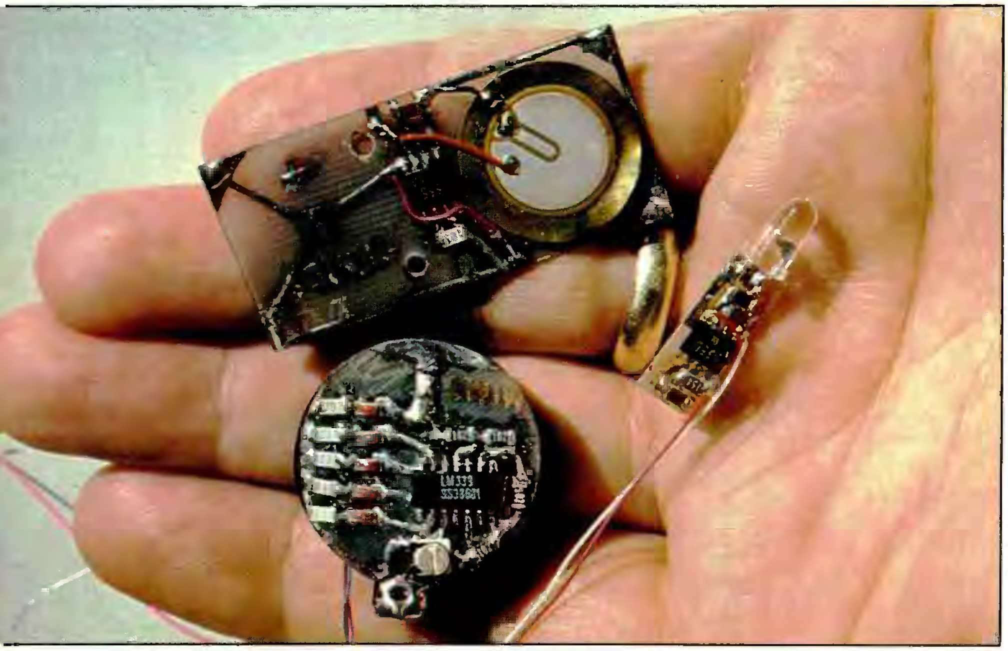
Surface-Mount-Device Circuits: A Design & Construction Guide

The author describes how to work with surface-mount technology to produce three personal subminiature devices



By Forrest M. Mims III

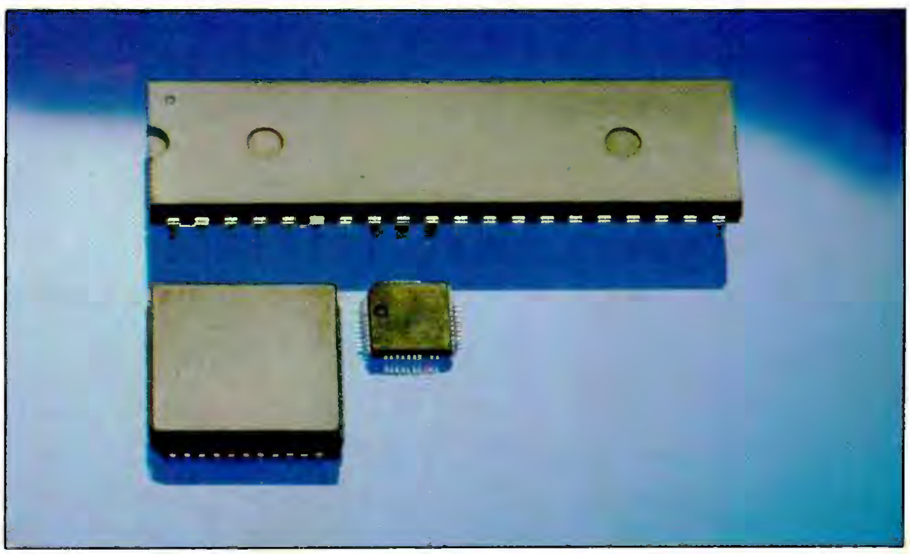
Last month, I set the stage for this article by discussing the current state of surface-mount technology and reviewing a kit that can get you started in SMT assembly techniques. Now I will describe how to assemble three subminiature circuits: an LED transmitter, an LED bargraph "meter" and a light probe. By using tiny surface-mountable components (SMCs), the overall size of these circuits is substantially smaller than if conventional components were used. The emphasis is on hand-assembly procedures that you can use both in your home workshop and on the job.

I am confident that once you master the easy techniques needed to work with SMCs, you will share my enthusiasm for this personal assembly method that is revolutionizing how electronic circuits are built.

Circuit Boards for SMCs

Surface-mountable components are are leadless or have very short pins. Therefore, wiring must be on a substrate having preformed conductive traces. Ordinary etched circuit boards work well in this role, with double-sided boards permitting SMCs to be installed on both sides.

