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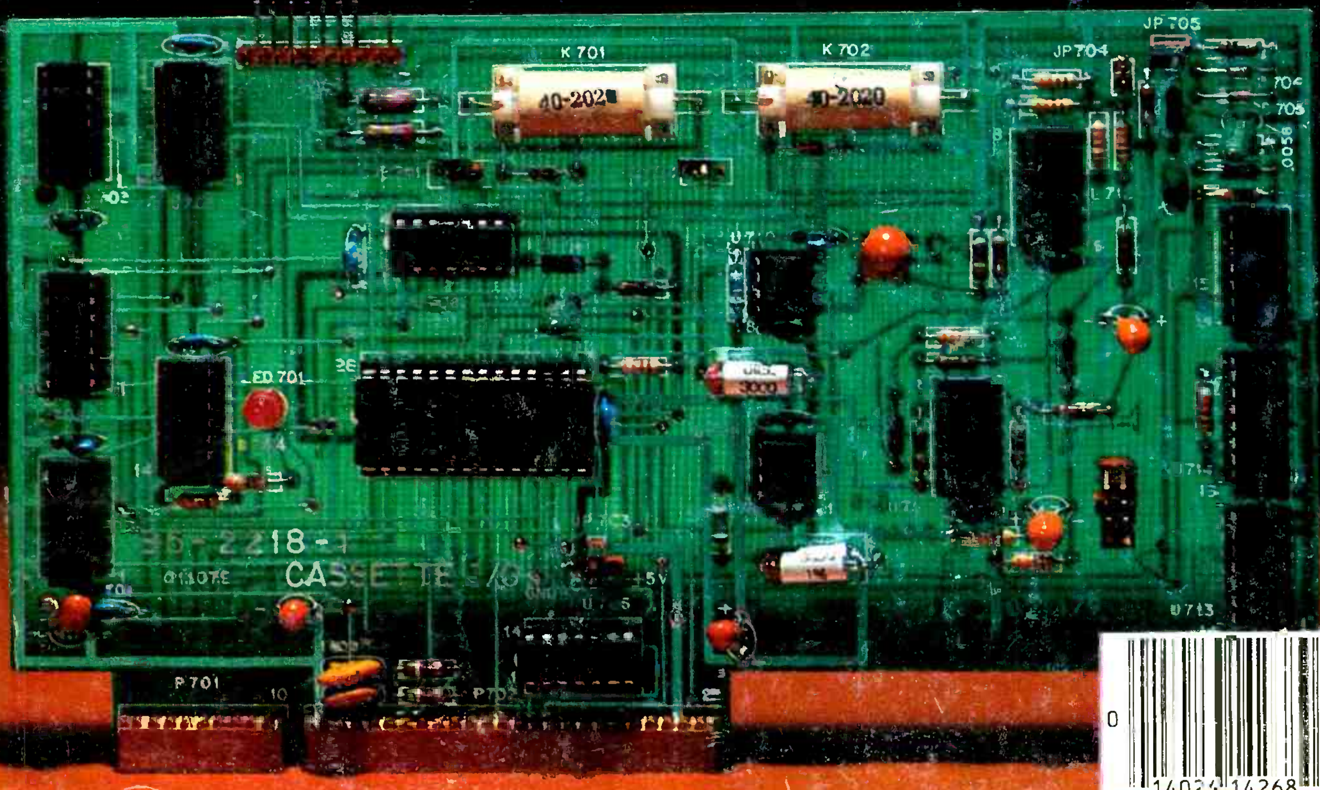

The Workbench

CHRIS HERRERA

POPULAR ELECTRONICS

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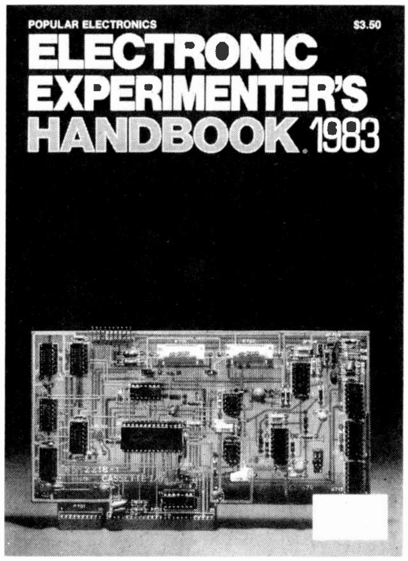

THE COVER

Personal computing has become one of the most popular of electronic hobbyist/experimenter pursuits. Among the various items required to make a personal computer into a practical reality for the hobbyist is the Heath No. H-88-5 cassette input/output (I/O) interface assembly shown on the cover. Designed to plug directly into the Heath Model H-89 all-in-one microcomputer (supplied in kit form), this assembly provides an inexpensive means for loading prepackaged programs (software) into the computer from, and saving locally generated programs on, tape using an ordinary low-cost audio cassette recorder/player. Heath and most other manufacturers offer special circuit board assemblies designed to plug into their computer buses and provide a means for experimenting with user-designed or published circuits, such as vocalizers, fire and security alarms, environment (cooling and heating) and lighting control, etc.

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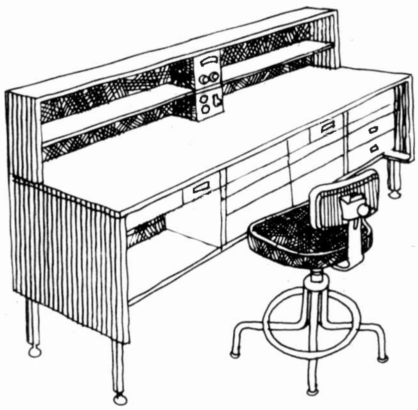
EQUIPMENT FOR ELECTRONICS WORKBENCHES

BY JOHN McVEIGH

"A craftsman is only as good as the tools with which he works" is as true in the field of hobby electronics as any other. Tools are no substitute for knowledge, of course, but lacking key items or using improper ones can put severe limitations on an experimenter's activities.

The type and variety of tools and test equipment that an electronics hobbyist possesses have a direct bearing on which areas of personal electronics he will be able to explore.

In this editorial focus, we discuss how an electronics workbench should be set up and consider several factors that should be taken into account in deciding what items you need for *your* workbench as related to your electronics interest.



The Work Area

The workbench is the one place above all others where the electronics buff pursues his hobby. It is there that he takes a circuit idea or description and reduces it to a working model. Since a serious hobbyist spends a substantial amount of his special-interest time at his workbench, it should be designed for maximum user comfort and safety, and minimum fatigue. If space availability and resources permit, the electronics workbench should be just that and only that, because many projects require more than just a day's work. Thus, a partially assembled (or repaired) project can be left undisturbed until the next time it is to be worked on. In contrast, a work area that serves double duty, as, say, a kitchen table, would cause gross inefficiency and frustrations. In this case, everything would have to be periodically removed so that the "work area" could be used for its original purpose.

The fundamental requirement for an electronics workbench is that it provide a solid, flat, rugged, nonmetallic surface on which one can work. Of course, an actual workbench—a structure specifically designed and constructed for this purpose—can be used. However, if budgetary constraints rule this out, a sheet of ½- or ¾-inch plywood and a pair of wood saw horses can form the nucleus of a fine workbench.

In any event, the work area should be at least 24 inches (61 cm) deep and 48 inches (122 cm) wide. Having a work area of that size or larger will allow you to spread out components, a schematic drawing or assembly manual, a chassis, and tools, and still have some elbow room! A smaller work area will likely lead to crowding, fatigue, impatience and wiring errors.

A highly desirable feature is having one or more shelves above the main work area. Such shelves allow one to mount frequently used test equipment (a multimeter, oscilloscope, power supply, etc.) within easy reach without permanently tieing up substantial portions of limited work space.

The work area surface should be covered with a ribbed rubber runner. This runner will absorb punishment that would otherwise damage an unprotected work surface. Also, its ribbed surface will pre-

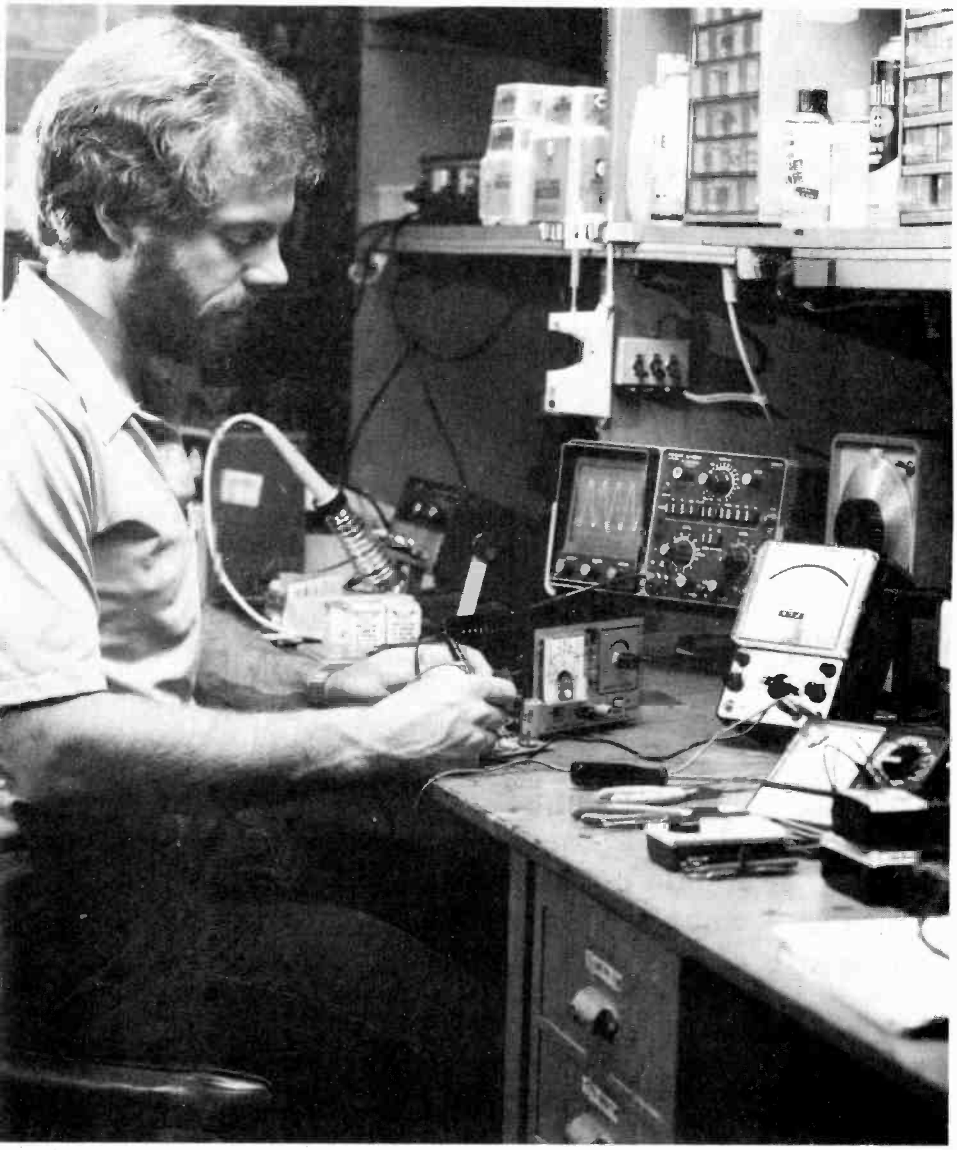


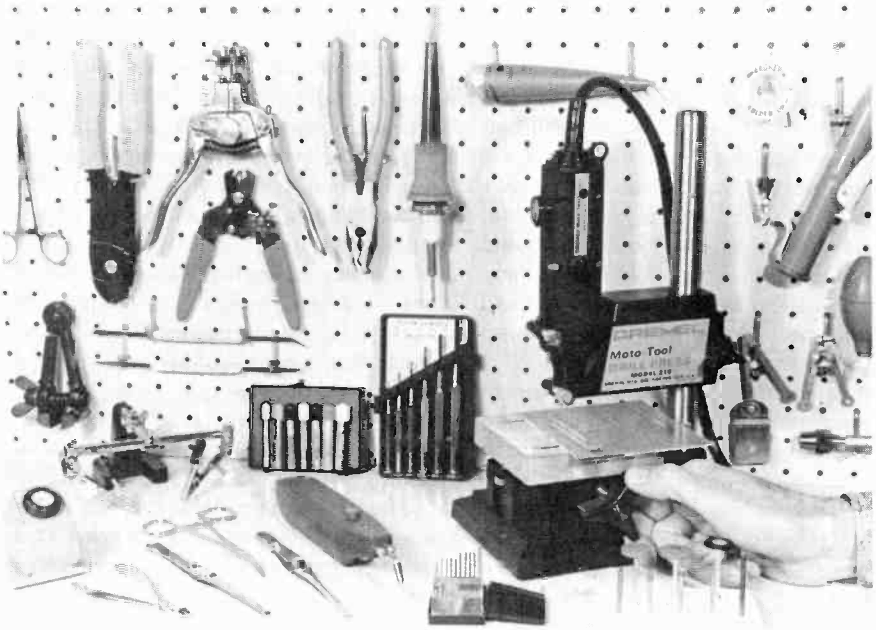
Photo courtesy GC Electronics

A well-planned electronics work area includes room for the project, test equipment, and storage.

vent hand tools, hardware, and small components from rolling off the workbench and onto the floor.

Selecting a chair will largely be influenced by the physical characteristics of the workbench. The chair should be high enough to put one's elbows at the same level as the work area. If the workbench is much higher than the average kitchen table, use of a common kitchen-type chair would be inadvisable. The ultimate in work chairs is a drafting chair with adjustable seat height and back support.

Lighting and Power. The area in which the workbench is installed should be well illuminated. If possible, the workbench should be directly below a ceiling light fixture. Light from this fixture can be supplemented with that from a lamp on the workbench. A compact high-intensity type will provide good spot illumination, but many experimenters prefer to use a drafting lamp with an articulated support arm, such as the Luxo Model LS-1/A. This lamp can accommodate a 100-watt incandescent bulb, has a 45-inch adjustable arm, and includes a clamp so that it can be mounted on the edge of the workbench. For work on densely packed circuit boards and compact projects, a similar lamp with an illuminated magnifier is an invaluable aid. If the need for an illuminated magnifier arises only occasionally, a less costly, hand-held unit such as the GC Electronics Model 22-282 is a good choice.



Use of pegboard and hooks permits convenient storage of tools.

Heath Model HD1274 power distribution strip.

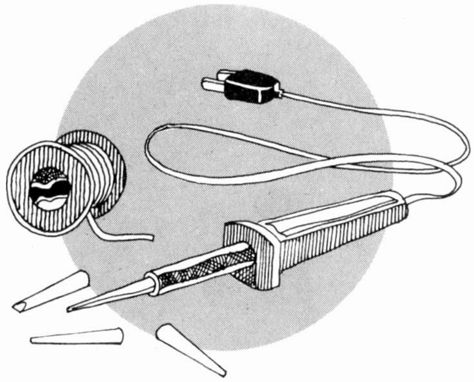
There should be a source of ac electrical power near the workbench. The bench should therefore be positioned near at least two electrical wall outlets, and a bench-mounted power distribution strip with a *minimum* of six sockets should be plugged into one of them. The strip will be used to channel power to test equipment, lamps, soldering tool, etc. Choose a strip with a minimum current rating of 15 or 20 amperes and three-conductor sockets. One with a master on/off switch or individual switches for each outlet is convenient to use. Some include a master fuse or circuit breaker, or even individual ones for each outlet to back up the line's master fuse or circuit breaker.

Storage. A key to high workbench utility is organization. Tools, hardware, electrical components and similar items should be stored in a logical manner that ensures quick accessibility. Certain tools, for example, can either be kept in nearby drawers or hung on a piece of pegboard mounted on a nearby wall.

The best way to store hardware and small electrical components is in suitably sized storage bins. There are modular ones with drawers that are made of transparent styrene to allow quick visual inspection of their contents.

Hobbyists with many items to store can buy several such small storage cabinets. Some manufacturers models with different characteristic drawer sizes to hold certain items. Modular storage cabinets can be stacked either vertically or horizontally on shelving above the main work area.

After a few years, most electronics hobbyists build up a respectable "junk box" of discarded chassis, old projects, etc., which are kept around for parts scavenging purposes. Such items are usually much too large to fit in modular storage cabinets. A nearby closet that is not being put to another use is ideal for junk-box storage. If one is not available, a wooden toy chest or a free-standing metal cabinet will probably do.



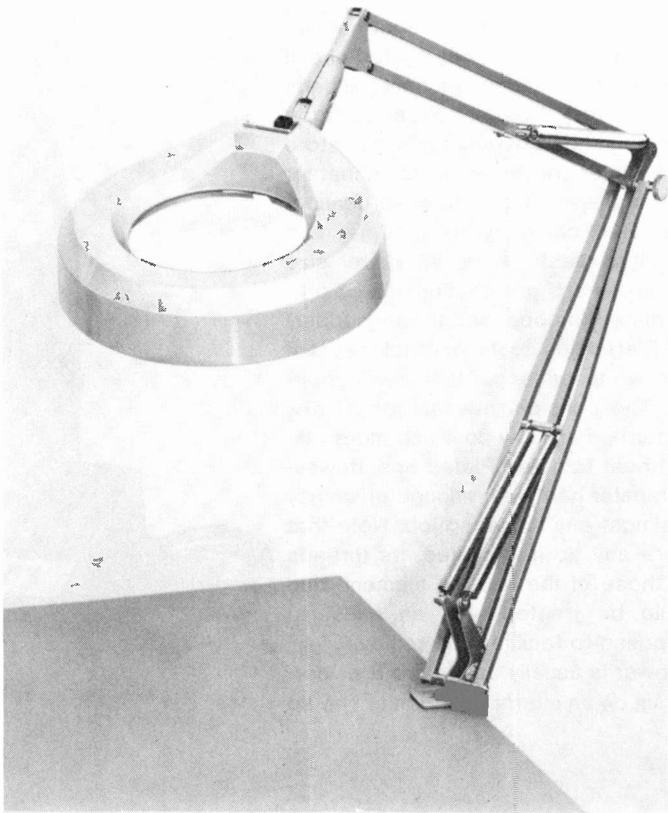
Tools for Electrical Work

Much electronic-building and service work is centered around the process of making secure connections between conductors by soldering. That is the process by which two or more pieces of metal are bound together by a metal alloy that's applied to the connection in a molten state. This section will deal with implements needed to do this work, as well as other facets that relate to electrical assembly.

Soldering Irons. A soldering tool should supply sufficient heat to melt solder by heat transfer when the iron tip is applied to a connection to be soldered. There are two general classes of soldering irons—*guns* and *pencils*.

A typical soldering gun is larger, heavier and generates more heat than the average pencil. Soldering of heavy-duty conductors or connectors calls for use of a gun because it can generate enough heat to quickly bring a heavy metal joint up to the proper soldering temperature.

Soldering irons in this category are called guns simply because they resemble pistols, as shown in an accompanying photo. The gun's "trigger" is actually a switch that controls application of ac power to a built-in transformer and thence to the heating element. The working temperature is reached almost immediately. Some models feature multi-position trigger switches to provide



Luxo Model LFM-1/A illuminated magnifier.

different heat levels. For example, a two-detent switch might give the user a choice of generating 100 watts or 150 watts, depending on whether the trigger is fully or partially depressed.

At the other end of the spectrum are small, lightweight soldering pencils. They can generate as little as 12 watts of heat, or as much as 50 watts, depending on the particular model. A relatively low-power pencil such as a 25-watt unit is well suited for light-duty work such as soldering on printed-circuit boards. Some medium-duty applications like chassis wiring require a higher-wattage heating element. Many pencils, called modular soldering irons, use interchangeable heating elements and tips which mate to a main pencil body. Such elements screw into a threaded receptacle at the end of the pencil.

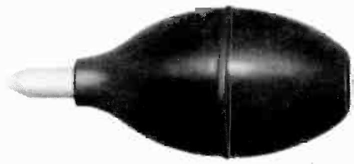
Some heating elements have ceramic bodies with tips of various shapes permanently bonded to them. Others are ceramic or stainless steel units that are terminated with threaded studs on which any one of several different-shaped tips can be mounted. The advantage of such a modular soldering pencil is that it can be assembled in any of several permutations that is optimized for a specific soldering job.

There are tips available for modular soldering pencils to handle most soldering tasks. Very fine, almost needle-like tips are used on printed-circuit boards with IC and component foil pads that are very closely spaced. Larger, blunt chisel and pyramid tips can store and transfer greater amounts of heat for more massive, widely spaced connections. Bent-chisel types can get into difficult-to-reach areas. Whatever size and shape tips are chosen, it's best to buy plated (as opposed to raw copper) tips. Plated tips cost more, but they last up to ten times longer than raw copper tips. The principal advantages of raw copper tips are low cost and more efficient heat transfer. Plated tips, however, transfer heat with enough efficiency for almost any soldering job. Note that before any tip is mounted, its threads and those of the heating element stud should be treated with an antiseize compound to facilitate tip removal.

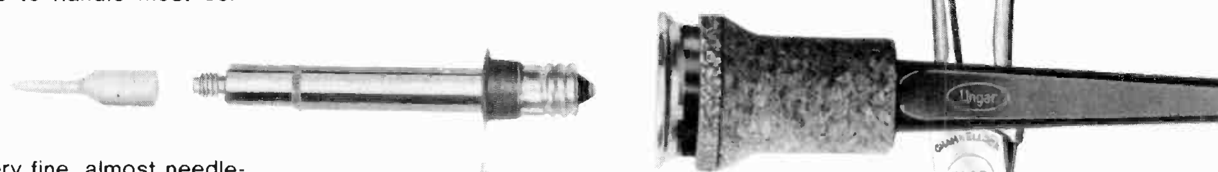
Power is usually applied to a soldering gun on an intermittent basis. The tip

Wahl Model 7295 safety stand holds iron and cleans tip.

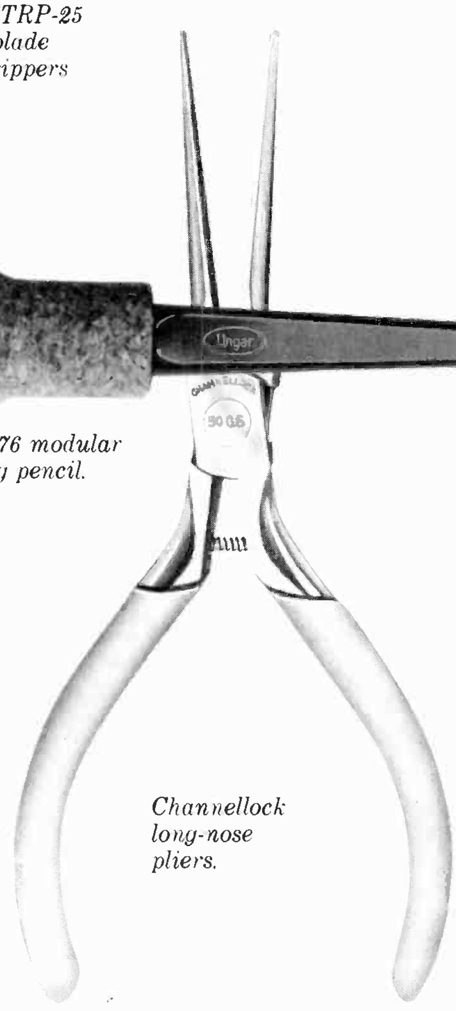
Alpha STRP-25 plastic-blade wire strippers



Ungar Solder-Off desoldering bulb.



Ungar 776 modular soldering pencil.

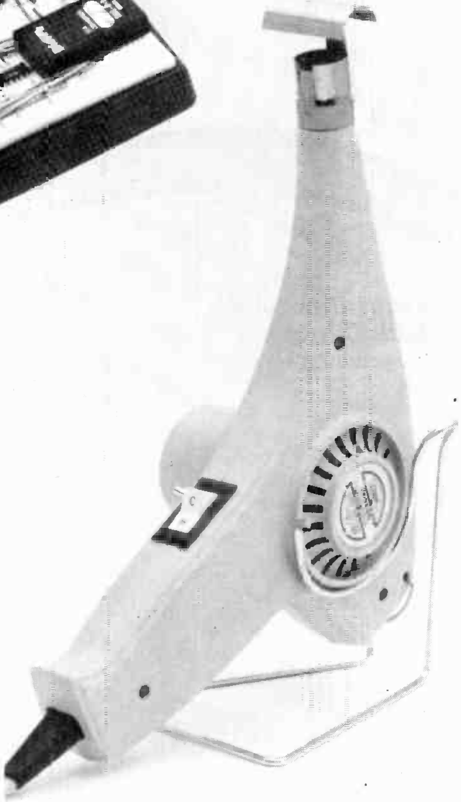


Channellock long-nose pliers.

