THOUGH its function as a personal warning monitor is not as important as that of a fire alarm or a gas detector, a radiation monitor can give peace of mind to people who are apprehensive about the hazards of possible radiation leakage and radioactive devices. This concern is obviously heightened whenever the news media report a nuclear incident of one kind or another.

The RED-ONE battery-powered radiation monitor project described here detects local radiation levels from man-made and natural sources. It indicates relative radiation, which is perfectly satisfactory for alerting one to excess radiation levels.

Two versions of the monitor are described. The simpler one produces an audible "chirp" for each detected gamma ray. The other teams up a three-decade counter with the basic circuit to count and display gamma-ray events over a controlled period of time, sounding a chirp for each event.

The RED-ONE is a sophisticated unit that offers many advantages over earlier radiation detectors. Replacing fragile, cumbersome, and less-sensitive Geiger-Muller tubes, this monitor is built around a solid-state cadmium-telluride (CdTe) detector. About the size of a transistor, the device offers high sensitivity, low bias-voltage requirements, extremely low power consumption, and solid-state reliability. Moreover, cost is competitive with tube-detector types.

Radiation and Its Detection. Gamma rays can occur naturally (from substances such as uranium) or can be man-made (as in a nuclear power plant). Radioactive gases, such as those released during the Three Mile Island nuclear power plant incident, and medical diagnostic and therapeutic isotopes are typical man-made gamma-ray sources.

Each radioisotope produces gamma rays of specific energies which are measured in electron volts (eV), the energy acquired by an electron accelerated by a potential difference of one volt. Gamma rays have high energies mea-

BUILD A Personal Radiation Monitor

Uses latest cadmium-telluride detector to provide audible or visual indication of radiation level

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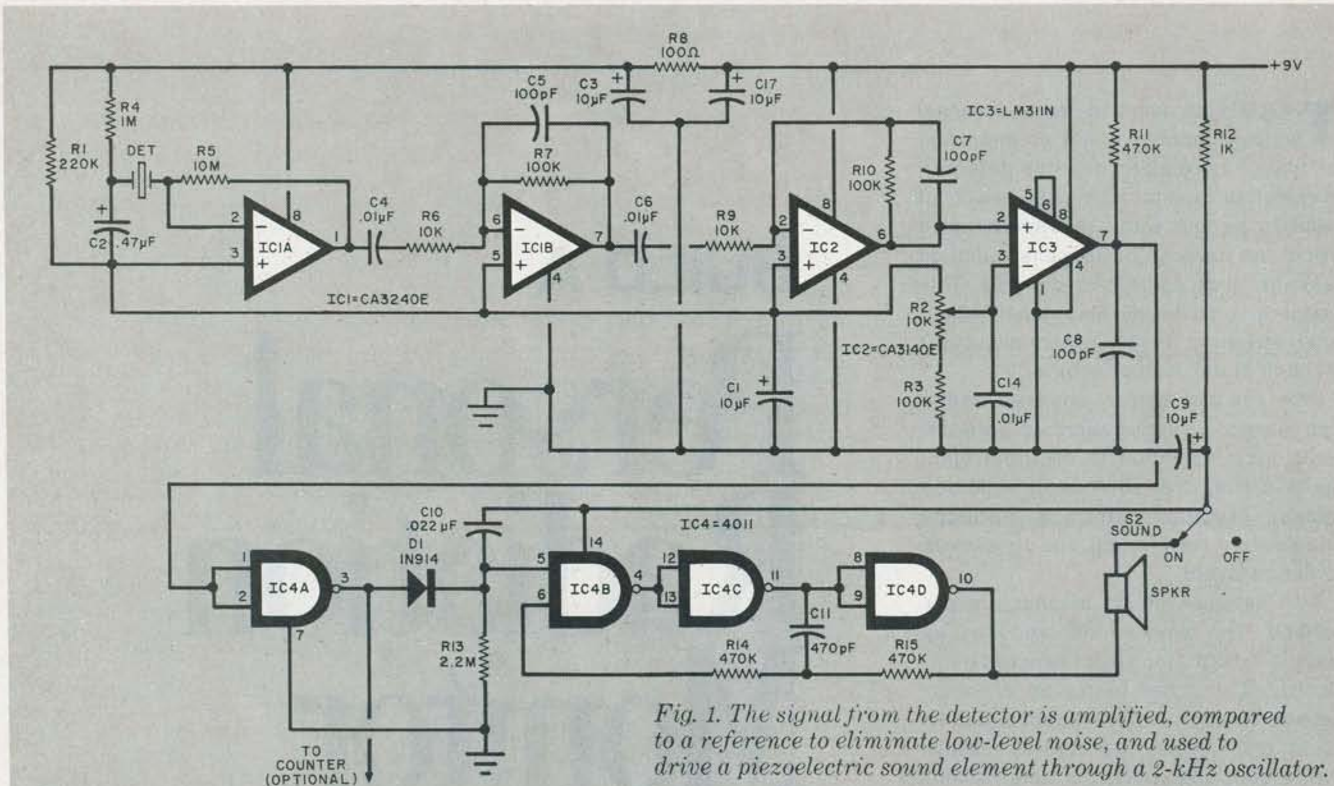