Although any copper-clad board



Standard 40-pin DIP and P-Tape Pak ICs dwarf surface-mount 44-pin plastic leaded chip carrier (PLCC) IC at lower right. (Photo courtesy: National Semiconductor) can be used for SMCs, to preserve their very-small-size advantage, I prefer to use very thin (20-mil or less) single- and double-sided board. Unfortunately, this thin a board is not readily available to small-quantity purchasers. Hopefully, as demands develop for supplies suitable for hand-assembled boards using SMCs, thin copper-clad board will be stocked by electronics suppliers.

If you are unable to locate a source for 20-mil boards, you can use standard boards, of course. Alternatively, you can use ultra-thin (5-mil), double-sided material from Edmund Scientific (Cat. No. G35,738; $2.50). Supplied in 12″ × 18″ sheets, this material is very flexible before etching and can be used as is or be cemented to a rigid substrate. Keep in mind that after this board has been etched, excessive bending will fracture the very thin substrate.

Of the many ways to create etched circuit patterns on copper-clad boards suitable for SMCs, the four most common are:

(1) Use of a standard resist pen to draw the desired SMC "footprints" and traces directly on a shiny copper-clad board. In view of the very small size of SMCs, this method may seem impractical. However, I have found it works surprisingly well, and is the method I used to assemble the miniature circuits described here.

(2) Use of dry-transfer component patterns and traces to form actual-size (1:1 or 1×) footprints and traces directly on the copper-clad side of a board. This one-shot method provides circuit traces as neat as those formed by photographic techniques. Datak sells a complete line of suitable dry transfers. Their flat-pack dry transfers have 0.05″ centers and can, therefore, be used for SO (small outline) integrated circuits.

(3) Use of dry-transfer or self-adhesive component patterns and traces to form a 1× circuit pattern on a clear substrate and then using this pattern to expose a copper-clad board coated with positive photoresist. Suitable patterns are available from Bishop Graphics and Datak.

(4) Use of dry-transfer or self-adhesive component patterns and traces to compose a 2× or 4× circuit pattern. Photographing the pattern to obtain a 1× negative yields a "mask" that can be used to photographically expose circuit boards coated with negative photoresist. This method permits boards to be made in batches.

How to Install SMCs

The principal manufacturing methods for installing surface-mountable components were covered last month. I will focus here on hand-assembly procedures, the method likely to be used for putting together prototype models by engineers and technicians, and for building microminiature products by electronics enthusiasts.

The circuits to be described were assembled with a hand-held 15-watt soldering iron. Most SMCs are so tiny that soldering them to a circuit board with a hand-held iron might at first seem impossible, as I initially felt. I soon learned that, with a little care and patience, the procedure is fast and simple. Here are the basic requirements:

(1) It is *essential* to use a low-power soldering iron with a sharp conical tip. Irons designed specifically for soldering and desoldering SMCs are an added expense, but I have had excellent results with an inexpensive 15-watt pencil iron.

(2) *Always* pretin the copper component footprints on the circuit board. You can do this chemically by immersing the etched board in TINNIT™ to plate the copper pattern with a thin film of tin. Datak sells TINNIT for $4.60 for a 1-pint bottle. The alternative is to heat the copper traces with a soldering iron and flow a thin layer of solder onto them, which is what I did to assemble the circuits to be described.

(3) The SMC must be secured in place before it can be soldered. Otherwise, the surface tension of the molten solder will attract it toward the tip of your soldering iron. Though you can cement SMCs in place before soldering, this requires extreme care to avoid getting cement on the component footprints. A much simpler and faster method is to simply secure one end or side of the SMC in place with a small piece of masking tape. Pick up one end or side of the SMC with the tape, position the SMC in place over its footprint, and press into place on the board.

To solder the connection, first touch the point of the iron to the junction of the footprint and SMC lead and then touch the end of a thin (0.03″ or less) diameter solder wire to the tip of the iron. When a tiny bit of solder flows between the footprint and the SMC terminal, quickly remove both the iron and the solder. Each connection should take only a second or two. After soldering one or more terminals to the copper pads, remove the tape and solder the terminal(s) previously covered and any remaining terminals.

(4) It is *very* important to inspect every solder connection through a magnifying lens immediately after the connection is made and before making the next connection so that SMC movement, solder bridges, etc. are immediately found and corrected.