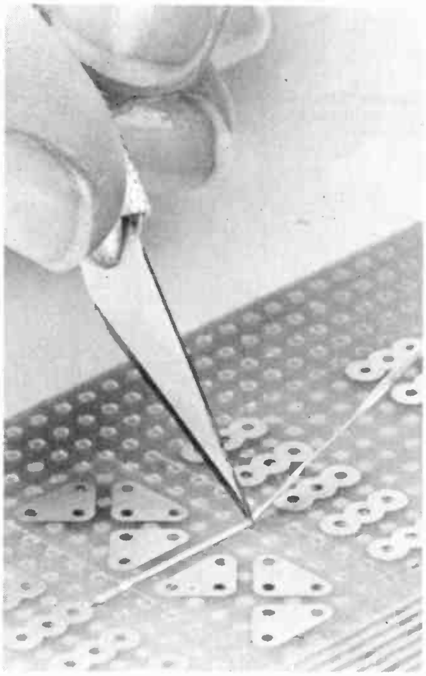
Wahl Model 7500 Isotip cordless iron and recharging stand.

Weller Model 8200 soldering kit.

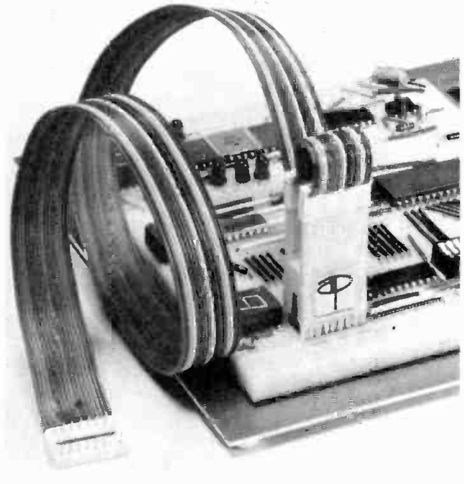
AP Products POWERACE 103 solderless breadboard



Ungar Model 6966 heat gun for heat-shrink tubing



Making a pc board using Bishop Graphics E-Z CIRCUIT aids and an X-acto knife.



AP Products Logical Connections for interconnecting breadboards

of the gun will heat up to working temperature very quickly, and it will cool off soon after power is removed. Therefore, the gun can be left lying on its side on the workbench, picked up and powered to make the required connection, and then laid on its side again. A typical pencil, however, takes a few minutes to attain working temperature. This means that during a typical work session the pencil will be continuously powered and its tip will remain hot for the entire interval. Therefore, some method must be employed to keep the iron secured in a safe place at working temperature.

One solution to this problem is a special soldering iron holder. This may be a coiled steel form into which the hot soldering iron can be inserted. Most stands of this type also include a sponge which can be kept moistened and used periodically to clean the soldering tip. A more deluxe solution incorporates the foregoing with an iron and a control console that offers switch-selectable temperatures, usually low, medium, and high. This system is called a soldering station. Obviously, this is more convenient than waiting for a modular pencil's heating element to cool, unscrewing it from the holder, and then replacing it with another heater/tip combination. Predictably, however, soldering stations are expensive compared to basic soldering pencils. Among the manufacturers that produce soldering stations are Weller, Ungar, and Heath.

Special Considerations. The proliferation of metal-oxide semiconductor devices has focussed the attention of some manufacturers upon characteristics of certain soldering irons that were largely ignored until recently. As you may know, MOS devices have gate structures that are extremely susceptible to damage by electric potential gradients such as those which can be generated by friction (i.e., static electricity). A source of such electric fields can be the soldering equipment itself.

There are two sources of troublesome potential differences associated with soldering irons. The first is common to most soldering irons—electrostatic tip potential. Static electricity can be set up in an ordinary soldering tip and can be transferred to the component to be soldered when the tip is placed next to one of its leads. If the electrostatic potential is high enough and the MOS device is unprotected, its delicate gate structure will be destroyed. The solution to this problem is to place the tip at ground potential so that static charges do not have a chance to accumulate. Several manufacturers now produce special soldering irons whose heater/tip assemblies are grounded. These units are readily identifiable by their three-conductor NEMA plugs for insertion into three-conductor power sockets.

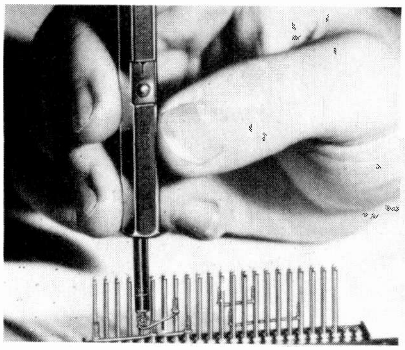
Another source of potential trouble is peculiar to a certain type of soldering iron. Some of the more sophisticated soldering implements (most of them soldering stations) feature automatically controlled tip temperature. These implements employ some type of heat sensing and closed-loop feedback control to gate power to the heating element. This allows the control circuit to compensate for variations in the amount of heat being drawn from the soldering tip and keep the tip at a constant temperature. The switching action of some controlled-output soldering implements can generate voltage spikes which can be transmitted to and adversely affect a MOS device. Some manufacturers, such as Ungar, have designed their controlled-temperature soldering stations and irons in such a way that voltage spikes are kept to a low value.

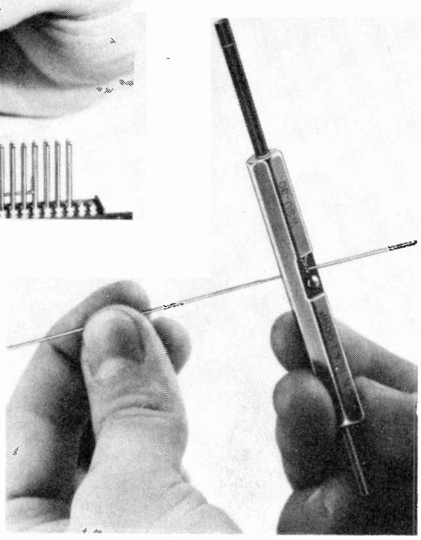
Cordless Irons. All of the soldering irons discussed so far rely on ac power cords. However, there are times when it is inconvenient to be tied to a 117-volt line. Here, a cordless, battery-operated soldering iron serves well. These compact, hand-held tools employ rechargeable NiCd batteries as a power source. Recharging is done automatically when the iron is placed in its recharger/stand (assuming the charger is plugged into an ac outlet, of course).

In operation, the tips come up to working temperature in five to eight seconds and cool off to ambient temperature in one minute or so. They can be used to make the same kinds of solder connections that pencils do.

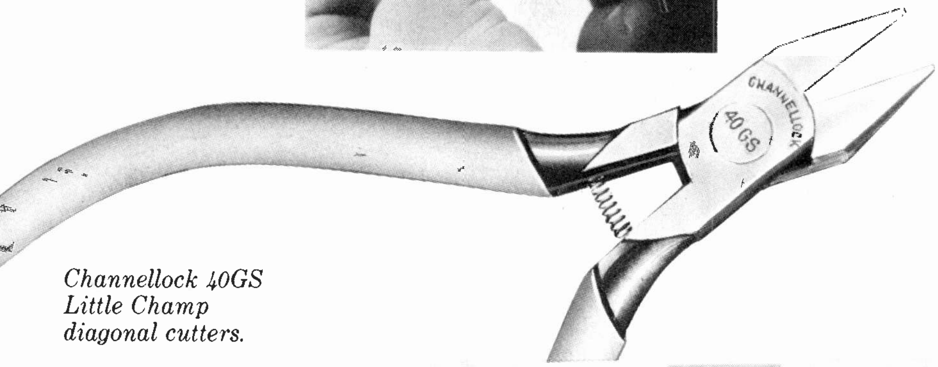
The number of solder connections able to be made before recharging is required varies according to a particular model. Typically, about 125 or so soldering connections can be made on one charge. For a standard iron, a typical charging interval of approximately 14 hours is needed to return the cells to full strength. There are quick-charge irons, however, that require only one hour. Others take three or four hours.

Many optional tips for battery-pow-

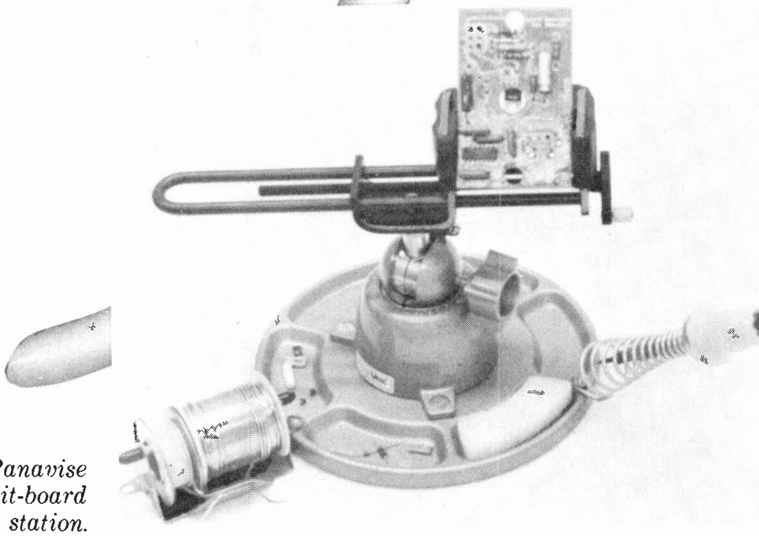




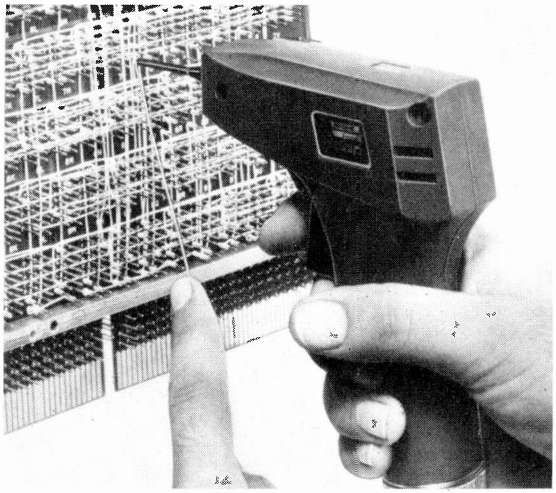
OK Machine & Tool HSU-30 Hobby-Wrap tool strips (right) wraps, and unwraps (above) wire.



Channellock 40GS Little Champ diagonal cutters.



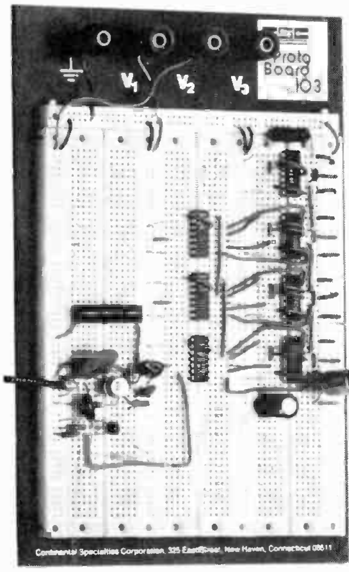
Panavise circuit-board work station.



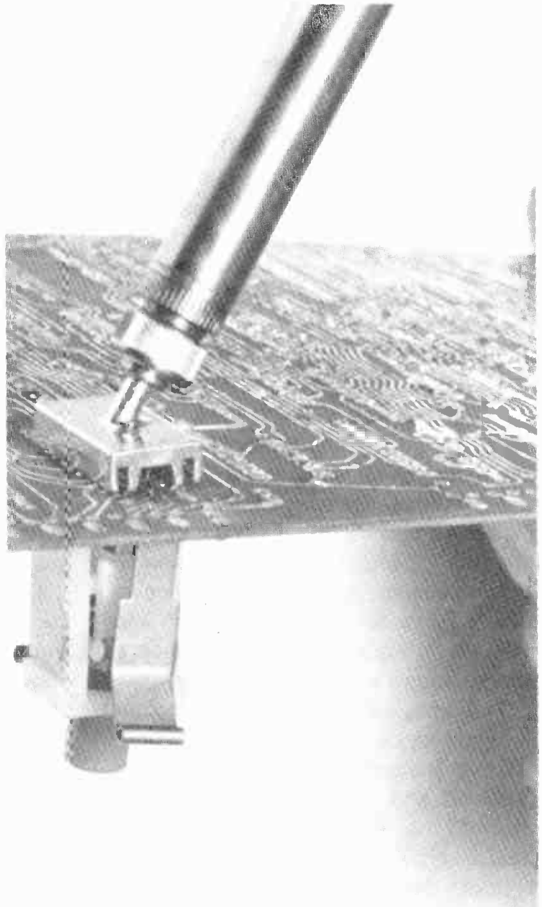
OK Machine & Tool BW-2630 motorized wrapping tool.

ered irons, all differing in shape and size, can be snapped into the bodies. A light is often built into the case of the iron to illuminate the work area whenever battery power is applied to the heating element.

It is obvious that there are many different types of soldering irons available. Some are better suited for a particular kind of soldering job than are others. An experimenter who works only with printed circuit boards will find that a soldering pencil (especially a modular one) will be adequate for most (if not all) of the soldering connections he has to make. Someone who builds projects employing coaxial connectors and heavy-gauge wiring will need a higher-power soldering gun. Another person will find a cordless soldering iron an invaluable implement for work far from ac outlets.The choice is often easy for hobbyists with broad electronics interests. They own one of each. In fact, many hobbyists have more than one modular pencil body so that much tip switching is avoided.



Continental Specialties Proto Board 103.



Ungar 50 DK desoldering implements.

Heathkit Model GH-17 soldering station.

GC Electronics Model 22-306 Deluxe Soldavac desoldering tool.

Solder. No solder connection can be made without solder. The most common type of solder used in electronic work is an alloy consisting of 60% tin and 40% lead. This alloy is drawn into a hollow wire whose center is filled with an organic paste-like material called rosin. The resulting product is known as "60/40 rosin-core solder." It is completely molten when heated to approximately 375°F (190°C) and solidifies as it cools. If conditions are right, it will form a rigid, conductive bond with the metals to which it has been applied.

There are other solder alloys containing different proportions of tin and lead that are sometimes used in electronics work. The eutectic alloy of tin and lead, that mixture having the lowest melting point, is 63/37. It melts at 361° F (183° C) and is used in applications where applied heat must be kept to as low a level as possible. An equal mixture of tin and lead, called 50/50 solder, is completely molten at 415°F (213° C), while a 40/60 tin/lead alloy has melted completely by the time it attains a temperature of 455° F (235° C). The latter two alloys are not used very often in electronics work today because their higher melting temperatures require more heating of the solder joint, which might damage heat-sensitive semiconductors.

For almost all electronics work, 60/40 rosin-core solder should be used.

This alloy is available in wire form in several gauges. Thinner gauges are to be preferred over thicker ones. For general-purpose soldering, 18-gauge wire solder is a good choice. Close printed-circuit work calls for the use of No. 20 or 22 solder. Finely drawn solder is not only easier to position above a connection on a densely packed board, but also requires less heat for the formation of a given joint. This is true because fine solder sinks away less heat into the roll of solder than do thicker gauges.

To allow solder to form a good joint, rosin *flux* must be applied to the connection. The flux is available separately, as well as imbedded in wire solder. Even with the latter, it's a good idea to have extra flux on hand so that some can be added to a stubborn joint that won't readily accept solder. Flux is needed to scrub away the microscopic film of oxides on the surfaces of metals to be soldered, and it forms a protective film that prevents reoxidation while the connection is heated to the point at which the solder melts.

For applications *other than* electrical wiring, solders with acid fluxes are available. However, the acid is highly corrosive and will damage both electrical components and wiring. Accordingly, it should *never* be used in electronics applications.

Other Soldering Tools. Very useful in soldering work is a small hand tool called the soldering aid. It consists of a plastic or wood wand with a pointed metal tip at one end and a notched metal tip at the other. The blunt end of the aid is used to clear solder from holes in pc boards and from solder lugs. The notched end can be used to make right-angle bends in components leads, to hold leads and wires while the solder joint is made, and to pry leads away from pc boards and lugs during desoldering operations. There are several other soldering aids available, each with different types of tips (metal brushes, reamers, scrapers, etc.) suited for a specific task.

To protect heat-sensitive components during soldering, heat sinks are required to divert potentially damaging heat from delicate components. A set of alligator clips or commercial clip-on heat sinks made for this purpose can be used. They are clipped onto component leads while the soldering job is accomplished.

Those who work with printed circuit or perforated boards will find a so-called "third hand" circuit-board holder a valuable aid. This type of device usually includes a pivoting head that can rotate to just about any desired angle to facilitate soldering.

Desoldering Equipment. On those occasions when a component must be replaced or a circuit rewired, *desoldering* must be performed. There is a whole series of desoldering implements and aids available to today's electronics hobbyist. Most rely on either vacuum or capillary action to remove the solder after it has completely melted.

A common desoldering tool that employs the vacuum principle is a rubber suction bulb with a Teflon tip. The bulb is employed in the following manner: A soldering iron is applied to the connection to be undone until the solder has melted completely. Then the bulb is squeezed and its tip butted up against the solder joint. The bulb is allowed to expand quickly, creating a mild vacuum which draws the molten solder up into the bulb. Another vacuum type uses a spring-loaded plunger.

The other method of removing solder is to employ capillary action. If a copper braid is placed over the solder to be removed and a soldering iron placed over it, the solder will melt and be drawn up by the wicking action of the copper braid. Specially constructed braids are available for this purpose.

Removing multi-lead components such as ICs presents a special problem. If the component to be removed is still functional, it must be unsoldered quickly lest it be damaged by heat. Alternatively, if the device is defective, it must be removed fairly quickly or else printed-circuit foil conductors might be lifted from the board by excessive heat. The solution to this problem is to employ specialized devices. These might be a special DIP-shaped soldering iron tip and a spring-loaded IC extractor tool. The tool is placed above the IC to be removed and locked into position. The special tip is then mounted on the heating element of a modular iron. When the tip is hot, it's applied to all the dual-inline IC's pins on the foil side of the board. The extractor tool lifts the IC off the board as soon as the solder holding it melts. There are desoldering tools available for use with other IC and transistor cases.

The final item we will mention with respect to solder is flux remover. Although rosin flux is not very corrosive and can usually be left on a circuit board with no ill effects, there are some purists who insist on removing all of it. The circuit board can be scrubbed with a toothbrush and an organic solvent like Toluene to remove flux, or it can be sprayed with a product such as GC Electronics No. 22-270 Flux Remover & Cleaner Spray.

Printed-Circuit Aids. For those who intend to make their own printed-circuit boards, special items are needed for layout and fabrication. If pc foil patterns are to be taken from the page of a magazine, a kit like GC Electronics' Lift It (No. 22-326 or 22-318) is ideal. Those who are designing complex boards from scratch might choose to employ Bishop Graphics or similar pc materials and photosensitizing compounds to produce sharp, detailed foil patterns. A glass or plastic pan, etchant solution, rubber gloves, blank boards, a heat lamp, a thermometer, and a small drill will also be needed.

Complex circuit boards are best produced by means of photographic techniques employing master artwork or the copying of etching and drilling guides published in magazines. Simple boards, however, can be fabricated by the direct application of etchant-resist ink by means of a felt-tip pen made especially for this purpose. Whichever means is employed to produce a printed-circuit board, it should be prepared to accept solder well. One item that's well suited for this application is a nonmetallic scrubbing pad such as the Scotchbrite pad. It can be used to remove etchant resist from the board prior to drilling as well as to remove oxidation from foil.

Wrapping Wire Equipment. A fairly new method of making connections between points in a circuit is the wrapped-wire technique. This involves tightly wrapping the stripped ends of a wire around square (usually 0.025-by-0.025-inch or 0.6-by-0.6-mm) terminal posts. Wrapped-wire connections are quickly and inexpensively made, and are used most often in digital circuits assembled on perforated board.

There are many tools available to those who want to assemble projects using the wrapped-wire construction method. These include a manual, multifunction tool that strips insulation from No. 30 wrapping wire, makes a modified wrapped-wire connection (which adds about 1½ turns of insulated wire to enhance mechanical stability), and unwraps the wire when a connection is to be changed or removed.

Besides the manual wrapping-wire tools manufactured by OK Machine and Tool Corp., Vector Electronics Corp., and other companies, there are motorized tools available for wrapping-wire applications. One such motorized tool is the Model BW-2630 by OK Machine and Tool Corp. It's powered by two NiCd C cells (not included) and accepts one of two bits—one for No. 30 wire, the other for No. 28 or 26 wire.

Besides a wrapping tool, there are several other items the hobbyist interested in utilizing this construction technique must have. The most obvious additional one is wrapping wire. This special wire is available in a variety of colors and comes in spools or in packs of precut lengths with stripped ends. Also necessary are IC sockets designed for wrapped-wire applications and perforated circuit boards with holes of the proper spacing.

Solderless Breadboards. Ideal for designing or experimenting with circuits is a solderless breadboard. This is a plastic block with arrays of holes spaced 0.1 inch (2.5 mm). The block is mounted on a supporting structure and has embedded in it a series of electrical conductors which interconnect adjacent rows or columns of holes. These boards readily accept IC pins and the leads of other electronic components, allowing the hobbyist to build up a circuit with secure, reliable connections without having to resort to soldering or wrapping wire.

A typical solderless breadboard is Continental Specialties' Proto Board No. 103. This board has binding posts for ground and three supply or signal voltages and offers enough tie points for a fairly complex circuit. AP Products, in turn, offers three sophisticated breadboards. These POWERACE models include power supplies and, depending on model, logic indicators, one-shots, pulse detection, two-phase clock, and data switches. Among other companies offering breadboard products are the OK Machine and Tool Corp. and the Heath Company. There are a large variety of finished breadboards available, ranging from simple units with perhaps two binding posts to complex models with built-in fixed or variable regulated supplies, signal generators, potentiometers, etc.

Solderless breadboards are valuable design and experimenting aids that greatly facilitate circuit prototyping. No well-appointed electronics workbench is complete without one!

Wire Cutters and Strippers. We now move into the area of hand tools designed for the manipulation of electrical wires. Before a wire can be soldered, wrapped, or a connector crimped onto it, it must be cut to length and its insulation removed.

The most popular implement used to cut electrical wires and the leads of electronic components is the diagonal-cutting pliers, usually called diagonals or dykes. The diagonal cutters intended for electronics applications should be used only to cut soft metal conductors—*never* to cut iron or steel wire.

The size of the diagonals to be used is determined by the diameter of the wires to be cut. Cutters up to 5 inches long are often employed in electronics applications. Any cutters chosen should be made of high-quality tool steel so that they will make a sharp, clean cut. The tips of the cutters should be tapered to allow the user to reach a particular wire in a crowded area. Cutter jaws should be very well aligned so that cutting edges meet squarely and allow little or no light to pass through when held together. Cutter action should be smooth and clean.

There are, too, a wide variety of specialized cutters—tip cutters, end nippers, etc.—that are handy to have if the budget allows. Diagonal cutters can, if used with care, be employed to strip insulation from wires. Also suited for this purpose is the familiar, inexpensive, yellow-plastic-handled wire cutters/strippers. The object of wire stripping is to remove insulation from the wire without nicking or cutting the conductor.

Far more convenient than traditional wire cutters/strippers are precision, automatic strippers. Although such tools are expensive, they can be real timesavers when there's a lot of point-to-point wiring to be done.

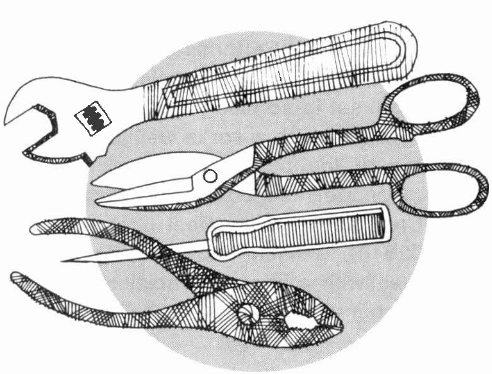
Sometimes a situation arises where insulation is to be *added* to a wire or wire splice. Although PVC (*not* cloth!) electrical tape can be used for this purpose, *heat-shrink* tubing is far more convenient. It is composed of a special plastic material which contracts when heated to a relatively high temperature. Heat-shrink tubing comes in a variety of lengths and diameters to suit any number of applications. There is even heat-shrink electrical tape available for a really *tight* fit.

Pliers. One of the most commonly used class of tools is pliers. In electrical work, needle- and long-nose pliers are necessities. Mechanical work, on the other hand, often involves the use of slip-joint or gas pliers.

Frequent tasks for long-nose pliers include holding wires in place during soldering, acting as a heat sink to protect a delicate component, bending component leads to fit mounting holes on a circuit board, and pulling wires through a panel or chassis hole.

Such pliers are available in a wide range of sizes and configurations. A small size (about 4.5 inches) with a long, thin nose is best for electronics applications. A single pair of longnose pliers is adequate for most jobs, but having several on hand can simplify a task.