Fig. 1. The signal from the detector is amplified, compared to a reference to eliminate low-level noise, and used to drive a piezoelectric sound element through a 2-kHz oscillator.

PARTS LIST—FIG. 1

C1, C3, C17—10-µF, 16-V tantalum
C2—0.47-µF, 35-V tantalum
C4,C6,C14—0.01-µF disc ceramic
C5,C7,C8—100-pF disc ceramic
C10—0.022-µF disc ceramic
C11—470-pF disc ceramic
D1—1N914 diode
DET—CdTe radiation detector (see text and Note below)
IC1—CA3240E dual FET op amp (RCA)
IC2—CA3140E op amp (RCA)
IC3—LM311N comparator (National)
IC4—4011 quad NAND gate
The following are ¼-watt, 10% resistors unless otherwise specified:
R1—220,000 ohms
R2—10,000-ohm pc potentiometer
R3,R7,R10—100,000 ohms
R4—1 megohm
R5—10 megohms
R6,R9—10,000 ohms
R8—100 ohms
R11,R14,R15—470,000 ohms
R12—1000 ohms
R13—2.2 megohms
SPKR—Piezoelectric sound element (Kyocera KBS 27DB-3A or similar)
S2—Spst switch
Misc.—Suitable enclosure, 9-volt battery including holder and power on/off switch, 0.005″ brass foil for shield, machine hardware, etc.

Note—For availability of kit and parts, see Parts List for Fig. 2.

sured in thousands of electron volts (keV), the typical range being from 100 to 1000 keV. Lower-energy rays are absorbed by even a fraction of an inch of lead, while high-energy rays can pass through many inches of lead.

When gamma rays are absorbed by a CdTe detector such as that used in RED-ONE, an electrical-charge burst is produced and amplified to detect the event. Higher-energy rays produce greater charge bursts.

The gamma-ray sensor in RED-ONE is designed to allow detection of reasonable gamma-ray levels and to permit many interesting experiments to be made. For example, bricks in many New England fireplaces have detectable (though very-low-level) amounts of radioactivity. By observing indications with either version of the monitor, an estimate of activity level can be made.

About the Circuit. The basic detector/beeper circuit is shown in Fig. 1. The output of radiation detector *DET* goes to the input of the FET operational amplifier, which provides impedance matching and initial amplification. Additional amplification is provided by *IC1B* and *IC2*. Feedback capacitors *C5* and *C7* shape the pulse and improve S/N.

The output from *IC2* at pin 6 is about 40 µs wide and has a height that is proportional to the amount of charge deposited on the detector. Signal level here is about 1 mV/keV of collected charge. Unfortunately, thermally generated charge carriers and leakage current in the detector also produce about 30 mV of noise impulses. Adjustment of *R2*, however, ensures that comparator *IC3* discriminates against and prevents this low-level noise from triggering the comparator. Signal pulses that override the noise cause the comparator's output and, hence, NAND gate *IC4A*'s input to go low. Resistor *R13* keeps pin 5 of *IC4B* low to turn off the 2000-Hz (approximately) oscillator made up of *IC4B, IC4C, IC4D, R14, R15,* and *C11*.

