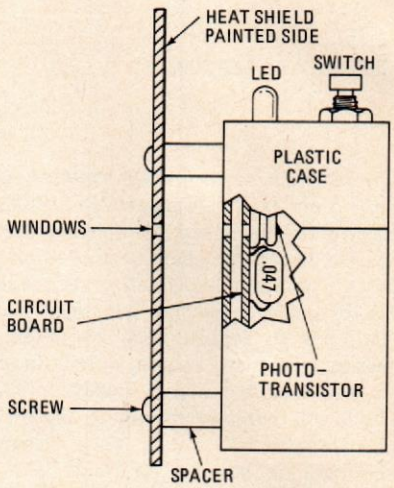


FIG. 7—FINAL ASSEMBLY of Flue-Bug.

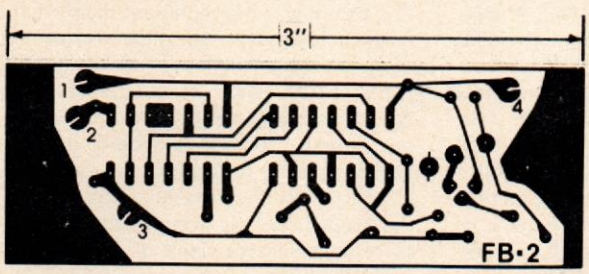
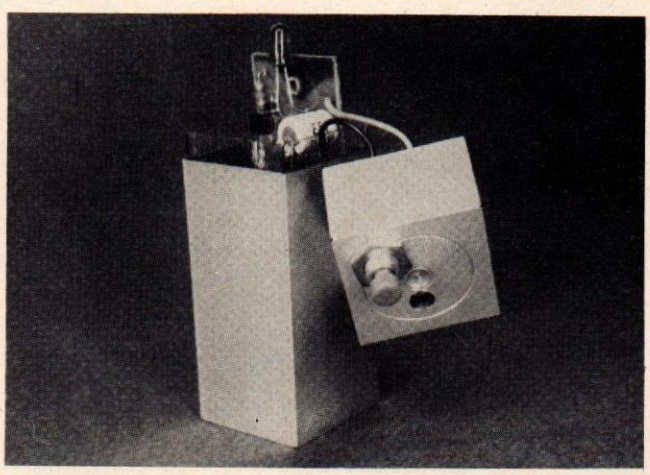
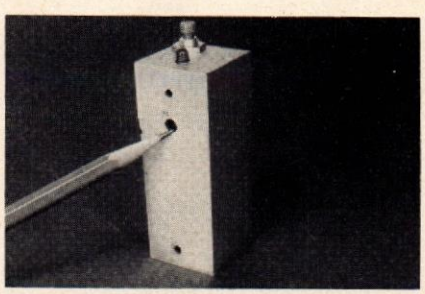


FIG. 5—PRINTED-CIRCUIT BOARD shown full size.



FLUE BUG with housing cover removed. Reset button is in top. Heat shield is on far side of case and can't be seen.



PENCIL POINTS TO WINDOW. Similar aligned windows are in heat shield and circuit board.

Energy Leak Detector Reveals Home Heat and Cooling Losses

Provides instantaneous readings of temperature changes to check leaks around doors, windows, etc.

BY RALPH TENNY

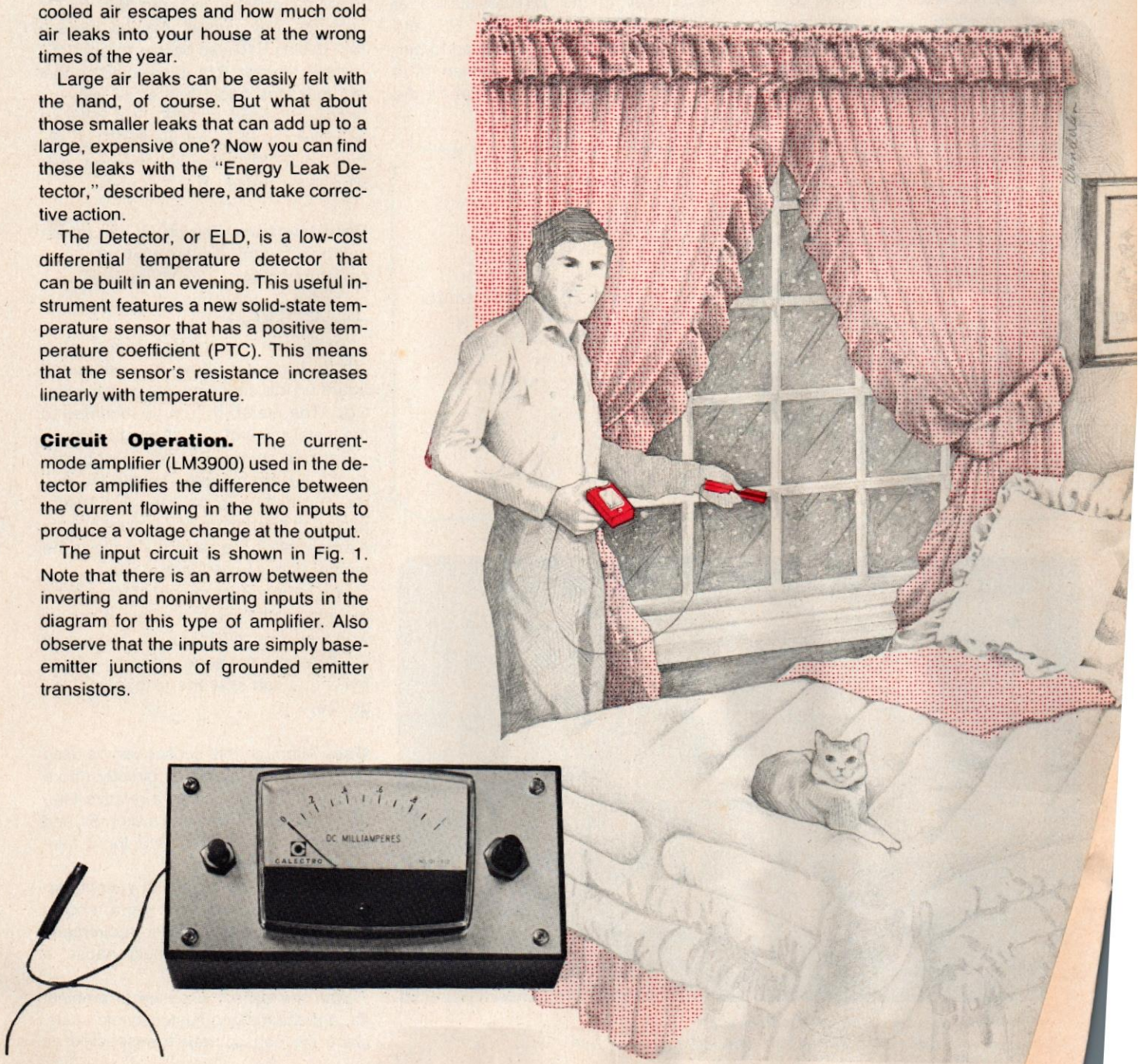
CONSIDERING the high price you pay for the energy to air condition and heat your home, you should be aware of how much of your expensive cooled air escapes and how much cold air leaks into your house at the wrong times of the year.

Large air leaks can be easily felt with the hand, of course. But what about those smaller leaks that can add up to a large, expensive one? Now you can find these leaks with the "Energy Leak Detector," described here, and take corrective action.

The Detector, or ELD, is a low-cost differential temperature detector that can be built in an evening. This useful instrument features a new solid-state temperature sensor that has a positive temperature coefficient (PTC). This means that the sensor's resistance increases linearly with temperature.