Alignment Tools. If a hobbyist intends to work on communications projects, he should have a set of alignment tools on hand. Among the items in this category are a neutralization tool (a plastic or wooden tubular holder with a small metal blade inserted in one end), a nonmetallic screwdriver, and a plastic hexagonal slug-alignment tool. Most alignment tools are nonmetallic and fairly long in size. Using a nonmetallic tool enhances safety because of the tool's insulating property. It also prevents disturbance to sensitive r-f circuits that can be detuned merely by bringing a metal tool near frequency-determining devices. Similarly, the use of a long alignment tool minimizes the effects of hand capacitance.



Tools For Mechanical Work

Drivers. This category includes screwdrivers and nut drivers. Both are extremely important to the mechanical work ancillary to personal electronics hobby activities.

There are two basic types of screwdrivers—blade and Phillips. A typical electronics project will employ a dozen or more screws to fasten circuit boards, terminal strips, etc., to the chassis or enclosure. Therefore, a complement of screwdrivers must be kept on hand.

Blade screwdrivers come in a great number of sizes. A minimum of three should be at hand for electronics work, with the following blade sizes: 1/8 inch; 3/16 to 1/4 inch; and 5/16 inch or larger. If possible, a larger selection of blade screwdrivers should be maintained.

There are several "specialty" screwdrivers which are not necessary, but are on occasion very handy. One is a "stubby" screwdriver with a short shaft. It's very useful in tight quarters. In really tight situations, an *offset* screwdriver can be especially helpful. Another useful "specialty" screwdriver is one that holds a screw against the blade of the driver. The Stanley Works makes such a device, called the "Screwstart", which can be added to an existing driver.

Phillips screws, those with star-shaped holes in their heads as opposed to straight slots, are often found in electronic equipment. Phillips screwdrivers, like many other hand tools, come in a variety of sizes. There are four standard points, No. 1 through 4. The star-shaped hole in a Phillips screw and the tip of a Phillips driver must fit together properly so that the walls of the screw head or the tip of the driver or both will not be damaged. In electronics work, No. 1 and No. 2 Phillips drivers are those usually employed.

One way to satisfy screwdriver requirements is to buy a driver set containing a handle into which any of several driver shafts can be inserted, such as Xcelite's Model CK-5 driver set. Each of the shafts is doubled-ended, yielding two different tips on each shaft.

Nutdrivers are like screwdrivers except that they fit nuts instead of screwheads. They are very useful in mounting a nut on a captive threaded stud and in holding a nut while its screw is being tightened. (A pair of pliers should *not* be used to hold hex- or square-head screws.) Nutdrivers are available as individual drivers with separate handles, as individual driver shafts that plug into a common handle, or as individual sockets that plug into a universal handle/shaft combination. There are master driver sets available that include nutdriver shafts, slotted screwdriver shafts, and Phillips screwdriver shafts.

Nutdrivers are available with either solid or hollow shafts. The major advantage to hollow-shaft drivers is that they allow the user to keep a grip on the nut even though the screw on which the nut is mounted is protruding. Stubby nutdrivers are handy when work is to be done in tight places. These can be bought in sets that include a large slip-on handle that multiplies torque. Extra-large nut drivers permit the installation of potentiometers and rotary switches without risking damage to the control panel.

Selecting Drivers. As in the case of pliers, cutters, and other hand tools, there are many, many companies manufacturing drivers. It is better and more economical in the long run to buy high-quality tools than so-called "bargains." How can the electronics hobbyist tell that the tools he is thinking of buying are of high quality? Here are a few things to look for.

The handles should be sturdy, made of heavy-duty plastic, and preferably have rubber grips for comfort. Tool shafts should be deeply and firmly embedded into handles in the case of individual drivers (as opposed to plug-in sets). The shafts of plug-ins should lock firmly into place when inserted in the master handle. Tools should have shafts of tempered, plated steel and have ground tips. They should be well-balanced and comfortable in the hand. Perhaps the easiest way to choose high-quality tools is to stick with established names such as Xcelite, Stanley, Vaco, Channellock and Sears Craftsman.

Allen Wrenches and Miniature Drivers. Many control knobs have small Allen or slotted setscrews. To install or remove such knobs, a set of Allen wrenches and miniature screwdrivers should be kept on hand. There are other uses for miniature tools, especially in such fields as remote control modeling, model railroading and slot-car racing, and the fabrication of miniaturized electronic projects. Performing such work when equipped with a precision miniature tool set is so much easier that the purchase of such a set is well justified.

One of the big names in miniature precision tools is Moody Tools, Inc. (42-60 Crompton Avenue, East Greenwich, RI 02818). Jensen Tools & Alloys is another, with a host of precision tools, including many tool kits (1230 So. Priest Dr., Tempe, AZ 85281).

Wrenches. There are several types of wrenches that the electronics hobbyist will need from time to time. Among them are the open-end wrench, the box wrench, and the plier wrench or "vise-grips" tool.

Open-end wrenches are used primarily on the large hexagonal nuts that secure switches and controls to project panels (actually, a large nut driver is better suited for this application) and to operate chassis punches. The box wrench has similar applications but has the advantage of completely enclosing the nut, thus eliminating the danger of slippage that can mar a finished front panel. Box wrenches are not essential, but are handy to have around if the workbench budget permits.

The plier wrench or "vise-grips" is a tool that is not found on every electronics workbench, but it should be. Not only is this an excellent tool for applying brute torque to the task of turning bolts, nuts and shafts, it can also serve as a restraining tool and as a "third hand" for holding small parts, circuit board assemblies, etc. A pair of vise-grips can be adjusted for a given jaw opening and has a locking lever and in some cases a separate unlocking lever for quick-action clamping and release. Vise-grips come in several sizes, but a 10-inch model is sufficient for most workbench applications.

Metal-Working Tools. Experimenters who mount their projects in metallic enclosures will need an assortment of metal-working and metal-finishing implements. A hacksaw is used to cut large and irregular-shaped chassis holes, to trim control shafts, to cut off brackets, etc. Most hacksaws are adjustable so that they can accept blades of several different lengths. More important than blade length, however, is coarseness. The number of teeth per unit length determines blade coarseness. For general-purpose work, a hacksaw blade should have between 14 and 18 teeth per inch. A relative of the hacksaw, the "coping saw," has a thin blade and is very handy when cutting curved and irregular-shaped holes.

Metal shears allow the hobbyist to cut sheet metal for chassis, brackets, shields and other items. Chassis punches take much of the drudgery out of cutting large holes in chassis and panels for meters, connectors, sockets, etc. Chassis punches, which are manufactured by such companies as Greenlee Tool and GC Electronics (both in Rockford, IL), come in a variety of shapes and sizes, and should be selected for the types of holes that might have to be made.

A metal nibbling tool can be used to make just about any needed chassis or panel opening. This tool starts at a predrilled hole and is guided along the area to be cut out, taking bite-size chunks out of the metal as it is moved along. Cutting a large hole in a piece of sheet metal can be a tedious procedure with a nibbling tool, but the nibbler will provide good results if care is taken in using it.

Drills. Perhaps the most commonly used metal-working tool from the electronics hobbyist's point of view is the electric drill. A drill for the electronics workbench should have a chuck capacity of 1/4 or 3/8 inch (6.4 or 9.5 mm) and should have variable-speed control. (Slow speeds are ideal for starting holes and for drilling through soft materials.)

The drill should also have either a three-conductor power cord and a metal body or a two-conductor cord and a double-insulated plastic body. Its motor should be rated at a minimum of 1/4 horsepower. For maximum user comfort, the drill should fit comfortably in the hand and should be well balanced.

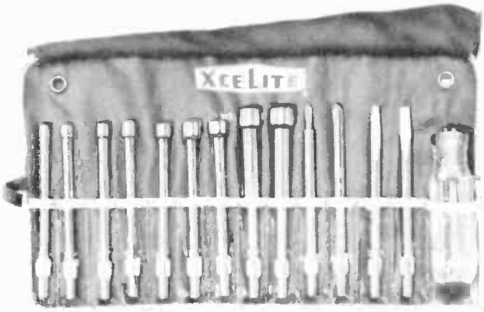
The piece of metal that does the actual cutting of the material being drilled is called a drill bit. There are two general classes of drill bits—those composed of carbon steel and those composed of tungsten-molybdenum steel. The latter is called "high-speed steel" and is used in the manufacture of high-speed drill bits. Because of their superior cutting and wearing characteristics, high-speed bits are the clear choice for the electronics hobbyist. The most economical way to purchase an array of high-speed drill bits is in a set that includes units with diameters ranging from approximately 3/32 inch (2.4 mm) to 1/4 or 3/8 inch (6.4 or 9.5 mm).

Ancillary items for drilling and other metal work are a center punch, a ball-peen hammer, a reamer, a heavy-duty bench vise and a set of files.

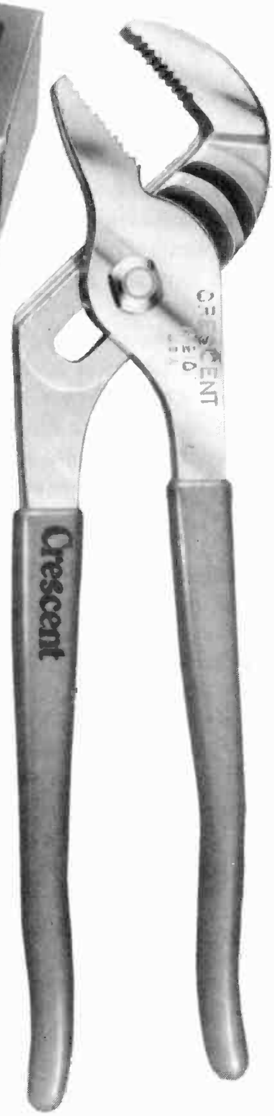
At least one centerpunch is needed to make indentations in the material to be drilled at the exact centers of the holes to be made. These indentations will prevent the bit from wandering around the surface when first brought up to speed.

A reamer is used to enlarge holes in sheet metal, and can also be used to remove burrs around the perimeter of a freshly drilled hole. General-duty work calls for a 1/2-inch (1.3-cm) tapered reamer. A heavy-duty bench vise will be

*Moody Tools
miniature precision tools.*

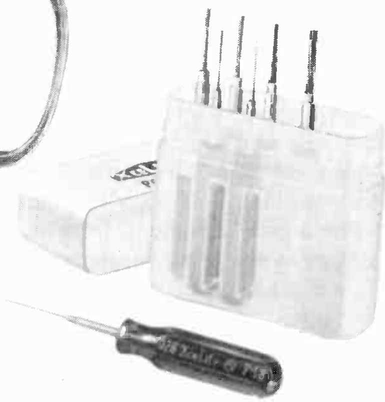


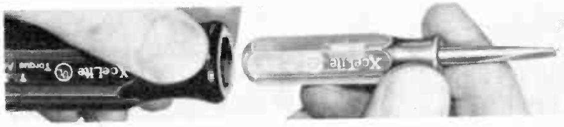
Xcelite Model 99-PR driver set.

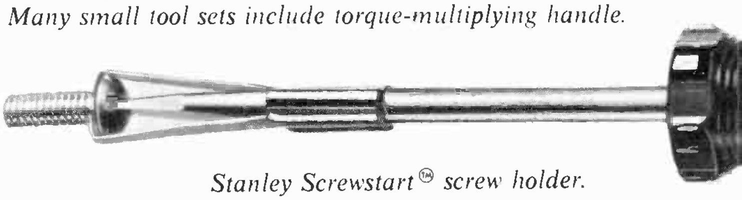


Crescent Tool adjustable offset wrench

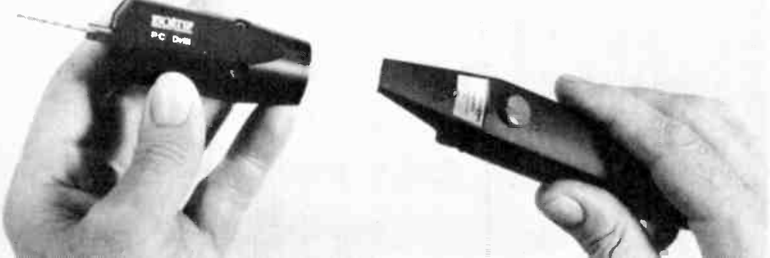
Wiss metal shears.


Xcelite Model PS-89 Allen drivers.


Many small tool sets include torque-multiplying handle.

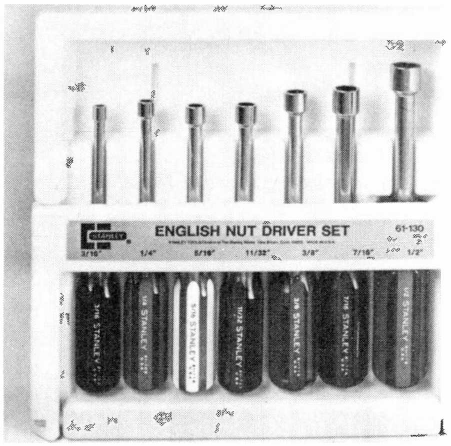

Stanley Screwstart® screw holder.

Wahl Model 6590 PC drill attachment for Isotip soldering irons.

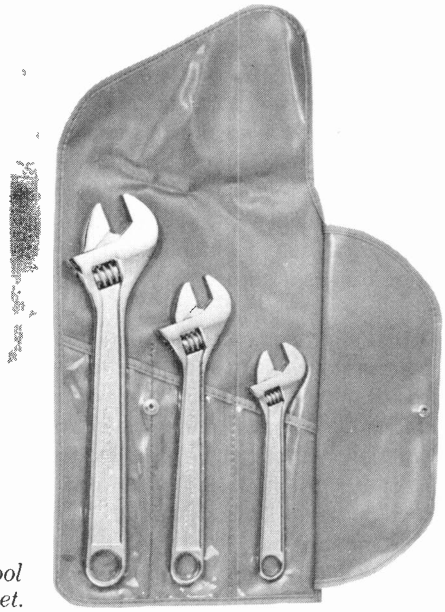


needed if a lot of metal working will be done. It is very useful in holding chassis and other items as they are drilled or sawed. The jaws of the vise should be at least 2 inches long, and the vise should be a swivel unit which rotates in the horizontal plane. This will allow its jaws to form any desired angle with respect to the edge of the workbench.

At least four files should be kept on hand for metal work. Round, half-round, and "rat-tail" files are especially useful in opening up a hole or deburring. Most electronics metal work involves aluminum chassis. Because aluminum is relatively soft, coarse files are the best.



Stanley Model 61-130 nut driver set.



Crescent Tool adjustable wrench set.

Miniature Power Tools. Hobbyists who do a lot of printed-circuit work will find most power tools to be too big and unwieldy. The answer to their problem is a miniature electric hand drill designed especially for pc applications. Among the companies that make such tools are Micro Electronics Systems, Weller, Dremel, and the Wahl Clipper Corporation.

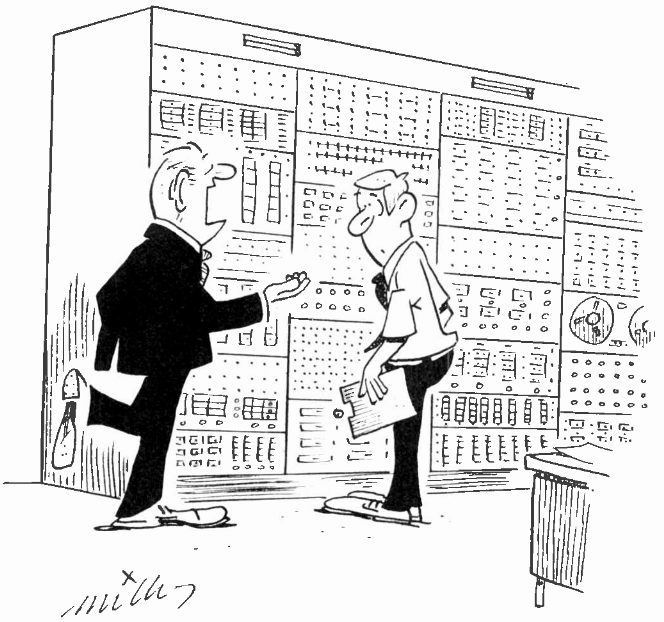
Those printed-circuit enthusiasts who already have a Wahl "Isotip" cordless soldering iron will no doubt be interested in Wahl's Model 6500 PC Drill attachment. This unit plugs into the body of the soldering iron and converts it into a battery-powered electric drill with a No. 56 bit and an operating speed of 10,000 to 12,000 rpm. Wahl also makes specialized Electronics Technician Drills with collet chucks designed specifically for pc applications.

A good tool to use for circuit-board work is the Dremel Moto Tool high-speed drill and grinder, which comes in models ranging from the general-purpose Model 260 to the heavy-duty, variable Model 380. Light in weight, the tool is easy to handle and accepts drill bits ranging from No. 80 to No. 30, depending on which of three chuck collets is to be used.

Another flexible hand-held power tool is the Weller Model 651K variable-speed Mini-Shop Kit. This kit includes a handheld power tool and a whole complement of drilling, grinding, polishing, sanding and cutting attachments. Such mini-tools are not for everyone, but those who do a considerable amount of close circuit-board work wouldn't be without one.

In Conclusion. Hands-on personal electronics calls for a work area stocked with a considerable assortment of tools, test equipment, hardware, etc. Some items are absolutely necessary; others are convenient and enhance work efficiency. Many implements can be found in any well-stocked hardware store. Others are specialty items that must be obtained from more exotic sources. Look into your needs now so that your future electronics work will be more enjoyable to pursue. ◇

"...IT'S HANNIGAN AGAIN...WHAT'S A 'GOOD' WAY TO INFORM A CLIENT THAT OUR MAN JUST RESTED THE C.R.T. DE-GAUSSER ON A COLLECTION OF VIDEOTAPE MOVIES WITH POWER SWITCH 'ON'?"

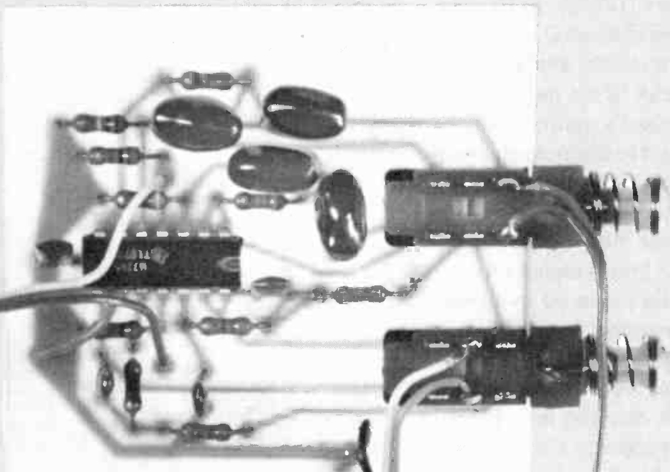


"THIS NEW MICROCOMPUTER REPLACES THAT UNIT. WHERE DO YOU WANT IT?"

HIGH PERFORMANCE "SCRATCH & RUMBLE" FILTERS

Low-cost ultrasonic/infrasonic circuit plugs into preamp's external jacks

BY JOHN H. ROBERTS



IN THEORY, "scratch" and "rumble" filters are useful additions to an audio system. In practice, however, the filters built into many components have either inappropriate cutoff frequencies or too gradual slopes (or both) to adequately perform their intended functions. If you're dissatisfied with those contained in your preamplifier, integrated amplifier, or receiver, try the quartet of high-performance active filters presented here.

These filters are designed around a quad BIFET operational amplifier IC, and can be inserted into or removed from the signal chain at the push of a switch. The project can be built at low cost, and its compact size allows it to be tucked into an existing audio component. Also, its modest power requirements can easily be satisfied by the host component.

About the Filters. One of the simplest active filter designs is based on the voltage-controlled voltage source configuration. This circuit is commonly known as the Sallen/Key design because it was described in a paper by R.P. Sallen and E.L. Key that appeared in the March 1955 issue of the *IRE Transactions on Circuit Theory*. Shown schematically in Fig. 1 are second-order, high-pass (A) and low-pass (B) active filters employing operational amplifiers. Although op amps as we know them were not available in 1955, Sallen and Key's paper is applicable to filters employing more recently developed active devices.

These filters have unity gain within their passbands, a gain that is independent of resistor values. They have second-order responses, which exhibit an attenuation of 3 dB at the cutoff frequency and an ultimate slope of 12 dB/octave. For audio applications, the most useful VCVS filter is one whose response is "maximally flat," whose *Q* is 0.707. This is true of the filters described in this article.

The cutoff (−3-dB) frequency of the high- or low-pass filter can be calculated from $f_c = 1/[2\pi(R1R2C1C2)^{1/2}]$. In the high-pass filter of Fig. 1A, the value of *C1* is chosen to equal that of *C2* and the resistance of *R1* is chosen to be half that of *R2*. This simplifies the equation for the cutoff frequency so that it takes the form: $f_c = 1/2.828\pi C1R1$. Similarly, in the low-pass filter of Fig. 1B, the resistance of *R1* is chosen to equal that of *R2* and the capacitance of *C2* is chosen to be half that of *C1*. The simplified equation for the low-pass cutoff frequency is: $f_c = 1/2.828\pi R2C2$. Note that the low-pass filter resembles the high-pass design except that the positions of the resistors and capacitors have been interchanged.

If optimal filter performance is to be achieved, the passive components used should be of high quality. For example, the resistors should be carbon- or metal-film components and the capacitors should have mica, polystyrene or Mylar dielectrics. The criteria for choosing the operational amplifier are those that make an op amp well suited for use as a voltage follower—high input impedance, low input current, and high speed. The author's choice is the Texas Instruments TL074CN, a quad BIFET op amp that satisfies these requirements handily.

The complete schematic of the project is shown in Fig. 2. In all, four filters appear in this diagram—a low-pass and a high-pass filter for each stereo channel. The component designations not shown in parentheses pertain to the left-channel circuit. Those component numbers given parenthetically pertain to the right-channel filters.

If both selector switches (*S1* and *S2*) are in their OUT positions, the filter outputs are left floating. Placing HIGH PASS selector switch *S1* in its IN position connects the outputs of the high-pass filters (*IC1A*, *IC1B* and their associated components) to the OUT positions of LOW PASS selector switch *S2* and to the inputs of the low-pass filters (*IC1C*, *IC1D* and their associated components).

If *S2* is in its IN position, signals pass through the low-pass filters before they appear at the project's output. Otherwise, they are routed to the output terminals without being high-pass filtered. This switching arrangement allows the connection of either filter alone, both together, or neither in the signal chain.

The circuit can be powered by either a bipolar or single-ended supply. Maximum voltages are ±15 volts for a bipolar supply and +30 volts for a single-ended one. Current demand is approximately 10 mA. Components *C9*, *R9*, and *R10* are required only if a single-ended power supply is used. They generate an artificial "circuit ground" which is designated in Fig. 2 using the conventional chassis-ground symbol. Contrast this with the system signal ground appearing at the input and output terminals of the project. An earth-ground symbol signifies system signal ground to differentiate it from the artificial "circuit ground."

A single-ended supply is represented to the right of the passive components as a battery generating voltage V_{SUPPLY}. Traditionally, the chassis on which a positive, single-ended power supply is mounted becomes the negative return and is also used as the signal ground for the circuit powered by the supply. In the case of these active filters powered by a single-ended supply, the chassis can be used as the input and output signal ground (which will be tied to system ground), but the artificial ground generated by the passive components must be kept isolated from it. The artificial ground will be at a dc level equal to one half of the supply voltage, and the chassis (system) ground will act as the −V negative supply for the quad op amp.

If a bipolar supply is used, the artificial and system grounds should be tied together. Direct coupling can be employed between the stage preceeding the filters and the project input terminals as well as between the project output terminals and the input of the next stage in the signal chain. However, if the circuit is powered by a single-end supply, capacitive coupling should be used.

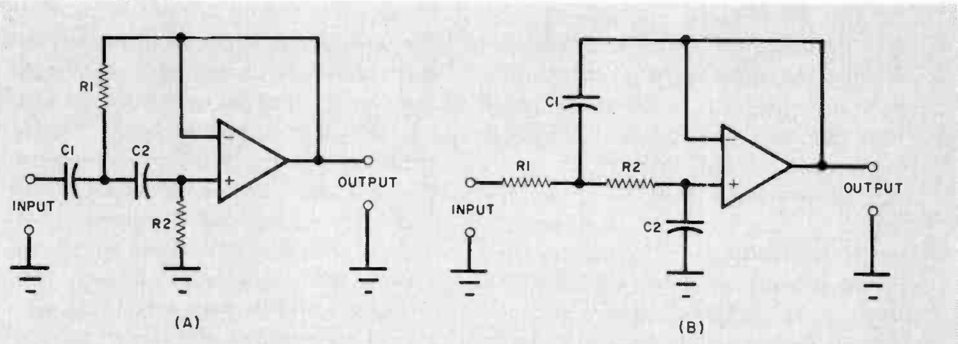


Fig. 1. Second-order high-pass (A) and low-pass (B) filters.