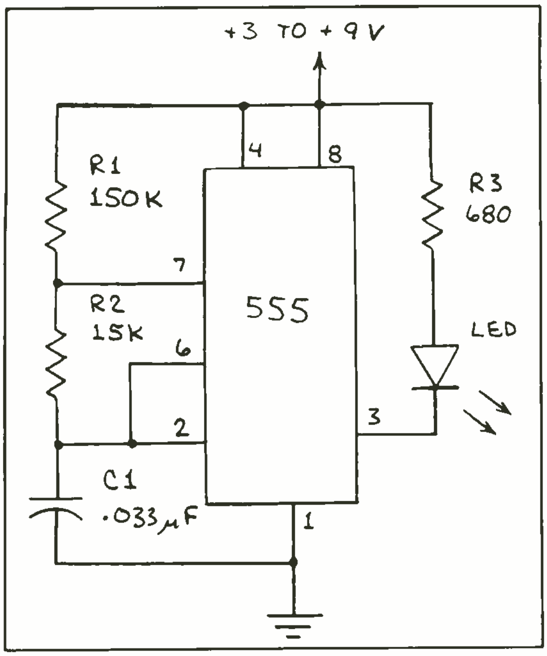
(5) If the SMC is a small outline (SO) integrated circuit, transistor, or diode, make sure all leads are lined up before *and* after the first lead is soldered into place. If necessary, slightly realign the device after making the first connection.

(6) If you tin the copper footprints with solder, be sure to slurp up any excess solder with copper desoldering braid.

(7) For best results, any pretinned solder layer placed over the footprints intended for SMCs should be as thin as possible. If solder tends to pool under an SMC's terminal while soldering, especially a chip resistor or capacitor, carefully press the SMC against the board while the solder is still molten. If the SMC is a leadless device, such as a chip resistor, this technique works for only the first terminal soldered. Otherwise, the chip SMC might be fractured. Therefore, the tinning over the second footprint should be as thin as possible.

Subminiature LED Transmitter

The first circuit I assembled with surface-mountable components was the LED tone transmitter shown at the left in Fig. 1. This is a 555 timer configured as an astable multivibrator that drives a high-brightness GaAlAs



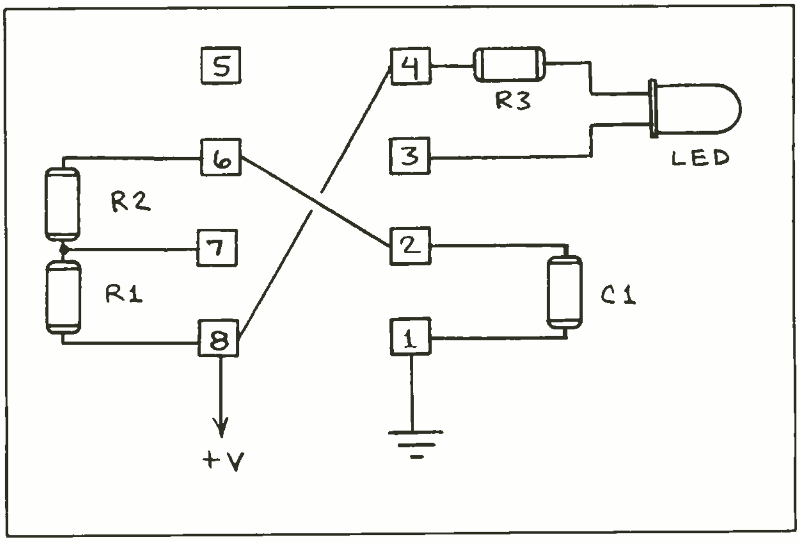


Fig. 1. A 555-timer-based miniature LED tone transmitter circuit (left) and preliminary circuit-board layout (right).

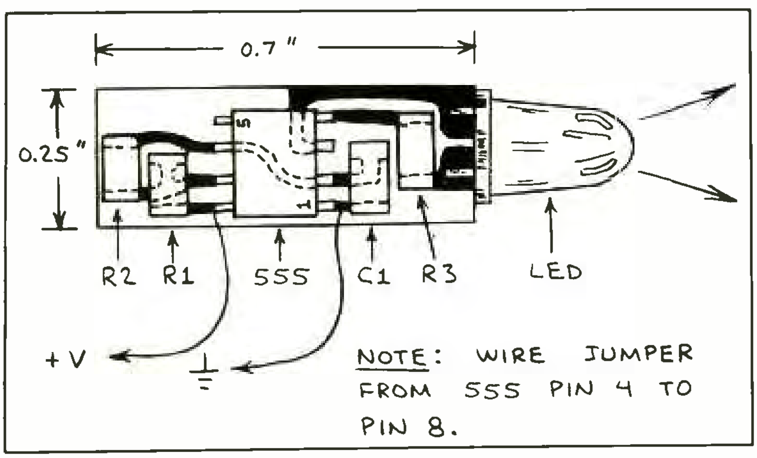
red LED at around 100 Hz. This circuit can be used as an optical transmitter for miniature remote-control systems, intrusion alarms, and object-detection systems. For higher output power or for applications in which an invisible beam is desired, the LED can be replaced with an infrared-emitting diode.