Circuit Operation. The current-mode amplifier (LM3900) used in the detector amplifies the difference between the current flowing in the two inputs to produce a voltage change at the output.

The input circuit is shown in Fig. 1. Note that there is an arrow between the inverting and noninverting inputs in the diagram for this type of amplifier. Also observe that the inputs are simply base-emitter junctions of grounded emitter transistors.



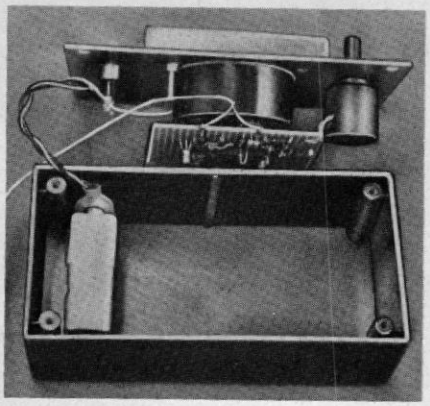


Photo of internal construction shows board attached to meter.

This leads to a very important consideration regarding current-mode amplifiers: *Never apply voltage directly to the inputs that can cause a current flow of 5 mA or more.* This limitation allows for some unusual circuitry that can be an advantage under some circumstances. Two other limitations must also be mentioned. The open-loop gain (gain without feedback) can be as low as 1000:1, and the amplifier will not respond to voltages lower than 0.6 volt.

The amplifier maintains correct operation over a wide variety of power supply voltages, and uses about the same amount of power supply current (exclusive of load current), regardless of the power supply voltage. Thus, the amplifier is well suited for battery operation.

As shown in Fig. 2, temperature sensor *TH1* is connected in a bridge circuit consisting of *R1*, whose value is nominally equal to the *TH1* resistance at 25°C (1000 ohms) plus *R2*, *R3*, and *R12*. Potentiometer *R12* is used to balance the bridge when the sensor is at any given temperature. Voltage for the bridge (+3 volts) is furnished by *IC1C* operated in conjunction with zener diode *D1* as a reference. The resulting +3 volts is stable since the current amplifier regulates the zener current. Power is applied only when pushbutton switch *S1* is depressed, thus extending battery life.

A change in bridge balance that occurs whenever *TH1* changes resistance is amplified by *IC1A*. The output of *IC1A* serves as the reference voltage for one input of *IC1B*, which is used as a current amplifier. When there is a bridge unbalance, the output current of *IC1A* flows through *R7*, forcing *IC1B* to drive *Q1* until the current through feedback resistor *R10* equals the current through *R7*. Since meter *M1* is in series with the *Q1* collector, any current passed through *R11* to bias *R10* also passes through the meter. Resistor *R11* is selected so that *M1* indicates about half scale with the bridge balanced at 25°C. If a different sensitivity is required for the ELD, the ratio of *R7/R10* can be changed and, most likely, the value of *R11* too.

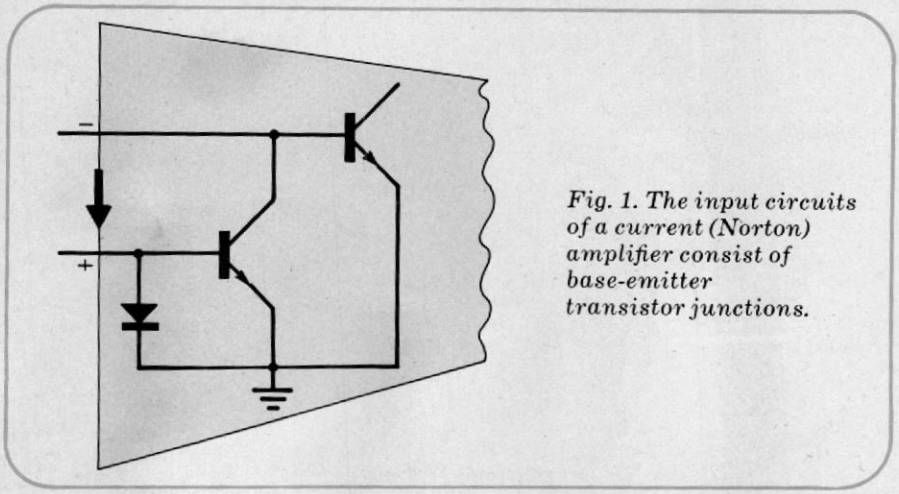
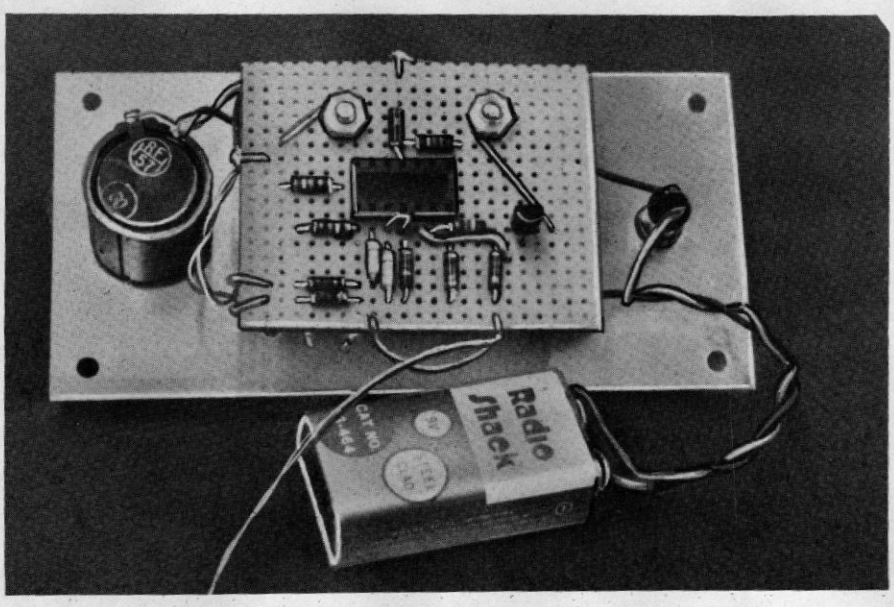


Fig. 1. The input circuits of a current (Norton) amplifier consist of base-emitter transistor junctions.



Rear view of the detector's front panel with perforated board mounted on meter and battery attached.

Construction. The circuit can be assembled by any desired method, using perforated board, Wire-Wrap, or a small pc board. A conventional 14-pin socket may be used for *IC1*.

The author's prototype pictured in this article illustrates how the perforated board (in this case) mounts on the meter lugs. The meter, in turn, is mounted to the metal cover of a small plastic box.

Balance control *R12* and pushbutton switch *S1* are mounted beside the meter. The battery is mounted in a holder affixed to the bottom of the plastic case. A small hole in the cover plate allows the temperature sensor leads to exit.

The temperature sensor (*TH1*) can be mounted at the end of a length of plastic, wood, or even thin metal rod. Make sure the sensor is not surrounded by a large mass that can slow the response of the device.

Use. Although this sensor can be used to measure temperature directly (more on this later), for use as a relative temperature sensor, depress switch *S1* and adjust balance control *R12* for a mid-scale meter indication.

Touching the sensor with your fingertips, which are relatively warm, should cause an up-scale meter movement. Cooling the sensor should cause a down-scale movement.