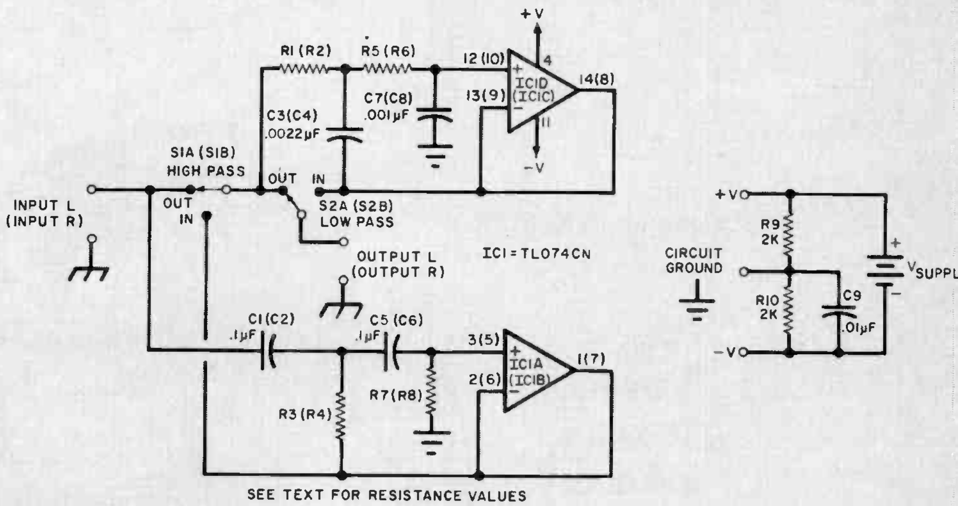


Fig. 2. Schematic diagram of the complete project.

PARTS LIST

C1,C2,C5,C6—0.1-µF 5% Mylar, mica or polystyrene
C3,C4—0.0022-µF 5% Mylar, mica or polystyrene
C7,C8—0.001-µF 5% Mylar, mica or polystyrene
C9*—0.01-µF Mylar, disc ceramic, mica or polystyrene
IC1—TL074CN quad BIFET op amp
The following are carbon-film, ¼-watt, 5%-tolerance (or metal film, ¼- or ⅛-watt, 1% tolerance) fixed resistors unless otherwise specified.
R1,R2,R5,R6—see text for value.
R3,R4—see text for value.
R7,R8—see text for value.
R9*,R10*—2000 ohms, ½-watt, 5% or 10% tolerance, carbon-composition or carbon film.
S1,S2—Dpdt switch
Misc.—Printed circuit or perforated board, IC socket or Molex Soldercons, suitable power supply and enclosure, hookup wire, shielded cable, circuit board standoffs, hardware, solder, etc.
* These components are required only if a single-ended power supply is used.

NOTE-*The following are available from Phoenix Systems, 91 Elm St., Manchester, CT 06040: kit of parts including printed circuit board, IC, switches, and resistors and capacitors for two 20- or 50-Hz high-pass and two 13,000- or 19,000-Hz low-pass filters, No. P-91S for $15.00. Also available separately are; TL074CN quad BIFET op amp IC, No. P-91C, for $2.50; etched and drilled printed circuit board, No. P-91B, for $5.00; push-on/push-off dpdt switch, No. P-91SW, for $1.00 each. Connecticut residents, add 7% state sales tax. If order is less than $10.00, add $1.00 shipping and handling.*

Construction. The project is relatively simple, so point-to-point, wiring, wrapped-wire, or printed-circuit assembly techniques can be used. Etching and drilling and parts placement guides for a suitable printed circuit board are shown in Fig. 3. If another assembly method is chosen, observe sound construction practices for circuits containing high gain-bandwidth devices. Keep leads short and run grounds carefully.

The use of Molex Soldercons or an IC socket is recommended. Be sure to orient the IC correctly and pay attention to polarities when making connections to the power supply. Use the minimum amount of heat and solder consistent with the formation of good connections.

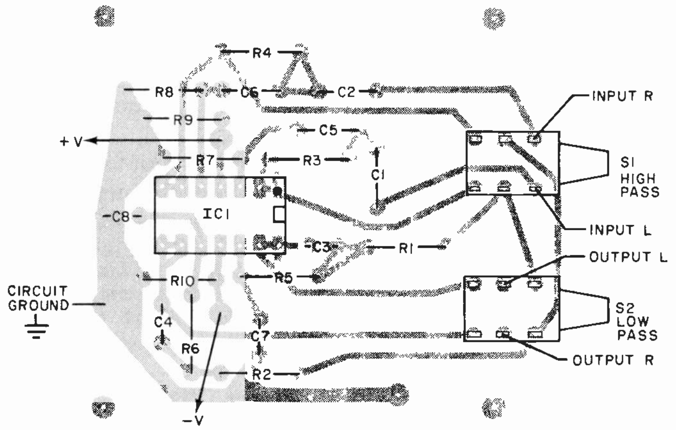
The circuit board has been laid out to accommodate pc-mount push/push switches. These switches are available from the source given at the end of the Parts List. If you want to employ another type of switch, simply interconnect the foil pads with the appropriate lugs of the remotely mounted switches with lengths of flexible hookup wire.

Mount the filter board either in the enclosure of a host audio component or in an enclosure specially selected for this purpose. The board should be installed in such a way that board-mounted switches (if used) are readily accessible. If the project is placed inside an existing audio component, the simplest way to satisfy the project's modest power requirements is to tap the host's supply. A high-voltage supply can be used to power the project by introducing zener voltage regulation.

You will note that the values of all of the *RC* components in the active filters have not been specified in the schematic or the Parts List. This has been done to allow you to choose the cutoff frequencies of the filters that you assemble. The design equations for the low- and high-pass filters were given earlier. In the high-pass design, use equal values of capacitance (0.1 μF) for *C1, C5, C2,* and *C6*. Select the resistance of *R2* so that it is double that of *R1*. The value of *R1* can be calculated using the high-pass design equation. In the low-pass filters, use equal values of resistance for *R1, R5, R2,* and *R6*. The capacitance of *C7* and *C8* should be half that of *C3* and *C4*. Recommended values are 0.0022 μF for *C3* and *C4* and 0.001 μF for *C7* and *C8*. Resistance values for any desired cutoff frequency can be calculated using the low-pass design data.

The most common application for the high-pass filter is to attenuate low-frequency turntable rumble. To be an effective rumble filter, the circuit should attenuate the low-frequency rumble without significantly altering the spectral power density of the program material. Most musical recordings contain little information in the bottom bass octave, so 50 Hz is an acceptable cutoff frequency. Component values that will produce a 50-Hz, −3-dB frequency are: *C1, C5, C2, C6*—0.1 μF; *R3, R4*—22,000 ohms; *R7, R8*—47,000 ohms. Those readers who want any deep bass present in their recordings to come through unattenuated will prefer a lower cutoff frequency. Component values that will result in a cutoff frequency of 20 Hz are: *C1, C5, C2, C6*—0.1 μF; *R3, R4*—56,000 ohms; *R7, R8*—110,000 ohms. For a cutoff frequency other than the two just given, calculate new resistance values.

Low-pass filters are frequently employed to attenuate FM hiss and disc surface noise. They are also useful to attenuate 19,000-Hz FM stereo subcarriers that can interfere with the taping of broadcasts off the air. To be an effective hiss or subcarrier filter, the circuit should attenuate high-frequency noise, etc., without the loss of program content at lower frequencies. Most musical program material contains little information in the extreme highs, so 13,000 Hz is an acceptable cutoff frequency. Component values that will produce this response are: *R1, R5, R2,* R6—8200 ohms; *C3, C4*—0.0022 μF; *C7, C8*—0.001 μF. For a higher cutoff frequency, say, 19,000 Hz, use the following component values: *R1, R5, R2, R6*—5600 ohms; *C3, C4*—0.0022 μF; *C7, C8*—0.001 μF. If you prefer a cutoff frequency other than the two just given, calculate new resistance values.



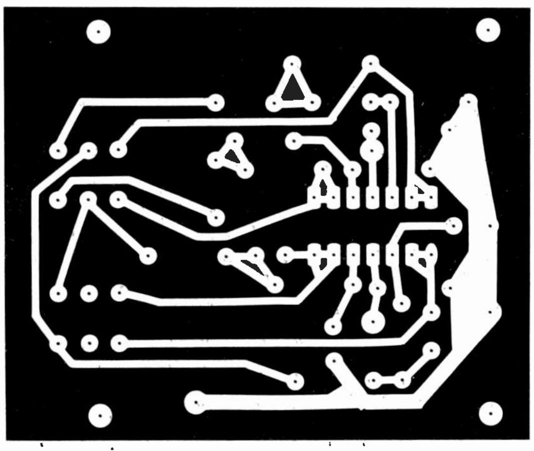
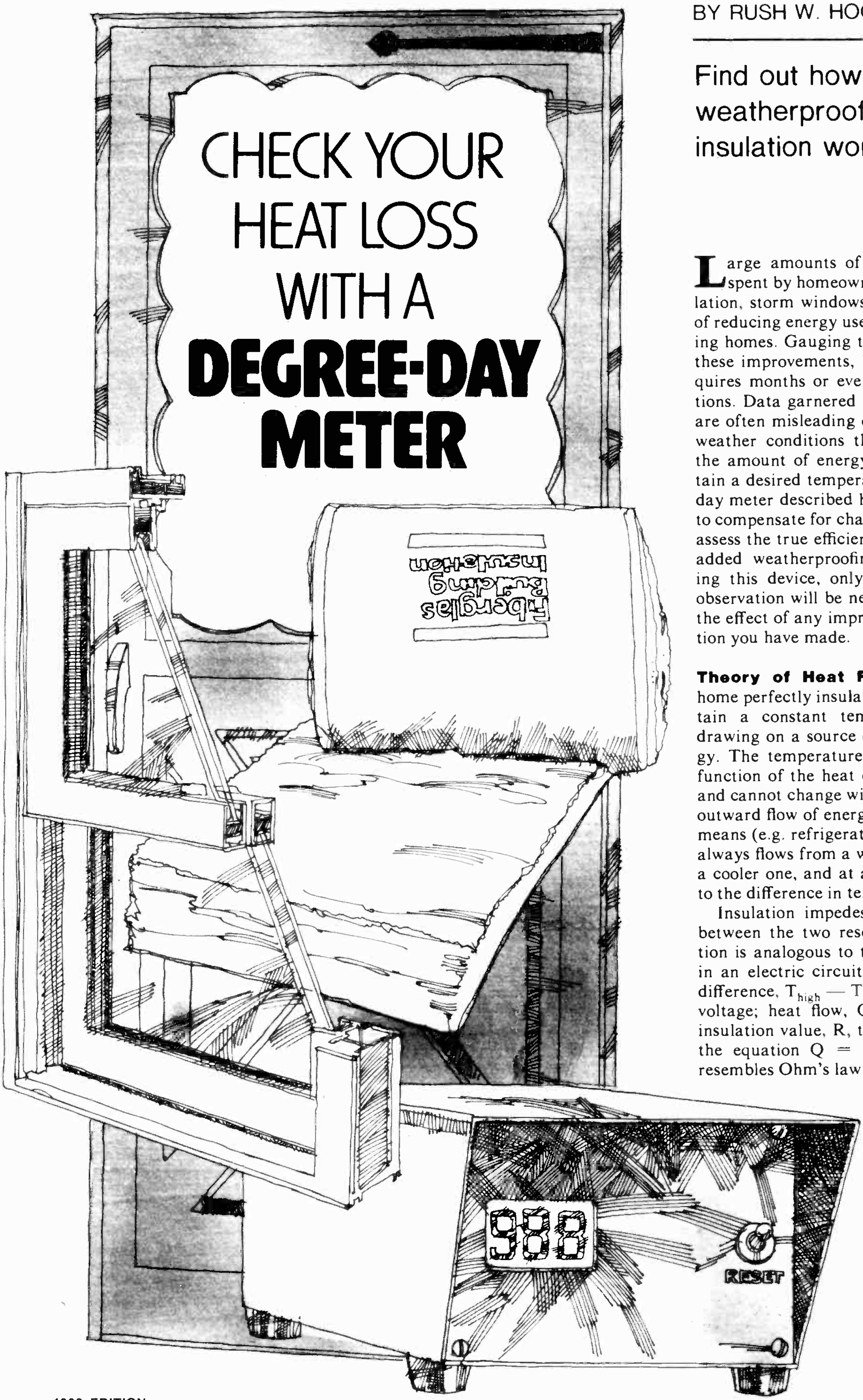


Fig. 3. Full-size etching and drilling guide for printed-circuit board is shown at left. Diagram for layout of components is above.

Installation and Use. The project can be introduced into the audio system at any point where signals are at line level. Two possibilities are at a tape monitor loop and between the preamp output and power amplifier input. It's good practice to insert a 51-ohm resistor between the "hot" output terminal of each channel's circuit and the inner conductor of the cable which carries signals to the input of the next stage. This can prevent oscillation due to the effects of cable or load capacitance.

In Conclusion. The active filters presented in this article offer a higher level of performance than those included in many audio components. A bit of experimentation will convince you how useful properly designed low- and high-pass audio filters really are. ◊

CHECK YOUR HEAT LOSS WITH A DEGREE-DAY METER



BY RUSH W. HOOD

Find out how well your weatherproofing and insulation work

Large amounts of money are being spent by homeowners today on insulation, storm windows and other means of reducing energy use and cost for heating homes. Gauging the effectiveness of these improvements, however, often requires months or even years of tabulations. Data garnered from supplier bills are often misleading owing to changing weather conditions that directly affect the amount of energy needed to maintain a desired temperature. The degree-day meter described here will allow you to compensate for changing weather and assess the true efficiency of your home's added weatherproofing. Moreover, using this device, only a day or two of observation will be needed to determine the effect of any improvement in insulation you have made.

Theory of Heat Flow. Were your home perfectly insulated, it would maintain a constant temperature without drawing on a source of additional energy. The temperature of an object is a function of the heat energy it contains, and cannot change without an inward or outward flow of energy. Unless artificial means (e.g. refrigeration) are used, heat always flows from a warmer reservoir to a cooler one, and at a rate proportional to the difference in temperature.

Insulation impedes the flow of heat between the two reservoirs. The situation is analogous to the flow of current in an electric circuit. The temperature difference, $T_{high} - T_{low}$, is equivalent to voltage; heat flow, Q, to current; and insulation value, R, to resistance. Thus, the equation $Q = (T_{high} - T_{low})/R$ resembles Ohm's law.

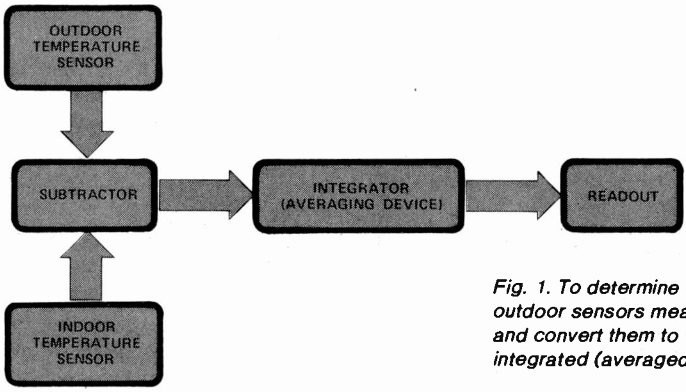


Fig. 1. To determine degree-days, the indoor and outdoor sensors measure temperatures and convert them to voltages, which are subtracted, integrated (averaged) and applied to readout.

If the temperatures inside and outside your home were constant for a long period of time, you could simply measure the temperature difference and the rate of energy use by reading the gas or electric meter and calculate the average insulation value of your building. Because the temperature of the outside air changes too rapidly to allow such procedure, the degree-day was devised.

A degree-day is computed from temperature readings taken at frequent, regular intervals throughout the day. These readings are subtracted from a reference temperature, usually 68°F, and the differences are averaged over one day. If a day is reported to have had 15 degree-days, for example, the energy needed to heat your home would have been the same as if outside had been 15 degrees cooler than inside all day.

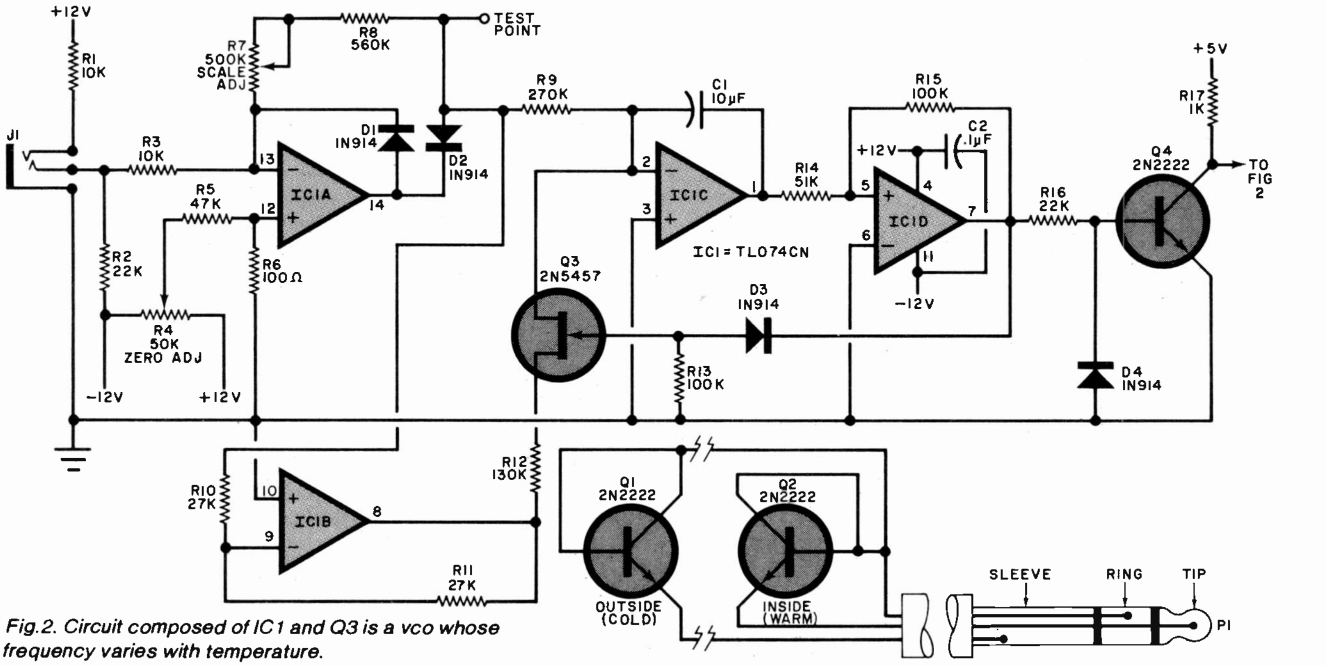


Fig.2. Circuit composed of IC1 and Q3 is a vco whose frequency varies with temperature.

PARTS LIST

C1—10-μF,25-V Mylar or polyester capacitor
C2—0.1-μF ceramic capacitor
C3—1000-μF, 25-V electrolytic
C4—100-μF, 25-V electrolytic
C5,C6—0.33-μF, 25-V tantalum capacitor
D1 through D4—1N914
D5,D6—1N4001 1-A, 50-V rectifier
DISP1,DISP2,DISP3—Common-anode display (MAN4610 or similar)
F1—1-A, fast-blow fuse
IC1—TL074CN quad BIFET op amp
IC2—74LS93 binary counter
IC3,IC4,IC5—74LS90 BCD counter
IC6,IC7,IC8—74LS47 BCD-to-seven segment decoder
IC9—7812 + 12-V regulator
IC10—7805 +5-V regulator
IC11—7912 − 12-V regulator
J1—Open-circuit stereo phone jack
P1—Stereo phone plug
Q1,Q2,Q4,Q5—2N2222 transistor
Q3—2N5457 FET transistor (Radio Shack 276-2028)
The following are ¼-W, 5% carbon resistors unless otherwise noted:
R1,R3—10 kΩ
R2,R16—22 kΩ
R4—50 kΩ trimmer potentiometer
R5—47 kΩ
R6—100 Ω
R7—500 kΩ trimmer potentiometer
R8—560 kΩ
R9—270 kΩ
R10,R11—27 kΩ
R12—130 kΩ
R13,R15—100 kΩ
R14—51 kΩ
R17,R18—1 kΩ
R 19—4.7 kΩ
R20 through R41—1.2 kΩ
S1—Spst normally open pushbutton switch
T1—12.6-V, 1-A transformer
Misc.—Aluminum enclosure, printed circuit or perforated board, IC sockets, red plastic for display window, line cord and plug, strain relief, etc.

Note: The following is available from HLW, P.O. Box 1026, Beaverton, OR 97075: complete kit of parts for $97.50, plus $3.50, postage and handling. Also available from the same source is an etched and drilled printed circuit board for $9.00.

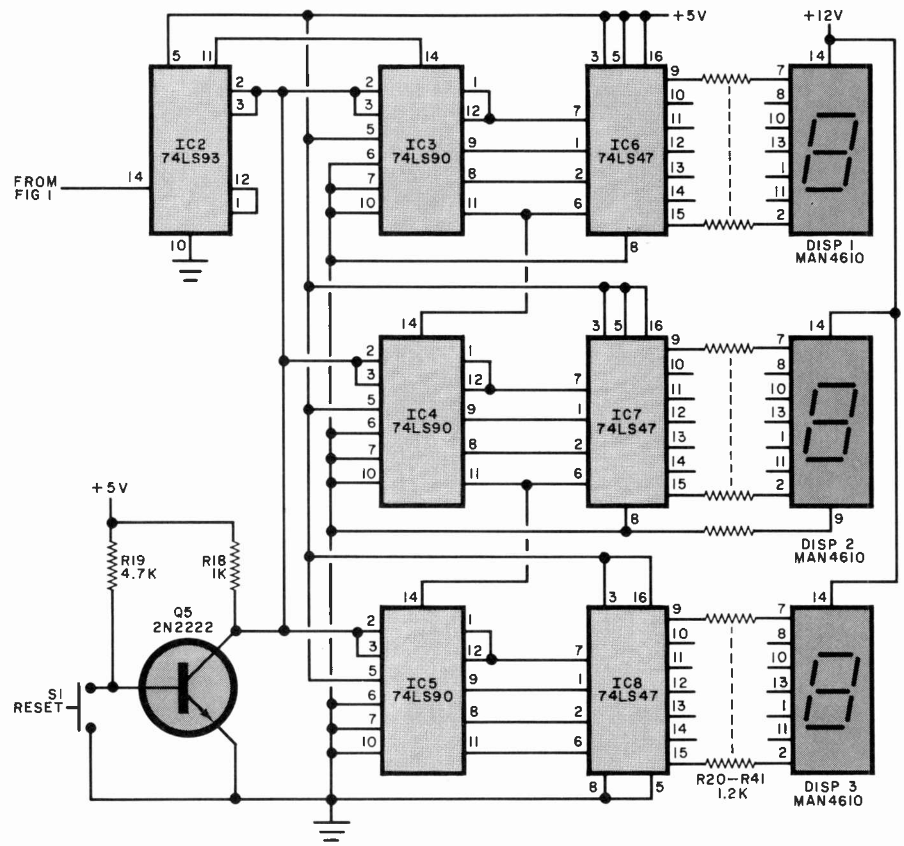
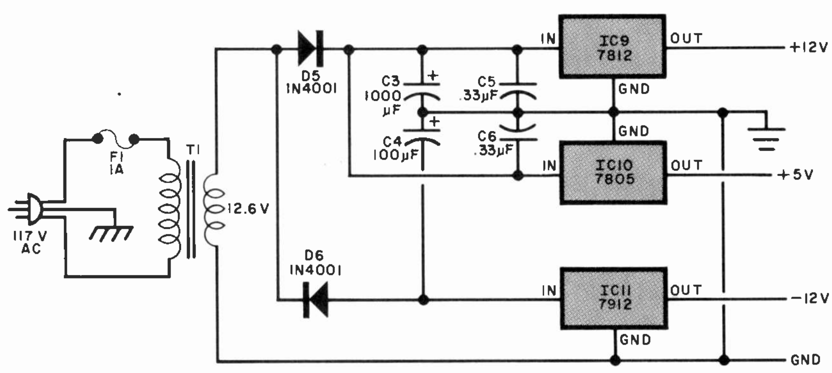


Fig. 3. Other than the divide-by-16 counter (IC2), digital circuit is conventional 3-digit counter, decoder and display.

Degree-days reported by your local weather service can be useful, but they may not be sufficiently accurate for critical measurements. Your inside temperature may not be the standard 68 degrees, and may vary through a 24-hour period. This degree-day meter project calculates the degree-days from the temperatures inside and outside your particular home.

How it Works. The meter continuously senses the indoor and outdoor temperatures, subtracts them and integrates the difference. Analog and digital circuit techniques are used to maintain the integration accuracy over long periods of time and to provide a numerical readout. The block diagram in Fig. 1 summarizes, in an easy-to-follow method, the device's operation.



