

# Surface Mount Technology— You *Can* Work with It!

Part 1—Start building your projects with surface-mount devices! I'll show you how!

**As** I look through the various electronic manufacturing companies' product datasheets, three things strike me. First, the large number of available ICs that perform functions formerly requiring several ICs. Second, the continuing shift to lower-power requirements, smaller size and usability at higher operating frequencies. Finally, the increasing number of new products are available *only* in surface-mount packages. It all fits together: Products today are smaller and more energy efficient. Look at modern H-Ts, cell phones, GPS equipment, laptop computers, microwave ovens, intelligent electronic ovens, TV remote controls and pocket calculators: One thing they have in common is their use of surface-mount (SM) ICs.

On the other hand, when I look at Amateur Radio projects, I see continued use of many discrete components and bulky DIP ICs that perform limited functions. Recently, I saw a voltage-controller project based on the use of transistors and relays! Frankly, it bothers me that there seems to be a growing divergence between the technology used by industry and that used by hams. The *Maxim Engineering Journal Vol. 29*, for instance, showcases such new ICs as an image-reject RF transceiver, a low-phase-noise RF oscillator that replaces VCO modules, a 3 V, 1 W, 900 MHz RF power transistor, a direct-conversion down-converter IC that replaces an IF mixer, an IF LO and SAW filter, and a low-voltage IF transceiver that includes the FM limiter and RSSI. All these multifunction ICs are available *only* in SM packages! I think hams are being left behind because they feel that SMT (surface-mount technology) is something they can't handle.

Since I built my first SM project two years ago, I have assembled a dozen others. I find that my skill levels have increased tremendously with practice, and I now routinely tackle projects I never thought possible just a year ago. Based on my experience, I know that amateurs *can* work with SMT. Perhaps



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when we show this ability, there will be more truly state-of-the-art projects in the amateur publications. How about a very small 2 meter rig, or a 900 MHz personal communicator? The ICs already exist and we need to adapt them to ham use. First however, it is necessary to develop a few basic building skills. This article series will help you develop those

skills by showing what I have learned and presenting several useful and easy-to-build projects. Once you have built these, you will be able to handle most of the SM ICs I have seen used in the industry.

## Nothing New

The concept of surface mounting parts is not new to Amateur Radio. In a September 1979 *QST* article,<sup>1</sup> Doug DeMaw, W1FB (SK), discusses a quick and easy circuit-board design that was basically SMT; Doug also proposed a universal PC-board layout for this kind of construction. You may think that there will *always* be DIP versions of all the SM ICs so engineers can experiment, but even today, many manufacturers are making evaluation boards available to designers so they can test the part using SM devices! I suspect it's cheaper for them to sell evaluation boards than to set up a production line to make a very limited number of DIP ICs when their real volume is in SM devices.

Some of the advantages of building with SM devices include:

- Smaller projects: I built a time-out switch that fits on a PC board one-sixth the size of a postage stamp! I was able to put the circuit into the battery compartment of a voltmeter I had so it could automatically power itself down.<sup>2</sup>
- Many SM versions of devices outperform the original DIP versions. Lower operating voltages and quiescent currents in the microampere range offer more efficient operation.
- Most RF projects require the use of short signal leads. SM capacitors are often recommended for use as bypass capacitors because they can be placed close to an IC and exhibit very low lead inductance. Nearly all VHF projects benefit from the use of SM devices.
- Once you've had some experience in working with SM devices, you'll feel more con-

<sup>1</sup>Notes appear on page 38.

fidient about repairing your own gear.

- Making a PC board for SM devices is easier than for through-hole parts because no component-mounting holes need to be drilled.
- Many new SMICs have entire modules built into them making it much easier to build a complex circuit than with older ICs.<sup>3</sup>

### Equipment Needed

Many people think you need lots of expensive equipment to work with SM devices.<sup>4</sup> Not so! You don't need an eagle's eyesight, either! My optometrist describes my eyesight as "moderately near-sighted, needing bifocals (2<sup>1</sup>/<sub>2</sub> diopters)." My wife thinks I am as blind as a bat.

- A fundamental piece of equipment for SM work is an illuminated magnifying glass. I use an inexpensive one with a 5-inch-diameter lens (see the accompanying trio of tools photographs). I use the magnifier for *all* my soldering work, not just for SM use. Such magnifiers are widely available (see the sidebar "Manufacturers and Distributors of SMT Equipment and Parts") and range in price from about \$25 to several hundred dollars. Most offer a 3× magnification and have a built-in circular light.
- A low-power soldering iron is necessary; one that is temperature-controlled (such as the Weller WCC100) practically eliminates the possibility of overheating a part. Use a soldering iron with a grounded tip as most SM parts are CMOS devices and are subject to possible ESD (static) failure. I have found the Weller 1/16-inch (EJA) screwdriver tip works well. I used to use an ETJ with its finer conical tip, but it does not seem to transfer the heat as well as the screwdriver tip.
- Use of thin (0.020-inch diameter) rosin-core solder is preferred because the parts are so small that regular 0.031-inch diameter solder will flood a solder pad and cause bridging.
- A wet sponge for cleaning the soldering-iron tip.
- A flux pen comes in handy for applying just a little flux at a needed spot. I find that RadioShack's flux is too sticky and it leaves a messy residue. The Circuit Works CW8200 flux pen with a type R flux is much cleaner.
- Good desoldering braid is necessary to remove excess solder if you get too much on a pad. Chem-Wik Lite 0.100-inch wide works well.
- ESD protective devices such as wrist straps may be necessary if you live in a dry area and static is a problem. I live in humid Florida, have never used these and have not had a problem.
- Tweezers help pick up parts and position them. I find that a pair of nonmagnetic, stainless-steel drafting dividers work well as tweezers. They have two very sharp needle-like points that allow me to pick up the smallest parts; and the parts seem less likely to slip from grasp perhaps because I use less force to hold them. The sharp points are useful tools for marking the

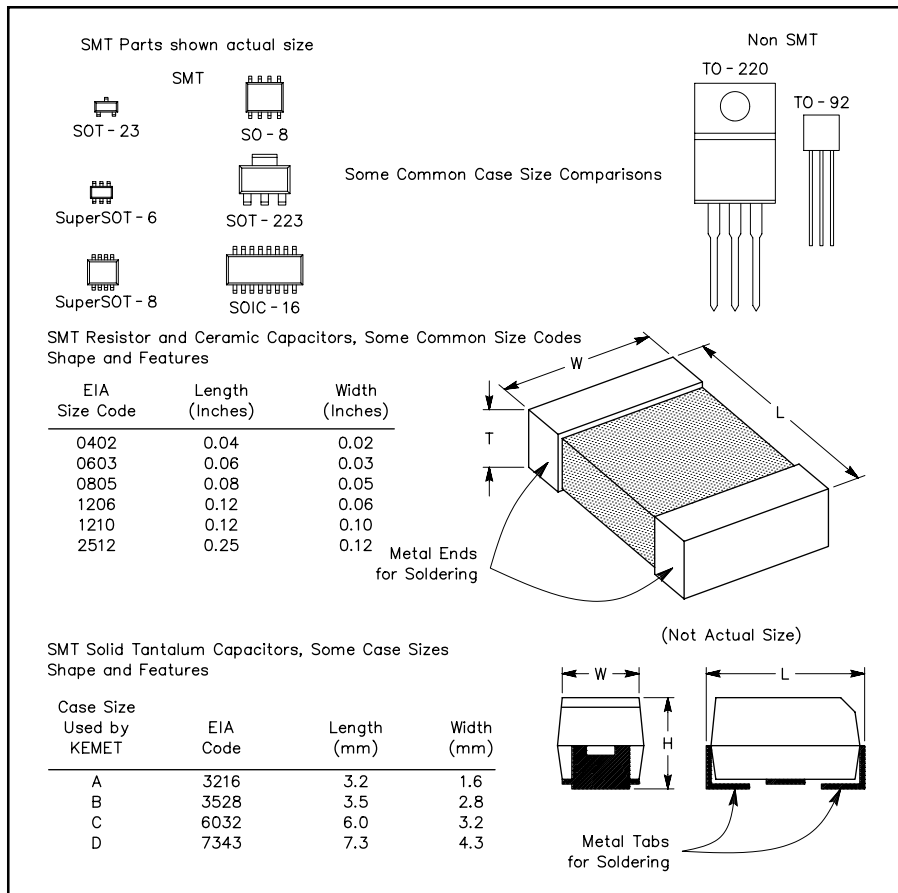


Figure 1—Size comparisons of some surface-mount devices and their dimensions.

PC-board copper foil before cutting out traces (more on this later). The nonmagnetic property of stainless steel means the chip doesn't get attracted to the dividers.

- If you want to make your own SM PC boards, I recommend using a Dremel Mototool (or something similar) and some ultra-fine cutting wheels.

### Parts

Figure 1 shows some common SM parts. Resistors and ceramic capacitors come in many different sizes, and it is important to know the part size for two reasons: Working with SM devices by hand is easier if you use the larger parts; and it is important that the PC-board pad size is larger than the part. Tantalum capacitors are one of the larger SM parts. Their case code, which is usually a letter, often varies from manufacturer to manufacturer because of different thicknesses. As you can see from Figure 1, the EIA code for ceramic capacitors and resistors is a measurement of the length and width in inches, but for tantalum parts, those measurements are in millimeters times 10! Keep in mind that tantalum capacitors are *polarized*; the case usually has a mark or stripe to indicate the positive end. Nearly any part that is used in through-hole technology is available in a SM package.<sup>5,6</sup>

### SMT Soldering Basics

Use a little solder to pre-tin the PC board.

The trick is to add just enough solder so that when you reheat it, it flows to the IC, but not so much that you wind up with a solder bridge. Putting a little flux on the board and the IC legs makes for better solder flow, providing a smooth layer. You can tell if you have the proper soldering-iron tip temperature if the solder melts within 1.5 and 3.5 seconds.<sup>7</sup> I use my dividers (or my fingers) to push and prod the chip into position. Because the IC is so small and light, it tends to stick to the soldering iron and pull away from the PC board. To prevent this, use the dividers to

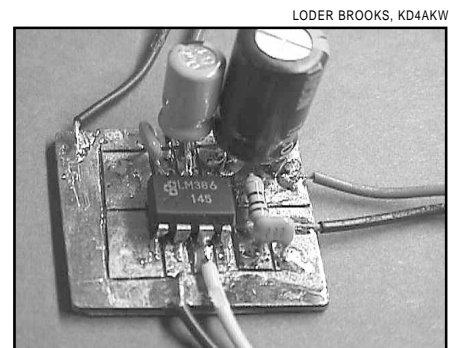


Figure 2—An LM386 audio amplifier built on a homemade PC board. The board's isolated pads are made by using a hobby tool to grind separating lines through the copper foil.

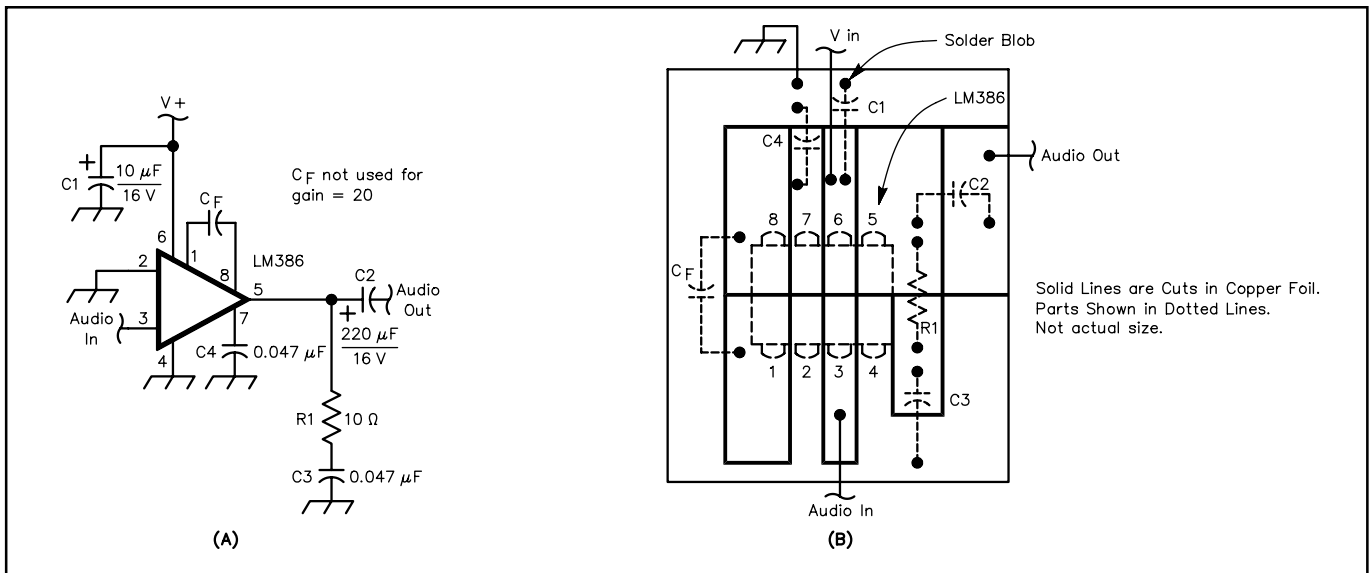


Figure 3—At A, the schematic of the LM386 audio amplifier. The component layout and PC board are shown at B. The solid, heavy lines indicate cuts made in the copper foil. This drawing is not to scale. The board is 1 inch long by  $\frac{3}{4}$  inch wide. No SM parts are used in this project, but my board-making method is shown. It allows one to get a feel for the process before tackling the smaller SM chips.