With the sensor exposed to ambient air, and the meter adjusted to mid-scale, place the sensor near a suspected air

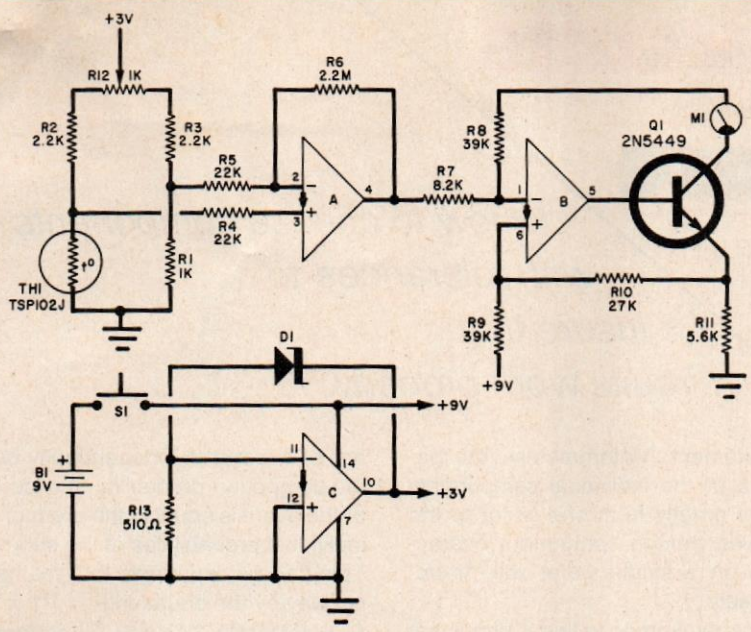


Fig. 2. Any unbalance in bridge circuit, containing TH1, is amplified and indicated on the meter.

PARTS LIST

B1—9-volt battery and holder
D1— 1N5226 diode
IC1—LM3900 quad Norton amplifier
M1—0-1 mA meter (Calectro D1-912, Radio Shack 22-052 or similar)
Q1—2N5449
The following are ¼-watt resistors unless otherwise noted:
R1—1000-ohm
R2, R3—2200-ohm
R4, R5—22,000-ohm
R6—2.2-megohm
R7—8200-ohm
R8, R9—39,000-ohm
R10—27,000-ohm
R11—5600-ohm
R12—1000-ohm, 10-turn potentiometer
R13—510-ohm
S1—spst NO pushbutton switch
TH1—TSP102J positive temperature coefficient thermistor (Texas Instruments)
Misc.—Suitable enclosure, mounting hardware, knob.
Note: Sensor, TSP102J, is available for $1.50 from Tenny, Box 545, Richardson, TX 75080.

leak. If there is cold air leaking in, the meter will show a sharp drop as the sensor gets closer to the air leak. Conversely, if there is a warm air leak, it can be pinpointed with great accuracy by watching the meter move upscale.

Keep in mind that in this configuration you are measuring relative temperature. Also remember that there is a temperature differential between the ceiling and the floor in a room even without an air leak.

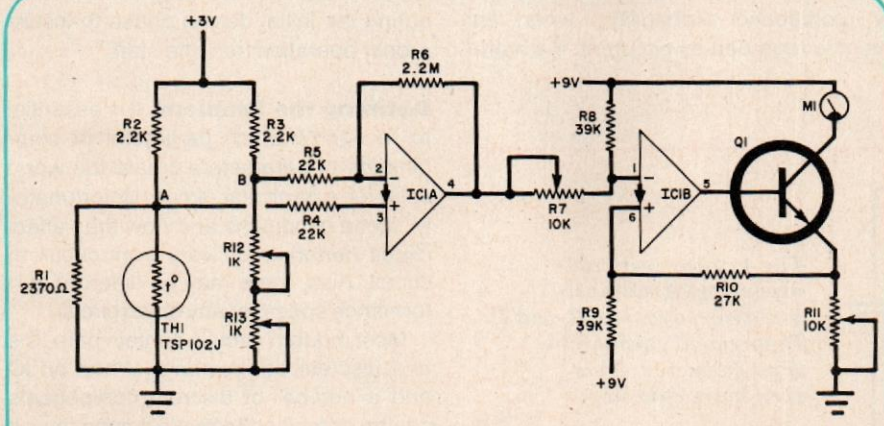


Fig. 3. Optional circuit shows how to convert the leak detector into a conventional thermometer.

Thermometer. The basic probe can be modified to create a thermometer by using the circuit shown in Fig. 3.

Potentiometer *R12*, used to balance the circuit, is still a 1000-ohm, 10-turn potentiometer. But now it has a turns-counting dial. Trimmer potentiometer *R13* is a 1000-ohm, multi-turn type, while *R7* and *R11* have been changed to 10,000-ohm, multi-turn potentiometers.

Since the circuit has now become a thermometer, it must be calibrated. The basic technique is to create two water baths at each end of the desired temperature range. Since water and ice reach an equilibrium at 0°C, and water boils at 100°C (at sea level), these are convenient to duplicate.

Assuming a linear sensor, the circuit is adjusted to 0°C and 100°C with the sensor immersed in the appropriate water bath. With the linear control and turns-counting dial, intermediate temperatures can be read from the dial after the meter is again center-scaled. Compensation for the 100°C range must be made if you live at high altitudes.

To calibrate the circuit, set up the ice bath and keep it stirred as long as the sensor is immersed in it; also prepare a boiling water bath.

Set potentiometers *R7* and *R11* to their maximum resistance, and *R12* to its minimum resistance. Be sure that the counter on *R12* indicates zero when *R12* is at its minimum resistance.

Immerse the sensor in the ice water, short the bridge at points A and B, and adjust *R7* and *R11* until the meter indicates at center scale. Remove the short across the bridge and adjust *R13* to center the meter again.

Then immerse the sensor in boiling water and set the turns counter of *R12* to 10.0. Adjust *R7* until the meter is centered, then return the meter to the ice water. Rotate the *R12* dial to 0.0 and adjust *R11* for a meter center. Return to the hot water and adjust *R7*, repeating the actions until the meter indicates the temperatures at each end of the scale.

Other temperature ranges may be calibrated, but the dial will no longer indicate the temperature directly. A chart can be created to translate dial indications into temperature.

If you wish to use the ELD as a remote thermometer, the circuit will tolerate a considerable length of lead between the circuit and the sensor. Just be sure that you calibrate the system using the long leads so that resistance will be taken into account.

Happy energy savings! ◇

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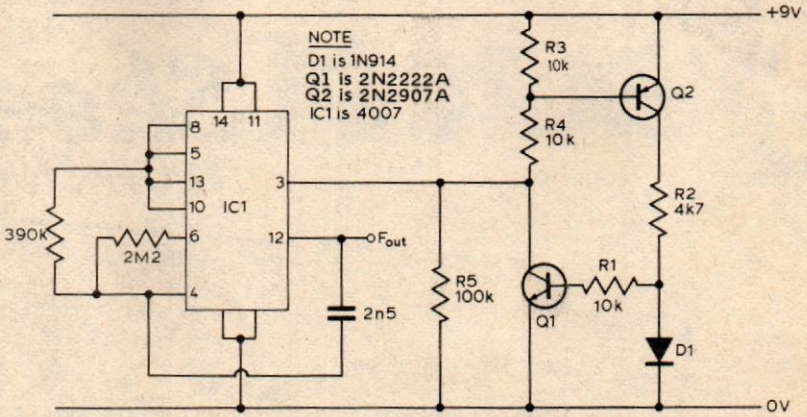


Temperature to Frequency Convertor

P. Reynolds

This circuit uses the fact that when fed from a constant current source, the forward voltage of a silicon diode varies with temperature, in a reasonably linear way.