When a detected event causes *IC4A* to go low, *IC4A*'s output goes high. This high signal is passed through now forward-biased diode *D1* to raise the pin-5 output of *IC4B,* which causes the oscillator to sound via the piezoelectric transducer, *SPKR.* The approximately 20-ms *C10R13* time constant maintains the high state of pin 5 of *IC4B*. When *IC4A* reverts to low, *D1* prevents rapid discharge of *C10* and maintains the time constant. The oscillator thus generates a 20-ms chirp for each detected gamma-ray event.

If you wish to count and display the number of events as they are generated

PARTS LIST—FIG. 2

B1—4 AA cells (not in kit)
B2—9-volt battery (not in kit)
C12—0.001-μF disc ceramic
C13—0.1-μF disc ceramic
C15—0.01-μF disc ceramic
C16—10-μF, 35-V tantalum
DISP1, DISP2, DISP3—7-segment, common-anode LED
IC6—555 timer
IC7, IC8—4518 dual BCD counter
IC9—4013 dual-D flip-flop
IC10—14553 3-decade counter
IC11—14543 7-segment decoder/driver
LED1, LED2—Red light-emitting diode
Q1, Q2, Q3—2N4402 transistors
The following are ¼-watt, 10% resistors unless otherwise specified:
R16, R17, R18, R30, R32, R33—10,000 ohms
R19 through R27—470 ohms
R28—100 ohms
R29—100,000-ohm pc potentiometer
R31—47,000 ohms
S1—Dpdt switch
S3—Spst switch
S4—Normally open pushbutton switch
S5—2-pole, 6-position rotary switch
Misc.—Suitable enclosure (LMB453 or similar); battery holders; control knob; machine hardware; red filter; etc.

Note—The following are available for non-commercial use from Radiation Monitoring Devices, Inc., 44 Hunt St. Watertown, MA 02172: complete kit of parts for Fig. 1 for $85; complete kit of parts for Figs. 1 and 2, including case but not batteries, for $125. Also available separately: CdTe radiation detector for $90. Add $5 for shipping and handling. Massachusetts residents, please add 5% tax. Allow 6 weeks for delivery. Available in U.S.A. only.