Before building this circuit you may wish to assemble a breadboard version to determine whether or not you want to modify component values. For example, increasing the value of *R1* or *C1* will slow the circuit's pulse repetition rate.

A sketch I made to determine where to place the components in the circuit is shown at the right in Fig. 1. Since I wanted the finished circuit to be as small as possible, I modified the location of the parts by placing them in a row. The result was the final layout shown at the left in Fig. 2, which is a drawing of the completed circuit. To duplicate this circuit layout, first draw the traces on the pc blank with a pencil, placing the SMCs on the board one at a time (use tweezers) and drawing the footprints. Then connect the footprints in accordance with the circuit diagram. Hand-trace the faint pencil traces with a sharp-pointed resist pen (Radio Shack Cat. No. 276-1530 or similar).

Next, etch the board in ferric chloride to remove the unwanted copper and strip the resist with resist solvent. (*Caution*: Always follow the precautions given with these chemicals.) The board shown measures on-

Fig. 2. Assembly details for the miniature LED transmitter circuit (left) and the assembled circuit (right).



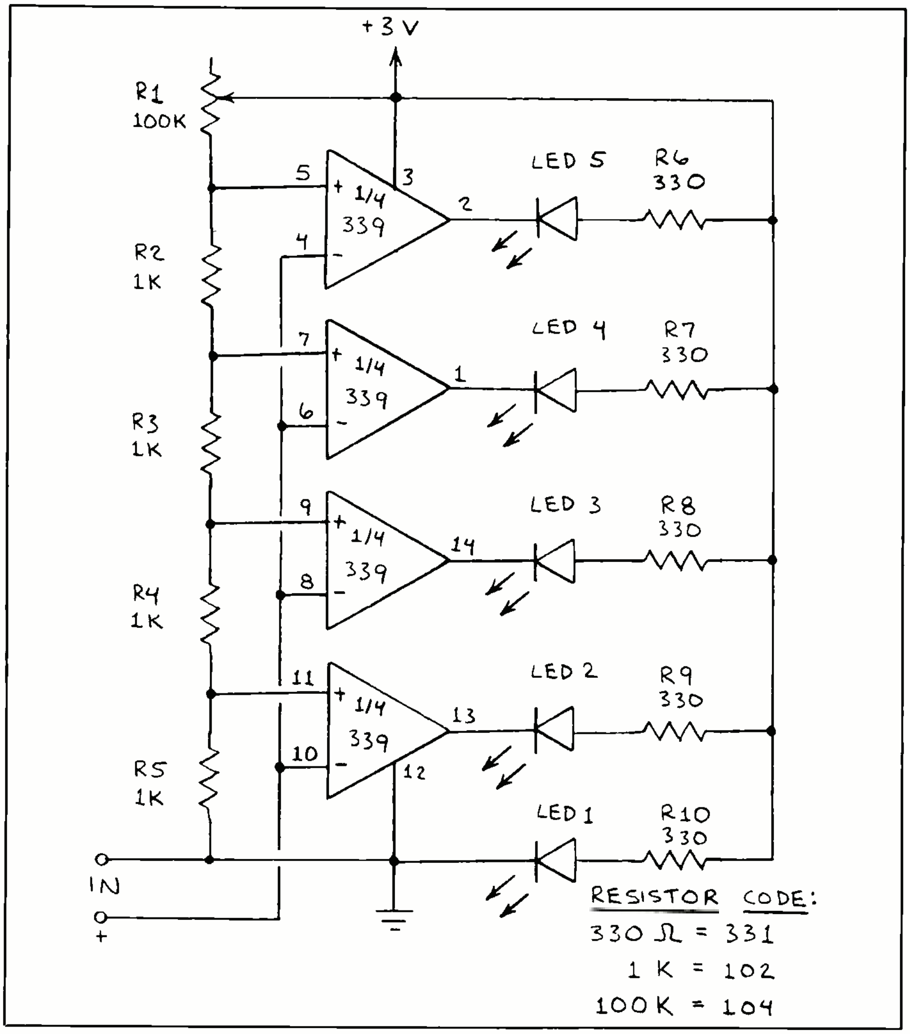


Fig. 3. A simple four-element LED bargraph or "metering" circuit.

ly 0.25″ × 0.7″. You may want to start with a somewhat larger board. After the SMCs are soldered into place, use scissors to trim the board to its final size.

Begin "wiring" the board by first soldering the SO 555 into place using the masking-tape technique described above. Tape one end of the board itself to your workbench to keep it from moving. It is important to work slowly and carefully, and remember that it is absolutely essential to check each connection with a magnifier before soldering the next one.

Although a tiny surface-mountable LED can be used, I used a standard LED because of its higher output power. All that's necessary to convert the LED into an SMC is to clip off all but 0.1″ of its leads. To finish the wiring, solder power supply leads to the board as shown. Wrapping wire works well here. The photo in Fig. 2 shows the completed circuit.