Diode D1, and resistor R2 form a potential divider, fed from the constant current source. As the temperature rises the forward voltage of D1 falls tending to turn Q1 off. The output voltage from Q1 will thus rise, and this is used as the control voltage for the CMOS VCO. With the values shown, the device gave an increase of just under 3HzC^{-1} (between 0° C and 60° C) giving a frequency of 470Hz at 0° C.

Self-balancing bridge standardizes thermistor mounts

by Richard P. Lanham
U. S. Army Calibration and Repair Support Center, Pirmasens, West Germany

Though Hewlett-Packard's HP-478A thermistor mount is often used with the HP-431 power meter to measure power in the microwave region, the matched thermistor elements it employs are sensitive to mechanical shock. These therefore need to be checked often and, if a number of mounts are to be tested, quickly as well.

A self-balancing bridge, with the aid of a digital voltmeter, can easily test for any thermistor mismatches. In this way the user can determine at once if the mount is fulfilling its primary job—minimizing the effect of environmental temperature changes on power measurements and thus providing a 50-ohm load for microwave generators over a wide band.

Just as important, this special bridge enables any thermistor mount to be quickly standardized, or made compatible, with any HP-431 meter. Other measurement techniques allow only one particular thermistor mount to be certified per HP-431 meter, mainly because it takes so long to perform the standard calibration procedure properly.

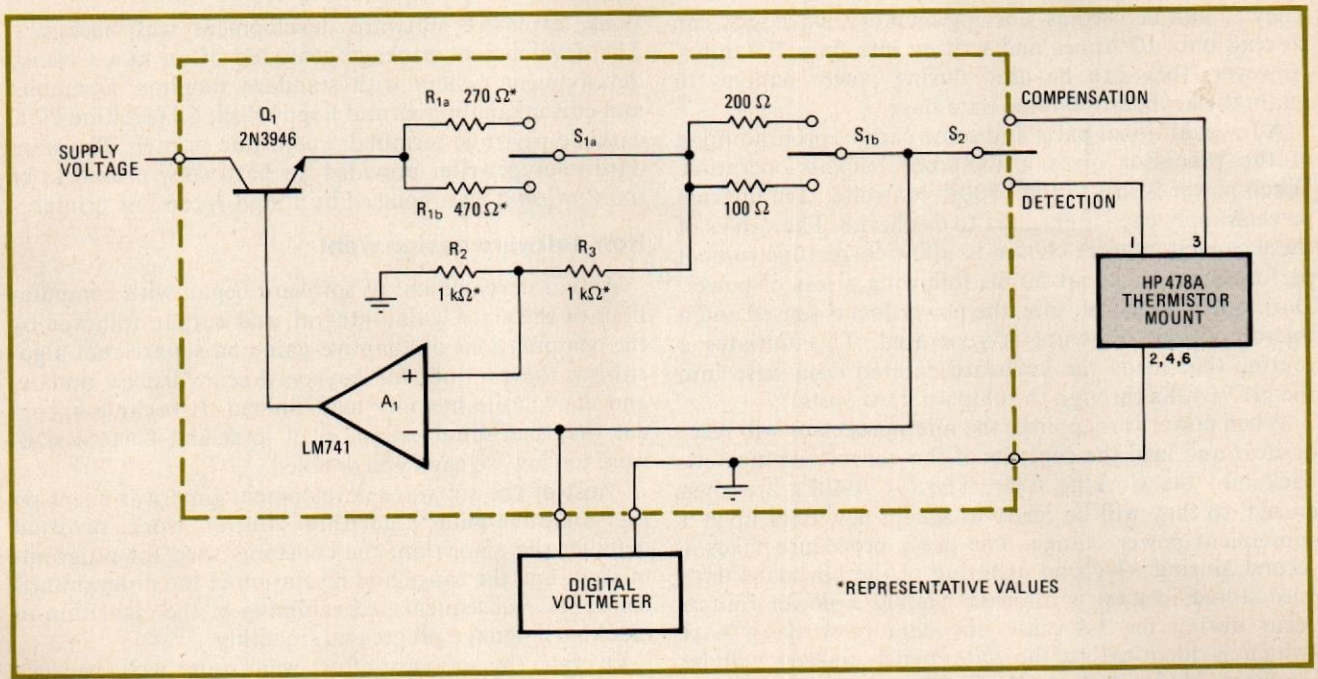
The system uses a resistance bridge to measure the difference in voltage between the detection and compensation thermistors in the mount. It also uses operational amplifier A_1 as a null detector and transistor Q_1 to control the bridge current.

S_1, a double-pole, double-throw switch in the measuring arm of the bridge, selects either a 100-Ω or a 200-Ω resistor, corresponding to the operating resistance (which can be specified for 100 or 200 Ω) of the thermistor mount to be measured. S_2 selects the thermistor elements in the mount to be tested.

The other leg of the resistance bridge contains two matched resistors, R_2 and R_3. R_{1a} and R_{1b} are current-limiting resistors whose values are determined by the supply voltage and the maximum current rating of the thermistor mount, which is 14 milliamperes. Q_1 can be any general-purpose transistor.

The bridge is self-balancing because the A_1–Q_1 loop automatically nulls the bridge independently of changes in temperature and so normalizes all readings. As the bridge current, which is controlled by Q_1, increases, heat is generated and changes the resistance of the thermistors monitored. A_1 detects any difference in voltage between its inverting and noninverting inputs and adjusts the base drive to Q_1 if needed, in order to reduce bridge current for a given supply voltage. In short order, the bridge becomes balanced as the voltages measured across the appropriate points in the bridge are equalized.

The absolute value of the voltage across the thermistor can then be measured between one end of the bridge and ground. In a standard bridge arrangement, in contrast, continued monitoring and adjustment for the null condition would be required for each mount being tested. In



Automatic null. Self-zeroing bridge enables fast check for mismatches of thermistors in HP-478A mount, independent of current through bridge and related temperature changes in thermistors. Circuit lets any mount be standardized to any HP-431 power meter.

actual operation, the system sends a dc output voltage across the compensation and detection thermistors of the mount under test. First the detection thermistors' output should be measured to within 0.001 volt of its true value. Then the voltage across the compensation thermistor should be measured. Readings should not differ by more than 0.030 v.