C1—10 μF, 16 V  
C2—220 μF, 16 V

C3, C4—0.047 μF, 50 V ceramic  
Cf—For overall circuit gains greater than

20, use 10 μF, 16 V  
U1—LM386N (8-pin DIP)

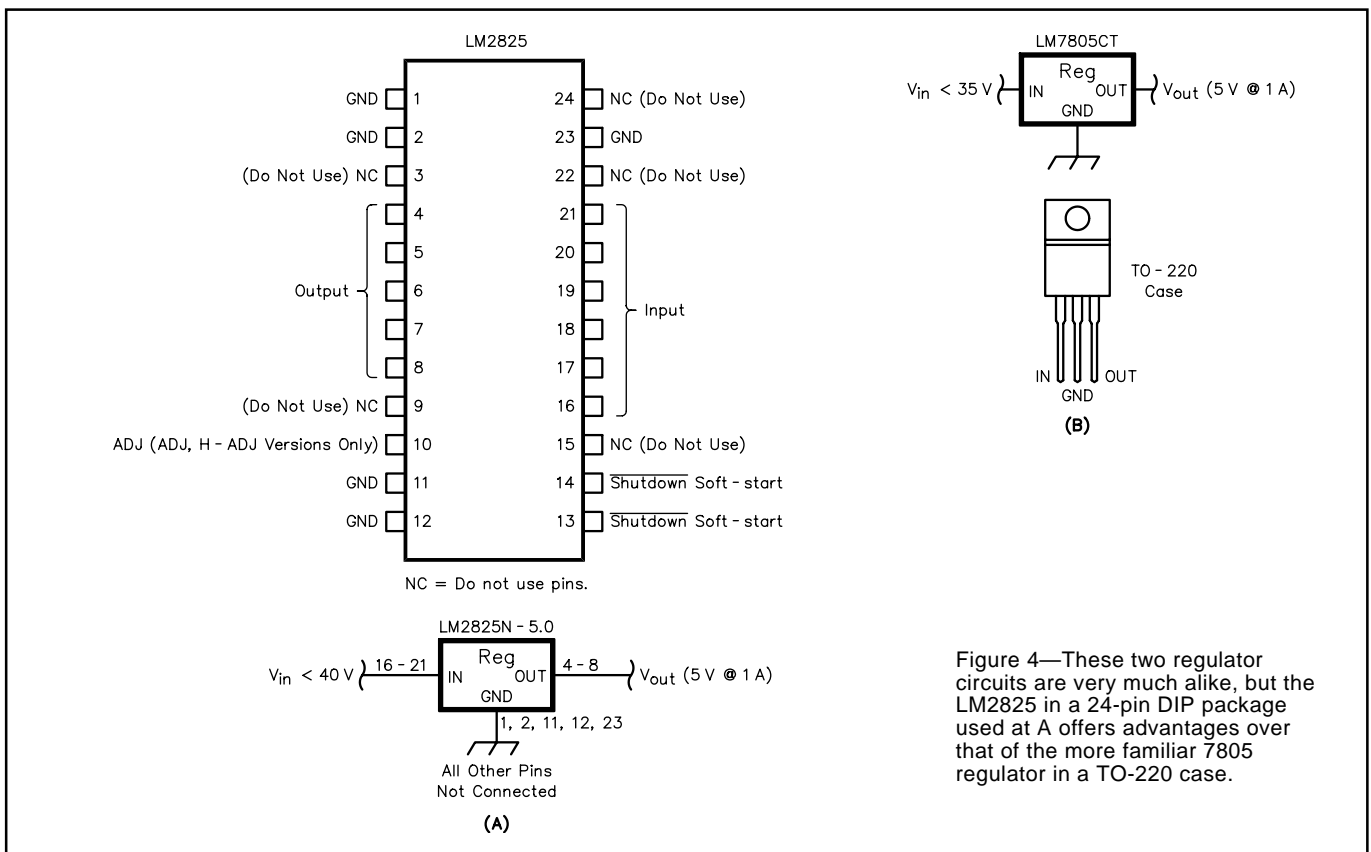


Figure 4—These two regulator circuits are very much alike, but the LM2825 in a 24-pin DIP package used at A offers advantages over that of the more familiar 7805 regulator in a TO-220 case.

hold the chip down while tacking two IC legs at diagonally opposite corners. After each tack, check that the part is still aligned. With a dry and *clean* soldering iron, heat the *PC board* near the leg.<sup>8</sup> If you do it right, you will see the solder flow to the IC.

The legs of the IC must lie flat on the board. The legs bend easily, so don't press

down too hard. Check each connection with a continuity checker placing one tip on the board the other on the IC leg. Check all adjacent pins to ensure there's no bridging. It is easier to correct errors early on, so I recommend performing this check often. If you find that you did not have enough solder on the board for it to flow to the part, add a little

solder. I find it best to put a drop on the trace near the part, then heat the trace and slide the iron and melted solder toward the part. This reduces the chance of creating a bridge. Soldering resistors and capacitors is similar to soldering an IC's leads, except the resistors and capacitors don't have exposed leads. My reflow method works well for these parts, too.

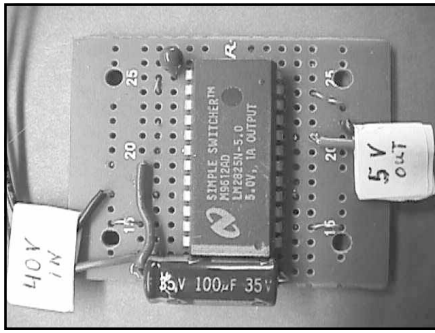


Figure 5—LM2825 circuit is constructed on readily available RadioShack perfboard (RS 276-150 or similar). Photo shows optional input filter capacitor and optional soft-start capacitor. Refer to the datasheet at the National Semiconductor Web page for suggested values for these optional components.

Attaching wires that connect to points of the board can be a bit of a challenge because even #24 stranded wire is large in comparison to the SM parts. First, make sure all the wire strands are close together, then pre-tin the wire. Carefully place the wire on the pretinned pad and heat it with the soldering iron until the solder melts.<sup>9</sup>

### Making a SM PC Board

It is possible to etch SM PC boards just like a conventional board, but I recall Doug (W1FB) DeMaw's comment on etching: "If you don't mind a few brown stains here and there on your garments, etching is one way to make the board." Evidently he, like I, *did* mind, and he proposed a strong-arm method of using a hacksaw to cut square pads in the board foil. Hacksaws are too large and wide for SM use; I use a Dremel Mototool and a thin cutoff wheel. With these, I can cut a line as narrow as 0.005 inch, which lets me build with most of the available SM ICs.

To make such a "PC" board, start by sketching a layout for it. Don't worry about drawing it to scale, but make the sketch large enough to see what is happening. Normally, we think in terms of *connections between parts* because schematics show lines from point to point, representing the interconnecting wires. I find it is more useful to think in terms of the *spaces between the lines* because I am removing copper material to separate traces, not adding material to make traces. Where wires attach to the board, leave a large surface because the wires are relatively large. When making cuts, it is easiest to do it using a large piece of material that you can hold securely. Cut the board to size after you have cut all the traces.

Once I have the layout drawn, I hold the IC to the copper and used a fine-pointed tool (a 0.5 mm pencil or my dividers) to mark the location of the cuts on the PC board. I then remove the IC and use my Dremel tool to cut the copper along the marks. For critical cuts between an IC's closely spaced leads, I make one cut, then reposition the IC on the board and verify that the remaining marks are still

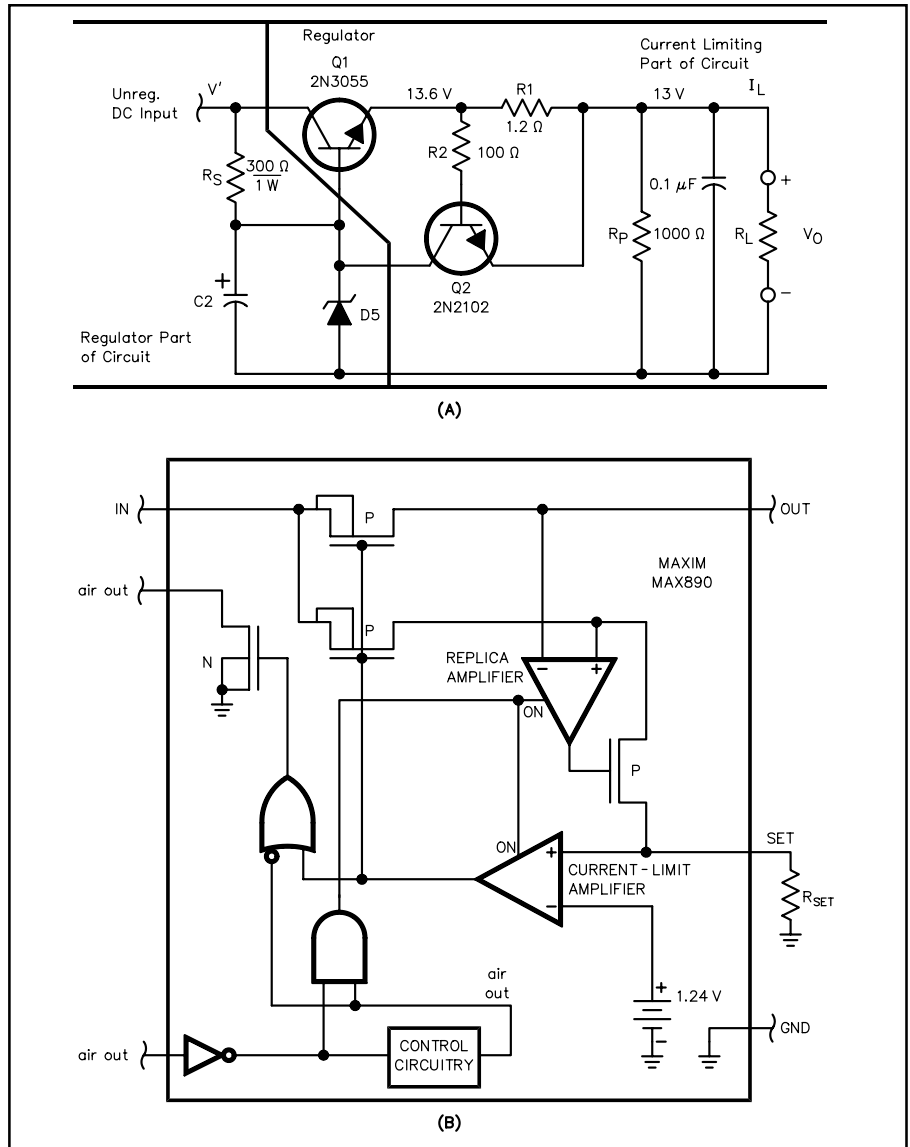


Figure 6—At A, a current-limiting circuit using older technology. Within the confines of the tiny MAX890, (B) newer technology offers a 1-A, P-channel MOSFET switch, a comparator, a voltage reference, a current-measuring circuit, control and fault-indicator circuits!

correctly aligned. I do all this freehand. Using an ultra-thin cutoff wheel, I find it is quite easy to cut in a straight line. At first, I used a fine cutting bit (#108), but that tip made a wider cut and it was difficult to cut a straight line. Dedeco (see the sidebar "[Manufacturers and Distributors of SMT Equipment and Parts](#)"), supplier of tools for jewelers and dentists, makes two ultra-thin wheels—0.009 and 0.005 inch. For the very small ICs—those in SOT23-5 and SuperSOT-8 packages—I use a 0.005-inch wheel, otherwise the 0.009-inch wheel is ideal. Be careful when handling these wheels as they break easily. Also, don't cut too deeply into the board material. At the intersection of the cuts, take care not to cut too far. Sometimes I cut close to an intersection, then use a razor blade to finish the job. A quick sanding deburrs the cuts. Run through the cuts with a small screwdriver or pen knife to ensure they are cleanly cut and without burrs.

Finally, use your ohmmeter to verify that the islands/pads aren't connected.<sup>10</sup>

I recommend you make your own PC boards: They're easier to produce than through-hole boards, and you'll then be able to experiment with *your own* projects rather than waiting for others' projects to come along. You can use this method with SM or non-SM projects.

### The Projects

All the projects I'll present are easy-to-build beginner projects, yet each offers significant advantages over similar projects based on the old (DIP) technology. As you build each project, you'll develop SM skills and wind up with some useful gadgets. I have tried to arrange the projects by degree of skill required. For those who want to make their own PC boards, I describe my layout. Ready-made PC boards are available for all of these projects except the first, Project 0A.<sup>11</sup>



## Project 0A—Getting a Feel for SM Techniques

This audio amplifier is a good starter project for those who want to learn to work with SM devices because the technique is the same, but the parts are physically larger because no SM parts are used. I made the layout, cut the board and assembled this project in a little over an hour. Try doing that with etching and through-hole construction! I think you'll agree that the finished product looks as good as if it were assembled on a commercially made PC board (see Figure 2).

This project is shown in *The 1996 ARRL Handbook* (and subsequent editions) on page 25.8 using "dead-bug" construction.<sup>12</sup> All the parts are mounted on a groundplane with no component-mounting holes. It is easy to duplicate this project using SM techniques. Figures 3A and B show the schematic and board layout, respectively. I bent and trimmed the pins on the LM386 so that they look like a large SO-8 package. You can make the cuts with a 0.015-inch wheel. When cutting the ends of the traces to pins 1 and 3, be careful that you don't cut too far and run through the cut from pin 2.