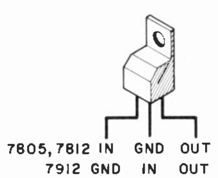


Fig. 4. The three voltage sources are derived from regulators. Note the pin-out differences between the ICs.

Circuit Design. The subtracting and integrating circuits are shown in Fig. 2. Indoor and outdoor temperatures are sensed by silicon transistors *Q1* and *Q2*, which are connected as diodes. A constant current passing through a silicon diode junction develops a voltage drop that varies approximately linearly with temperature at a rate of 1.2 mV/°F. The two sensors are connected in series opposition, so that the voltages across them are subtracted. The difference voltage taken from the junction of the two transistors is proportional to the difference between the two temperatures.

Integrated circuit *IC1A* supplies enough gain to boost the difference signal so that it varies at a rate of 100 mV/°F. It also acts as a half-wave rectifier, making the meter insensitive to situations in which the outside temperature exceeds the inside temperature, which could happen on sunny days. Sections, B, C, and D of *IC1* and FET *Q3* with its associated components form a voltage-controlled oscillator (VCO) whose average output frequency is 160 cycles per degree-day. The output of *IC1A* is coupled to the inverting (−) input of integrator *IC1C* (which averages the signal) via R9 and to inverter *IC1B* through *R10*. The output of *IC1B* is coupled through *R12* and FET switch *Q3* directly to the inverting input of *IC1C*. When *Q3* is turned on, its drain-to-source channel resistance, coupled with *R12*, is one-half the value of *R9* and the *IC1B* signal to *IC1C* is twice that from *R9* and is of the opposite polarity. Thus, the integrator is fed with either a plus or minus 100-mV/°F signal depending on the state of switch *Q3*. A negative voltage applied to the gate of *Q3* turns the transistor off.

The integrator output is coupled to comparator *IC1D*, which has a hysteresis of 10 volts. The output of *IC1D* at pin 7 is either +10 V or −10 V depending on the polarity of the input signal with respect to ground. This output is coupled to the gate of *Q3* through diode *D3*. Assume that the integrator is developing a positive-going ramp at its output. When this reaches the trigger voltage of the comparator, the latter rapidly switches to its maximum positive output, which reverse biases *D3*. This turns *Q3* on and routes the inverted signal to the integrator, which now develops a negative-going ramp until the comparator switches to its maximum negative output. This turns off *Q3*, and the cycle is repeated.

The output of comparator *IC1D* is converted into a TTL-level signal by *Q4*. Diode *D4* is used to limit the negative-going signal to the base of *Q4*, while *R16* is the base-current limiting resistor.

The TTL signal is used to drive the conventional 3-digit counter, decoder and display shown in Fig. 3.

The 160 cycles per degree day output from *Q4* is divided by 16 in *IC2* to provide a square wave having one cycle per tenth of a degree day. This signal is coupled to pin 14 of LSB counter *IC3*. Zero set is provided by depressing RESET pushbutton *S1* which places a ground on pins 2 and 3 (reset to zero) of the four counting ICs. Note that *DISP2* has its decimal point (pin 9) permanently activated by a resistor to ground.

The power supply, shown in Fig. 4, provides +5 volts for the TTL logic, ±12 volts for the analog circuit, and +12 volts for the seven-segment common-anode readouts. Be sure to observe the pin-out difference between the regulator ICs.

Construction. The meter can be constructed using the foil pattern shown in Fig. 5, or perforated board and Wire-Wrap techniques. If you design your own layout, arrange it so that the digital portion—especially *IC6*, *IC7* and *IC8*—are along one long edge. In this way, the three-digit display can be mounted on a separate small board that uses the display current-limiting resistors for electrical and mechanical interconnection.

Select an enclosure large enough to accommodate the circuit board and *T1*. A rectangular front-panel cutout (covered by a red filter) should be made for the three-digit display. RESET switch *S1* is also mounted on the front panel. Jack *J1*, the fuseholder and an insulating grommet for the line cord can be mounted on the rear apron. The 5-volt regulator *IC10* and +12-volt regulator *IC9*, which handle appreciable power, should be mounted to the rear apron to allow this wall to act as a heat sink. Capacitors *C5* and C6 can be soldered directly to the respective pins on their regulators.

The sensor circuit (Fig. 2) is made by soldering the base and collector of each transistor together to form one lead. Select a length of slender two-conductor zipcord having sufficient length to reach the meter from each selected location. At one end, separate the leads for an inch or so. Remove about 1/4-inch of insulation and slip a short length of narrow heat-shrinkable tubing on each lead, solder one to the base-collector lead and the other to the emitter lead. Slide the heat-shrinkable tubing down over the soldered connection and shrink it. The outdoor sensor (*Q1*) can be encapsulated in epoxy if it is not mounted in a weatherproof location. After both sensors are fabricated, connect the far ends of both pairs to the stereo-type phone plug.

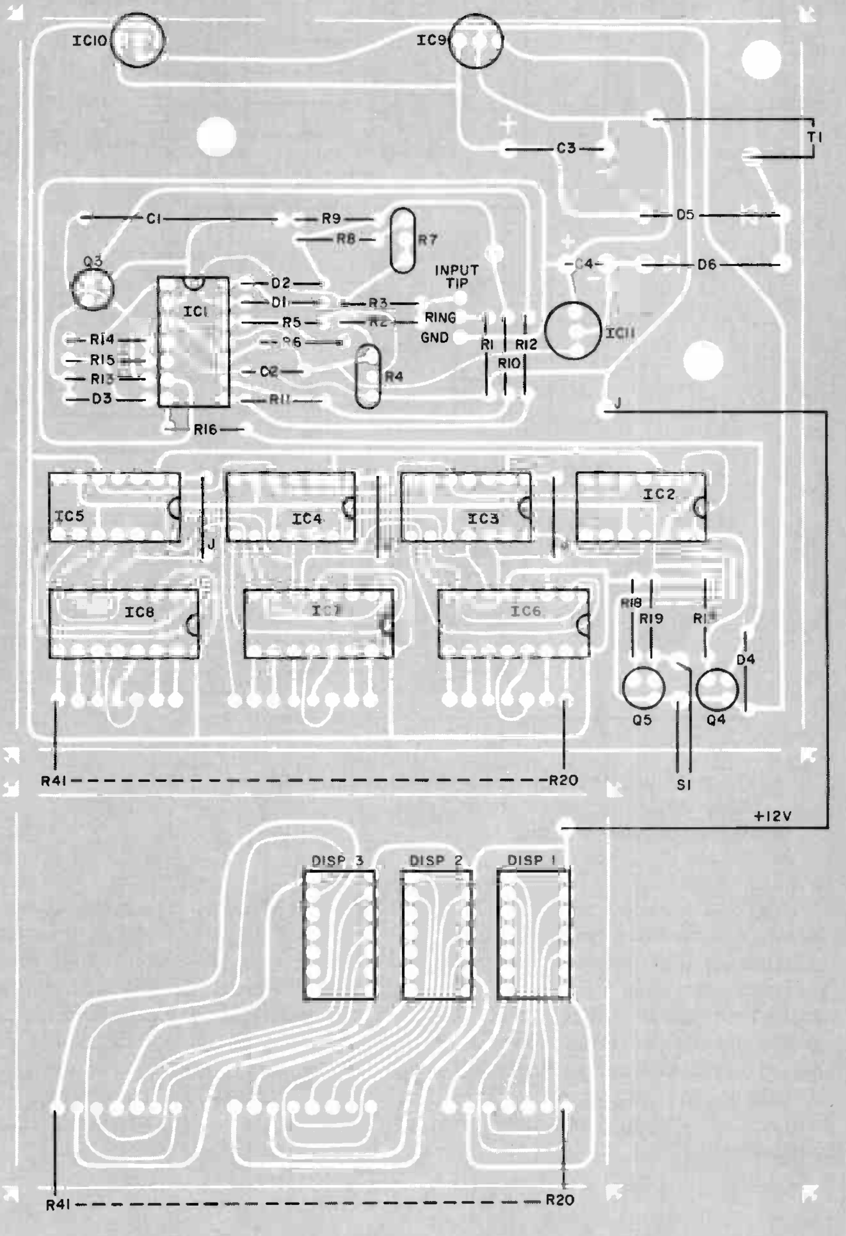
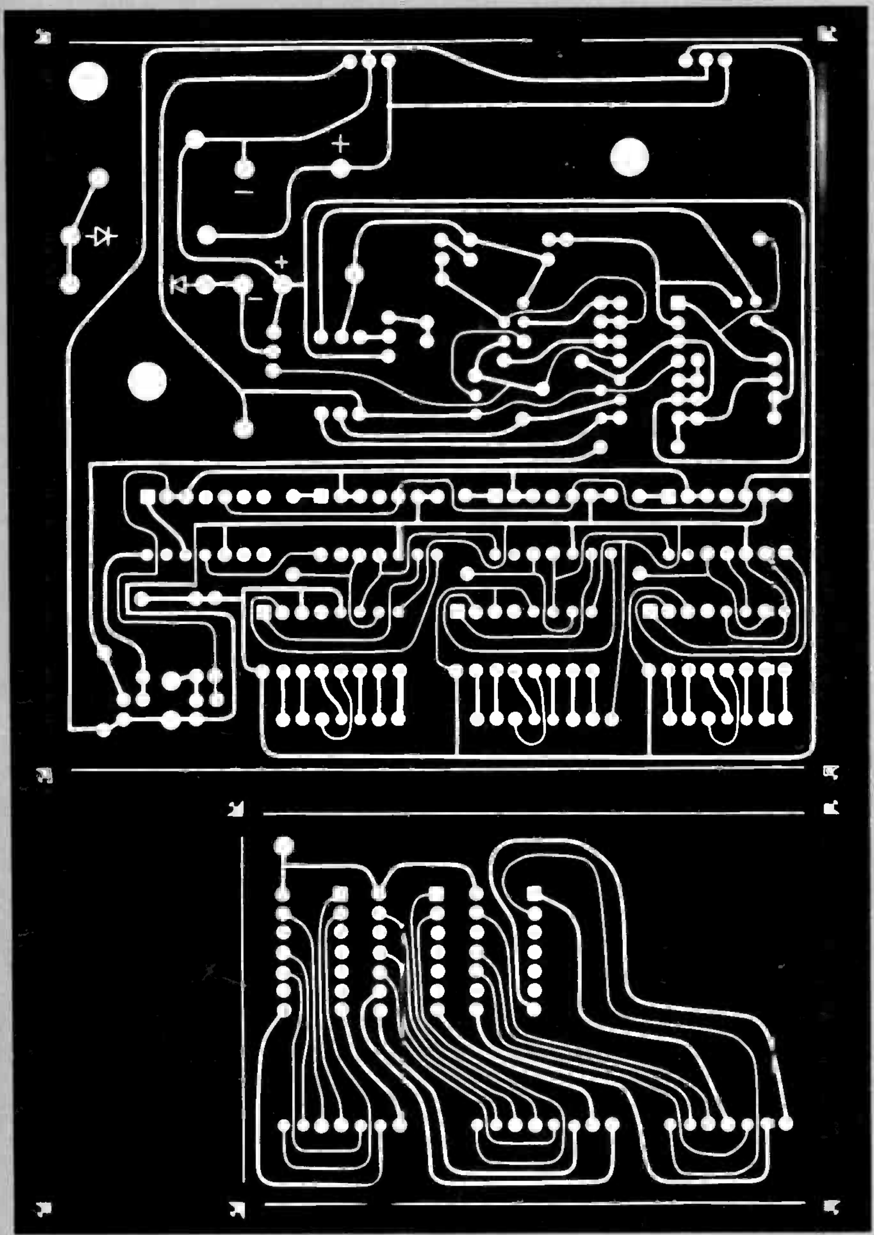


Fig. 5. The large foil pattern (opposite) is for the electronic circuit, while the smaller board below it is for the display. The two boards are interconnected by the current limiting resistors. Installation of these and other components is shown above.



Operation. To calibrate the degree-day meter, all you will need is a dc voltmeter and an ordinary thermometer. Then proceed as follows: Connect the voltmeter between the test point shown in Fig. 2 and ground. Set the voltmeter for its most sensitive dc voltage range, and place the sensors close to each other. Turn on the degree-day meter, allow it to stabilize for 10 to 15 minutes, and then adjust *R4* for exactly zero volts on the dc voltmeter. Then place the outdoor sensor in a cool place (outdoors or in the refrigerator), and adjust *R7* until the voltmeter indicates −0.1 volt for every degree of difference in the temperatures between the sensors. For example, if the inside temperature is 70°F and the outside sensor is at 40°F, adjust *R7* for (70−40) × −0.1 or −3.0 volts at the test point. Install the sensors where desired and you're ready to measure degree-days. The outside sensor should be mounted in a shaded location away from the house and protected from the weather. The inside sensor should be mounted in a central location away from heat sources.

To start a measurement, depress RESET push button *S1*. The display should be "00.0" and should be observed to increment through the day if the outside sensor is cooler than the inside sensor. The greater the temperature difference between outside and inside, the faster the display will increment.

To measure actual energy efficiency of your home, you must measure the energy used over the same time interval that you measure degree-days. Your utility company can tell you how to read your gas or electric meter, or an elapsed-time meter may be connected to measure the total length of time the furnace is heating. Simply divide the energy (therms, BTUs, or kilowatt hours) by the degree-days to obtain a figure in energy per degree-day. This number should be nearly constant from day to day, and any improvement you make in your building's heat retention will lower this factor.

The degree-day meter can also be used to check your home's heat gain while air-conditioning is in use. Simply reverse locations of the inside and outside sensors. It is suggested that regular records be kept throughout the season to enourage conservation. It will be obvious from the efficiency determinations when real improvements are made in the weatherization of your home. (Note that frequent opening and closing of doors is tantamount to a reduction in insulation efficiency.)

Use of the degree-day meter can help a homeowner accurately estimate the payback period on money spent weather-proofing his building. ◇

Extra Keyboards for Microcomputers

BY ADOLPH A. MANGIERI

A keyboard can be connected directly in tandem with the main board of most computers to expand operating versatility.

AN ADDITIONAL keypad or keyboard in tandem with the main keyboard of a computer can have a myriad of uses. A small numeric keypad can be convenient for entering arithmetic data and allows players to enter game moves easily. A full typewriter keyboard duplicating the main one makes one computer setup almost as useful as two for group use and instruction. In any case, a second keyboard, can be used for remote data entry.

The tandem keyboard connects directly to the computer keyboard matrix lines and requires no additional components. Once the warranty on your computer expires, there is no reason why you should not open the cabinet and bring out the keyboard matrix lines. It's both safe and simple. Details are given here for the Radio Shack TRS-80 computer, but the modification can be applied to many other makes.

Circuit Operation. Most computer keyboards employ normally-open spst keyswitches wired with keyboard characters assigned to row and column lines of a matrix. As shown in the diagram, the TRS-80, keyboard is arranged as an 8 ×8 matrix. The eight D0 through D7 column lines connect to column line output buffers (not shown) that, in turn, connect to the data bus. The eight A0 through A7 row lines are driven by row-line buffers connected to the address bus. Each intersection of the matrix has an spst keyswitch, as shown for column lines D0 and D7. When the A key is pressed, row line A0 and column line D1 are connected to each other to generate an output on column line D1 and the appearance of character A on the monitor screen.

To add a remote keypad or a full keyboard in tandem, you merely carry out the required row and column lines to the switches of the remote keyboard. Just how the computer encodes key closure is not material. In the TRS-80, encoding of the keyboard is accomplished with a program in ROM. (See the TRS-80 Microcomputer Technical Reference Manual for details.) Many computers employ a chip encoded keyboard.

The only consideration to be taken into account when connecting a tandem keyboard into an existing microcomputer system is whether cable capacitance and stray pickup will affect computer operation. Fortunately, almost any keyboard can tolerate several feet of connecting cable to the tandem keyboard.

Before you install the connecting socket on the computer, make temporary connections to a row and column line to determine whether this method is suitable for your keyboard. Once you have determined that your computer can, indeed, tolerate a tandem keyboard, you can proceed to modify it.

Cable Connections. Open the TRS-80's cabinet, following instructions detailed in the Technical Reference Manual. Carefully raise the keyboard to avoid any strain on the short ribbon cable that connects the two boards. Pull off the board spacers and set the keyboard on its keytops in front of the cabinet with the main circuit board riding loosely in the bottom half of the cabinet. Although the CPU and several other MOS devices wired into the circuit are largely protected from static discharge, it still pays to observe standard handling precautions when working with MOS circuits.

Locate the eight column line resistors, which are clearly identified on the keyboard. Mark the solder pad at the lower end of each resistor with its associated column line. You may or may not be able to locate row lines at row-line buffers because some buffers were interchanged in some keyboard models. A better approach would be to identify row lines directly at the key terminals.

For the TRS-80, touch the negative (COM) lead of an ohmmeter set to a medium range, to limit current, to column line D1 at the lower end of resistor *R5* and the other test lead to either terminal of keyswitch A (see board labelling). If you obtain a zero resistance reading, the remaining terminal is row line A0; but if resistance is infinite, the terminal being tested is row line A0. Label the solder pad as A0. Similarly, select other keys and locate all row lines. Keyboard ground is line 19 on the board's interconnect cable. Line 1 is at the extreme edge of the keyboard. Trace ground to a convenient solder pad location.

Decide how you wish to route a cable from the computer's or terminal's cabinet. There is ample unused space at the edges of the keyboard in the TRS-80 for installation of an internal disconnect. For a clean cable exit away from heat sinks and main-board adjustment pots, locate the disconnect at the front edge and pass the cable through the front.

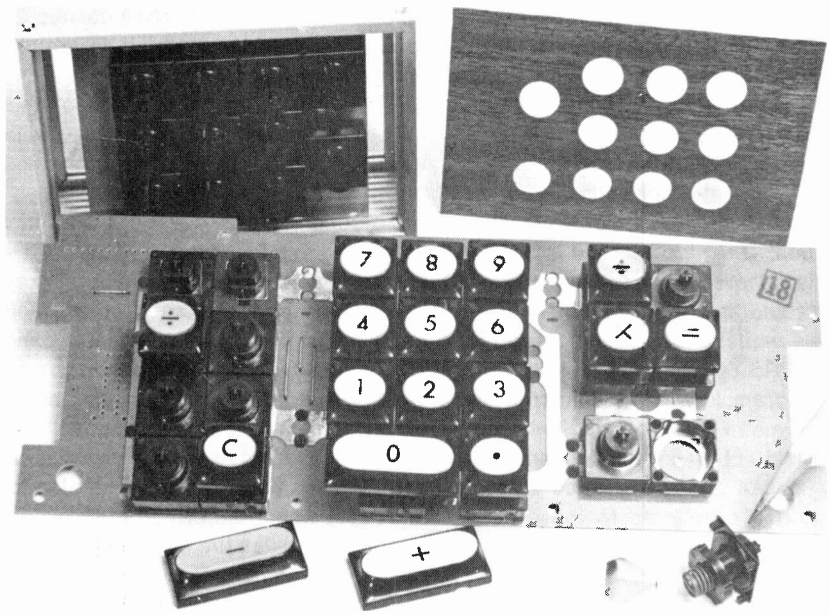
A 16-pin DIP socket that mates with a DIP patchcord is very easy to install. When not in use, the exposed male pins at the other end of the patchcord can be protected with a DIP socket. Less easily installed is a male IDC (insulation displacement connector) made up of Wire Wrap posts inserted on the keyboard to allow use of female IDC patchcords. Also, IDC cables are more rugged, easy to assemble and patch end-to-end with homemade adapters.

Cover the main circuit board to exclude debris and solder splatter. With a wood-block backup, drill the keyboard to accept the 16-pin socket, using p-pattern board retained with double-stick tape as a drilling template. For the male IDC, drill 0.042″ (1.1-mm) holes to accept 20 Vector No. T46-5-9 wrap posts. For front exit, position the disconnect as far from the edge as possible, but do not drill into board traces! Normally, the male IDC is formed using the No. MB45-20 perforated alignment block to back up the board and maintain the installed pins perpendicular. However, to use this block, you must remove both boards from the cabinet to obtain clearance. Lacking the alignment block, use a hardwood block for board backup, keeping it very close to the pin. If you remove the main board from the cabinet, do not disturb trimpots on it.

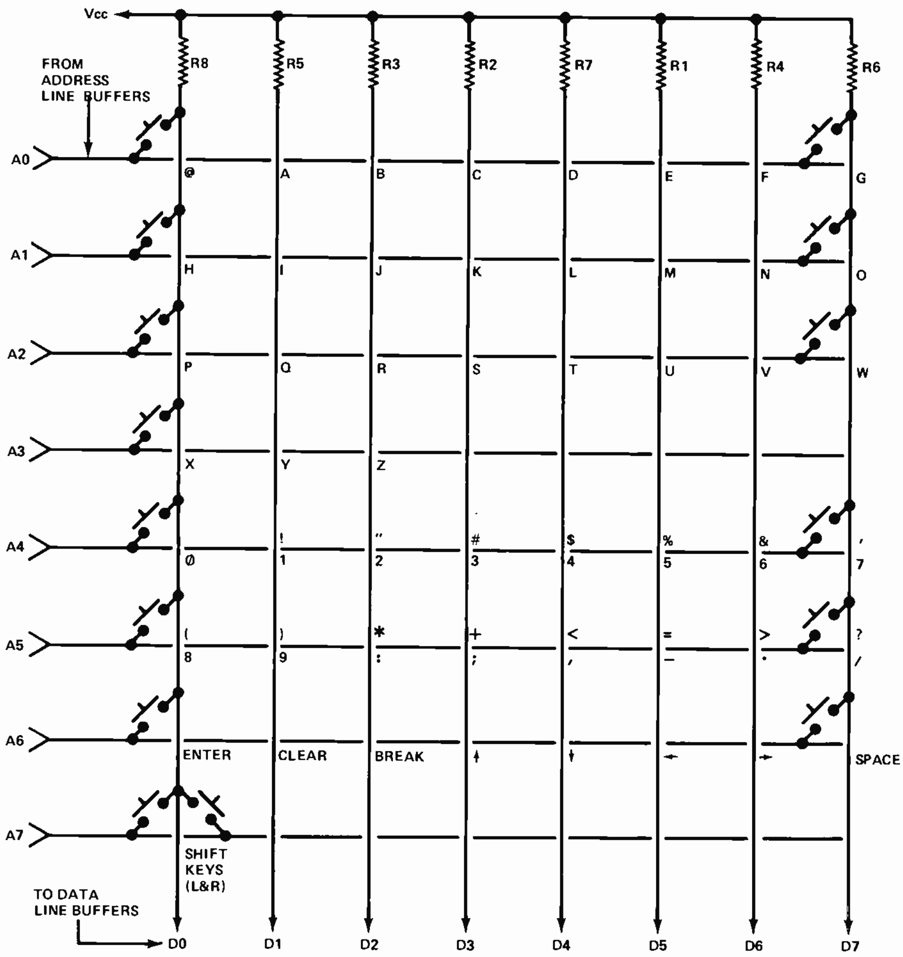
Use a Vector No. P205 board-pin insertion tool to install No. T46-5-9 wrap posts for the male IDC. This tool eases installation of pins with cross bars in alignment as required to accept a female IDC plug. Lacking this tool, overdrill board holes slightly to ease pin insertion and install using longnose pliers. Wire the connections to the marked row and column lines. Use the four extra wires on the 20-conductor IDC cable as a ground screen. Assign the outermost and two intermediate conductors to ground. Check soldered connections for presence of solder splatter and excessive solder. Install the keyboard into the cabinet and straighten any misaligned wrap posts on the top with longnose pliers.

Install a 12″ (305-mm) cable for front exit. Fabricate the IDC cable using Vector No. KS2-20 20-pin female IDC plugs and mating cable No. KW2-20-10. Press the IDC plug onto the end of the cable using a smooth-acting vise or use the P187 IDC fixture. For a longer cable run, make a second 24″ (610-mm) cable and fabricate a male IDC adaptor to join IDC cables end to end. Cut the top half or long end of the No. T46-5-9 wrap post down to 1/4″ (6.4 mm), round off the burr and install posts on a small piece of perforated board. Note: you can face IDC plugs the same way or one up and one down on a cable. If you use a cable-splice adaptor in lieu of changing the entire cable, you must use the adaptor in every setup because cable line transpositions occur at the splice.

Keyboard Assembly. Inexpensive surplus desktop calculator keyboards as shown in the photos are suitable for tan-



Desktop calculator keyboard can be cut apart to make smaller keypads. The pencil at right points to removed top part of keyswitch. Topside brass stampings form part of switch and key strings.



Schematic shows 8 × 8 matrix layout of the TRS-80 keyboard, which is typical of boards of this type. A keyswitch is located at each intersection of the matrix to generate an output for a specific character.

dem hookups and require only slight alterations. The key bodies are thermally staked to the phenolic board, and one terminal of each switch is available on the bottom. A top-side circuit made up of thin brass stampings serves as switch contacts and interconnecting lines to form key strings that have a common connection. The top portion of each switch is removable to reveal the working parts and snap-action disc.