Before applying power to the circuit, carefully inspect the "wired" board with a magnifier. Use a sharp instrument to remove all solder balls. Carefully remove solder bridges with a soldering iron and desoldering braid. Use caution to avoid overheating or moving nearby SMCs.

Apply power (a 3-volt lithium coin cell works well) and point the LED at a nearby optical receiver to test the circuit. A suitable receiver can be made by connecting a solar cell or phototransistor to the input of a battery-powered audio amplifier. [For more specialized receivers, see *The Forrest Mims Circuit Scrapbook* (McGraw-Hill, 1983) and *Forrest Mims Circuit Scrapbook II* (Sams, 1987). Also see *Engineer's Mini-Notebook: Optoelectronic Projects* (Radio Shack, 1986).—Editor] If you use the parts values shown in Fig. 1, you can determine if the circuit is oscillating by simply swinging it sideways. The LED will then be seen to emit a series of fast flashes as it moves.

LED Bargraph

The circuit in Fig. 3 is a parallel or flash analog-to-digital (A/D) converter. Though this basic circuit shows only four LEDs (not counting *LED1*, which indicates when power is applied), the comparator/LED string can be extended indefinitely.

When the inputs are open, all LEDs glow. Connecting a variable resistance across the inputs causes the LEDs to extinguish successively as the resistance is decreased. A variable voltage source connected across the inputs causes *LED2* through *LED5* to extinguish. The LEDs begin to glow in sequence when the voltage is reduced. In both cases, *R1* determines the trigger points for the LEDs.

Since this basic circuit responds to both resistance and voltage, it has many applications as an LED "meter." For example, it can function as a miniature light meter if a photoresistor or solar cell is connected across the inputs; it can be adjusted to indicate the voltage of small batteries and power cells; and can even indicate the resistance of the human body.

At the left in Fig. 4 is a drawing of how the circuit in Fig. 3 can be assembled on a board measuring only 1.05″ in diameter. (Incidentally, if you are skeptical about your ability to assemble these miniature circuits, keep in mind that more time was required for me to make the Fig. 3

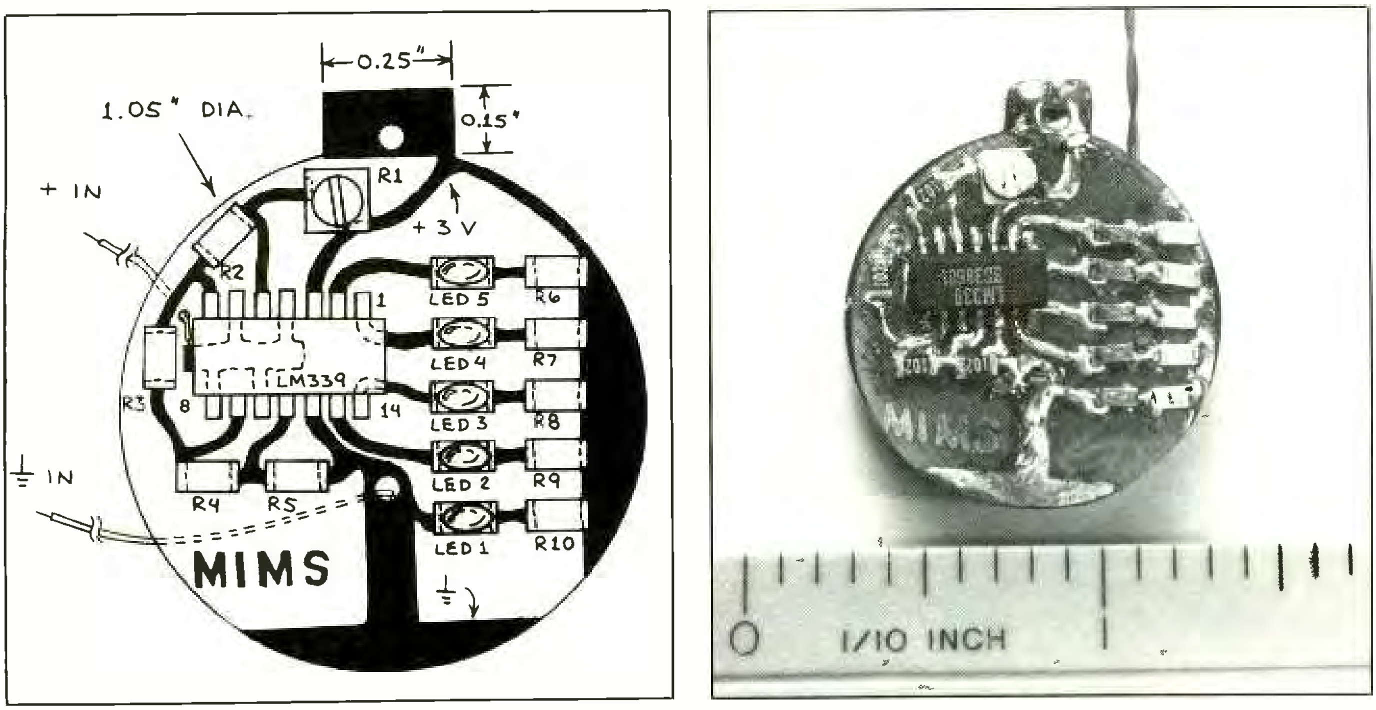


Fig. 4. Assembly details for the four-element bargraph circuit (left) and the assembled circuit (right).