An LM386 is *not* state of the art. If you want to see the difference between it and a state-of-the-art amplifier, build the SMALL.<sup>13</sup> It uses an LM4861, which is available only in an SO-8 package. In addition to its smaller size, the SMALL has more power output, far better fidelity and the ability to work with low-voltage power sources.

## Project 0B—The World's Easiest Surface-Mount Project

You may be curious about comparing SMT with conventional technology, but not want to solder those small ICs. If so, this

project is for you. It is based on the LM2825, a large DIP 5 V regulator used in the circuit shown in Figure 4A. Next, build a conventional 5 V regulator using an LM7805 in a TO-220 case, Figure 4B. Both can be built on a RadioShack universal PC board; the LM2825 project is shown in the photograph (Figure 5). Although the circuits look nearly identical, if you use a 12-V source to power both of them and put a load of 0.5A or more on each, you'll see that the LM7805 gets *very hot*, while the LM2825 stays cool. That's because the LM2825 is a sophisticated *switching regulator* with all of the tiny SM parts packed in a DIP case.

### Out with the Old...

The (*1996 ARRL Handbook*) current-limiting circuit of Figure 6A uses a resistor (R1) and series pass transistor (Q1) in series with the load. R1 detects the current flow and Q1 limits it when necessary. This design has a voltage drop from input to output of 600 to 1200 millivolts depending on the load (before any overload). Its voltage regulation is poor and its efficiency is low.

### ...In with the New

By contrast, Maxim's MAX890 (Figure 6B) operates with voltage levels from 2.7 to 5.5 V (6 V maximum) with a current drain of only 15  $\mu$ A. On this tiny chip are a 1-A, P-channel MOSFET switch, a comparator, a voltage reference, a current-measuring circuit and control and fault-indicator circuits! The maximum voltage drop across the switch is only 90 mV unless an overcurrent condition exists. Instead of using a series resistor to monitor current, the MAX890 uses a current replica circuit that controls the MOSFET limiting switch. For a short circuit—or for a

large initial surge current—the circuit shuts off the switch in just five microseconds, then slowly turns it on while limiting the current to 1.5 times the maximum current. For prolonged overcurrent situations, there is a large amount of power dissipated in the MOSFET. To combat this, the chip has a thermal shutdown circuit that cycles the switch on and off, if necessary, to keep the temperature within a safe range.

## Project 1—The SmartSwitch

This project is based on Maxim's MAX890, available in a common and fairly large SO-8 SM package that is relatively easy to work with. The switch is smart because it limits the current it passes to an amount you *preset*. This device not only protects your expensive electronic projects against a short circuit, but extends their life by limiting in-rush current, a major cause of component

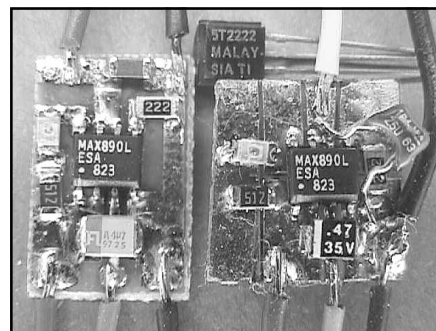


Figure 7—Here are two versions of the SmartSwitch compared in size to a TO-92 package transistor. The board on the right is homemade; the one to the left is available from N4UUA; see Note 11.

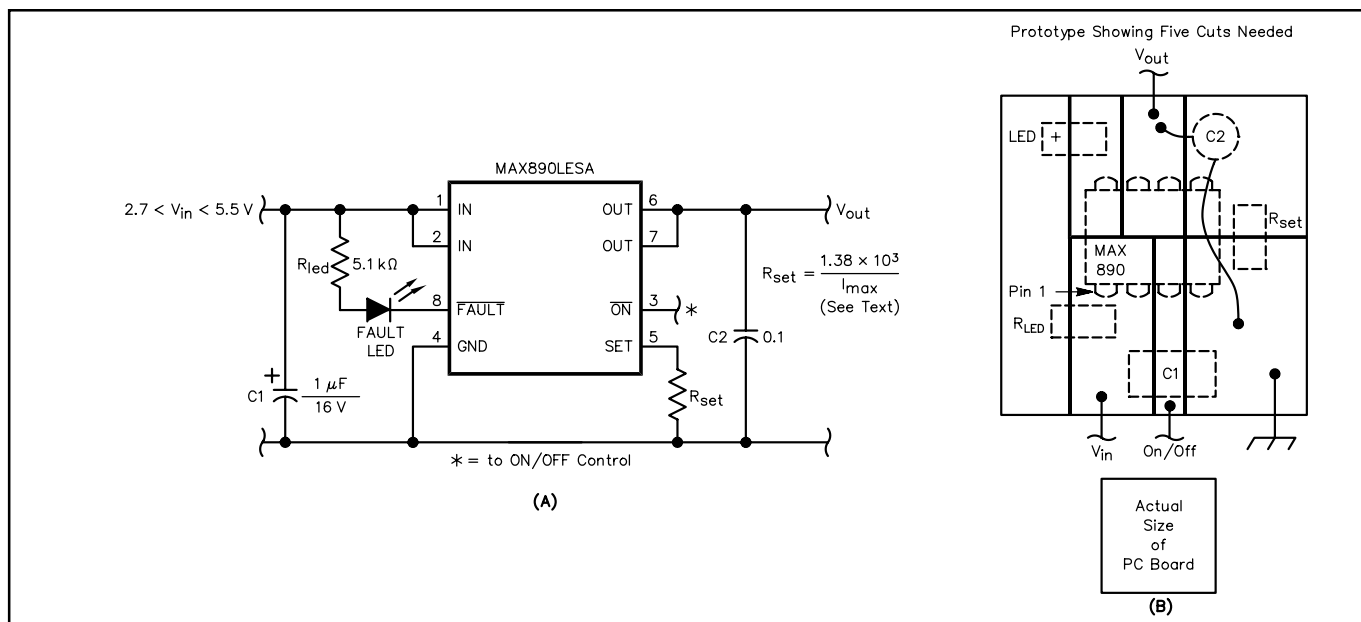


Figure 8— The SmartSwitch circuit (A) and board layout (B).

U1—MAX890LESA  
Rset—See Eq 1 in text.  
Rled—5.1 k $\Omega$

C1—1  $\mu$ F tantalum capacitor, 10 V or greater

C2—0.1  $\mu$ F ceramic

failure. The IC has an output that can be set to trigger a fault indicator, such as an LED or bell. The **ON/OFF** pin exhibits a high impedance and can be controlled by a computer or low-output sensor such as a photoelectric cell. Building the SmartSwitch is straightforward and relatively easy. [Figure 7](#) shows

how physically small the switch is.

[Figure 8A](#) is the SmartSwitch schematic; the board layout is shown in [Figure 8B](#). Circuit operation is simple: Power connections are made at pins 1 and 2, the high side of the switch and switched power are available at pins 6 and 7, respectively. **Rset** sets the trip current:

$$I_{limit} = 1.38 \times 10^3 / R_{set} \quad (\text{Eq 1})$$

where  $I_{limit}$  is the trip current in amperes, and **Rset** is the controlling resistance value in ohms.

I used a 2.2 kΩ resistor at **Rset** to establish a current limit of 625 mA. (Current-trip levels can be set to values between 200 mA and 1 A.) C1, the input capacitor, prevents input-voltage drop with current surges; in many cases, C1 can probably be eliminated. Output capacitor C2 protects the circuit against inductive spikes. When a current or thermal overload trips the switch, **FAULT** pin 8 goes low. I put a SM LED on the board to indicate when a fault occurs. Pin 8 is not intended to sink a lot of current, so I used a 5.1 kΩ resistor to limit the LED current to about 1 mA. You could use a 100 kΩ pull-up resistor instead and an external high-impedance indicator.

### Construction Comments

To make this project's PC board, I used a Dremel tool and a 0.009-inch disc. For my prototype, I found it easiest to use a monolithic (non-SM) capacitor for C2, mounting it across the top of the IC. (There is no rule that prohibits you from mixing technologies, and this made construction easier.) Notice how large the capacitors are compared to the IC. As is true with most SM projects, circuit layout is important: Short leads offer low inductance to promote fast switching in the event of a current overload. In case of a short circuit, the board's ground plane helps dissipate heat.

### Tune In Again...

Next month, we will look at two chips that turn a positive voltage into a negative voltage and are only available in SM cases. One of these is in the large SO-8 case (as in Project 1); the other is in a smaller SOT-23 case. I hope you build Projects 0A and 1 because the skills you develop working with them will be useful in completing the projects to come.

### Notes

- <sup>1</sup> Doug DeMaw, W1FB, "Quick-and-Easy Circuit Boards for the Beginner," *QST*, Sep 1979 pp 30-32.
- <sup>2</sup> Sam Ulbing, N4UUAU, "Mega-Mini Micropower Timeout Switch," *73 Amateur Radio Today*, Jul 1998, pp 42-48.
- <sup>3</sup> I was intrigued to come across an engineer's comment in an industry magazine: "RF circuits are readily available as easy to use building blocks, so you needn't fully understand their operation to employ them in an application." Perhaps he had Amateur Radio builders in mind!
- <sup>4</sup> Flex-mounted illuminated magnifying lenses are available at office-supply stores and electronic-component suppliers such as Office Depot, Office Max, Digi-Key, Newark, etc. Dremel tools are available from discount stores, Home Depot and Lowe's. Thin 0.020-inch diameter solder can be found at RadioShack (#64-013). Digi-Key, Contact East and Newark sell rosin flux pens.
- <sup>5</sup> I have found the best way to locate state-of-the-art parts is via the Internet. Virtually every manufacturer has their component datasheets, applications notes and other information posted. It's a design engineer's dream! No longer do you need lots of databooks. Distributors, too, have catalogs

### Manufacturers and Distributors of SMT Equipment and Parts

AAVID (manufacturer)—143 North Main St, Suite 206, Concord, NH 03301; tel 603-224-9988; fax 603-223-1738; <http://www.aavid.com>; heat sinks, information about them.

AVX (manufacturer)—<http://www.avxcorp.com/products/capacitors/smtc.htm>; low-ESR capacitors

Bourns (manufacturer)—<http://www.bourns.com/>; resistors and potentiometers.

Chemtronics (manufacturer)—8125 Cobb Ctr Dr, Kennesaw, GA 30152-4386; tel 800-645-5244, 770-424-4888; <http://www.chemtronics.com>; soldering paste, solder, solder wick.

Contact East (distributor)—tel 800-225-5370, 888-925-2960, fax 800-743-8141; <http://www.contacteast.com>; flux pens, soldering equipment, illuminated magnifying glasses.

Dedeco International (manufacturer)—Long Eddy, NY 12760; tel 800-964-6616; <http://www.dedeco.com>. Manufactures the cutoff wheels I use. My 0.005-inch wheel is #5190, the 0.009-inch wheel is #5187. I found an assortment of Dedeco wheels at Home Depot, but they did not include the 0.005-inch wheel.

Digi-Key (distributor)—701 Brooks Ave S, PO Box 677, Thief River Falls, MN 56701-0677; tel 800-344-4539, 218-681-6674, fax 218-681-3380; <http://www.digikey.com>. Carries a wide selection of National, Maxim and International Rectifier ICs, many SMT parts, lithium batteries, holders and soldering equipment. They have good links to manufacturers' Web pages. Digi-Key has a \$5 handling charge on orders less than \$25.

FAR Circuits (manufacturer)—18N640 Field Ct, Dundee, IL 60118; tel 847-836-9148 voice/fax; <http://www.cl.ais.net/farcir>; custom PC boards.

Gerber (distributor)—Gerber Electronics, 128 Carnegie Row, Norwood, MA 02062; tel 800-225-8290, 781-769-6000, fax 781-762-8931; <http://www.gerberelect.com>. National Semiconductor products, most of the new ICs; \$25 minimum order.

Hosfelt Electronics Inc (distributor)—2700 Sunset Blvd, Steubenville, OH 43952; tel 800-524-6464, 888-264-6464, 740-264-6464, fax 800-524-5414; (no e-mail address, no Web site); tilt switches and some SMT parts, 3 V lithium batteries and battery holders.

International Rectifier (manufacturer)—233 Kansas St, El Segundo, CA 90245; tel 310-726-8000, fax 310-322-3332; <http://www.irf.com>; IRF7201, IRLML2402, IRFZ46 and other MOSFETs, diodes, etc.

Kemet (manufacturer)—PO Box 5928, Greenville, SC 29606; <http://www.kemet.com>; capacitors; lots of technical information at this site.

Keystone Electronic Corp—(manufacturer), 31-07 20th Rd, Astoria, NY 11105; tel 718-956-8900; <http://www.keyelco.com>. Manufactures a complete line of battery holders, components and hardware.

Maxim (manufacturer)—120 San Gabriel Dr, Sunnyvale, CA 94086; tel 800-998-8800, 408-737-7600; <http://www.maxim-ic.com>; MAX871, MAX890 and other ICs.

Micrel (manufacturer)—1849 Fortune Dr, San Jose, CA 95131; tel 408-944-0800; <http://www.micrel.com>; MIC1555 and other ICs.

N4UUAU (distributor)—5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; supplies parts kits for most of *QST* projects.