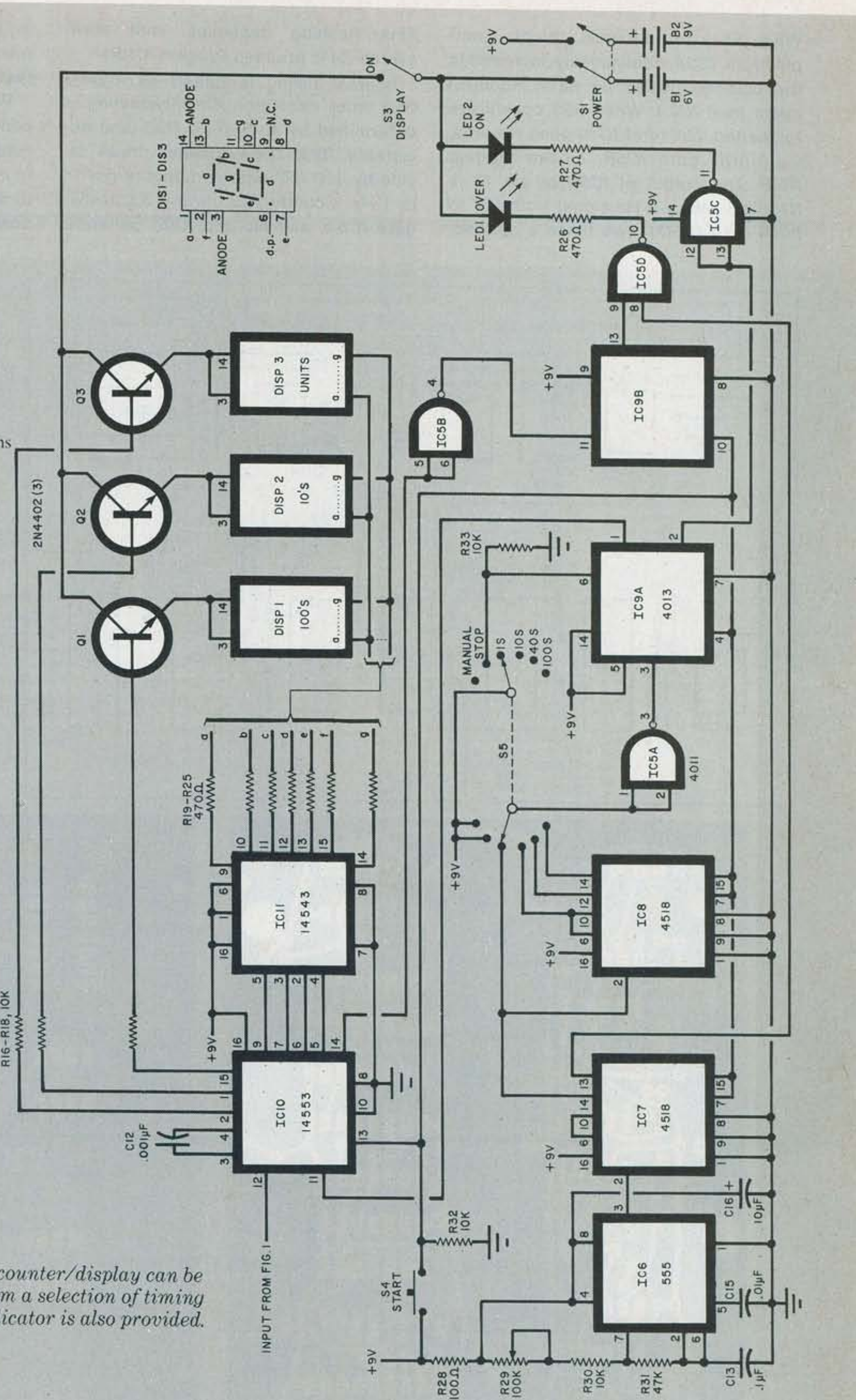


Fig. 2. The conventional 3-digit counter/display can be enabled either manually or from a selection of timing signals. A blinking overrange indicator is also provided.

at the output of *IC4A*, you can add the circuit shown in Fig. 2 to that in Fig. 1. The combination of *IC10*, *IC11*, and seven-segment displays *DIS1*, *DIS2*, and *DIS3* and digit drivers *Q1*, *Q2*, and *Q3* make up a conventional three-digit counter/display system. The output of *IC4A* drives counter *IC10*.

Operation of *IC10* is controlled by the signal at its pin-11 input. This signal can be either manually applied or automatically generated by an internal timer.

When *S5* is set to MANUAL, the pin-1 output from *IC9A* continuously increments the counter/display for each incoming count from *IC4A*. When 999 counts are exceeded, pin 14 of *IC10* goes low and, via NAND gate *IC5B*, clocks flip-flop *IC9B*. The output of *IC9B* at pin 13 is NANDed with a 2-Hz signal from *IC7* to flash OVER (*LED1*) two times a second. This flashing continues until START switch *S4* is pressed to reset *IC9B*.

Internal timing is based on 100-Hz 555 timer oscillator *IC6*. Frequency is determined by *C13*, *R13*, *R30*, and adjustable *R29*. The oscillator drives divide-by-100 *IC7*, whose output at pin 14 is 1 Hz. Counter *IC8*, switch *S5*, NAND gate *IC5A*, and flip-flop *IC9A* generate 1-, 10-, 40-, and 100-second timing periods. START switch *S4* initiates timing by resetting the two counters and flip-flop.

Power for the Fig. 1 circuit can be a conventional 9-volt battery or dc power supply. When the Fig. 2 circuit is added, four AA cells in series can be used to power the LED display. POWER switch *S1* controls both power sources.