drawing than to design and assemble the entire circuit!) The board is designed to be soldered to the two terminals that protrude from the back of a 3-volt lithium coin cell holder (Mouser Electronics Cat. No. 534-106 or 534-105 or similar). The entire circuit, including the coin cell holder, is ⅜" thick.

Lay out the board with a pencil, coat the traces with a resist pen, and etch it in ferric chloride. Then remove the resist with solvent and drill two holes to receive the coin cell's terminals. Solder the SMCs in place as detailed above. Start with the SO IC and work outward from the center of the board. I used Stettner ceramic chip CR 10 red LEDs for *LED1* through *LED5*. Slightly larger chip LEDs are also available from Mouser Electronics and other sources. Though the LEDs may seem more fragile than the chip resistors, they can be soldered using the masking tape method described above.

Trimmer potentiometer *R1* will be difficult to hand solder if the center terminal is under the device. Therefore, use a 4-mm trimmer having exposed terminals. For best results, select a trimmer having the two stator terminals on one side and the rotor terminal on the opposite side. I used a Bourns single-turn cermet trimmer (Part No. 3304X-1-104). This remarkably tiny device can be adjusted with a small screwdriver.

After the SMCs are soldered in place, slide the board over the terminals of the coin cell holder and carefully solder them into place. You may wish to trim the terminals before soldering to avoid damaging any of the SMCs or the relatively fragile circuit board.

Finally, solder the input leads to the circuit as shown. The ground lead can be threaded through a small hole near the IC. The ground lead can be threaded through the negative battery terminal hole. Use a short piece of heat-shrinkable tubing for a switch. Force the tubing over the exposed battery terminal to switch off the power.

Figure 4 also shows the completed LED bargraph circuit. (After thoroughly testing this circuit, I misplaced it somewhere in my office shortly after taking the photo. The lesson here is that special attention should be given to storing SMCs and subminiature circuits made from them.)

Subminiature Light Probe

Figure 5 shows a simple light-sensitive oscillator designed around a 555

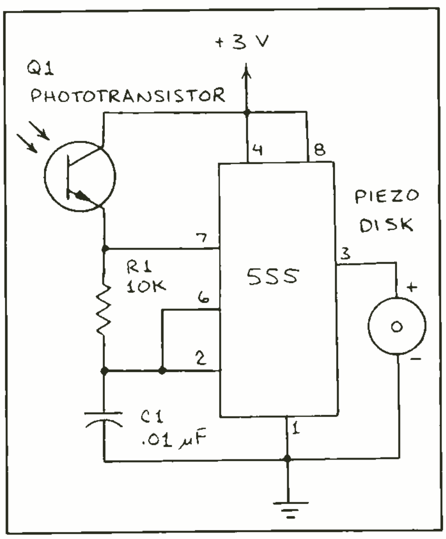


Fig. 5. A light-probe circuit.