National Semiconductor (manufacturer)—2900 Semiconductor Dr, PO Box 58090, Santa Clara, CA 95052-8090; tel 408-721-5000, 800-272-9959; <http://www.national.com>; LM2662 and many other ICs.

Newark (distributor)—tel 800-463-9275; call this number to get the phone and fax information of the representative in your area; <http://www.newark.com>. Carries products from many manufacturers including National, Maxim, International Rectifier, Micrel, Motorola, Sprague, Bourns. Many SMT parts, batteries, holders. There is a \$5 handling charge for orders less than \$25.

Motorola (manufacturer)—<http://www.mot-sps.com/sps/General/chips-nav.html> MC14020 and almost every other IC in the world. Motorola has a large Web site. This is where I have found the most useful information. If the site does not have what you want, try the links to other of its sites.

Sprague (manufacturer)—PO Box 231, Sanford, ME 04073; tel 207-490-7257, fax 207-324-7223; <http://www.vishay.com/products/capacitors.html>; low-ESR capacitors.

Star Micronics (manufacturer)—<http://www.starmicronics.com>—information on buzzers.

on-line. If you want to know if a company stocks the Maxim 890 for instance, you need only go to the Maxim home page, check out who their distributors are, then go to those sites and see if they have the part. It's true that some distributors have large minimum quantities for orders, but others don't. If you want more information on the parts in this project, see the sidebar "Manufacturers and Distributors of SMT Equipment and Parts."

<sup>6</sup>You might wonder "How small can they go?" National Semiconductor has recently introduced a device (the LMC6035) in a Micro-SMD package that is one-quarter the size of an SOT-23 package! According to National, the package is only slightly larger than the die itself: "This time we may have reached the packaging limits with the smallest possible footprint." Paul McGoldrick, Senior Technology Editor for *EDTN* said he "...expects to see a lot of licenses being sought in the next months for other manufacturers seeking to take advantage of this huge jump in process 'packaging' and in the lower costs associated with it," *EDTN*, Sep 1998. This is available for viewing at <http://www.EDTN.com/analog/prod194.html>.

<sup>7</sup>Per Kemet Electronics Corp monograph F-2103A, *Repair Touch Up Hand Solder—Can These Be Controlled*, by Jim Bergenthal. This and other free literature can be obtained from Kemet Electronics at their Web site (<http://www.kemet.com>). In the upper-left-hand corner of the page, select **Literature Request** after clicking on **Tantalum Capacitors**, then fill in the information form. Finally, click on **Request Selected Literature**. Or, use the Kemet mailing address given in the sidebar "Manufacturers and Distributors of SMT Equipment and Parts."

<sup>8</sup>See [Note 7](#). Kemet emphasizes that: "UNDER NO CONDITIONS SHOULD THE IRON TOUCH THE PART. This is a major cause of part damage." I have touched parts often while soldering them and they have not sustained damage. Perhaps I have been lucky!

<sup>9</sup>Another approach to SMT soldering was suggested to me by Fred, W3IT0. He uses solder paste and a hot plate. He believes it is the only reliable method for amateur SMT (but he was dealing with equipment that had to meet military standards). I have not tried this approach as it appears to need fairly accurate temperature control and the solder paste is difficult to locate, expensive and must be specially stored in a cool dry environment. I would be interested to hear from others who may have tried this method.

<sup>10</sup>Universal SM prototype boards are also available from FAR Circuits. See Paul Pagel, N1FB, "Breadboards from FAR Circuits," *QST*, Nov 1998, p 74.

<sup>11</sup>If you are interested in learning to make your own boards as described, I have a limited number of parts kits consisting of a 3x6-inch double-sided, copper-clad board, eight cut-off wheels (two 0.005 inch, four 0.009 inch and two 0.025 inch) and the special mandrel recommended for use with the ultra-fine cut-off wheels. This kit allows you to make boards for all the projects in this series and many more. Price \$13. (Florida residents must add sales tax. For orders outside the US, please add \$3 for shipping.)


Project #0B, Gerber Electronics has agreed to sell this chip to readers of this article at a special price of \$12.50 (\$8 less than the normal unit price) and waive their normal \$25 order minimum. Be sure to identify yourself as a *QST* reader to qualify for this price.

Project #1, A limited number of parts kits are available from me for \$6, without a PC board. If you want a premade PC board add \$1.50. (Florida residents must add sales tax. For orders outside the US, add \$1 for shipping.)

Order from Sam Ulbing, N4UAU, 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). Credit cards are not accepted.

<sup>12</sup>I omitted the feedback capacitor between pin 1 and pin 8 to reduce the gain but my layout allows for it to be added if desired.

<sup>13</sup>Sam Ulbing, N4UAU, "SMALL—The Surface Mount Amplifier that is Little and Loud," *QST*, Jun 1996, pp 41-42 and 68.

*Sam Ulbing, N4UAU, studied electronics in the 1960s, but spent his work career in the financial area. Since he retired in 1986, Sam has enjoyed exploring the opportunities offered to the amateur builder by the new ICs. He feels that electronic design for amateurs has become much easier than it used to be. Sam recalls how in the '60s, he spent hours sweating over complex equations to design even simple circuits. Now, although he has forgotten almost all of his math, the circuits he has built with the new electronics do very sophisticated functions and best of all they work! Presently, Sam is playing with three projects, choosing to build all of them using his "surface-mount style" because "It's just more fun to do it that way." You can contact Sam at 5200 NW 43rd St, Suite 702-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). *



# Surface Mount Technology— You Can Work with It!

*Part 2*—Last month, we built a couple of simple projects with surface-mount devices. This month's inverter projects go a bit farther.

## Projects 2A and 2B— Two 5 V Inverters

A low-current, negative 5 V supply is often a handy item to have on the workbench. Many amplifier circuits are simpler to design using positive and negative voltage sources. Perhaps you have an alphanumeric LCD and found it needs a negative voltage on the **CONTRAST** pin to work. A simple way to supply this negative voltage is to use an ICL7660 voltage inverter, which has been around for a long time. (I'll present another voltage-inverter application in Project 4.) Advances in technology have improved on the '7660. Two ICs I know of that offer significant improvements over their precedents, but both are available only in SM cases: The LM2662 by National is in an SO-8 package and Maxim's MAX871 is available only in SOT-23. Certainly it is possible for manufacturers to make these improved IC versions in a DIP, but neither National nor Maxim have chosen to do so. This appears to me as another signal that the industry is moving toward SM-only parts.

### The Technology

Figure 9 shows how these voltage-inverter ICs operate internally. Each consists of four CMOS switches (S1 through S4) sequentially operated by an internal oscillator. During the first time interval, S1 and S3 are closed and S2 and S4 are open; the +5 V input charges C1 with its + terminal being positive and the opposite terminal at ground. At time interval two, S1 and S3 are open and S2 and S4 are closed. There is still 5 V across C1 with the pin 2 side being positive, but pin 4 is no longer at ground potential. The 5 V charge across C1 is transferred to C2—and since C2's positive side is connected to ground—the other side must be 5 V lower than ground, or -5 V. The reason the SM switches can

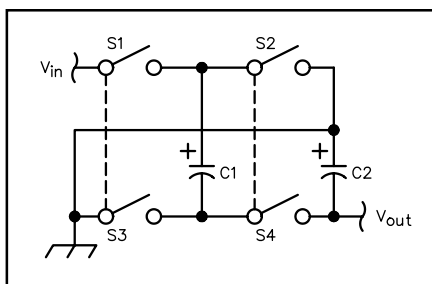


Figure 9—Diagram of the internal workings of the three voltage inverters. See the text for an operational explanation.

handle more current and still be physically smaller is related to their lower resistance and, since both operate at higher frequencies, smaller-value capacitors can be used for a given current output. For best efficiency, low ESR (equivalent series resistance) capacitors should be used. An input bypass capacitor (the value of which depends on the IC and application) improves performance if the power source has a high impedance.

With the trend toward smaller ICs and fewer IC pins, there are often families of nearly identical but specialized ICs. The LM2662 is one of two nearly identical inverters described in the same data sheet. The other, the LM2663, uses pin 1 as a shut-down control instead of a frequency control. This is a common feature with the new technology because of the ever-increasing use of battery power sources, and is especially useful when the inverter is computer controlled. During shut-down, the IC's current drain is reduced to only 10  $\mu$ A. The MAX871, like the LM2662, has a brother described in the same data sheet. The MAX870 is identical to the MAX871n except that it runs at 125 kHz, and although it needs larger capacitors, it draws only 0.7 mA.

Because large-value capacitors increase a circuit's physical size, it's good to know

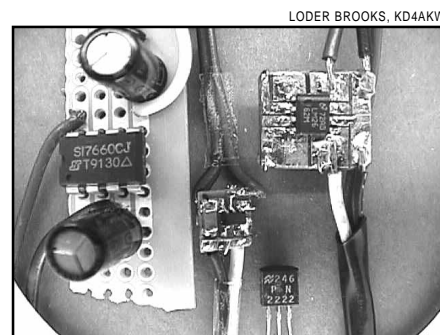


Figure 10—Here, the three voltage-inverter projects are compared in size to a PN2222 transistor.

the minimum capacitance value you can use. This depends on the frequency of operation and the ESR of the capacitor. Nonpolarized capacitor types commonly recommended are Sprague series 593D or 595D, AVX series TPS and the ceramic X7R series. Unfortunately, a capacitor's ESR is often not given in a parts catalog and you may have to consult a data sheet. If you want to try other capacitor values, use the following formulas to calculate output resistance and ripple. Note that C1's resistance is four times as important for reducing resistance as C2, but C1 has no effect on ripple.

$$R_{out} = 2R_{sw} + 1/f \times C1 + 4ESR1 + ESR2 \quad (\text{Eq 2})$$

$$V_{ripple} = I_{load}/f \times C2 + 2I_{load} \times ESR2 \quad (\text{Eq 3})$$

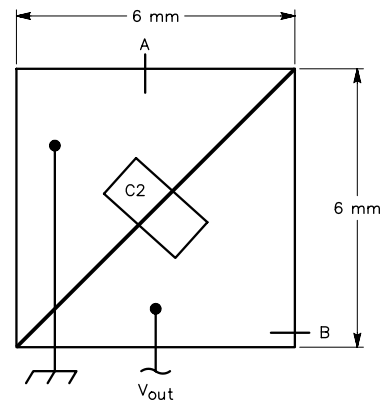
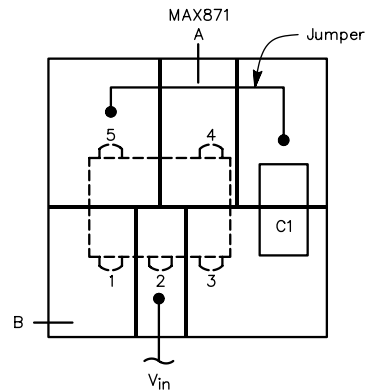
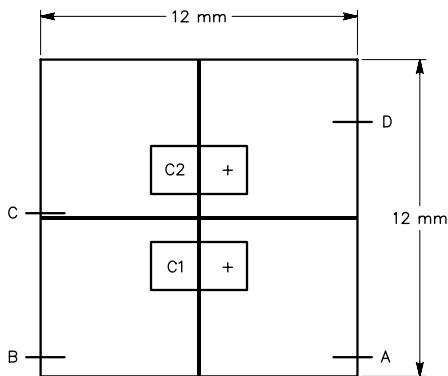
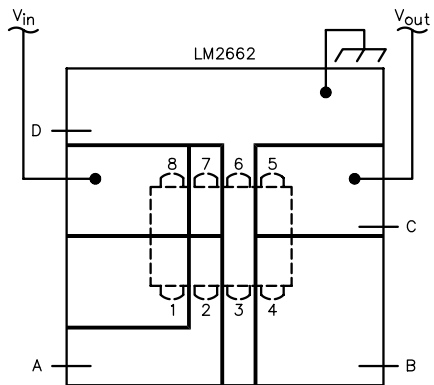
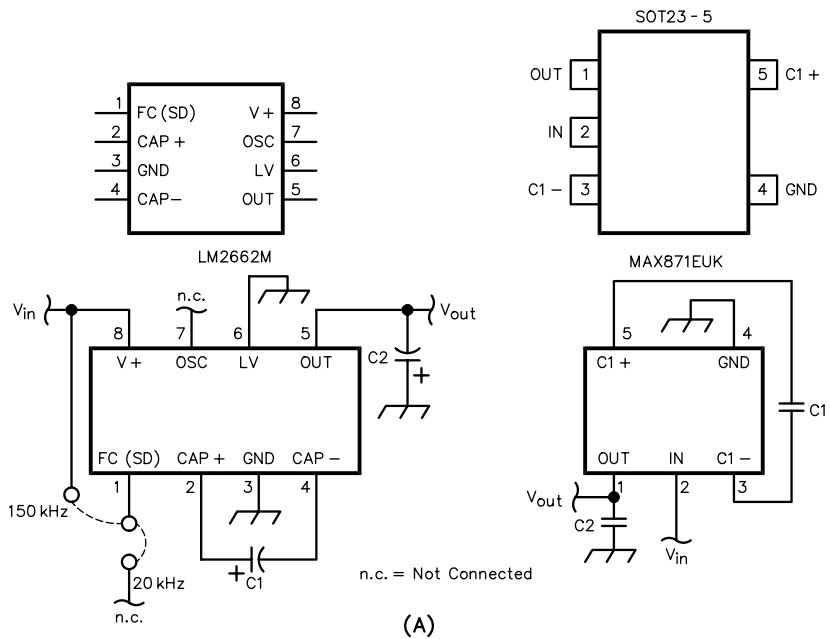
where

- $R_{out}$  = output resistance of the circuit
- $R_{sw}$  = sum of the *on* resistances of the internal switches
- $f$  = frequency of the oscillator driving the inverter
- ESR1 = equivalent series resistance of C1
- ESR2 = equivalent series resistance of C2

<sup>16</sup>Notes appear on page 50.