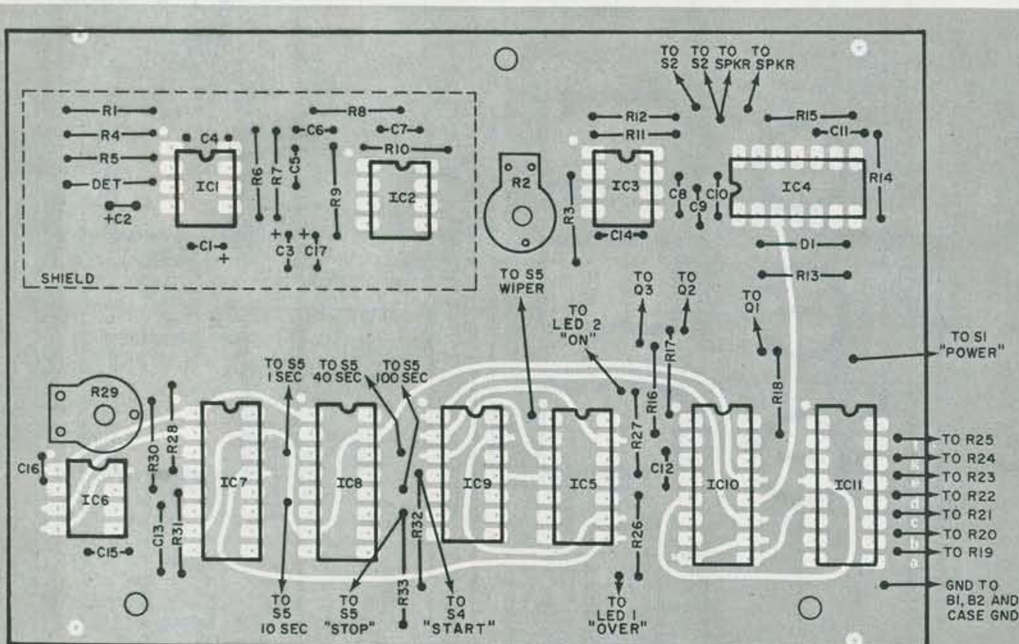
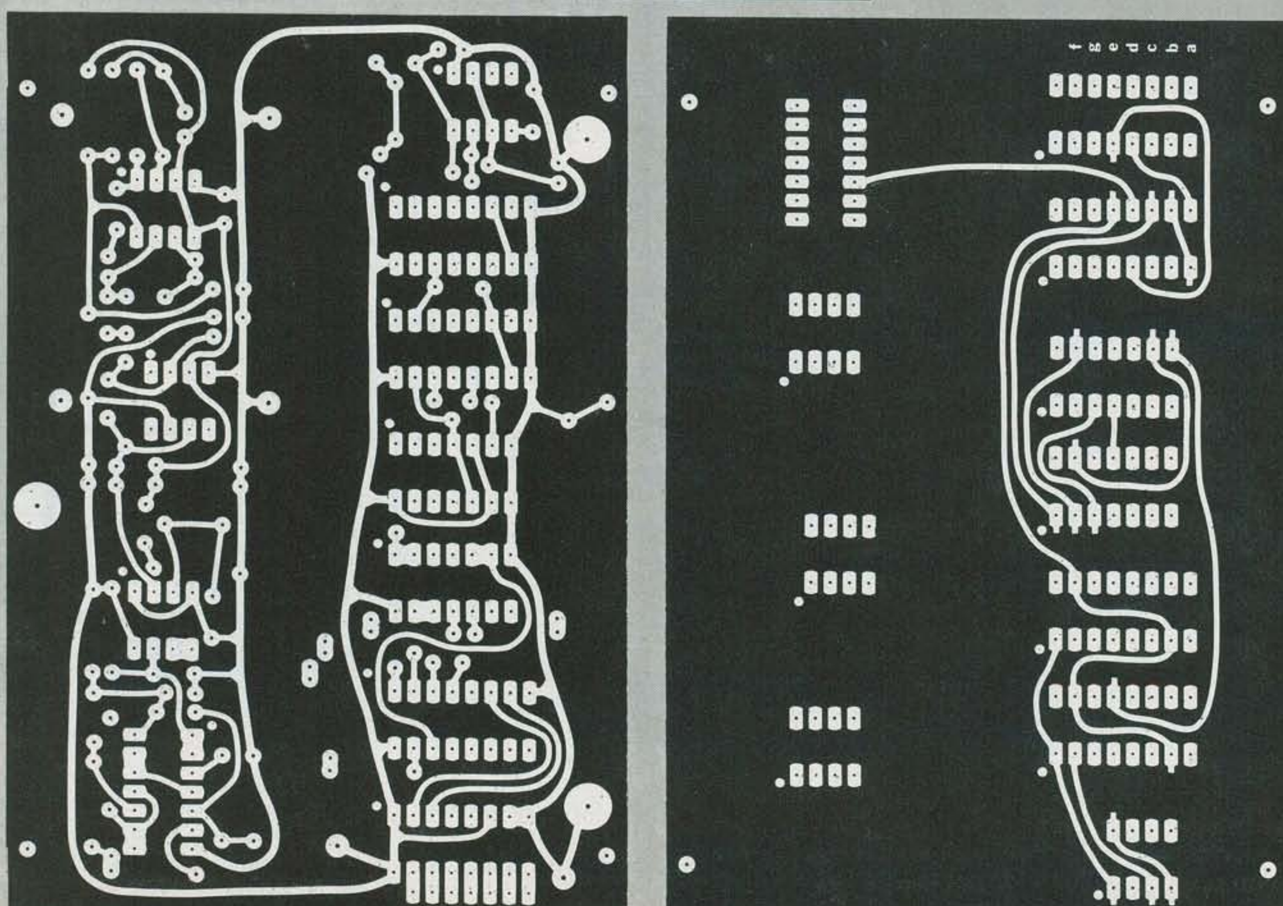
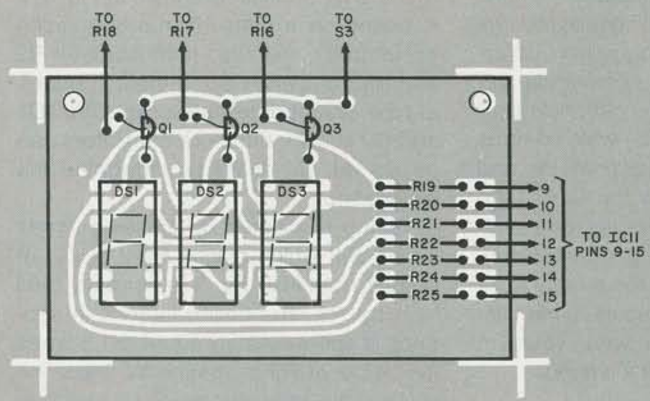