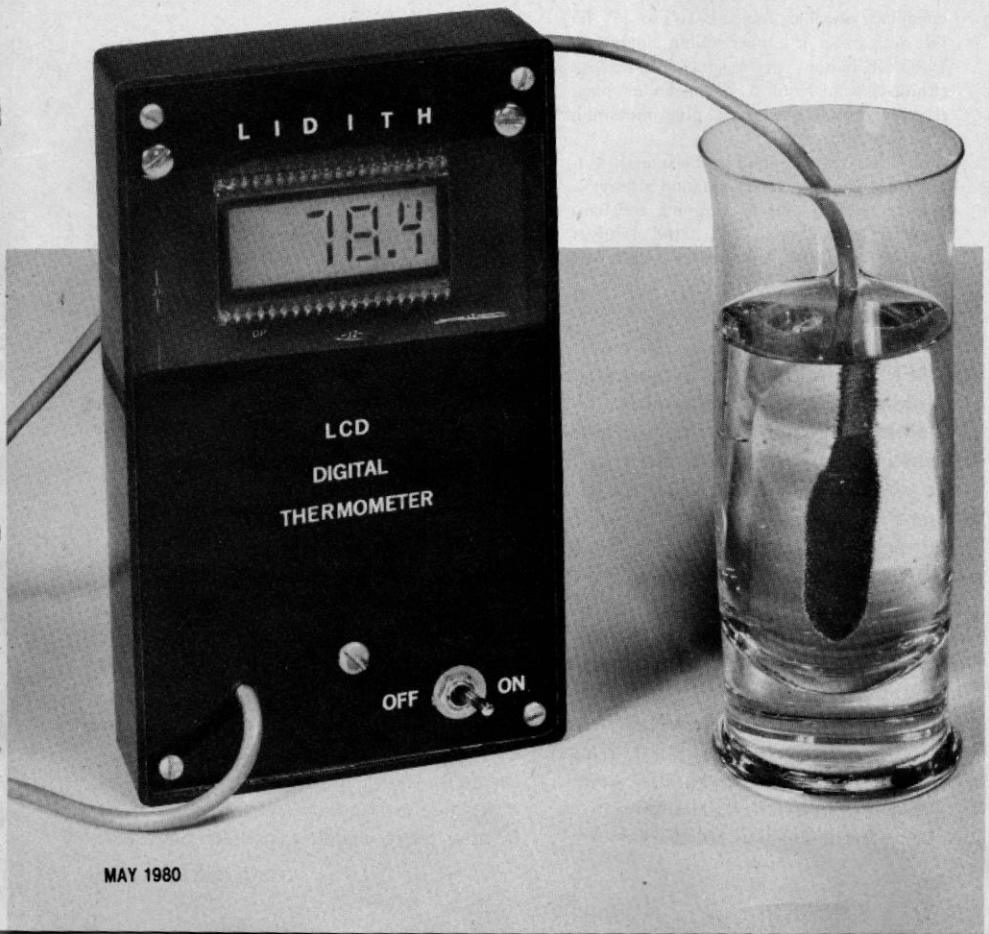
If readings are out of tolerance, two adjusting screws inside the thermistor mount permit compensation of the thermistors, within limits. □

BY TOM FOX

BUILD 'LIDITH'

A 3½-Digit LCD Digital Thermometer

Measures from −30° to +199° F with 1° accuracy and 0.1° resolution



HERE IS AN easy-to-build, battery-operated 3½-digit thermometer, which we call "LIDITH" for LIquid-crystal DIgital THermometer. It can measure temperatures from −30° F to +199° F. Basic accuracy is better than ±1° over its entire range and averages better than ±0.5° from 0° to 100° F. Each degree is divided into 10 equal parts, giving Lidith a 0.1° F resolution. Readout is on a ½" (12.7-mm) liquid crystal display.

With some simple circuit modifications, Lidith can perform other functions, such as reading the temperature in °C, measuring accurately down to −67° F and displaying both indoor and outdoor temperatures.

Circuit Operation. Shown in Fig. 1 is the schematic diagram of Lidith. (See Box for details on sensors.) Resistor *R11* is the series voltage dropper for the 6.8-volt zener diode in the temperature transducer (*IC2*). The *R12/C6* network provides additional stability if the transducer is used as a remote sensor. Resistors *R9* and *R10* form a precision voltage divider to insure that the proper proportion of the transducer's output voltage goes to the digital panel meter (DPM) circuitry.

Several points should be noted about the *IC2* circuit. At room temperature (77° F), the transducer's output from pins 1 and 2 to pin 3 is nominally 2.98 volts and increases by 10 mV for every 1° C or 1.8° F increase in temperature. This potential is measured with respect to +9 volts, not ground. This means that at 77° F, pins 1 and 2 are at −2.98 volts, with respect to +9 volts.

The heart of the DPM is the Intersil ICL7106 single-chip 3½-digit MOS A/D (analog-to-digital) converter that drives the LCD. The 7106 uses dual-slope conversion, in which linearities tend to cancel out. Therefore, the circuit does not require extremely accurate or stable (and expensive) components. Also, as long as it remains unchanged for a single conversion cycle, the clock frequency does not have to be precise or extremely stable. The only real requirement is a stable current reference.

In addition to ease of use and relatively low cost, the 7106 has several other features that make it ideal for use in Lidith. Since the thermometer employs CMOS circuitry, it consumes little current (about 0.8 mA). It has true autozeroing, will directly drive LCD displays, and has a guaranteed ±1-count accuracy over its entire ±2000-count range.

The RC network for the 7106's inter-

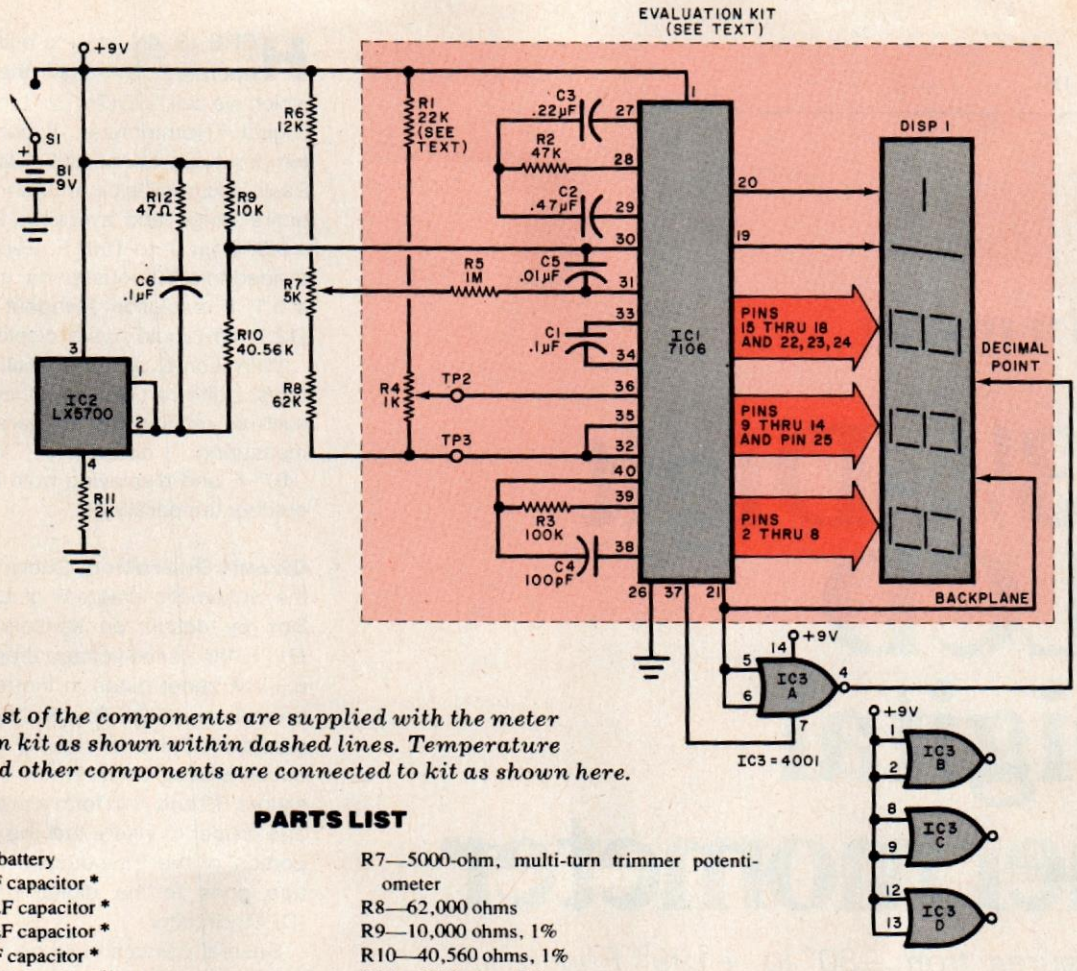


Fig. 1. Most of the components are supplied with the meter evaluation kit as shown within dashed lines. Temperature sensor and other components are connected to kit as shown here.