Figure 11—At A, schematics of the LM2662 and MAX871 inverter circuits. Nonpolarized ceramic capacitors are used in the MAX 871 circuit. See Table 1 for suggested capacitance values. The etchless homemade board layouts (B) show where the copper foil is scored to produce component-mounting islands and how the components are mounted on opposite sides of each board. Wire jumpers made of #26 enameled wire (labeled A, B, C and D) interconnect islands of the top foil to those on the bottom.



$V_{\text{ripple}}$  = peak-to-peak ripple voltage at the output

$I_{\text{load}}$  = load current delivered by the inverter

All three ICs can be used in other modes, such as voltage doublers, connected in cascade to increase output voltage, or connected in parallel to increase output current. For information on circuits to use and more information about design

considerations, refer to the device data sheets.

The SOT-23 is a popular IC size and it is important to develop the skills to work with it if you want to make full use of the new technology. When you build the MAX871 project, set it aside because you may find it useful in Project 4.

Table 1 summarizes some features of the ICs mentioned, and Figure 10 shows

you what the three completed circuits look like. You can see that the LM2662 circuit is somewhat smaller than the '7660, yet it provides 10 times the current output! The MAX871 circuit is extremely small and outperforms the ICL7660.

Figures 11A and 11B show the schematics and board layouts, respectively. The circuits are simple, each requiring but two capacitors and one IC.<sup>17</sup>

**Table 1**

	<b>ICL7660</b>	<b>LM2662</b>	<b>MAX871</b>
Package	DIP, SO-8, Can	SO-8	SOT-23
Circuit Resistance (Ohms)	55	3.5	25
Osc Frequency (kHz)	10	20	500
Recommended Cap ( $\mu\text{F}$ )	10	100	0.2
$V_{\text{out}}^*$ @ $I = 0$	10.0	10.0	10.0
$I = 14 \text{ mA}$	9.41	9.97	9.71
$R = 100\Omega$	6.30	9.66	8.04
$I_{\text{supply}}$ (mA)	0.17	0.30	2.7

\*These figures are based on actual circuit measurements with the load connected between the positive and negative outputs.

### Building the LM2662 Circuit

To save space, I put the IC on one side of a double-sided board, mounting the capacitors on the opposite side. Interconnections between the two board sides are made by short pieces of #26 enameled wire. The wires (labeled A, B, C, D in Figure 11B) bend around the edge of the board. If you have built Project 1, you will have no problem with this one. Be careful to observe capacitor polarity. Even though the LM2662 is smaller than the ICL7660, it offers more features. Pin 1 (which is not used in the ICL7660) controls the LM2662's internal oscillator. The inverter runs at 20 kHz when this pin is left unconnected, and at 150 kHz when connected to  $V_{\text{CC}}$ . If you want the circuit to operate at 150 kHz, add a jumper between pins 1 and 8 of the IC. This allows you to use smaller capacitors, but at the price of a higher supply current.

### Building the MAX871 Circuit

The first time you see this project,

you may think "It's too small to build by hand!" But I've built four different circuits this size and made a PC board for each one—so can you! Because the SOT-23 package is smaller than the SO-8, I used a 0.005-inch wheel to make the island-separating cuts on my PC board. Although the IC's pins are small and closely spaced, the SOT-23-5 board requires only two critical cuts: those between pins 1 and 2 and between pins 2 and 3. The spacing between pins 4 and 5 is as large as that of an SO-8 package. Mounting C2 beneath the board makes component layout much easier.

SOT-23 packaged devices are too small for manufacturers to imprint the part number on them—MAX890EUK just will not fit! Instead of MAX890EUK, Maxim uses the marking **ABZO**. If you get two SOTs mixed up, you will have to consult the data sheets to determine which is which.

### Next Month

In Part 3, we'll look at a low-voltage

battery protection switch that makes use of a few SM ICs: three SO-8s and one SOT-23.


### Notes

<sup>16</sup>Part 1 of this four-part series appears in the April 1999 issue of *QST*, pp 33-39.

<sup>17</sup>Obtaining the parts—Project #2A: Gerber Electronics stocks the LM2662 and Newark Electronics stocks low-ESR tantalum SM capacitors. If you cannot find an LM2662, use the LM2660, Maxim MAX660 or the Linear Technology LTC660; all have similar characteristics and identical pin outs. Digi-Key carries some of these ICs, but does not stock the low ESR SM capacitors. Low-ESR SM capacitors are quite expensive, so you may want to use standard tantalum capacitors instead. These are available from most suppliers. I have a PC board for the layout described; price: \$1.50. Contact Sam Ulbing, N4UAU, 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). Credit cards are *not* accepted.

Project #2B: A limited number of parts kits, with hard-to-find 1  $\mu\text{F}$  ceramic capacitors (to permit maximum current output with minimum ripple) are available from me for \$6 *without* a PC board. If you want a pre-made PC board add, \$1.25. (Florida residents add sales tax.)

If you are interested in making your own boards as described, I have a limited number of parts kits consisting of a 3x6-inch double-sided, copper-clad board, eight cutoff wheels (two 0.005 inch, four 0.009 inch and two 0.025 inch diameter) and the special mandrel recommended for use with the ultra-fine cutoff wheels. Price: \$13. This kit allows you to make the boards for all the projects in this series and more. (Florida residents must add sales tax. For orders outside the US, please add \$3 for shipping.)

You can contact Sam Ulbing, N4UAU, at 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). 

# Surface Mount Technology— You *Can* Work with It!

**Part 3**—This more-complex SM project employs a total of four ICs and seven other parts on a PC board three-quarters of an inch square! Despite its small size, it can control current levels of up to 10 A—without using mechanical relays!

**W**hen Hurricane Georges came through in 1998, my friend, Dave, N0LSK, had left his boat at a marina in the Keys. Although he had the boat tied up well, he forgot that his refrigerator shifts to battery power if the ac-line power is lost. When he returned to the boat after the storm, his boat was okay, but its battery was dead. With the switch about to be described, Dave wouldn't have lost his expensive battery.

## Project 3—A Low-Voltage Battery-Protection Switch

This switch, based on a MAX835 (available only in an SOT-23 case), is a *latching* voltage monitor—ideal for controlling a switch. A recent *QST* project used a MAX8211 (a DIP IC) in an undervoltage circuit,<sup>18,19</sup> but because it doesn't latch, that chip wouldn't work well for controlling a switch. Here's why: Every time the voltage dropped low enough to trip the monitor, it would disconnect the load, and the voltage would rise and turn the monitor back on. Such cycling could injure the equipment.

Figure 12 is a schematic of the switch. When  $V_{CC}$  drops below 12 V, and the voltage at U1 pin 4 goes below 1.2 V. That causes the output voltage on pin 5 to drop from about 5 V to 0 V. Pin 2 of U2, an MIC5014, accepts a logic-level signal and uses it to control an on-board charge pump. Q1 and Q2 are N-channel MOSFETs used as a 10 A high-side switch. (See the sidebar "Selecting a MOSFET for Power Control.") To turn the switch on, the gate must be at least 10 V above the source voltage (5 V for logic-level MOSFETs). That means you need 22 V to turn on the switch. This voltage is supplied by the charge pump in U2. U2 also acts as a buffer for U1, which cannot operate at 12 V. R1 through R4 provide a nominal 5 V power source for U1 and provide the voltage-level input signal to pin 4 of U1. Pull-down resis-

tor R5 prevents unplanned resetting. Although the data sheet doesn't show that R5 is required, the very high impedance of this pin (the current drain is 1 nA) makes a pull-down resistor a wise investment, especially in an RF environment.

Depending on your circuit needs, you

will use a variety of values for R1 to R4. Here's how I selected my values: U1 can operate with voltages of 2.5 to 11 V, so the R1-R4 divider must keep the voltage at pin 3 in this range as  $V_{CC}$  changes. The maximum  $V_{CC}$  I ever expected to encounter was 15 V, and the least, 11 V. U1 draws 2  $\mu$ A,

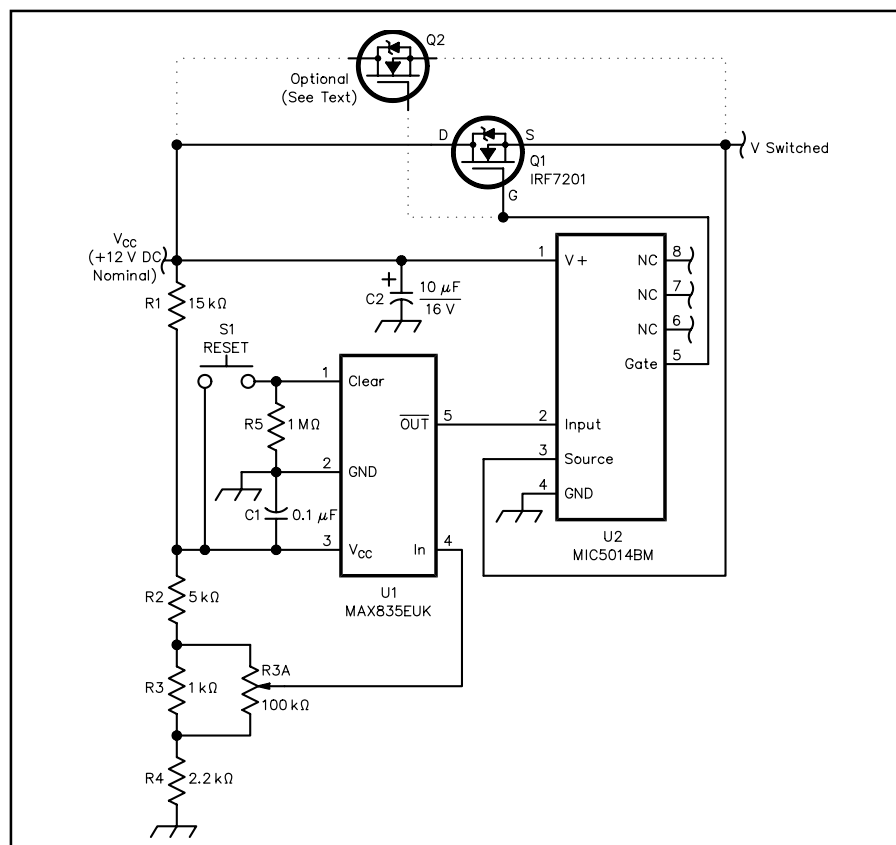


Figure 12—The low-voltage battery-protection circuit schematic. Unless otherwise specified, resistors are 1/8 W chip resistors in a 1206 package. Equivalent parts can be substituted. See Note 21 and notes and sidebar in Part 1 for parts availability.

C2—10  $\mu$ F, 16 V tantalum  
R3A—100 k $\Omega$  pot  
S1—SPST pushbutton

Q1, Q2—IRF7201  
U1—MAX835EUK  
U2—MIC5014BM

<sup>18</sup>Notes appear on page 36.

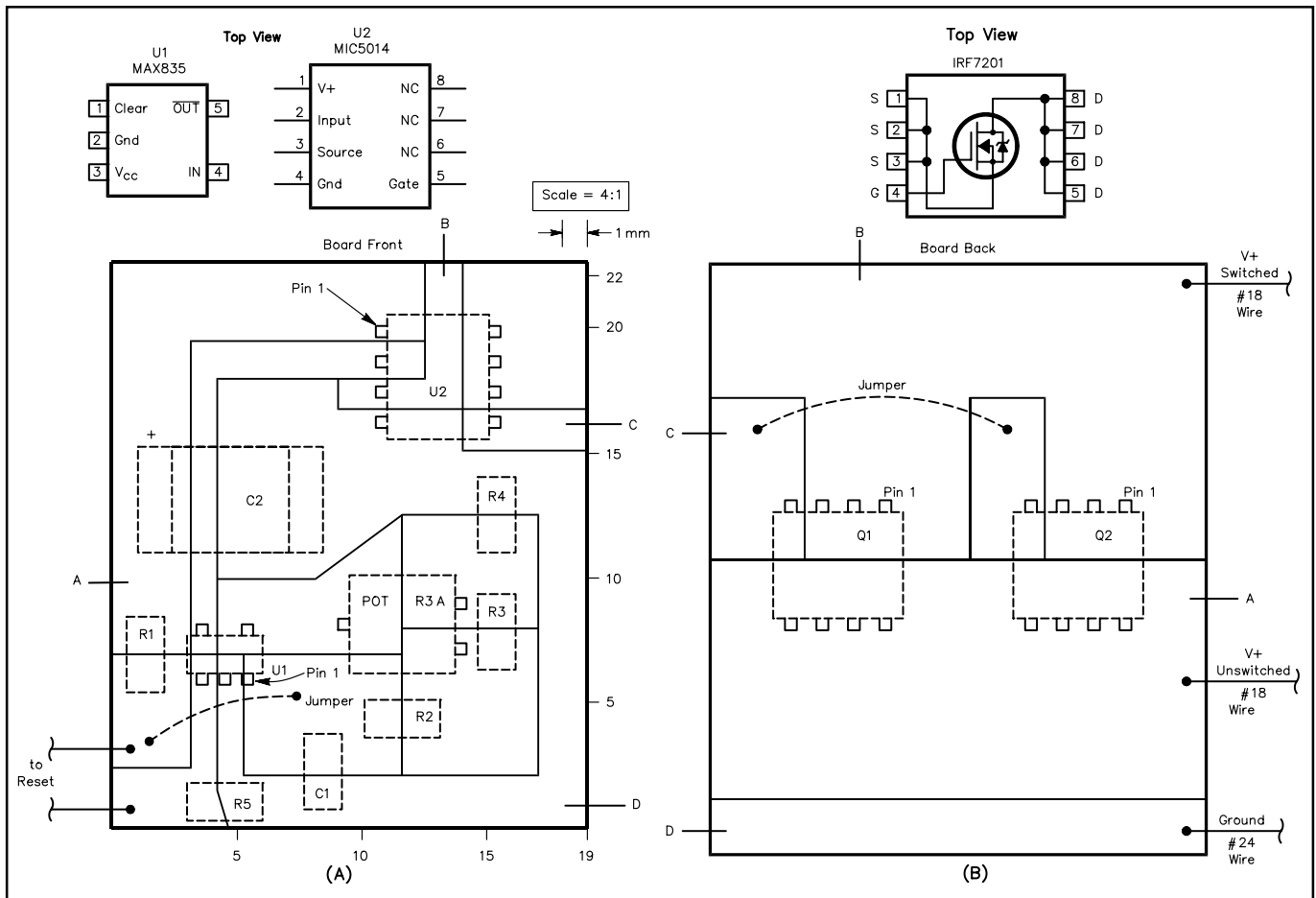


Figure 13—Part placement for the PC-board top (A) and back sides (B), respectively.