Fig. 3. Actual-size etching and drilling guides for the two-sided pc board are shown below. Component mounting on the top is at left. Note that the upper portion of the board (containing the audible circuit shown in Fig. 1) can be detached if only that circuit is to be used.





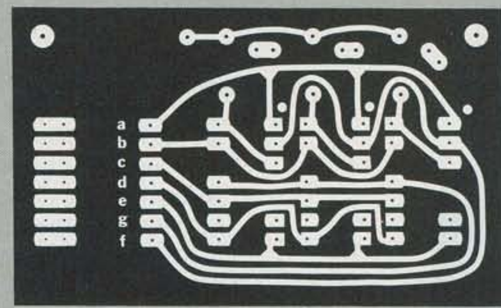


Fig. 4. Actual-size etching and drilling guide and component layout for the display board.

Construction. Since there are relatively high-impedance, low-level analog signals present in the *IC1* and *IC2* stages of RED-ONE, good circuit-board construction techniques *must* be exercised. The use of a printed circuit board and Molex Soldercons is strongly recommended.

Actual-size etching and drilling guides for the double-sided board and its component-placement diagram are shown in Fig. 3. At some component locations, pads appear only on the bottom side of the board. At these points, holes should be drilled from the bottom and components mounted from the top. If you elect to build only the beeper version of the Red One, you can separate and disregard the upper half of the guide. The only interconnecting trace between the two guide sections is from *IC4* to *IC10*.

The etching-and-drilling guide and component-placement diagram for the optional display board are shown in Fig. 4. This is a single-sided board.