PARTS LIST

B1—9-volt battery
C1—0.1-µF capacitor *
C2—0.47-µF capacitor *
C3—0.22-µF capacitor *
C4—100-pF capacitor *
C5—0.01-µF capacitor *
C6—0.1-µF capacitor
DISP1—3½-digit LCD display *
IC1—7106 3½-digit A/D converter (Intersil) *
IC2—LX5700 temperature sensor (National)
IC3—4001 quad 2-input NOR gate
The following are 5%, ¼-watt resistors unless otherwise specified:
R1—22,000 ohms
R2—47,000 ohms *
R3—100,000 ohms *
R4—1000-ohm trimmer potentiometer *
R5—1 megohm *
R6—12,000 ohms
R7—5000-ohm, multi-turn trimmer potentiometer
R8—62,000 ohms
R9—10,000 ohms, 1%
R10—40,560 ohms, 1%
R11—2000-ohm, 5%
R12—47 ohms, 10%
S1—Spst switch
Misc.—Battery holder, IC socket (1), three-conductor flexible cable, 3/16" to ¼" ID thin-wall brass or copper tubing, spaghetti, E-POX-E ribbon, acrylic spray, plastic case (Radio Shack 270-627). ⅛"-thick clear plastic sheet, black spray paint, glue, mounting hardware, etc.

* These items are supplied in the Intersil Single Chip Panel Meter Evaluation Kit available for $29.95 plus $1 shipping and handling from Ancrona, Box 2208P, Culver City, CA 90230. Ancrona also sells the ICL7106 IC for $14.70.

Note: The following are available from T. R. Electronics, RR#1, Box 604, Newaygo, MI 49337: Kit containing one LX5700, R9, and R10 at $9.75 postpaid (ask for #ST2R for conventional kit, #CT2R for Celsius version, or #AT2R for "Alaskan" version). Also available separately: LX5700 temperature sensor (with data sheet) at $6.50 plus $0.50 postage and handling; a matched pair of LX5700s (±1° C or better) at $15.00; R9 and R10 at $1.75 each.

nal oscillator is made up of *R3* and *C4*. With the values shown, oscillator frequency is about 48 kHz. Capacitor *C3* and resistor *R2* are the integrating components, while *C1* is the reference capacitor and *C2* is the auto-zero capacitor. Low-pass RC filter *R5*/*C5* is used for improved noise rejection.

A stable 2.8-volt reference potential between pin 1 (V+) and pin 32 (COMMON) is provided by the 7106. Resistors *R1* and *R4* form an adjustable voltage-divider network that applies a suitable proportion of this reference voltage to pin 36 (REF HI) and pin 35 (REF LO). Adjustment of *R4* is made for a potential of 0.110 volt (110 mV) between REF HI and REF LO. In Lidith, *R4* is basically a scale-adjust trimmer potentiometer.

Another adjustable voltage-divider that uses the 7106's 2.8-volt reference is made up of *R6*, *R7*, and *R8*. Notice that temperature-adjust trimmer *R7*'s wiper is connected through filter resistor *R5* to pin 31 (IN HI) of the 7106.

Once the thermometer is calibrated, with *R7* at a fixed position, IN HI is at a fixed voltage. For the DPM to display 00.0, its IN LO (connected to the transducer's voltage-divider network) must be exactly equal to its IN HI point. Thus, after calibration, the voltage at *R7*'s wiper must be identical to that coming from the transducer's *R9*/*R10* divider network (and connected to IN LO) when the transducer's temperature is at 0°. We can conclude, then, that *R7* can be viewed as a 0° trimmer pot. However, since 0° F is not easy to achieve, *R7* will actually be set for a display of 32.1 when the transducer is immersed in ice water.

As the transducer's temperature rises, its output at pins 1 and 2 becomes more negative, with respect to +9 volts. This more-negative potential is felt at the 7106's IN LO input. When IN LO becomes more negative, with respect to IN HI (which is set at a constant voltage after calibration), the 7106 senses this as a positive voltage at its input, since IN HI is now more positive, or less negative,

than IN LO. Therefore, the DPM displays a positive number.

When the transducer's temperature goes below 0°, IN LO is less negative than IN HI and the DPM indicates a negative temperature.

The 7106 directly powers all segments of the LCD. Pin 21 goes to the display's backplane, while the frontplane segments connect to pins 2 through 25, excluding pin 21, which connects to the decimal point between the units and tenths decades in the display. Between the decimal point and pin 21 is a CMOS inverter that provides the proper ac voltage with an insignificant dc offset. It may seem wasteful to use an entire 4001 for this trivial task when a single MOS transistor would do the same job, but a 4001 is less expensive and more readily available.

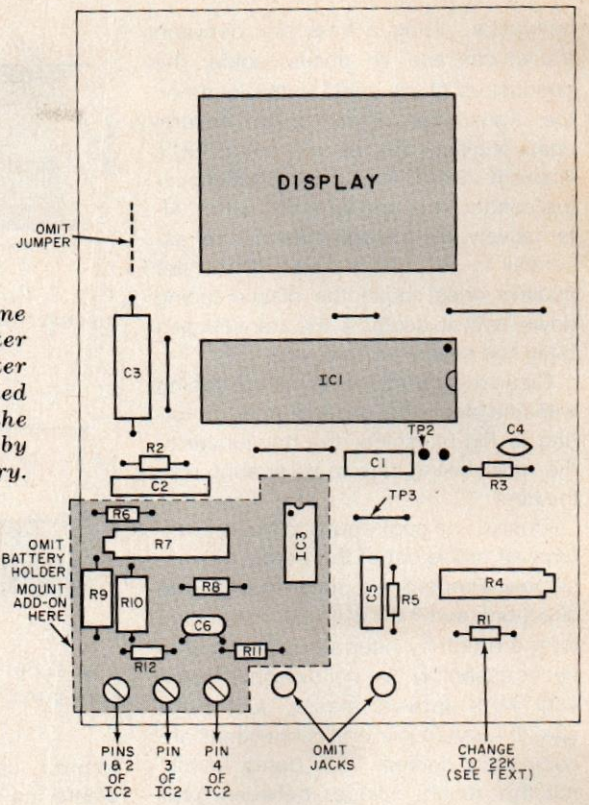


Fig. 2. The main outline here is that of the meter evaluation kit. Thermometer components can be added to the "open" area on the kit board created by taking off the battery.

Construction. Unless you can obtain a suitable 3½-digit LCD at reasonable cost, we strongly recommend Intersil's ICL7106EV/KIT Single Chip Panel Meter Evaluation Kit. It is available from Ancrona Corp. (see Parts List) and other Intersil distributors. If you are set on building your thermometer from scratch instead, follow Fig. 1 and the pin configuration guide for the LCD you buy.

Except for the remote sensing transducer, all thermometer components mount on the Evaluation Kit's circuit board. Build the Kit following the instructions supplied with it. Then, referring to Fig. 2, replace *R1* supplied with the Kit with a 22,000-ohm 5% (or better) tolerance carbon or metal-film resistor. (If you can adjust *R4* for 0.115 volt or more between *TP2* and *TP3*, *R1* need not be changed.) Eliminate the battery holder, specified jumper, and banana jacks. Drill holes for and mount the extra circuitry as shown. Refer back to Fig. 1 and interconnect all on-board components.