so to keep a stiff supply, I wanted the current through the voltage divider to be at least 200  $\mu$ A. This calls for a total resistance of not more than 50 k $\Omega$ . As current drain is not important, I decided to use a total resistance of about 20 k $\Omega$ . Using an Excel spreadsheet, I calculated the values shown. The voltage on pin 3 is 5.3 V for V<sub>CC</sub> of 15 V, and 3.8 V for V<sub>CC</sub> of 11 V. I used four fixed-value resistors and a SM potentiometer (R3B) in parallel with R3 to allow better control when setting the trip level at 12.0 V. You can run U1 at a lower voltage, but keep in mind that U2 needs at least 2 V to trigger it.

This basic circuit can be optimized for other uses. To handle more current, you need only replace the MOSFET with a more-robust one. I use an IRFZ46 and a heat sink with my ICOM IC-735. If you want to control a low-voltage NiCd-powered circuit, you could use U1 alone, connecting it directly to a logic level *low-side* N-channel MOSFET. In that case, increase the resistances of R1 to R4 for minimum current drain.

### The Technology

There is a lot of new technology in this simple circuit. The entire project—including the 10 A MOSFET switch—is on a PC

board smaller than the MAX8211 project. Because the quiescent current of U1 is only 2  $\mu$ A—and it has a wide operating-voltage range (2.7 to 11 V)—it's possible to power it from a resistive divider rather than a 5 V regulator. U2 is a single-chip charge pump that requires no external parts. Like U1, it can operate over a wide voltage range (2.75 to 30 V) and draws only a few microamperes. U2 is designed to let low-level signals control high-voltage and high-current circuits through low resistance *N-channel* MOSFETs used on the *high side*. This arrangement is important for at least two reasons: High-side switches are usually needed with Amateur Radio applications because there is almost always more than one path to ground: the antenna, keyer, computer etc. A low-side switch would force the current to go through one of those connections rather than shutting off the rig. Second, N-channel MOSFETs have much lower resistance than equivalent P-channel MOSFETs (typically, 2.5 times less<sup>30</sup>). This permits the use of smaller MOSFETs for a given current.

MOSFET technology has advanced dramatically. The circuit shown uses two small SO-8 MOSFETs in parallel to control the power to my Kenwood TM-241, which draws a maximum of 11 A on high power.

The two MOSFETs in parallel have an *on* resistance of only 15 m $\Omega$  (milliohms). The voltage drop across the plug connections and fuses is greater than the drop across the MOSFET! Unlike power transistors, no equalization resistors are needed when paralleling MOSFETs. That's because MOSFET *on* resistance increases with temperature, so they tend to be self-equalizing. MOSFETs make better circuit breakers than fuses or relays because they have no moving parts, are resettable, do not arc or bounce, emit less EMI and are much faster than relays or fuses. The latter can be important in an overcurrent situation. Typical MOSFET shut-down time is less than a microsecond (excluding circuit delays). The blow time on a fast-acting fuse is usually longer than 1000  $\mu$ s.

U1 and U2 have families. U1 has a push-pull output; the output is internally held at either 0 or V<sub>CC</sub>. The other version (MAX834) has an open-drain output that requires a pull-up resistor to provide the logic-high output. This is a common family in the SM world. One advantage of the open-drain output is that you can control a circuit with a voltage level different than the V<sub>CC</sub> of the IC itself. U2's brother is the MIC5015, which operates exactly like the



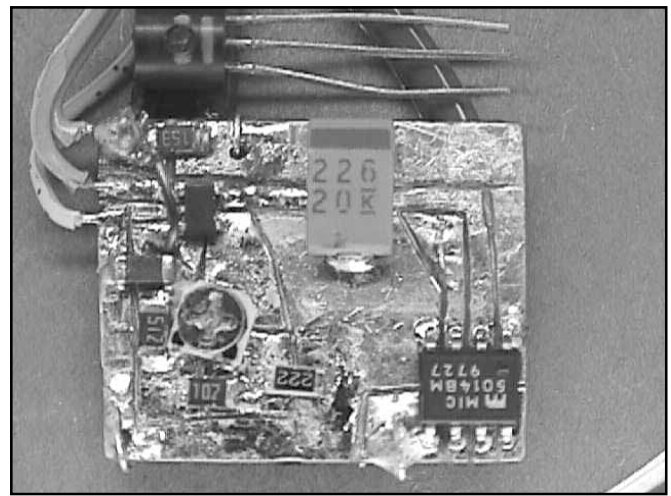
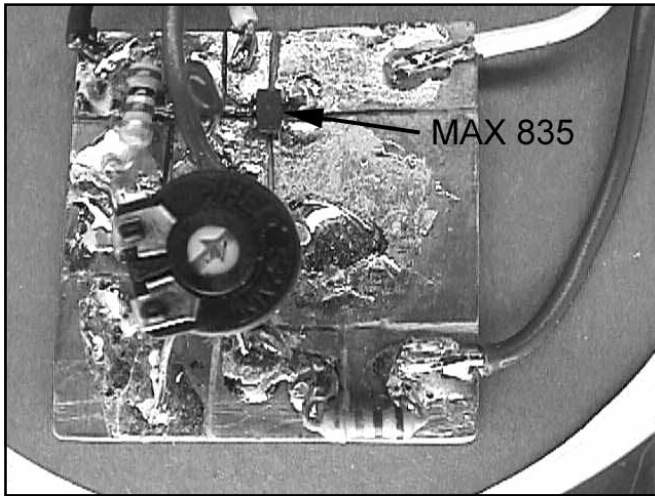


Figure 14—Close-up views of the low-voltage battery-protection switch using a Maxim MAX835 SM IC. At A (left) is a trial board made using the MAX835 and non-SM parts. The MAX835 can be seen above the large pot and to the right of the  $\frac{1}{4}$ -W resistor. At B (right) is the top side of a PC board made using the hobby tool and all SM parts. The MAX835 is above the SM pot and to the left of the tantalum capacitor. The board size can be compared to the TO-92 case transistor above it. The MIC5014 is at the bottom right of the board. The SM MOSFETs are on the bottom side of the board and not shown.

'5014, but 0 V at the input turns it on, and a high level turns it off.

### Making the PC Board

Figures 13A and B show the part placement for the top and back sides of the PC board for this project.<sup>21</sup> Before I made the all-SM version (shown in Figure 14B), I built a quick-and-dirty prototype using two PC boards. Except for the ICs, I used all standard-size leaded parts (one side of one of these boards is shown in Figure 14A), so the only critical cutting area was around the IC; all the rest was old-fashioned pad construction such as used in Project 0A. If you want to use an SM-only IC but don't need small size, this is an easy way to do it. You can also add solid wires as leads from the board and plug the entire circuit into a protoboard to use the subcircuit in a larger through-hole circuit. If you realize that SM projects needn't require *only* SM devices, experimentation becomes easier.

Once more, four jumpers (A, B, C and D) make connections between the top and bottom sides of the board where necessary. Because the board has parts on both sides, soldering is a little trickier than dealing with a board with parts mounted only on one side. Once you solder parts to one side of the board and turn the board over to solder the backside parts, it won't lie flat. Here's where a small vise can help by holding the board steady. I place parts on the more-congested side first. It isn't difficult to use the two SO-8 chips because they are so large; soldering SOT-23 packages would be more of a challenge.

### Tune In Again

Before we wrap up this series next month, we'll look at a project with a large number of small parts mounted on both sides of the board. This project is one you can use as an appeasement gift to your

### Selecting A MOSFET for Power Control

The MIC5014 can drive just about any N-channel MOSFET. Which MOSFET you use depends on your current load. My circuit uses two small SO-8 MOSFETs in parallel. Although the specs show the maximum current for each as 7 A, a check of the  $I^2R$  (power) loss and thermal resistance shows that 4 or 5 A is a more reasonable amount when the chip is mounted on a small PC board. Using two MOSFETs in parallel, the circuit has no problem passing 10 A continuously. When selecting a different MOSFET, *calculate its heat loss* and don't be fooled by the maximum-current figure which—for nonsurface-mounted MOSFETs—is achievable only with a perfect heat sink.

The data sheets give the thermal resistance as temperature rise per watt of heat dissipated in the MOSFET ( $^{\circ}\text{C}/\text{W}$ ). For surface-mount MOSFETs, the data sheet gives a single number: junction-to-ambient thermal resistance. For the IRF7201 used in the project, that is  $50^{\circ}\text{C}/\text{W}$ . At 10 A total, each MOSFET carries 5 A, and the  $I^2R$  loss is  $25 \times 0.030 = 0.75 \text{ W}$ , giving a temperature rise of  $37.5^{\circ}\text{C}$  ( $100^{\circ}\text{F}$ ) above room temperature.

For nonSMT MOSFETs, the junction-to-ambient figure applies *only* if you are *not* using a heat sink. To gain the most from the MOSFET, you need to use a heat sink. In this case, you can determine the thermal resistance by adding the thermal resistances of the junction to case, the case to sink and the sink to ambient, which depends on the heat sink used. (This is just like electrical circuits: Resistances in series are added.) When in doubt, try a heat sink and see if things get hot. If so, use a larger heat sink, or add another MOSFET in parallel to reduce the current through each one.\*—Sam Ulbing, N4UUAU

\*If you want to use a junk-box MOSFET, be sure to check its *on* resistance as it will probably be much higher than those of the MOSFETs I am using. The IRF510, a common MOSFET in a TO-220 package, has an *on* resistance of  $0.54 \Omega$ . Even with a rather large heat sink, the *maximum* current it can pass is about 4 A.

loved ones for spending so much time at the workbench!

### Notes

<sup>18</sup>Parts 1 and 2 of this series appear in the April and May 1999 issues of *QST*, pages 33-39 and 48-50, respectively.


<sup>19</sup>Donald G. Varner, WB3ECH, "A Battery-Voltage Indicator," *QST*, October 1998, pp 50-51.

<sup>20</sup>Micrel Applications Note 5 (Micrel, 1849 Fortune Dr, San Jose, CA 95131; tel 408-944-0800; <http://www.micrel.com>).

<sup>21</sup>If you are interested in learning to make your own boards as described in this series, I have a limited number of parts kits available. Each consists of a  $3 \times 6$ -inch double-sided, copper-clad board, eight cut-off wheels (two 0.005 inch, four 0.009 inch and two 0.025 inch) and the special mandrel recommended

for use with the ultra-fine cut-off wheels. Order from Sam Ulbing, N4UUAU, 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). Price \$13. (Florida residents must add sales tax). For orders outside the US, please add \$3 for shipping.

A limited number of parts kits for Project 3 are available from me for \$12 without a PC board. If you want a premade PC board, add \$1.50. (Florida residents add sales tax). The kit includes only one IRF7201 MOSFET. If you want to parallel more MOSFETs or try an IRFZ46, Digi-Key, Newark and other suppliers carry those parts.

You can contact Sam Ulbing, N4UUAU, at 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). 

## Part 4—This month, we wrap up the series. Before we do, though, here’s that project I mentioned last month...

version of “A Simple 10-Minute ID Timer,” that appears in *The ARRL Handbook*.<sup>23</sup> You can use the Hourglass as an egg timer, or to remind you to move the sprinkler, or put the laundry in the dryer, or as a two-hour timer to remind your teenager it’s time to get off the telephone! You start the timer by *turning it upside down*, just like a sand hourglass! As you’ll see, the operations of the old and new circuits are similar, but not exactly the same.

### The Old-Technology Circuit

The *Handbook* circuit (Figure 15) is specified for use with a 12 V supply, which could limit its portability and application. LM555 timer U1 is set up for a short duty cycle: 1 second *on* and 59 seconds *off*. Pin

3 of the 4017 counter, U2, triggers after 10 cycles, increasing the time delay to 600 seconds. The alarm sounds, the circuit resets and starts counting again. Ten minutes is about the maximum practical time delay of this circuit.