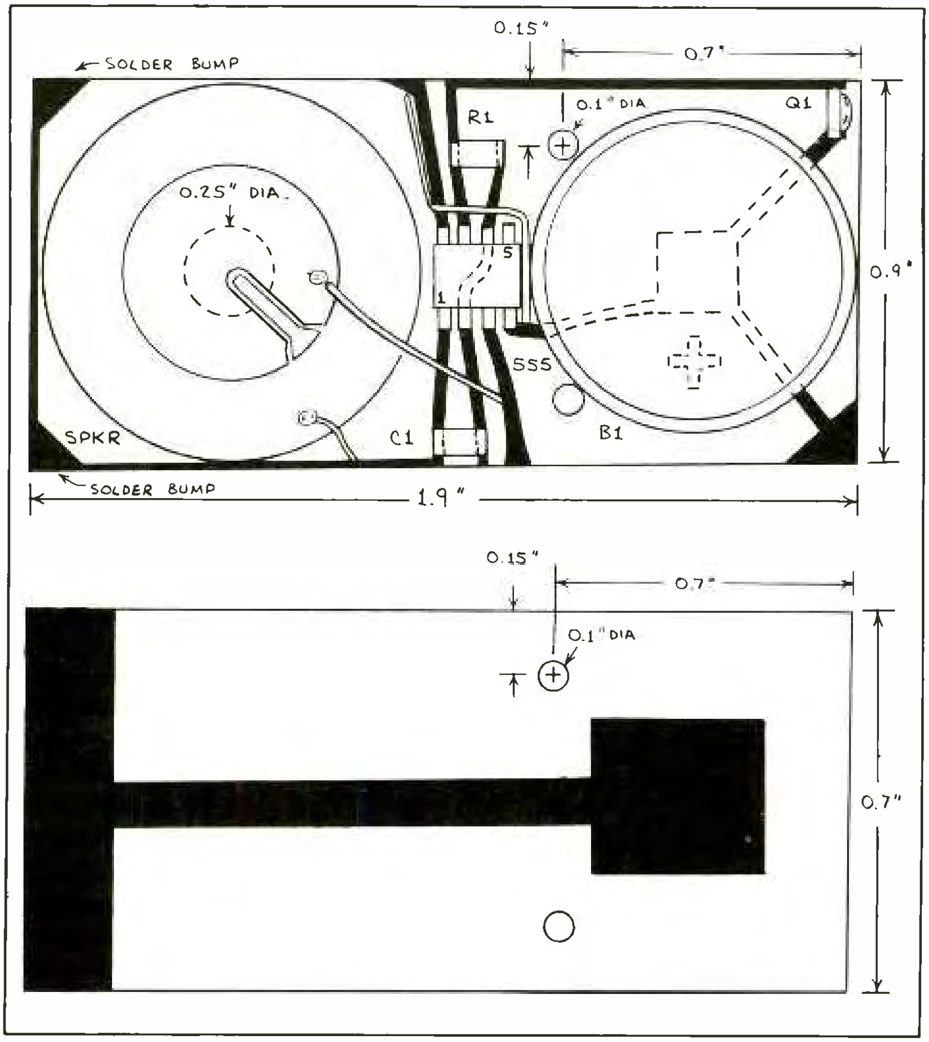


Fig.6. Assembly details for the light-probe circuit (upper) and a switch board for the light-probe circuit (lower).

timer. In operation, light falling on the active surface of phototransistor *Q1* causes the frequency of oscillation to increase. Pulses from the oscillator are made audible by a small piezoelectric alerter element. Among the uses for this circuit is a light probe for the blind.

Figure 6 illustrates how the light probe can be installed on a circuit board measuring 0.9″ × 1.9″. The speaker is a MuRata ¾″ piezoelectric alerter disk. If you cannot find this item, remove the disk from the plastic housing of a Radio Shack Cat. No. 273-064 piezo buzzer element, and clip the blue lead flush with the element.

Fabricate the circuit board as described above, being sure to leave space for the alerter disk and a CR2016 3-volt lithium coin cell. After the board is etched, solder the SMCs into place. The phototransistor is a CR10TE-1 ceramic chip unit available from Stettner Electronics. Though *Q1* can be mounted flat on the board, I soldered it on its side so that its lens faces in the same direction as the plane of the board. Since one terminal of the phototransistor was not fully metalized, it was necessary to use a bit of wire to bridge the space between it and the footprint pad.

Form two solder bumps on the corners of the board as indicated. These bumps should extend very slightly above the back of the piezo disk. If necessary, use short bits or wire to extend the bumps.

After the components are installed carefully drill a ¼″ hole in the board centered under the space for the piezo disk and a pair of 0.1″ holes in the board adjacent to the space for the battery.

Next, form a thin ring of flexible silicone sealant on the face of the disk, invert the disk, and place it face down over the ¼″ hole. Don't press the disk against the board; instead, allow it to ride just above the board on the sealant bead so that it can resonate.

Incidentally, it's important to apply the sealant bead to the annular node around the center of the disk. Otherwise, the disk will not vibrate freely. If you use a Radio Shack disk, apply the sealant bead to the remnants of the original sealant ring that attached the disk to its plastic case. If you use a new disk, place it flat on a table, connect it to a signal source and place powdered sugar on its surface. The sugar will form a ring directly over the nodal region. Use a pencil to outline the node. (For more details, see *Modern Electronics*, September 1986 "Electronics Notebook.") After the sealant cures, trim the leads to the disk and solder them as shown in Fig. 10.

The lower drawing in Fig. 6 demonstrates how to make a squeeze switch for the light probe from a second circuit board identical in size to the first. Apply resist to the board as shown and etch the board. Remove the resist and plate the copper with TINNIT or solder. Then drill two 0.1″ holes as shown, lined up with the 0.1″ holes in the main board. The left photo Fig. 7 shows the assembled circuit and the switch boards.