A 1" to 2" (25.4- to 50.8-mm) length of 3/16" to ¼" (4.8- to 6.4-mm) inner-diameter thin-walled brass or copper tubing should be used as a heat sink for the transducer if you plan to measure air temperatures. If you plan to use Lidith primarily for taking body and liquid temperatures, you can omit the tubing. Use a length of flexible three-conductor cable to interconnect transducer and circuit assembly. The cable can be up to 50' (15.2 m) long with no problems.

Referring to Fig. 3, slip the metal tubing onto the cable as shown. Then remove about 1" of the cable's outer jacket and prepare the ends of the conductors. Slip a length of plastic tubing over each

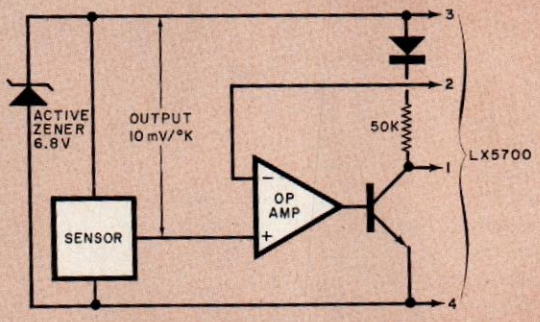
TEMPERATURE SENSOR SUPPLIERS

There are a number of manufacturers who produce temperature sensors suitable for use with Lidith. The following is a list of a few such manufacturers, followed by brief descriptions of the suitable sensors.

Precision Monolithics Inc. (1500 Space Park Dr., Santa Clara, CA 95050) produces Ultra-Matched Monolithic Dual Transistors, Series MAT-01, which, with suitable amplification, can be used in an electronic thermometer. For details, consult the company's application note No. AN-12 titled "Temperature Measurement Method Based on Matched Transistor Pair Requires No Reference."

Analog Devices (Rte. 1, Industrial Park, P.O. Box 280, Norwood, MA 02062) has recently released the AD590 Two-Terminal Temperature Transducer. It produces an output current proportional to the absolute temperature. At room temperature (77° F or 25° C), a 298.2-μA output is available. For every 1° C rise or fall, current increases or decreases by 1 μA. Premium model AD590M has a guaranteed maximum calibration error of ±0.5° C at 25° C. If you prefer to deal with voltages instead of currents, simply add a precision resistor in series with the transducer.

National Semiconductor Corp. (2900 Semiconductor Dr., Santa Clara, CA 95051) produces the LX5600/5700 series of IC temperature transducer specified in Lidith's Parts List. As shown in the diagram in this box, the transducer includes a built-in operational amplifier, internal zener diode to provide voltage regulation, and output transistor whose collector can be returned to a potential as high as 36 volts.



There are undoubtedly other semiconductor manufacturers who make sensors and transducers similar to those mentioned above, and this is not intended to be a complete list. ◇

conductor. Using a heat sink between transducer and tie points, solder the conductors of the cable to the leads on the transducer. Then spray several coats of plastic insulation (such as GC's Koloid K-29 or Clear Acrylic Plastic) over the connections and exposed wires. Alternatively, dip the entire transducer assembly in GC Liquid Tape. When the coating dries, push the plastic tubing down until it contacts the transducer's body and covers all bare wires.

Clean the transducer and metal tubing with fine steel wool or sandpaper. Referring to Fig. 4, solder the transducer to the tube, taking care to be sparing with the heat.

Finally, use epoxy putty to make a waterproof probe out of the transducer assembly. Prepare the putty according to directions and then wet your hands and form a rough cylinder around the transducer assembly. Do not be concerned if your work appears messy. Just make sure the transducer and connections are completely sealed. With damp hands, roll the rough cylinder between your hands until it is smooth and nearly perfectly cylindrical and has a blunt cone-shaped tip.

Mount the thermometer circuit inside a housing large enough to accommodate it and its battery.

Calibration. If possible, the following reference-voltage adjustment should be performed with the aid of a digital multimeter. However, a good-quality analog voltmeter can be used if its input impedance is 1 megohm or greater. If you have a laboratory thermometer, you can do away with the need for a meter altogether, but calibration will take considerably more time. (More about this later.)

Turn on the power and let the thermometer warm up for at least 2 minutes. Then, with the meter set to its lowest range, connect the negative prod to *TP3* (actually a jumper) and positive prod to *TP2*. Referring to Fig. 2, carefully adjust *R4* for a reading of 0.110 volt.

To calibrate the thermometer, you will need a plastic bucket filled about three-quarters full with compact clean snow, ice chips, or ice cubes. Pour in enough cold water to nearly fill the bucket. Place the transducer probe in the center of the ice/water mixture and wait a few minutes until the LCD stabilizes at some number.

Vigorously stir the ice mixture and adjust *R7* for a display of 32.1. This display figure is more desirable than the usual 32.0 because you will most likely be performing calibration in a warm room where ice water will be melting. In any event, what you are really measuring is the temperature of the *water*, which will not be exactly 32° F. If Lidith was calibrated exactly as described above, there are only two possible sources of error left—the transducer's slope and linearity errors. Fortunately, the transducer specified is almost perfectly linear. According to the conservative specifications, the nonlinearity of the LX5700 is less than ±0.5%. The only possible significant error left, then, is a slight slope error, the worst case of which is about ±0.4 mV/°K. With a laboratory thermometer and some patience, even this error can be removed.

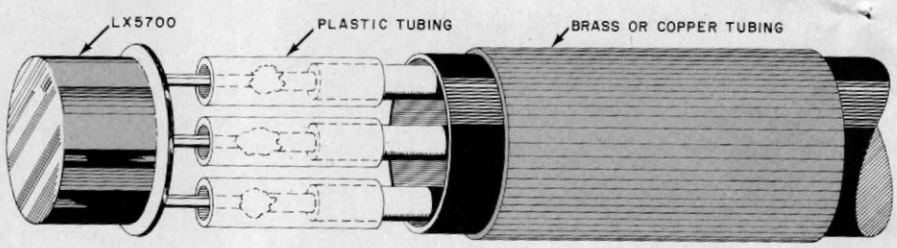


Fig. 3. Temperature probe construction. Make sure all soldered connections are well insulated. Thin metal tubing is optional.

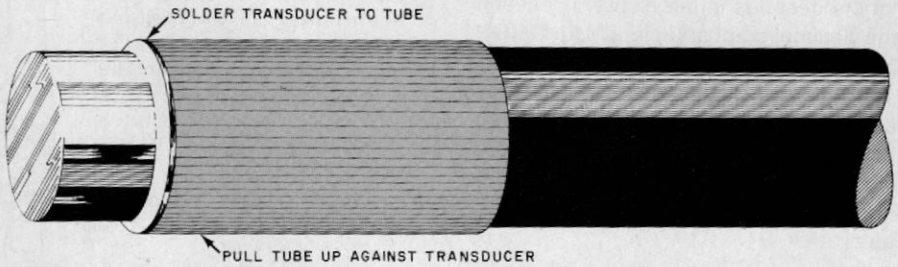


Fig. 4. Solder the optional heat sink to the heat sensor. Then use epoxy putty to form a waterproof probe out of the transducer assembly.