Let us implement a numeric keypad for the TRS-80. From the keyboard matrix diagram, keys 0 through 7 require a 1 × 7 matrix or key string, with the common side of the switches connected to row line A4 and the isolated side of the switches connected to the column lines. Keys 8, 9, and decimal point require a 1 × 3 key string, with the common side of the switches connected to row line A4 and the isolated side of the switches connected to the column lines. Keys 8, 9, and decimal point require a 1 × 3 key string, with the common side of the switches connected to row line A5 and remaining switch terminals connected to column lines D0, D1, and D6. The numeric set of this keyboard was a 1 × 10 key string, with keys 8, 9, and decimal point at one end of the string.

To separate the required 1 × 3 key string, cut off four plastic nubs on the bottom and remove the number 7 key body. Use a fine-toothed, broken-off hacksaw blade to cut the metal band alongside key 8 and remove the top part of the switch body. Sparingly, apply epoxy cement to the plastic pegs of the key body and install using a clamp for a tight fit. Clean switch parts with alcohol and reassemble the switch.

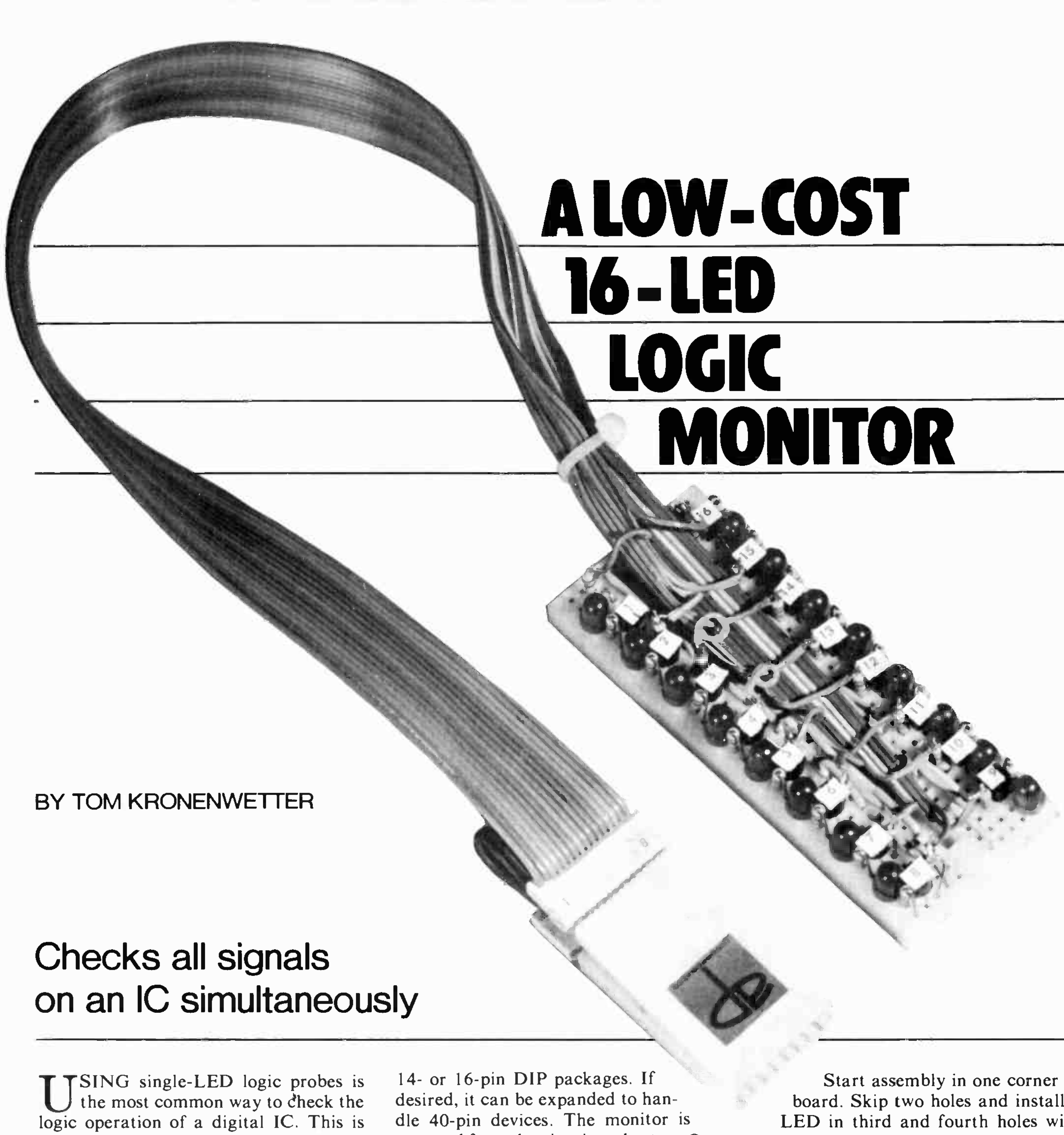
Trim and install the keypad in a small case. The numeric keypad shown is housed in a Vector No. W20-46-31B Multi-Mod case. The trimmed keypad slides into case-card grooves. Punch holes in the panel using a Greenlee chassis punch to pass the key shanks. Using the full keyboard, install in the Vector No. 51X-1 aluminum frame. Trim the keyboard to length to fit frame grooves and cut a top panel to size. Secure the keyboard to the punched panel using four machine screws and extra nuts for spacing. Finally, mark keyswitch terminals with the required row and column lines and wire to an IDC male connector or DIP socket. The aluminum frame accepts the M6088-3-1 perforated bottom plate; otherwise, cut a plate to size and install.

Assign extra keys to any desired matrix character or command. Six keys already wired in a 1 x 6 key string provide hex letters A through F. With some trace cutting, remaining keys can be assigned to the TRS-80 T-Bug monitor commands. Two keys on this keyboard were latching on/off switches. We removed the top part and snap disk from two switches of a spare keyboard and installed them in the on/off switch bodies. Then we relabelled keytops.

Keyswitches on a full typewriter keyboard are usually fully isolated, normally-open spst types, but check before you buy. The surplus typewriter keyboard may differ in some respects and may contain extra keys and keytop label variations. With some relabelling of keys, these make excellent tandem keyboards that allow a student and instructor to operate the same computer from different locations.

The possibility of connecting several additional keyboards in tandem may occur to some readers. However, you cannot run long lengths of ribbon cable with wild abandon. Our tandem keyboard was tested using 10′ (about 3 meters) of KW2-20 ribbon cable with four lines assigned as a ground screen. This is not good practice because the lengthy cable is not adequately buffered and is not fully ground-planed. Also, its lines are not terminated. The TRS-80 performed satisfactorily but in all likelihood with a reduction in noise margin. It is recommended that cable length be limited to 4′ or 5′ (1.2 to 1.5 m) and no more than required in any case.

Conclusion. From the foregoing, you can readily see that adding a keyboard in tandem with one in an existing computer system or terminal is a relatively simple matter. Although we used a Radio Shack TRS-80 computer to demonstrate how to perform the modification, the procedure is readily adaptable to most other types of personal computer systems. ◇



A LOW-COST 16-LED LOGIC MONITOR

BY TOM KRONENWETTER

Checks all signals on an IC simultaneously

USING single-LED logic probes is the most common way to check the logic operation of a digital IC. This is fine as long as all you want to know is whether a particular pin is high or low or is switching between these two states. But most logic circuits require that correct *timing* be maintained between a number of signals from the same IC. This is something that a single-LED probe cannot test.

The logic monitor described in this article allows *all* of the pins of an IC to be examined simultaneously, which means that timing can be observed. The monitor reads out via 16 LEDs, each connected via a high-input resistance driver to a pin of the IC. Interconnection between the monitor and the IC is through a length of ribbon cable terminated to a clip that clamps on to the IC.

The project can be constructed for 8-, 14- or 16-pin DIP packages. If desired, it can be expanded to handle 40-pin devices. The monitor is powered from the circuit under test. Operating characteristics are given in Table I.

Basic Circuit. As shown in Fig. 1, the basic circuit consists of a relatively high-input resistance (100,000 ohms) Darlington transistor driving a LED. Resistor *R2* ensures that when the input is logic 0 (low), the transistor will be cut off and the LED will remain dark. This circuit is duplicated for each required pin connection. Current-limiting resistor *R3* is common to all LEDs.

Construction. In constructing the logic monitor, a solderless breadboard (see photo) is used. In this breadboard, the five holes across each row are interconnected inside the plastic housing.

Start assembly in one corner of board. Skip two holes and install a LED in third and fourth holes with the LED cathode in hole 4 as shown in Fig. 2. Install the transistor in the second column with the collector lead in the same row as the LED cathode, the base lead in the fifth row hole and the emitter lead in the sixth row hole. The cathode of the LED is thus connected to the transistor collector internally.

Cut one lead of a pair of 100,000-ohm resistors to 0.7" and the other lead to 0.3". Each of these resistors will be mounted vertically. Insert the short lead of *R2* into the second hole past the LED, then bend the longer lead over and insert it into the hole adjacent to the LED. Thus *R2* is connected between the base and emitter of *Q1*. Insert the long lead of the remaining resistor into the hole above the base of *Q1* so that it connects to the base of *Q1*. The short upper lead of this resistor will be connected to the cable later on.

If you are making a 16-pin arrangement, follow the above assembly procedure seven more times to produce eight LEDs on one side. If you are making a 14-pin array, then only seven LEDs are needed.

To complete the assembly, start the component installation at the diagonally opposite corner (no hole spaces), and work up the other side. Resistor *R3* is installed in a hole near the last LED.

Cut 32 one-inch long jumpers from #22-gauge solid insulated wire and strip 0.3" of insulation from each end. Sixteen of these jumpers are used to interconnect the 16 ground points to form a common bus. The remaining jumpers are used to couple the anodes of all the LEDs into a common bus. This bus is then connected is to *R3*.

At this time, each LED must be identified as to pin number. Make up some small stick-on labels, each identified in numerical sequence from 1 to 16, and affix one to the top of each transistor. The sequence should be 1 through 8 from top to bottom on the left side, and 9 through 16 from bottom to top on the right side.

The final step is wiring the 1.5-foot ribbon cable from the clamp-on connector to the breadboard. Lay the connector down with its color-coded side facing up. Using Fig. 3 as a guide, from the tip of the brown conductor at one edge of the cable, measure a diagonal 3-inches long to the blue conductor on the opposite side of the cable. Use masking tape to mark this diagonal. Cut the ribbon cable with scissors along the upper edge of the masking tape. Separate the leads to a length of about one-inch, then strip about 0.2" of insulation from each lead. Tin each lead and form into small closed loops so that they will fit over the ends of the leads at the top of each *R1*.

Place the prepared end of the cable in the center of the breadboard, rainbow side up. Connect the second shortest lead (green) to the short lead of the *R1* for the first LED. This corresponds to pin 1 of the connector. The shortest lead (blue) is connected to the *R1* associated with the sixteenth LED. Using the cable color-code chart shown in Table II, connect the remainder of the ribbon-cable leads to their respective *R1*'s.

When all the connections are completed, fold the ribbon cable over on itself, slightly above the breadboard,

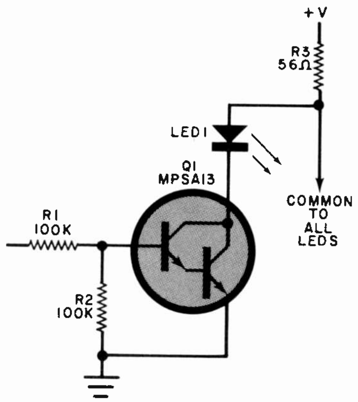


Fig. 1. Basic circuit consists of a Darlington transistor driving a LED.

TABLE I—OPERATING CHARACTERISTICS

Input impedance:	100,000 ohms
Logic threshold:	2.2 volts dc
Operating voltage range:	4 to 15 volts dc
Maximum current drain:	200 mA

TABLE II—CABLE COLOR CODE

Pin	Color
1	Green
2	Orange
3	Brown
4	White
5	Purple
6	Green
7	Orange
8	Brown
9	Red
10	Yellow
11	Blue
12	Gray
13	Black
14	Red
15	Yellow
16	Blue

PARTS LIST

LED1—Red LED (FLV-117 or similar, 16 required)
Q1—MPSA13 Darlington transistor (16 required)
R1,R2—100,000-ohm, 1/4-watt resistor (32 required)
R3—56-ohm, 1/4-watt resistor
Misc.—Solderless breadboard (AP Products Model 234), 16-pin clamp-on logic clip with cable (AP Products Model LC 160), small tie wrap, #22 AWG wire, labels.

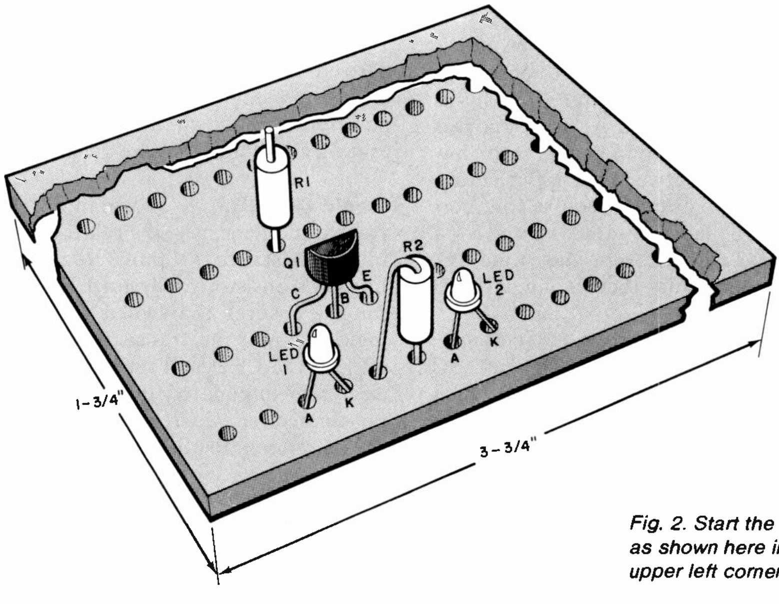


Fig. 2. Start the assembly as shown here in the upper left corner of board.

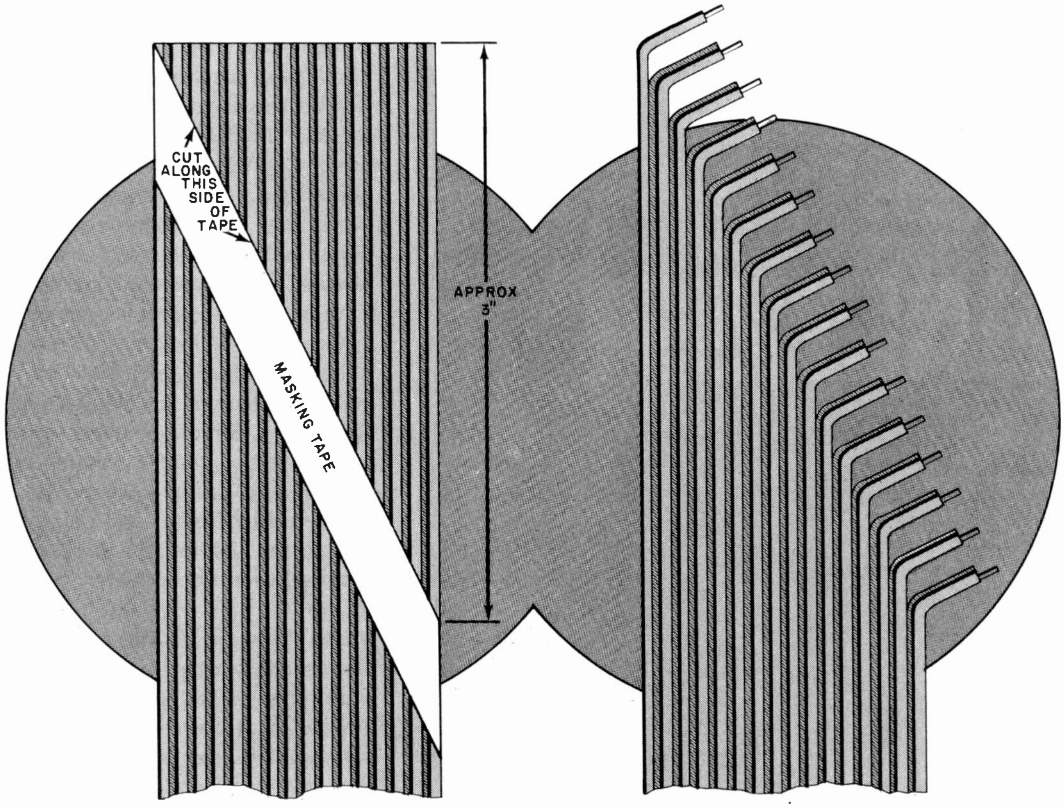


Fig. 3. The 16-lead ribbon cable is prepared as shown here with the leads cut diagonally so that they can be connected easily to circuits on the board.

and use a tie wrap to act as a strain relief for the cable.

Most 16-pin DIP packages use pin 16 as the dc source and pin 8 as ground. If you want to follow this convention, jumper input 16 (blue) to the common LED bus, and input 8 (brown) to the common ground bus. This means that the sixteenth LED will always glow and the eighth LED always remain dark.

Some digital IC's, the 7490 as an example, use pin 5 as the dc input and pin 10 as the ground. In this case, the circuit shown in Fig. 4A may be used. Here, two silicon diodes are used to pick off the dc voltage from either the pin-16 or pin-5 inputs for application to the common dc bus. A separate ground lead can be connected between the monitor common-ground bus and the ground of the circuit under test. It is also possible to keep each input isolated from either dc or ground, and use a separate lead connected between the monitor dc bus and the 5 volts of the circuit under test as shown in Fig. 4B. In this latter case, all the LEDs will be active. The human eye can distinguish flashing of the LEDs at rates up to about 15 Hz. Above that frequency the LEDs will appear to be constantly "on." ◇

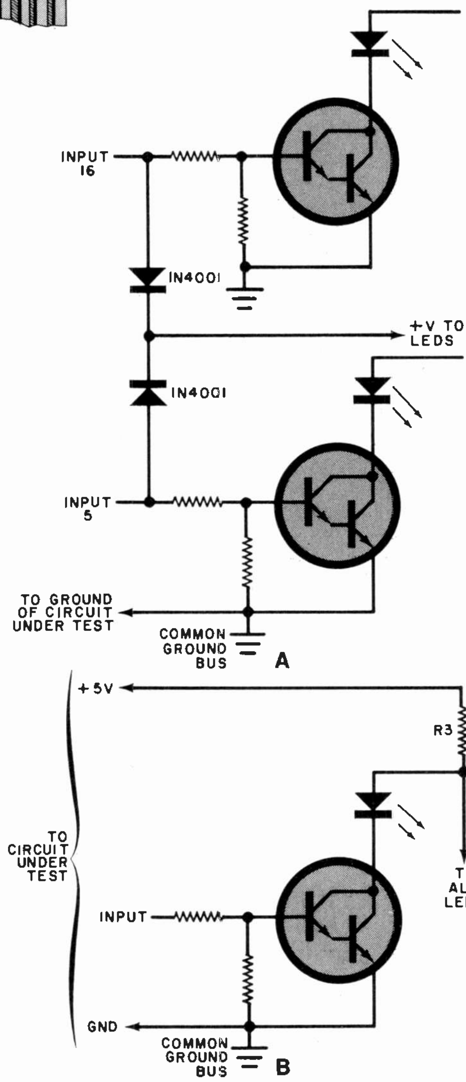
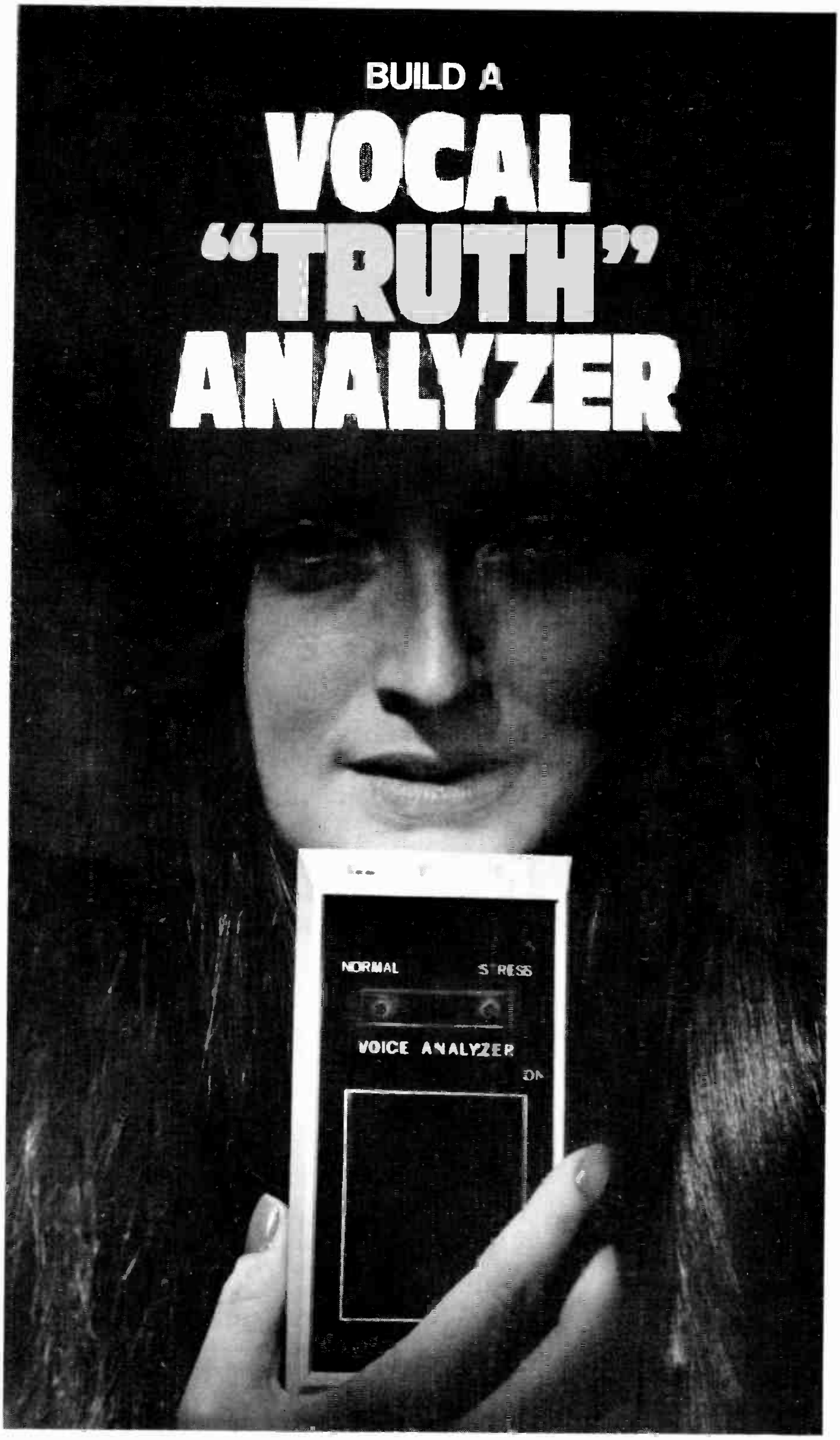


Fig. 4. If pin 5 of the IC to be tested is the dc input and pin 10 is ground, use the circuit at (A). To keep each input isolated from dc or ground, use the connections at (B).

BUILD A VOCAL "TRUTH" ANALYZER



BY COLLEEN McNEICE AND ROGER COTA

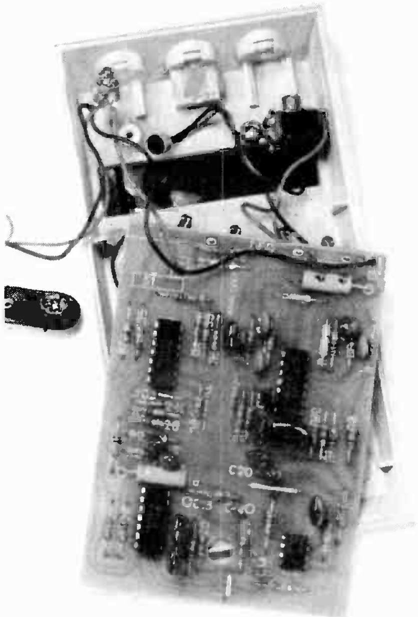
Hand-held LED-display instrument is said to detect voice stress

SO-CALLED "electronic lie detectors" have become controversial items. Some workers in the fields of security and law-enforcement swear by them, while others (including some psychologists) hold that the principles on which the devices are based are ill-founded and unscientific. Still other individuals denounce the application of lie detectors as an invasion of privacy.

Actually, the best that these detectors can do is measure psychological stress. Even then, the measurement is indirect. Basically, the device makes its determination by sensing an effect of one type or another that many researchers believe is an accurate indicator of stress. Validation studies have been used to compile an impressive record of successes, but it should be remembered that a high degree of interpretational skill is required and there is always an appreciable probability for error in using such an instrument.