### The New-Technology Circuit

Surface-mount technology allows us to build this month’s project (including its power supply) on a board that fits inside a 35-mm film canister (see Figure 16), so it’s completely portable.<sup>24</sup> The low voltage and current demands of the ICs allow powering the circuit with a 3-V lithium battery.

Refer to Figure 17. An RC controlled timer, U1, is routed to a counter, U2, to extend the time base to 10 minutes. When

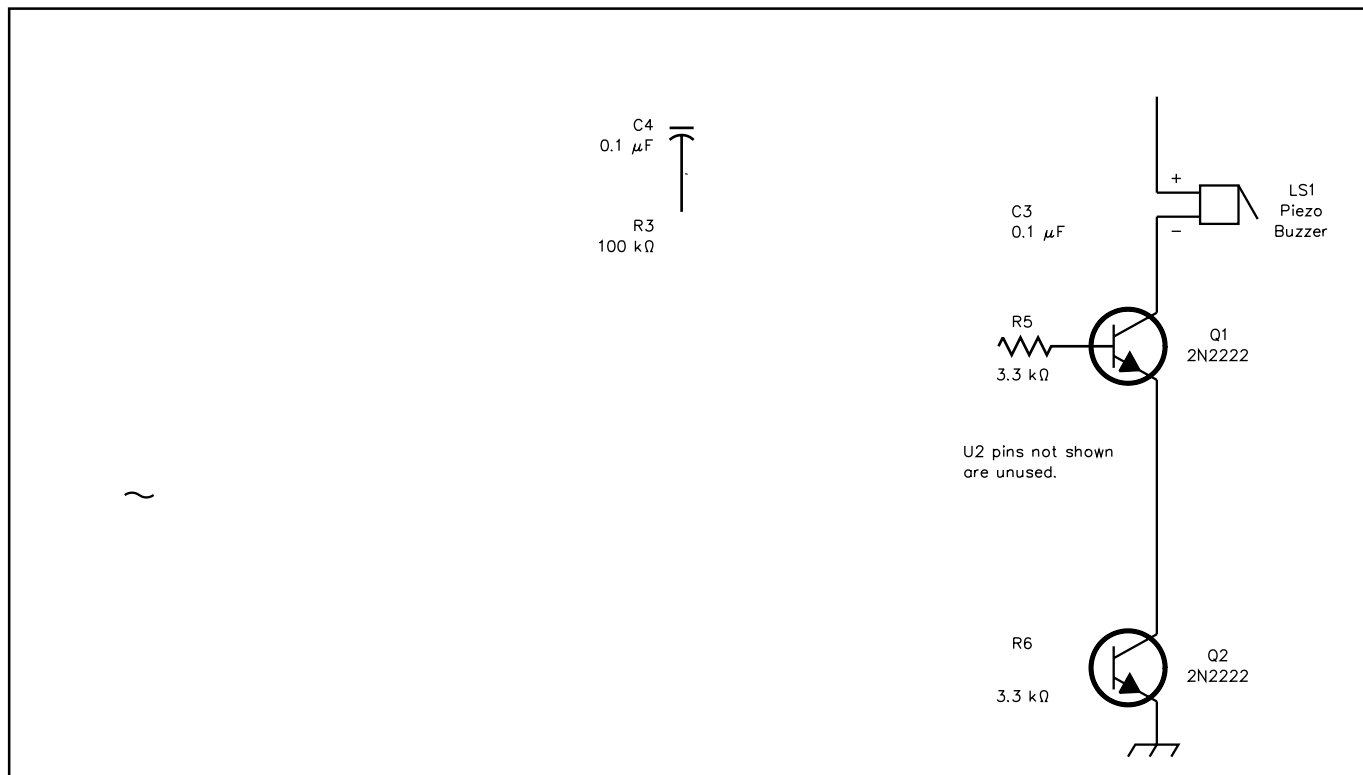


Figure 15—Schematic of the older 10-minute timer. Unless otherwise specified, resistors are 1/4 W, 5% tolerance carbon-composition or film units. Equivalent parts can be substituted.

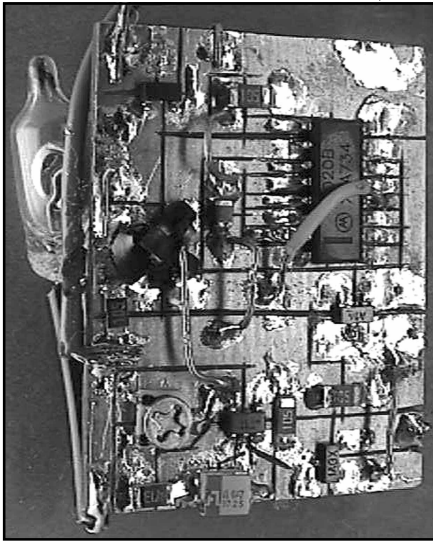


Figure 16—A top view of the SM version of the timer described in the text. The 3-V battery that powers the circuit is mounted on the bottom side of the board.

the 10 minute limit is reached, the appropriate pin on U2 goes high, turning on a switch, Q1, which sets off an alarm.

U1 of Figure 17 is an MIC1557. Dubbed the “IttyBitty RC Timer” by the manufacturer,<sup>25</sup> it’s an SOT-23 version of the 555. R1 and C1 set the cycle time. (R1 is composed of a pot, R1A, and a fixed-value resistor, R1B.) I use a 50%-duty-cycle timer because it requires fewer parts than an asymmetrical-duty-cycle timer. I selected a cycle time of about one second because the data sheets for the LM555 and the MIC1557 indicate that capacitor leakage affects the accuracy of periods longer than 10 seconds. With just a one-second cycle time, it’s necessary to use a longer delay in U2, so I added an MC14020, a 14-bit binary counter that can count up to 16,384. By using a count of 1024—and adjusting the values of R1 and C1—I achieved an accurate 10-minute delay.

This flexible circuit can be modified for longer or shorter delays, from as little as a few seconds to as long as 24 hours! (See [Experimenting with the Timer](#) later.) I had a difficult time finding counters in SM packages, and as you can see in the photo, the chip is “huge.” (Perhaps this indicates there’s a better way to handle delay circuits with SMT.)

The output at pin 15 of U2 triggers Q1 through D1. Q1 is not just any MOSFET—the IRLML2402 is a state-of-the-art device. Its gate turn-on voltage is only 1.5 V, and at 3 V, the MOSFET is fully on. (Not too many years ago, MOSFETs required 10 or 12 V to turn on. Most logic-level MOSFETs today still require 5 V, which makes them useless in a 3-V supply project.) Although the IRLML2402 is packaged in a Micro 3 package (which is smaller than an SOT-23 package), its *on* resistance is only 0.25  $\Omega$  and it can switch current levels up to 1 A.

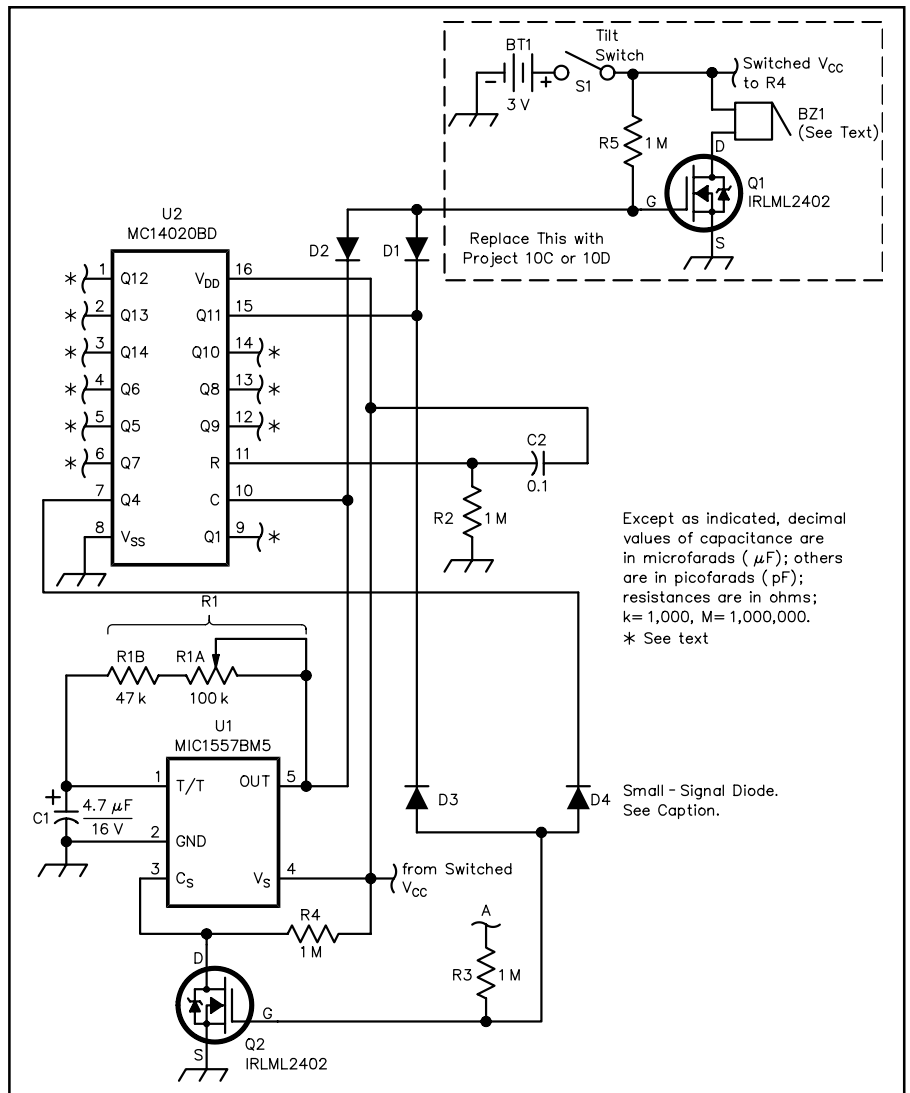


Figure 17—Schematic of the SM “hourglass” 10-minute timer. A 3-V lithium battery powers the circuit. The section of the circuit enclosed in dashed lines can be replaced by either of the circuits shown in Figures 18A and 18B. Unless otherwise specified, resistors are 5% tolerance SM units. The resistors I used are SM devices in 1206 cases. Equivalent parts can be substituted. See the sidebar “Manufacturers and Distributors of SMT Equipment and Parts,” in Part 1, *QST*, May 1999, for a list of suppliers.

BT1—3-V, lithium CR2032, etc.

BZ1—Piezo buzzer (see text)

C1—4.7  $\mu$ F, 16 V tantalum.

C2—0.1  $\mu$ F ceramic (I used a SM device in a 0805 case).

D1/D2, D3/D4—BAW56LT1 (common-anode diode pairs in an SOT23 case); pairs of 1N914 or 1N4148 diodes can be substituted.

Q1, Q2—IRLML2402 MOSFET

R1A—100-k $\Omega$  pot (Bourns 3364W)

SW1—Encapsulated tilt switch (available from author)

U1—MIC1557BM5, Micrel IttyBitty RC timer/oscillator

U2—MC14020BD, 14-bit binary counter

Misc: Battery holder, Keystone #3002.

You might ask, “Why not use a bipolar transistor instead of a MOSFET?” There are several reasons. Transistors require bias current, MOSFETs do not. A small transistor with a 30 mA load develops a 300 mV drop. The MOSFET has only a 4 mV drop, an important consideration when the supply voltage is only 3 V.<sup>26</sup> Also, a MOSFET can be used as a comparator. At levels less than 1 V (for this device), the MOSFET is *off*, and for levels above 1.5 V, it is *on*.

I wanted to use an **AND** condition to sound the buzzer, BZ1. D2 connects the gate of Q1 to the output of U1. This ar-

angement turns on the buzzer only when U2 pin 15 is positive *and* pin 5 of U1 is positive. Because the level at U1 pin 5 changes at about one cycle per second, the result is a pulsating buzzer that is more noticeable and uses less power than a continuously sounding buzzer. Another reason I could not use a transistor at Q1 is because the voltage drops of D1 and D2 result in a low voltage level of 0.6 V at Q1; that is too high to turn off a transistor.