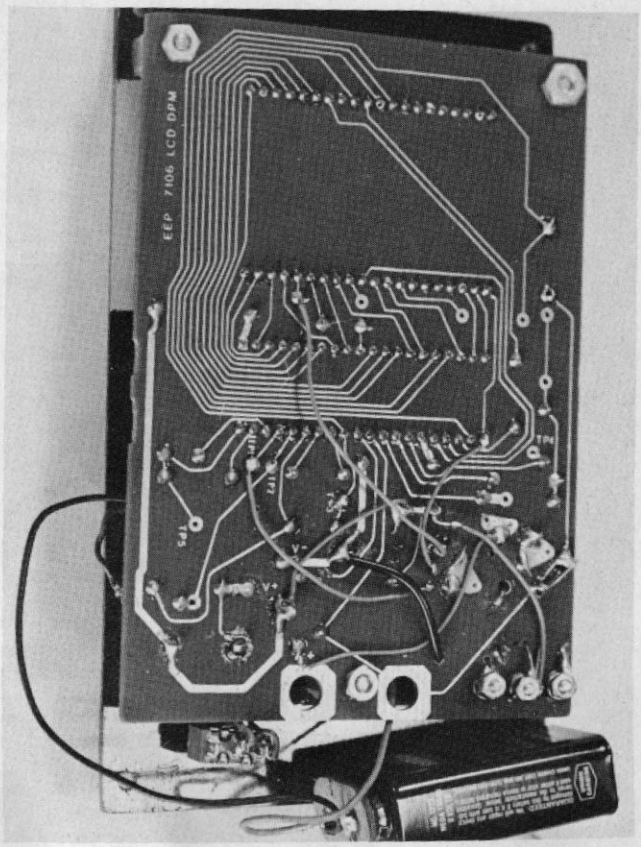


Photo showing back of meter evaluation kit board after extra holes have been drilled and components for temperature sensor have been added.

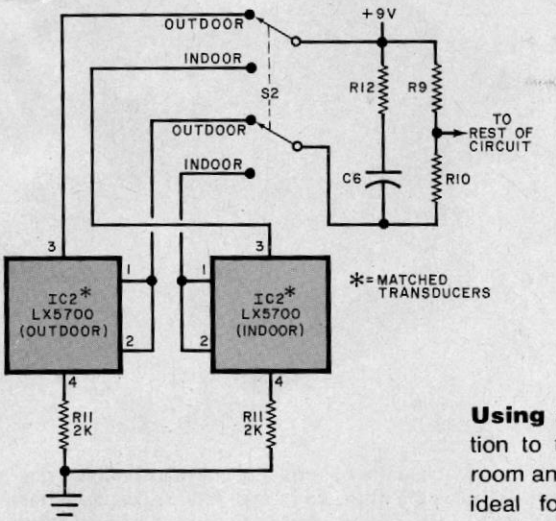


Fig. 5. Diagram shows how to connect two temperature sensors to the basic thermometer. For best results, sensors used should be matched.

To remove the slope error, adjust *R4* and *R7* exactly as described above. (If a DMM is not available, initially set *R4* to its midpoint.) Place the probe and lab thermometer in warm (about 120° F) water and, while stirring the water, adjust *R4* until Lidith's display indicates exactly the same temperature as the lab thermometer. Then place the probe in a bucket of ice/water and adjust *R7*, if necessary, for a reading of 32.1. Return the probe to the warm water and, if necessary, readjust *R4*. Repeat the immersion-and-adjustment procedure until it is no longer necessary to trim the settings of the potentiometers.

Using the Thermometer. In addition to the obvious use of measuring room and ambient temperature, Lidith is ideal for measuring temperatures in pools, for isolating excessively warm electronic components in an operating circuit, as a remote-indicating freezer or refrigerator thermometer, and as a medical thermometer. (If you calibrate accurately for 98.6° F against a good-quality oral mercury thermometer, the accuracy of Lidith can approach ±0.1° F over a 92° to 110° F range.) The Celsius version can also be used by auto hobbyists as a water-temperature monitor.

To accurately measure outside-air temperatures, you need both an accurate thermometer like Lidith and a suitable thermometer shelter. (For details on measuring outside-air temperature, see pages 23 and 25 of *Unique Electronic Weather Projects* published by Howard W. Sams & Co., or refer to some other suitable book on weather instruments.)

If you turn on Lidith only when you wish to know the temperature and leave the power off at all other times, a standard 9-volt battery should last more than a year. For a continuous display, omit *S1* and use six alkaline D cells in series instead of the 9-volt battery. In continuous use, the D cells should last about a year or more.

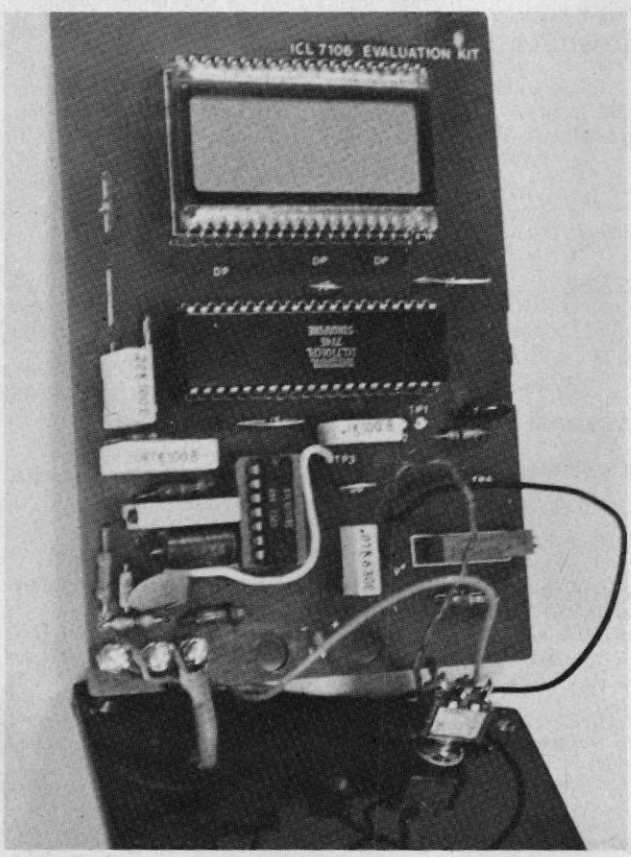
The thermometer can be used to measure temperatures in two different locations, such as indoors and outdoors, using the circuit shown in Fig. 5. Bear in mind, however, that if you select two LX5700 transducers at random, one of the temperatures measured can be off by as much as 14° F, due to the possible ±8° C maximum offset error of the device. This error can be reduced to 4° C if you use premium-quality LX5700As. Even so, your best bet would be to use a pair of custom-matched transducers (see Parts List).

With a few changes in component values, you can make Lidith measure temperatures in Celsius degrees from −55° to +125° C. You can even make an "Alaskan" version that measures down to −67° F and up to +199° F.

The following changes are required for both the Celsius and Alaskan versions. First, change *C2* to a 0.1-μF Mylar capacitor, *R2* to a 220,000-ohm, 5% tolerance carbon-film resistor, and *R4* and *R7* to 10,000-ohm, 15-turn trimmer potentiometers. Then adjust *R4* so that the potential between *TP2* and *TP3* is 0.500 volt.

For the Celsius version, change *R6* to 20,000 ohms, *R8* to 22,000 ohms, and *R10* to a 10,000-ohm 1% tolerance precision resistor. Calibrate by adjusting *R7* for a 00.1 reading on the LCD when the probe is immersed in an ice/water mixture as before.

For the Alaskan version, change *R6* to 82,000 ohms, *R8* to 15,000 ohms, and *R10* to a 1120-ohm, 1% tolerance precision resistor. Calibrate exactly the same as for the regular version, but adjust *R4* for a potential of 0.500 volt between *TP2* and *TP3*.



Front view of meter evaluation kit showing components for temperature sensor added in area where battery holder was.

Summing Up. Lidith is a truly state-of-the-art precision digital thermometer. With a few minor changes, it can be "tailored" to your needs. And, in ordinary use, it is highly energy-efficient, thanks to the use of low-power MOS circuitry and liquid-crystal display. ◇