The circuit can be installed in the lid of a 1″ × 1″ × 2″ plastic box available from gift and craft shops. Using the switch board as a pattern,

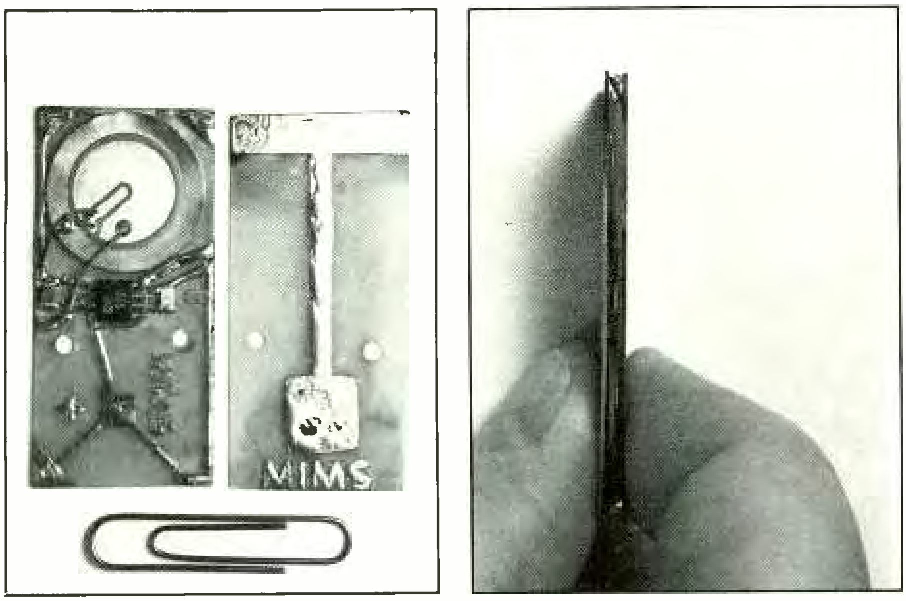


Fig. 7. The completed circuit boards for the light probe circuit (left) and the 0.1"-thin "sandwich" the two make (right).

drill ¼" and 0.1" holes in the plastic lid. Place the assembled circuit board, component side up, in the lid. Then place a small piece of foam plastic on the center of the piezo disk and a CR2016 lithium coil cell, positive side down, over the battery space on the board. Finally, place the switch board, copper side down, over the circuit and secure it with 2-56 screws and nuts.

Gently squeeze the piezo disk end of the switch board to switch on the probe. This will bridge the gap between the negative battery terminal and the two solder bumps.

You may have to experiment with the light probe to obtain best results. If the circuit fails to switch on when squeezed, the foam plastic may be too thick, the solder bumps may not extend high enough above the board, or the light level may be too high. The phototransistor is so sensitive it may be necessary to restrict the light striking it with tape or a daub of paint. Sound volume can be increased by stacking two CR2016 coin cells, but this will increase the thickness of the circuit.

Though the encased circuit is 0.25" thick, the photo at the right in Fig. 7 shows that the two circuit boards sandwiched together form an assembly only 0.1" thin.

Going Further

The circuits presented here provide convincing proof that experimenters, technicians, and engineers can readily assemble subminiature circuits that rival in size considerably more expensive hybrid microcircuits. Consequently, building tiny circuits is now in the grasp of individuals. Though SMCs are more difficult to acquire than conventional components, they will become much more readily available in coming years.

In conclusion, I invite you to join the surface-mount era now by using SMCs to assemble one or more working circuits. In the meantime, stay tuned to my future "Electronics Notebook" columns for more surface-mount ideas and projects.

This article was substituted for the author's "Electronics Notebook" column, which will return next month.—Ed. **ME**

SMT Materials Suppliers

Bishop Graphics, Inc.
5388 Sterling Center Dr.
Westlake Village, CA 91359

Bourns, Inc.
1200 Columbia Ave.
Riverside, CA 92507

Datak Corp.
3117 Patterson Plank Rd.
North Bergen, NJ 07047

Edmund Scientific Co.
101 E. Gloucester Pike
Barrington, NJ 08007

International Instrumentation
Box 3751
Thousand Oaks, CA 91361

Mouser Electronics
2401 Hwy. 287 North
Mansfield, TX 76065

MuRata Erie North America, Inc.
645 W. 11 St.
Erie, PA 16512

Newark Electronics
4801 N. Ravenswood St.
Chicago, IL 60640
(Plus major cities)

Radio Shack
One Tandy Center
Ft. Worth, TX 76102
(Plus local retail stores)

SMD Technology Development Center
5855 N. Glen Park Rd.
Milwaukee, WI 53209

Stettner Electronics, Inc.
P.O. Box 21947
Chattanooga, TN 37421

Vector Electronic Co.
12460 Gladstone Ave.
Sylmar, CA 91342

Note: Since we published our report on the Vector Electronic Model SMT2000 Surface-Mount Technology Training Kit last month, the company has announced an almost 20-percent decrease in price for the kit, from the originally reported $348 to $279.95.