In addition to normal precautions used when soldering solid-state devices, special care must be taken with the detector. Use a low-wattage, fine-tipped soldering pencil and fine solder and provide a heat sink for the leads with longnose pliers. Use only enough heat and solder to give reliable, solid connections.

Begin assembly by installing and soldering into place the resistors, capacitors, and Soldercons (if used) on the main pc board. Some points that require soldering on both sides of the board are indicated by short tabs on the pc pads. In addition, any pad on the component side of the board from which a foil runs requires soldering to the component lead. This suggests the use of Molex Soldercons as opposed to IC sockets. Provisions for using miniature clips at critical test points and where interboard connections occur are indicated in the Fig. 3 component-placement diagram.

Tape a ⅛" (3.2-mm) thick piece of foam rubber around the detector to cushion it from mechanical shock. (Because of its piezoelectric design, any mechanical shock to it will cause the detector to generate a false output.) Use copper foil or 0.005" (0.13-mm) thick brass to fabricate an electrical interference shield to prevent external influence on the low-level analog signals generated in the detector. Shape it as an open-faced box measuring 2½" × 1" × ½" (63.5 × 24.5 × 12.7 mm). Then solder the box to four miniature clips spaced on the board as indicated in Fig. 3. (This box also holds the foam-rubber-wrapped detector gently against

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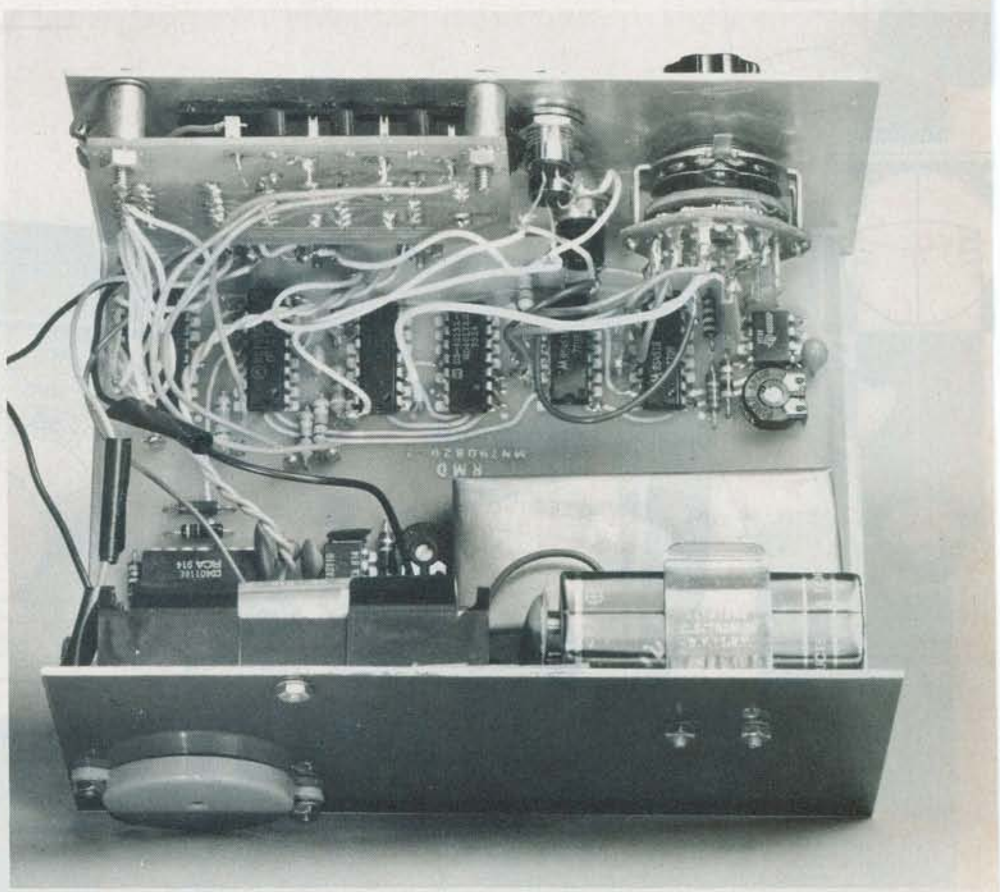

Photo of the author's prototype shows the main pc board mounted on chassis bottom with sound element on back and display on front.