With a battery-powered device, I didn’t want the timer to cycle continually; that would deplete the battery if I forgot to shut

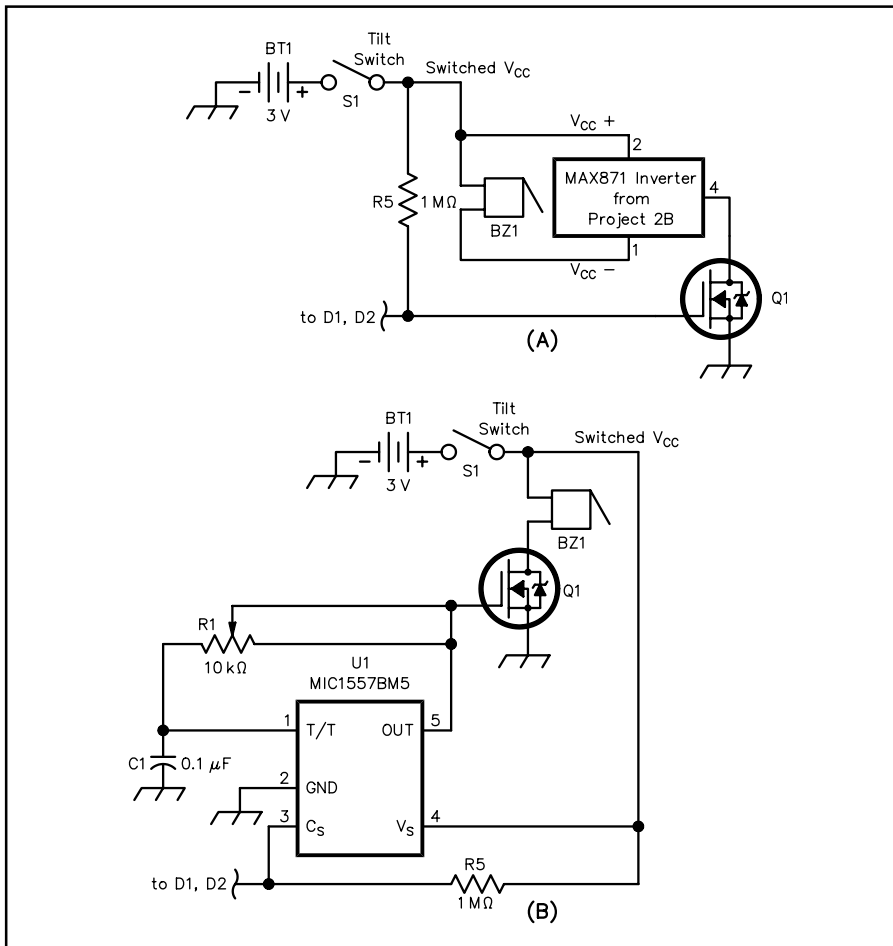


Figure 18—Two modifications you can make to the basic hourglass timer of Figure 17. At A, use of a piezo buzzer requiring a higher supply voltage (6 V) can take advantage of the MAX871 inverter circuit described in Project 2B. R5 is a 1 MΩ resistor in a 1206 SM case. An externally driven buzzer can employ the circuit shown at B using an MIC1557. Component identifications are those given in Figure 17. Note the value change of R1. R1—10-kΩ pot (Bourns 3364W)

off the timer. This circuit shuts itself off. The buzzer sounds for about three seconds, and if it is not restarted, the circuit goes to sleep. It works like this: D3 and D4 form an **AND** gate controlling Q2. After pin 15 of U1 goes high and the buzzer sounds, the timer continues to count until U2 pin 7 also goes high. Then, Q2 turns on and pin 3 of U1 goes low. Pin 3 is U1's **CHIP SELECT** pin; when it goes low, U1 stops running and its current drain is reduced to 1 μA. With U1 sleeping, its output goes low. That shuts off the buzzer via D2. Total current drain while sleeping is about 5 μA. Under these conditions, a lithium 2032 battery should last several years.

To restart the timer (from sleep mode or when it is buzzing), just turn it upside down and then right side up. The tilt switch turns the power off, then on. C2 and R2 form a power-up reset that restarts U2 at 0 with a positive pulse to pin 11 through C2.

### Experimenting with the Timer

Using the right audio transducer makes a major difference in audibility. Most transducers require more than 3 V to operate. I

tried a RadioShack 273-074 transducer and it worked, but its output level was quite low. One way to raise the sound level is to raise the buzzer voltage. I did that with the circuit of Project 2B, as shown in Figure 18A. Some parts catalogs list piezo transducers that are externally driven and operate at 1.5 or 3 V. (The RadioShack buzzer mentioned earlier is internally driven: It has a square-wave generator built into it). I used a piezo transducer driven by an MIC1557, as shown in Figure 18B. It has a loud signal, but I found that setting the exact frequency needed for maximum sound was tricky. The best signal I could obtain came from a TMB-05<sup>27</sup> buzzer that I placed in a resonator and drove with the MAX871 circuit.

### A Resonator

A neat way to improve the loudness and purity of the buzzer's tone (some piezo resonators have a harsh note) is to place the buzzer in a Helmholtz resonator.<sup>28</sup> This is a cylinder or tube designed to resonate at a certain frequency. Every resonator I used made the sound available from the trans-

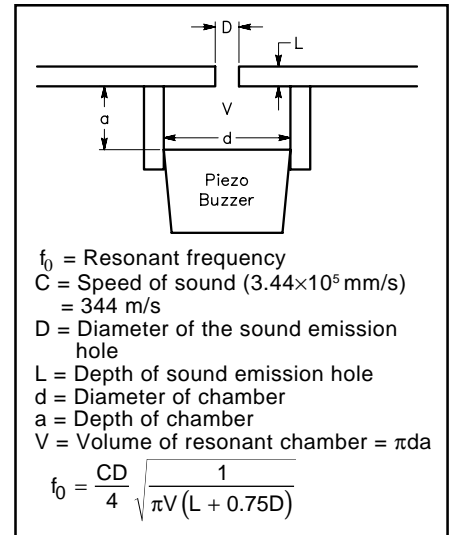


Figure 19—Here's the fundamental approach to constructing a resonator to improve the loudness and purity of the buzzer's tone. The resonant frequency ( $f_0$ ) should equal twice the frequency of the buzzer to increase sound pressure. Do not make dimension D too small, or the acoustic resistance will increase. The equation is a starting point; experimentation will optimize your results (see text). Dimensions are in millimeters unless otherwise noted.

ducer louder and clearer. The information in Figure 19 can help you design a resonator. If the math bothers you, try using a simple resonator made from a half-inch water pipe PVC end cap and drill a 3-mm diameter hole in the end; it worked well for me. I ground down the material surrounding the hole to make it thinner (smaller L) and adjusted the distance (A) for maximum sound. Best results are obtained when the tube's resonant frequency is about twice that of the piezo transducer's frequency.

### Other Time Delays

In Figure 17, instead of connecting D1 to pin 15 of U2, you can attach it to another pin to obtain a different time delay. Table 2 shows the delays you can achieve when using a one-second cycle time at U1. By adjusting the values of R1 and C1, you can obtain nearly any time delay you want. For the arrangement to work correctly, the U2 pin you use to trigger Q1 must have a greater number of counts than the pin you use to shut down the circuit, which is why the data in Table 2 starts at 16 counts.

If you make your own PC board, you can customize it as needed. The premade PC board (see Note 24) is designed so you can add the circuits of Figure 18A or B on a separate board to drive the buzzer.

### Construction Comments

I used a 0.005-inch wheel for the critical cuts at U1, Q1 and Q2 (see Figure 20). For the other cuts, I switched to a 0.009-inch wheel. The 0.005-inch cut is so narrow that



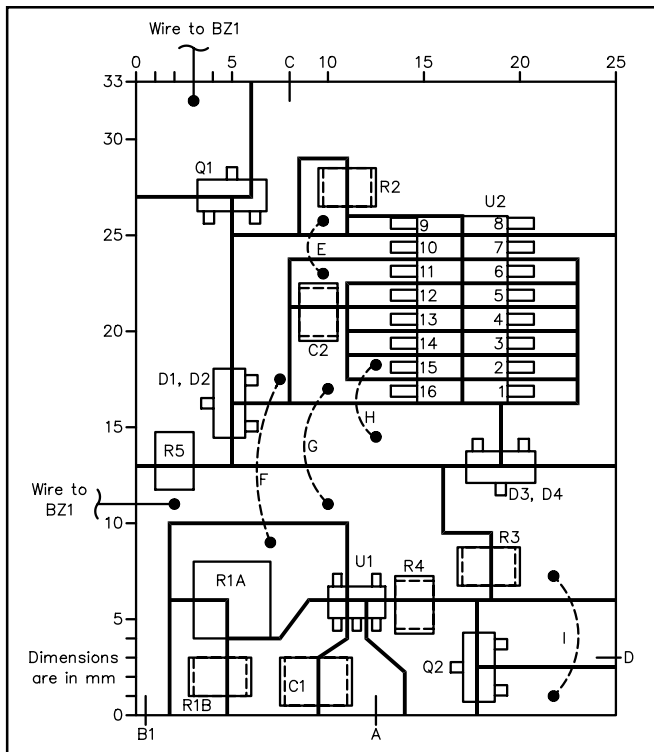


Figure 20—PC board layout of the 10-minute timer. Heavy lines designate cuts made in the foil to create component-mounting islands as described in Part 1 of this series.

solder tends to bridge the gaps. With a 0.009-inch cut, bridging is much less likely to occur. The circuit is on the board's top side; the battery and holder are on the bottom as shown in Figure 20. The tilt switch is connected between B1 of Figure 20 and B2 of Figure 21.

### Summary

After completing these projects described over the past months, you should feel comfortable working with SMT devices. And, as I do, you'll probably be turning the pages of *QST* looking for a neat SMT radio project. A couple of the projects I would like to see include: a small, inexpensive VHF transceiver and a pocket-size HF receiver. In addition to the Maxim parts I mentioned earlier, Phillips Semiconductor sells a single-chip SMT AM receiver, MicroChip has an SMT microprocessor and Texas Instruments (TI) has a highly efficient SMT Class-D stereo amplifier. The parts are there. I hope we amateurs start to make use of them. [Let's see some of those projects! *QST* depends on readers and authors such as Sam and you for projects. Send your manuscripts to Steve Ford, WB8IMY, 225 Main St, Newington, CT 06111; [sford@arrl.org](mailto:sford@arrl.org).—Ed.]

### Notes

- <sup>22</sup>Parts 1, 2, and 3 of this series appear in the April, May and June 1999 issues of *QST*, pages 33-39, 48-50 and 34-36, respectively.  
<sup>23</sup>R. Dean Straw, N6BV, Ed., *The 1999 ARRL Handbook* (Newington: ARRL, 1998), p22.58  
<sup>24</sup>A limited number of parts kits are available

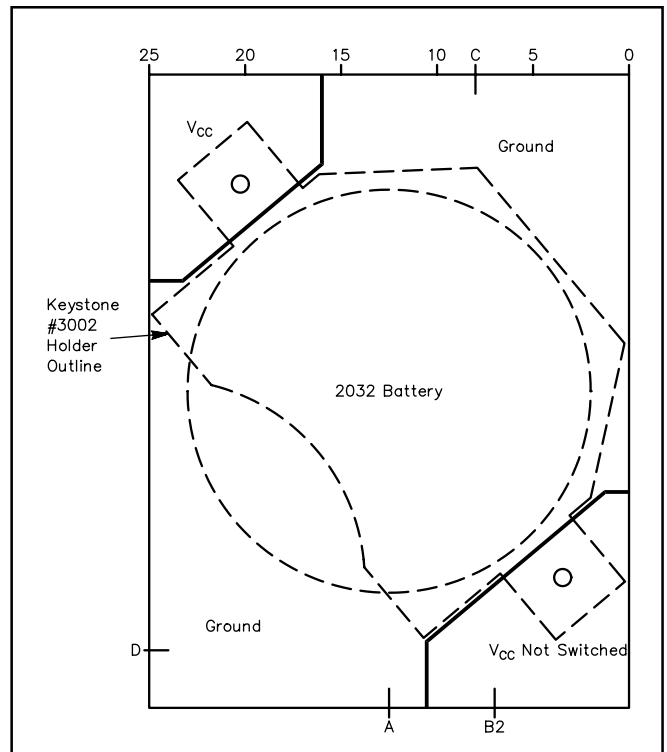


Figure 21—The 3-V battery occupies the bottom side of the 10-minute timer. Again, the heavy lines indicate where cuts are made in the PC-board foil.

**Table 2**  
**Timer Delay for a U1 Cycle Time of One Second**

Pin	Counts	Time
5	16	16 s
4	32	32 s
6	64	1 m 4 s
13	128	2 m 8 s
12	265	4 m 16 s
14	512	8 m 32 s
15	1024	17 m 4 s
1	2048	34 m 8 s
2	4096	1 h 8 m 16 s
3	8192	2 h 16 m 32 s

Time shown in hours, minutes and seconds.

from me for \$11, which includes all the parts (including the hard-to-find tilt switch) except for the buzzer and PC board. If you want a premade PC board, add \$2 (Florida residents must add sales tax). Piezo buzzers are widely available at places like RadioShack or many of the parts sources listed in the article.

If you are interested in learning to make your own boards as I described in Part 1, I have a limited number of parts kits available. These consist of a 3 × 6-inch double-sided copper-clad board, eight cutoff wheels (two 0.005 inch, four 0.009 inch and two 0.025 inch) and the special mandrel recommended for use with the ultra-fine cutoff wheels; price: \$13. (Florida residents must add sales tax.)

<sup>25</sup>The MIC1557 has a brother, the MIC1555, optimized for monostable operation. It is described in the same data sheet.

<sup>26</sup>These are the results of measurements I made.

<sup>27</sup>The TMB-05 internally driven buzzer is made by Star Micronics, 70-D Ethel Rd West, Piscataway, NJ 08854; tel 800-782-7636 (X512), fax 732-572-5095; [sales@starus.com](mailto:sales@starus.com);

<http://www.starmicronics.com/product/audio/index.cfm>. See the Star Micronics Buzzers and Transducers catalog, page 5.

<sup>28</sup>A resonator based on this principle is described by Wally Millard, K4JVT, "A Resonant Speaker for CW," Hints and Kinks, *QST*, Dec 1987, p 43—Ed.

You can contact Sam Ulbing, N4UAU, at 5200 NW 43rd St, Suite 102-177, Gainesville, FL 32606; [n4uau@afn.org](mailto:n4uau@afn.org). 