One popular indicator of stress has been the relative amplitude of certain vocal modulations in a person's speech. The Voice Stress Analyzer described here is a small, readily portable unit. It is designed to operate on the principles pioneered by Dektor and other companies in the field whose products have received wide acceptance.

Basic Theory. Extensive military research and wartime counterintelligence work have yielded several theories and devices that have been used during interrogation in an attempt to separate truth from falsehood. One of these theories is that human voices, which have fundamental frequencies ranging from about 90 to 200 Hz, are normally modulated by an 8-to-12-Hz "microtremor" signal. The latter's effect is usually masked by other voice components: but, according to these researchers, reasonably simple electronic circuitry can detect and measure the microtremors.



LEDs are positioned in window area, miniature microphone is put in center cutout at top of case.

When a person is under stress, says the theory, normal vocal microtremors diminish greatly in amplitude. The autonomic nervous system, preparing the body for emergency reactions, causes the pupils to dilate, blood to rush away from the limbs, and the muscles to tense. Since the vocal chords are principally muscular tissue, they, too, tighten and decrease the amplitude of microtremors. Thus, it is claimed, measuring the relative amplitude of vocal microtremors gives an indication of stress. The waveform of a human voice with microtremor, indicating no or very little stress, is shown in Fig. 1A, its spectral content in Fig. 1B.

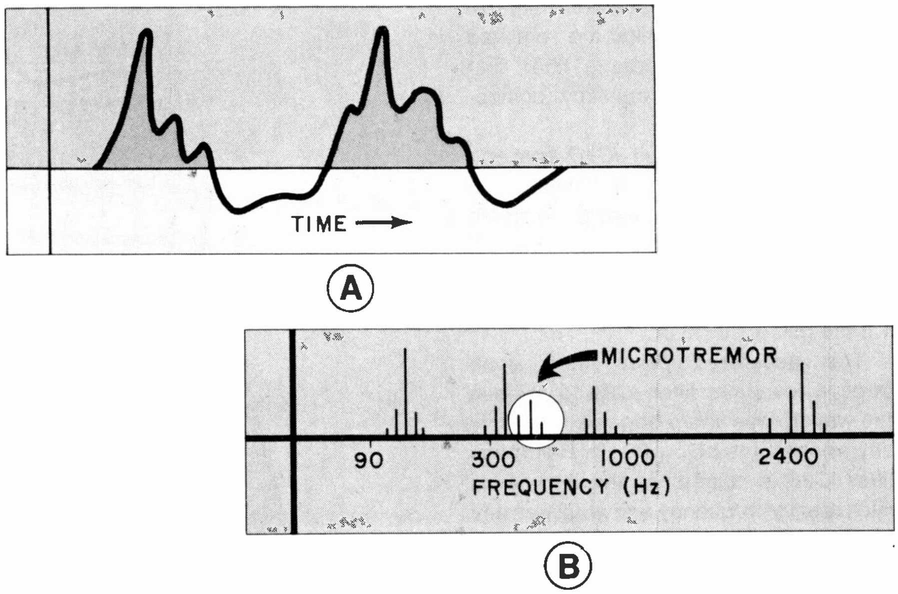


Fig. 1. Waveform of the human voice with microtremors is shown at (A), spectral content of voice is at (B).

System Operation. Basic operation of the Voice Stress Analyzer is shown in Fig. 2, while Fig. 3 illustrates typical waveforms (not drawn to scale) that occur in the circuit.

The input voice signal in Fig. 3A illustrates the somewhat closer peak spacing attributed to microtremors as compared with the "normal" spacing of the peaks in the voice signal. After amplification, the composite voice signal goes to a voice-frequency bandpass filter to remove extraneous noise. Then the signal input is half-wave rectified. In a 150-Hz low-pass filter, the higher voice frequencies are attenuated, leaving only the lower frequencies, including those of the microtremors (Fig. 3B). The positive-going output then toggles a Schmitt trigger (Fig. 3C) to produce a squared-off waveform. The latter is suitable for toggling a one-shot multivibrator that then produces the 1.5-ms pulses shown in Fig. 3D.

As the 8-to-12-Hz microtremor modulates the fundamental, spacing between pulses changes. Pulses from the one-shot then pass through a 20-Hz low-pass filter and an 8-to-12-Hz filter, after which it is rectified and integrated to form a smooth voltage. This signal may rise above a preset threshold when the microtremors are closely spaced, in a manner similar to that of the vertical-sync scheme used in a TV receiver. When the integrated output is above the threshold, it causes the LEDs to come on in a particular sequence (Fig. 3E).

The Circuit. Figures 4 and 5 illustrate the complete schematic diagram of the Voice Stress Analyzer. The *IC2D* circuit (Fig. 5) supplies the ground tap required by the op amps. Resistors *R1* and *R2* and capacitor *C1* provide power from battery *B1* for the condenser microphone. Jack *J1* is a transfer type that disconnects *MIC* when an external audio source is plugged into it. (The external source can be a telephone pickup, dynamic microphone, or output from a tape recorder.)

Audio amplifier *IC1A* operates close to its open-loop gain whose output goes to the *IC1B* bandpass-filter circuit. Recti-

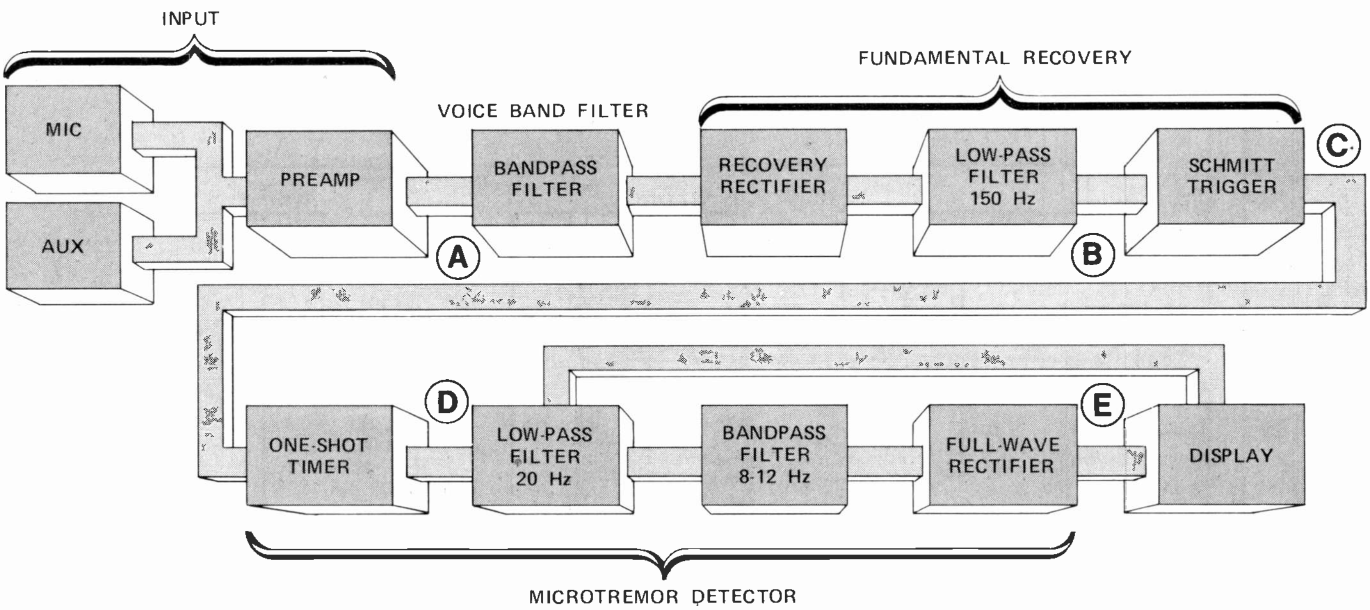


Fig. 2. The analyzer circuit is designed to extract the 8-to-12-Hz microtremor from the voice input and use the resultant signal to turn on a LED display.

fier *D1* half-wave rectifies the signal to recover the fundamental modulating frequency. Higher harmonics are removed by *IC1C*, an 18-dB/octave filter that passes only those frequency components below 150 Hz.

Schmitt-trigger circuit *IC1D* converts the recovered fundamental into steep rising and falling edges that are suitable for driving timer *IC4*. As shown in Fig. 3C and D, the Schmitt trigger's sharp rise time toggles the timer, which produces a 1.5-ms pulse.

The generated pulse train goes through low-pass filter *IC2A* to remove the waveform's sharp edges and amplify any frequencies below 20 Hz. Bandpass filter *IC2B* is "tuned" to the 8-to-12-Hz microtremor frequency and amplifies any signal within this range

Full-wave rectifier *IC3A/IC3B* accepts this signal and produces a dc output voltage that is proportional to the amplitude of the microtremor (Fig. 3E). This voltage is developed across *C19*, which is constantly being discharged by time-constant resistor *R32*.

Display drivers *IC3C* and *IC3D* are

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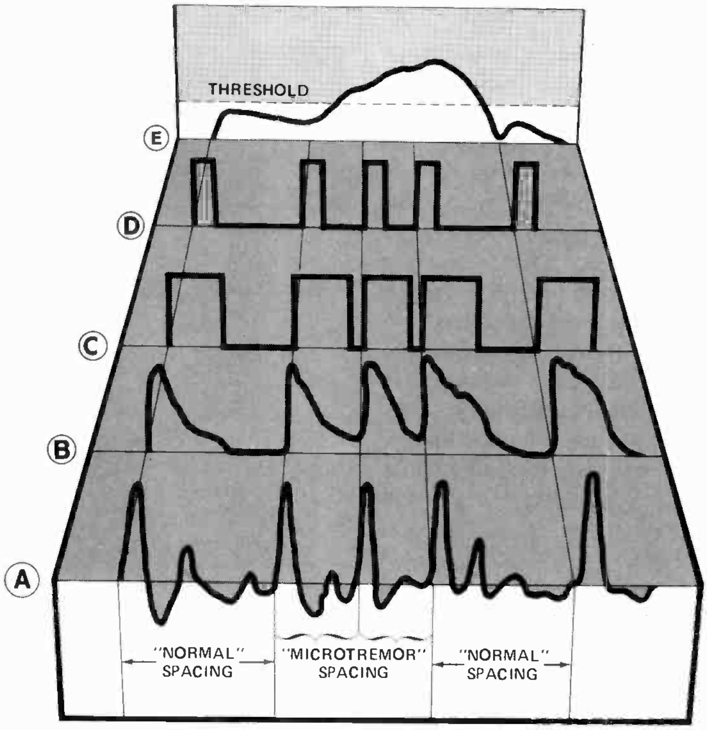

Fig. 3. Typical waveforms within the analyzer. According to the authors, the "trick" lies in detecting the presence of the narrower microtremor peak spacing within the voice frequencies. Integrated one-shot pulses derived from these signals are used to toggle the readouts.

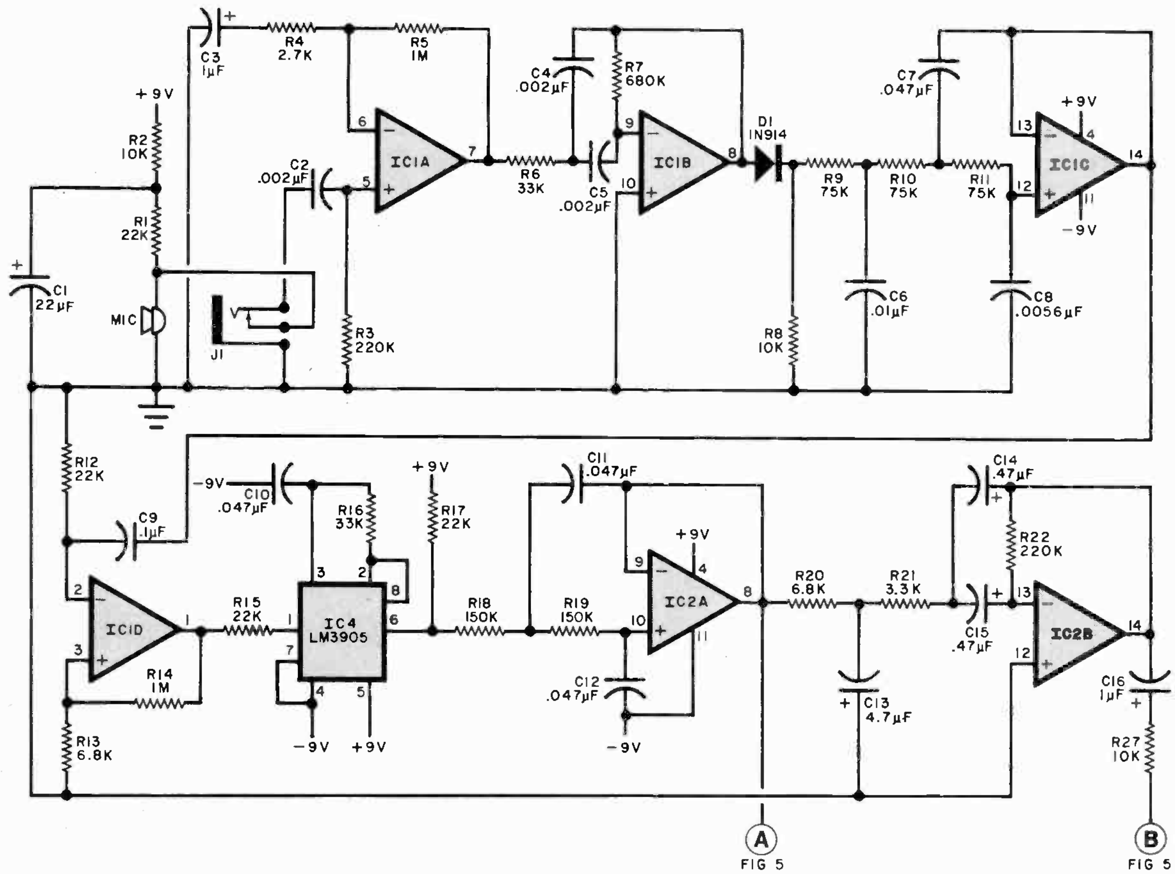

Fig. 4. The voice processing circuits of the analyzer result in 20-Hz signals from IC2A and 8-to-12-Hz signals from IC2B. These signals drive the rectifier/display section shown in Fig. 5.

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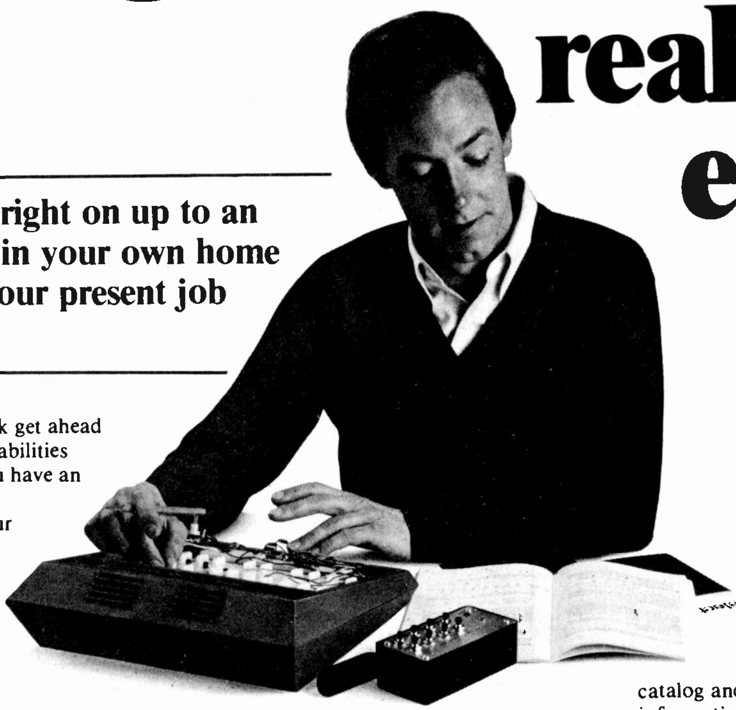

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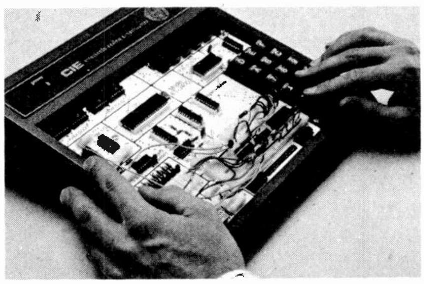

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connected as comparators, using the voltage generated across *R33*, *R34*, and *R35* as the reference. The comparators then drive the LEDs. When *LED1* comes on, presence of microtremors is indicated, meaning no stress. When these frequencies are missing, *LED4* comes on to indicate high stress. As microtremors come and go, *LED2* and *LED3* come on.

The display also receives a control signal from the 20-Hz filter that turns off the LEDs when no input signal is present, conserving battery life.

Construction. Using the actual-size etching and drilling guide shown in Fig. 6, the Analyzer was designed to fit in a calculator-type case. Referring to the component-placement guide in Fig. 6, mount the components in their respective locations, taking care to properly orient the diodes, polarized capacitors, ICs, and LEDs. When installing components on pc board, be sure to properly orient diodes, LEDs, ICs, and electrolytic capacitors, as shown in the component placement guide.

With exception of the microphone, auxiliary input jack, power switch, and battery, all components mount directly on the circuit board. The microphone and auxiliary jacks mount in holes at the top of the plastic case. (Make certain that the pickup end of the microphone points outward.) Mount the power switch on the upper surface of the case, below the display window and label its ON position with a dry-transfer lettering kit. Connect and solder the positive lead of *B1*'s battery connector to the hole A-pad on the circuit board, the negative lead to the hole B-pad.

Examine the jack and schematic diagram and connect and solder lengths of hookup wire from the jack's lugs to the appropriate E, F, and G pads on the circuit board. If you choose a rechargeable battery for *B1*, mount a suitable power jack on the plastic case and wire it to the battery.

Now, use a dry-transfer lettering kit to label the LEDs in the display. Label *LED1* NORMAL and *LED4* STRESS. Leave transitional *LED2* and *LED3* without legends. This completes construction.

Construction. Using the actual-size controls, it should be operational as soon as power is turned on. As you speak into the microphone, you should note that the LEDs flicker, with the NORMAL LED on most of the time.

A number of tests were performed on the Voice Stress Analyzer by one of the authors. Using the audio from a TV-network news broadcast, it was noted that when the newscaster spoke, the NORMAL LED was on most of the time. When actors and actresses were speaking their roles, basically the same results were observed. However, when

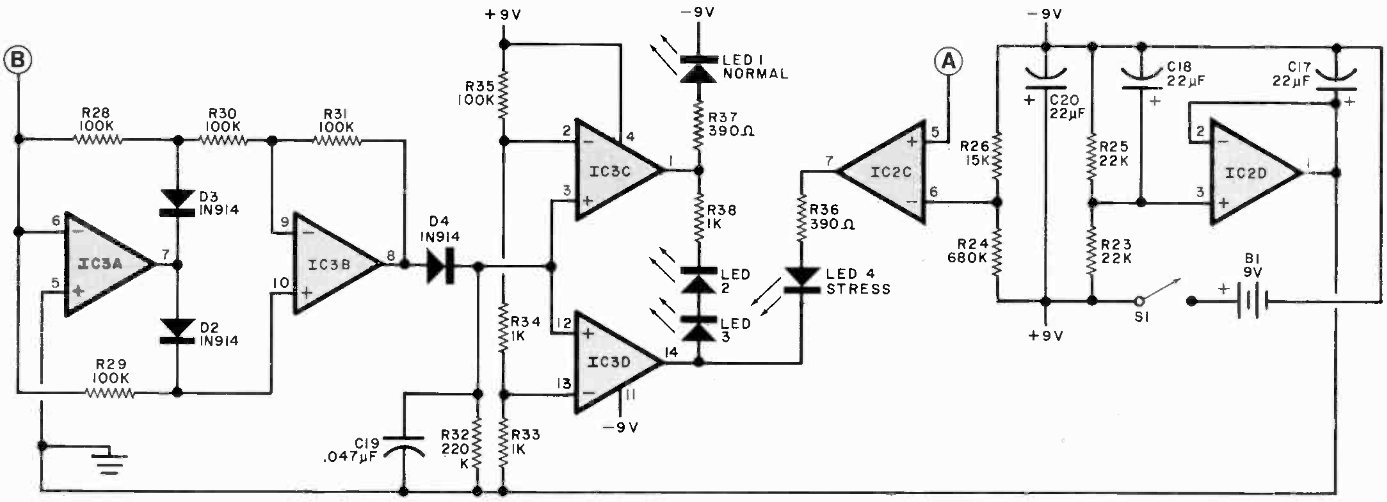


Fig. 5. The 8-to-12-Hz signals are rectified in IC3A and IC3B, integrated in C19 and used to turn on a comparator (IC3C, IC3D) that causes the LED (s) to glow. IC2C shuts down the LEDs when there is no 20-Hz signal, while IC2D creates a bipolar supply from a single 9-volt battery.

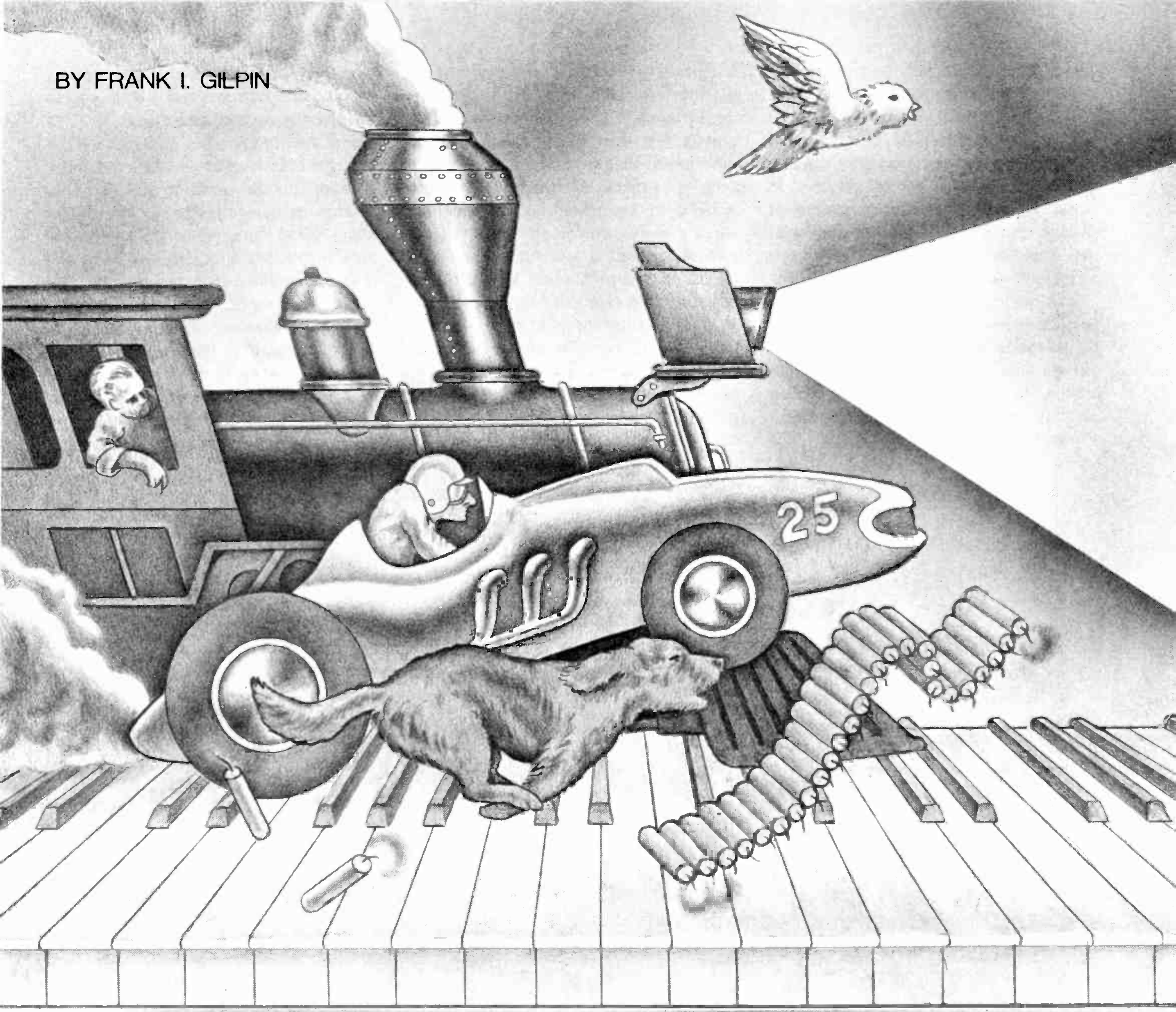
PARTS LIST

B1—9-volt battery
C1,C17,C18,C20—22-µF, 16-volt tantalum
C2,C4,C5—0.002-µF, 100-volt Mylar
C3,C16—1-µF, 100-volt electrolytic
C6—0.01-µF, 100-volt Mylar
C7,C10,C11,C12,C19—0.047-µF, 100-volt Mylar
C8—0.0056-µF, 100-volt Mylar
C9—0.1-µF, 100-volt Mylar
C13—4.7-µF, 35-volt tantalum
C14,C15—0.47-µF, 35-volt, tantalum
D1 through D4—1N914
IC1,IC2,IC3—LM324 quad op amp
IC4—LM3905 precision timer
J1—subminiature phone jack with switch
LED1 through LED4—red LED
The following are ¼-watt 5% resistors:
R1,R12,R15,R17,R23,R25—22,000 ohms
R2,R8,R27—10,000 ohms
R3,R22,R32—220,000 ohms
R4—2700 ohms
R5,R14—1 megohm
R6,R16—33,000 ohms
R7,R24—680,000 ohms
R9,R10,R11—75,000 ohms
R13,R20—6800 ohms
R18,R19—150,000 ohms
R21—3300 ohms
R26—15,000 ohms
R28 through R31,R35—100,000 ohms
R33,R34,R38—1000 ohms
R36,R37—390 ohms
Misc.—suitable enclosure, battery clip, hook up wire, mounting hardware, etc.