Radiation Detector

(Continued from page 91)

the main pc board.) Rubber cement a 4" × 2½" × ⅜" (102 × 63 × 9.5 mm) piece of foam-rubber carpet pad to the bottom of the main pc board. Assemble the display board, if used.

All components should be mounted inside a prepared metal case that measures 5"W × 3¾"D × 2¾"H (127 × 92.3 × 70 mm) if you build the counter/display version of the project (smaller if you elect to build only the beeper version). Install the *SPKR* chirper on the outside surface of the box's rear wall, the battery holder on the inside surface. Rubber cement the main pc board assembly to the floor of the box, making sure it will not interfere with the controls or battery holder and does not contact the case. (The foam rubber between main pc board assembly and case ensures maximum mechanical protection and vibration insulation.)

Mount the display board with ⅜" (9.5-mm) long spacers and machine hardware, using a ground lug on one post. Install the switches, LEDs, and connecting wires, referring back to Fig. 1 and the component-placement guides. Don't forget the ground wire to the chassis (case), and use twisted-pair leads for *S2* and *SPKR*. Label the front panel.

Calibration and Use. Prior to applying power to the RED-ONE, recheck all wiring and component orientations. Then turn on the power and, with a voltmeter connected from pin 3 of *IC3* to ground, adjust *R2* for minimum voltage. This lowers the noise threshold so that triggering will occur even on electrical noise. Output pin 7 of *IC3* will now fire rapidly or be continuously at ground potential. This will cause a steady tone.

Using the voltmeter, or an oscilloscope set to the dc mode, slowly adjust *R2* to raise the *IC3* pin-3 reference voltage toward maximum. Chirp rate will gradually decrease, eventually ceasing altogether. Continue to adjust *R2* only slightly past this point. This eliminates false triggering on electrical noise. Gamma rays that deposit less than the minimum energy required to overcome this threshold will also be rejected. The equivalent energy of a typical low-level gamma photon is 30 keV.

Calibrate the timing chain by adjusting *R29* and observing total ON time of *LED2* with *S5* in one time position. With a little patience, you can adjust *R29* to obtain accuracy within a fraction of a second. Gross adjustment can be made in the 10- and fine adjustment in the 100-second periods. Accuracy is determined by the stability of *IC6* and its associated resistors and capacitors.

RED-ONE can be used to estimate exposure to radiation from natural and man-made isotopes and to measure changes in exposure. Units of radiation exposure include the roentgen, which is approximately equal to the absorption of 0.01 joule of gamma radiation by 1 kg of matter, and the rem (roentgen-equivalent-man), which measures the equivalent biological damage to man by any form of radiation. Average radiation exposure in the U.S. is about 0.2 rem/yr from natural sources. RED-ONE's sensitivity is between 20 and 40 counts/min/millirem/hr. Hence, natural background radiation produces about 1 count/min.

Natural background radiation levels can vary by as much as a factor of two, depending on where you live, the materials from which your house is built, and your altitude above sea level (the last due to cosmic rays). In addition, variables in detector construction and electronic components influence noise level and, therefore, overall detection sensitivity. Actual count-rate measurements are not as important as are changes in count rate due to the presence of radioactive material or environment changes.

It is important to note that random emissions of radioactivity will cause the monitored rate to apparently change from reading to reading. To estimate this statistical deviation, assume that any given count is accurate to within plus and minus the square root of the number of counts. Therefore, a display of 100 should be interpreted as 100 ± 10 counts, a display of 120 counts as 120 ± 11, etc. This means that the numerical difference between any two measurements is significant only if it is greater than the sum of the two square roots. For example, if your readings are 100 and 120, the numerical difference is 20 and square-root sum is 21 (10 + 11); because 20 is less than 21, there is no reason for concern. However, if your figures are 100 and 169, the difference is 69 and square-root sum is 23 (10 + 13), which gives you reason for concern because 69 is much greater than 23.

Once you have established a normal background level for your RED-ONE, you can compare readings at various locations and investigate possible radioactive sources. So now you can satisfy your curiosity about radiation levels in your locale. ◊