Note: The following is available from Video Control, 3314 H St., Vancouver, WA 98663 (Tel: 206-694-7905): complete kit including microphone, battery clip, pc board, case, and manual for $96.00. Also available separately: etched and drilled pc board at $12.50; hand-held case, battery clip with power jack and condenser microphone at $18.00. Please add $3.50 for postage/handling. Washington state residents, please add 5.1% sales tax. Allow four weeks for delivery.

(Continued on page 52)

BY FRANK I. GILPIN



EXPERIMENTING WITH A SOUND-EFFECTS GENERATOR

UNTIL a couple of years ago, experimenting with sound-effects circuitry was difficult, requiring a large breadboard to accommodate oscillators of various descriptions, modulators, noise sources, mixers, envelope generators, etc. Now, thanks to Texas Instruments' SN76477 complex sound generator, an integrated circuit that sells nationally for about $3.00, sonic experimentation is far more convenient. What makes the 76477 unique is that it contains all the active circuitry needed to generate just about any sound imaginable. A few resistors and capacitors and a power supply are the only external components required.

Inside the IC Package. By considering its complex circuit as a series of function

With a minimum of extra components and a single Texas Instrument SN76477 IC, you can create a host of different sounds "blocks," it is relatively easy to understand and follow the 76477's operation. In Fig. 1, the IC's function blocks are reduced to simplest form, with basic sound-generating blocks in gray shading and supplemental control blocks in color. Typical waveforms available at various points in the system and what the final output before amplification might look like are also shown.

A more complete picture of all the function blocks contained in the IC's 28-pin package is shown in Fig. 2. Fabricated from bipolar analog and I²L digital blocks, this IC contains all the active circuitry needed for a user to create an almost unlimited range of sounds.

a nominal 0.1-to-30-Hz range, contingent on the values of resistance (*R*) and capacitance (*C*) connected from pins 20 and 21, respectively, to ground. Two outputs are available from this oscillator: a 50% duty-cycle square wave that is applied to the mixer and a triangular wave that can be routed to an external voltage-controlled oscillator (vco) via pin 16 or through the SLF's select logic block to modulate the internal vco.

Modulation of the internal vco covers a 10:1 range, with the lowest frequency determined by the *R* and *C* values connected between pins 18 and 17 to ground. This vco's output goes to the mixer and envelope-select circuits.

signal is present or absent, the system inhibit logic controls the output of the envelope generator and modulator. This signal also toggles the one-shot multivibrator that is used to generate the short-duration pulses used to simulate the sounds of gunshots, bells, and explosions. Time duration of the multivibrator's output signal is determined by the *R* and *C* values connected from pins 24 and 23 to ground. Maximum usable period is approximately 10 seconds.

The output from the one-shot multivibrator is passed through the envelope-select circuit that determines envelope shape and is used to modulate the envelope generator and modulator.

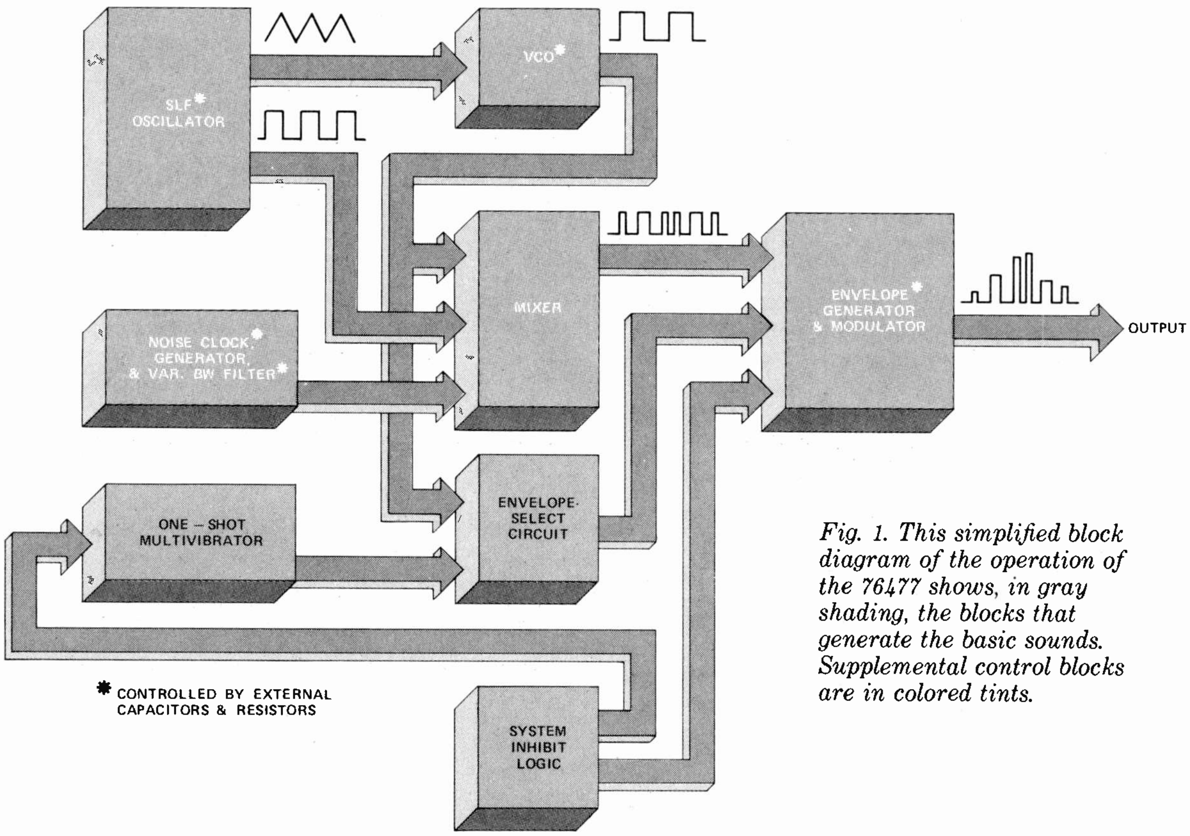


Fig. 1. This simplified block diagram of the operation of the 76477 shows, in gray shading, the blocks that generate the basic sounds. Supplemental control blocks are in colored tints.

Desired sounds are all user defined. You simply switch into and out of the IC's circuit resistor and capacitor values and set a few logic states to "tailor" the audio parameter you require. Sounds of gunshots, explosions, sirens, musical instruments, "phaser" guns, etc., can be simulated. You can even create sounds you never heard before.

An audio amplifier is built into the IC, but you can route its output to a high-quality audio amplifier to obtain a louder, richer sound.

Chip Operation. The super-low-frequency (SLF) oscillator in the 76477 has

Output pulses from the noise clock, whose frequency is determined by the resistance values connected from pins 3 and 4 to ground, are used to control the noise generator. The output from the noise generator is passed through a variable-bandwidth noise filter, controlled by the *R* and *C* values from pins 5 and 6 to ground, to the mixer.

The mixer combines the three inputs (from the noise filter, the SLF's square-wave generator, and the vco) and, contingent on the dc states of its three selector inputs, at pins 25, 26, and 27, determines type of mixer-output signal.

Depending on whether a 5-volt control

Modulator attack and decay are controlled by the *R* and *C* values connected from pins 7, 8, and 10 to ground.

The final signal is applied to the audio amplifier, which develops a 2.5-volt peak-to-peak maximum low-impedance output at pin 13. A feedback resistor can be connected between pins 12 and 13 to modify the amplifier's gain.

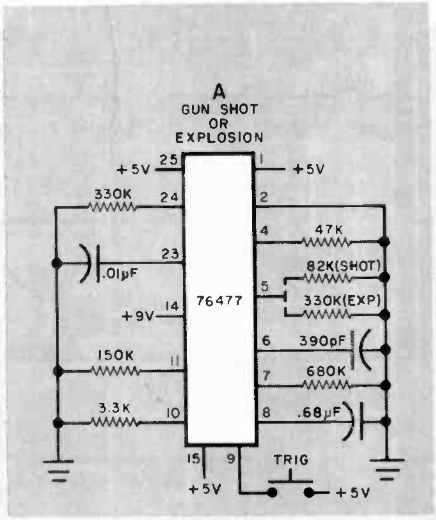
There are 23 variables under user control with the 76477 sound generator. Hence, you can be kept occupied for a considerable time exploring the effects that can be obtained with various combinations of controls.

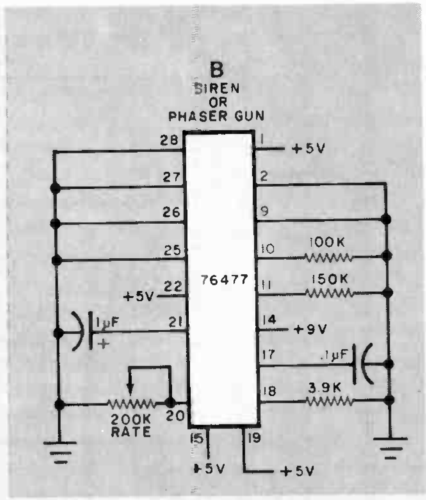
(continued on next page)

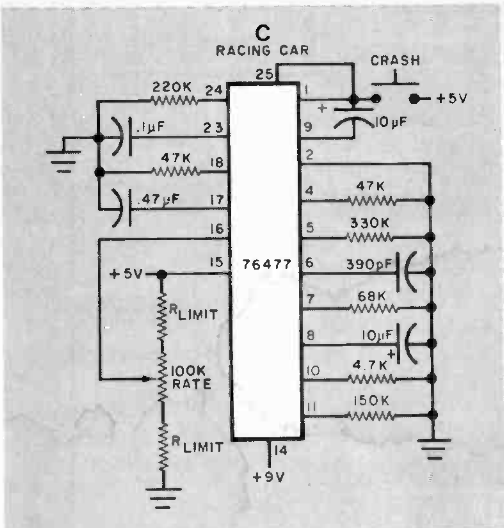
Fun Circuits You Can Build

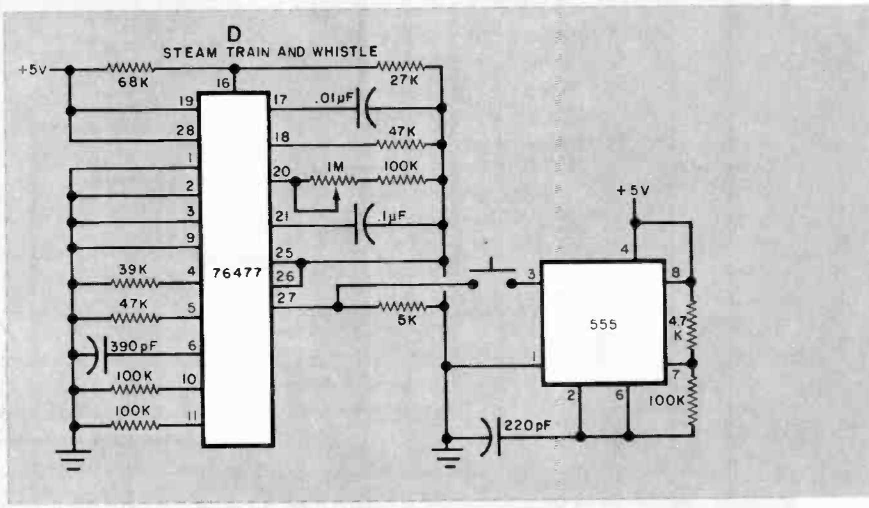
In this section, we present five fun circuits that typify some of the uses to which the SN76477 complex sound generator IC can be put. All are relatively simple and inexpensive to build, because the IC contains all the active circuitry needed.

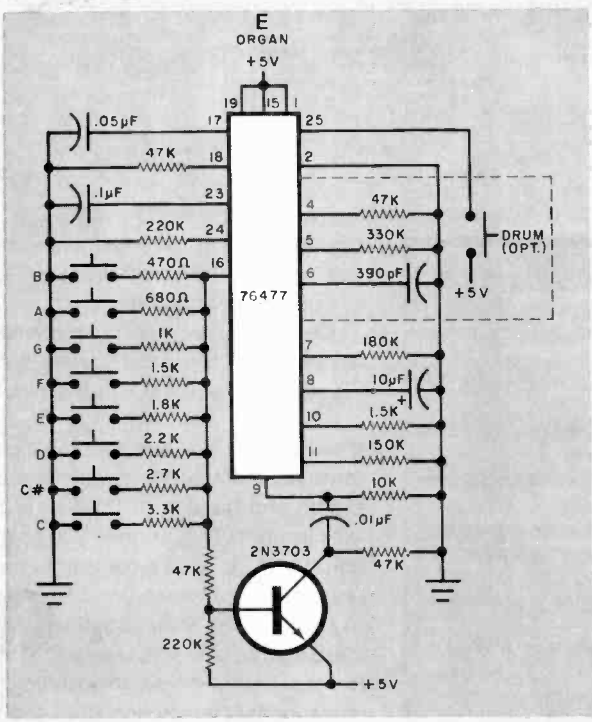
Circuits A, B, and C can be used to add realistic sound effects to the animation in video games. The model railroader will find circuit D useful, while the electronic "organ" in circuit E should appeal to all, especially children. Finally, circuit F illustrates how an outboard transistor amplifier stage can be added to increase the power delivered to the speaker.

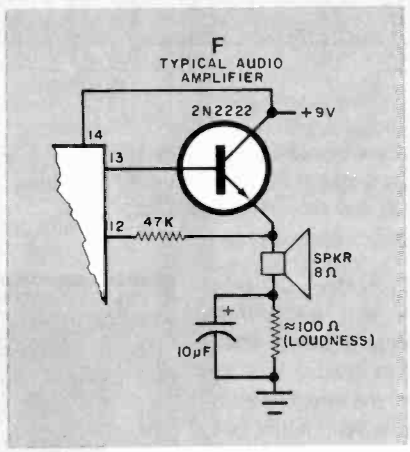












Practical Breadboard. Shown in Fig. 3 is the circuit of a practical experimenter's "breadboard." Although the circuit is really quite simple, to utilize the full capabilities of the 76477 sound generator, a rather large cabinet is required to accommodate all the switches and jacks shown.

You can use a small piece of perforated board on which to mount *IC1* (a socket is recommended) and the *Q1/Q2* audio amplifier circuit. Alternatively,

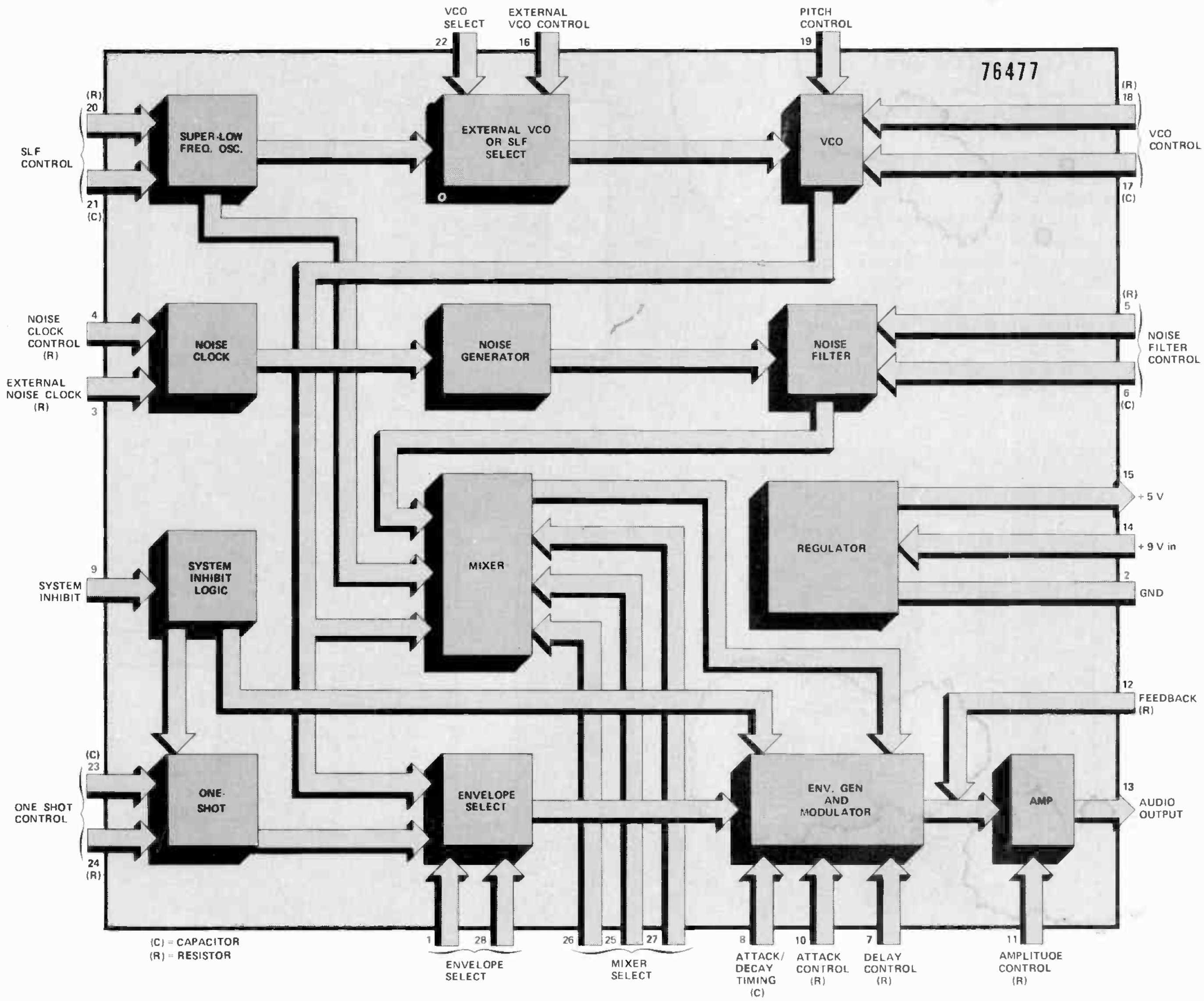


Fig. 2. The block diagram of the internal operation of a 76477 complex sound generator IC shows how it contains a complete sound-effects lab in a 28-pin package.

you can design and fabricate a printed-circuit board. If you use perforated board, you can Wire Wrap or pencil wrap the components into the circuit.

Although the system will operate from a standard 9-volt battery, you might opt for a small power supply that can deliver 7.5 to 9 volts instead, if only to free yourself from having to replace batteries periodically. Make sure, however, that the cabinet you select will accommodate all controls, jacks, and circuitry.

All 28 switches, 12 banana or tip jacks, and 8 potentiometers should be mounted on the front "control" panel and suitably identified with a dry-transfer lettering kit. To simplify experimenting, switches, jacks, and pots should be identified according to function as shown in Tables I through III. Table IV is an example of grouping according to function. Group arrangements can be outlined on the control panel with a heavily inked or painted line.

Once the various components are mounted on the front panel, refer to Fig. 3 and wire them into the circuit.

TABLE I—JACK IDENTIFICATION

J1	Input for external noise oscillator
J2	Input for external voltage-controlled oscillator
J3	Noise filter resistance measurement jack with *R4*
J4	Decay resistance measurement jack with *R6*
J5	Attack resistance measurement jack with *R8*
J6	Audio output
J7	External vco measurement jack with *R15*
J8	Vco control resistance measurement jack with *R18*
J9	Pitch control resistance measurement jack with *R23*
J10	SLF oscillator control resistance measurement jack with *R25*
J11	One-shot resistance measurement jack with *R27*
J12	Common ground

Use. Note in Fig. 3 that each IC pin that terminates in a potentiometer has both a switch and banana or tip jack in series with the pot. This permits you to use an ohmmeter to measure the resistance required for a given sound, arrived at experimentally. After obtaining the desired sound, you simply open the switch for the pot and use the ohmmeter to measure the resistance from the associated jack to ground. If you keep a log of the various resistances and capacitances required for particular sounds, they can be duplicated on demand.

(continued on page 80)

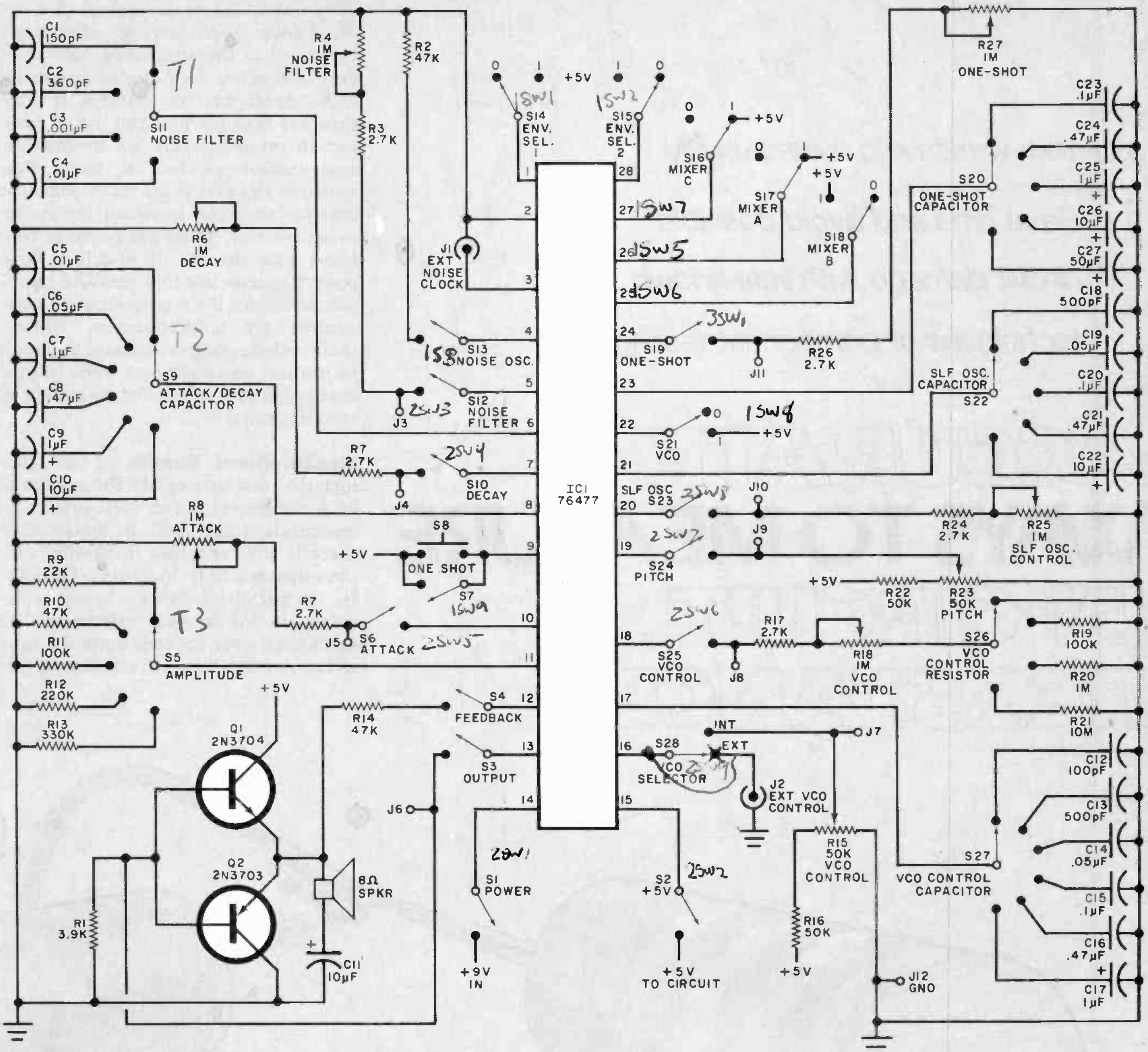


Fig. 3. The circuit for a complete sound-effects generator uses 28 switches, 12 banana (or tip) jacks and eight potentiometers to allow a broad selection of controllable parameters.

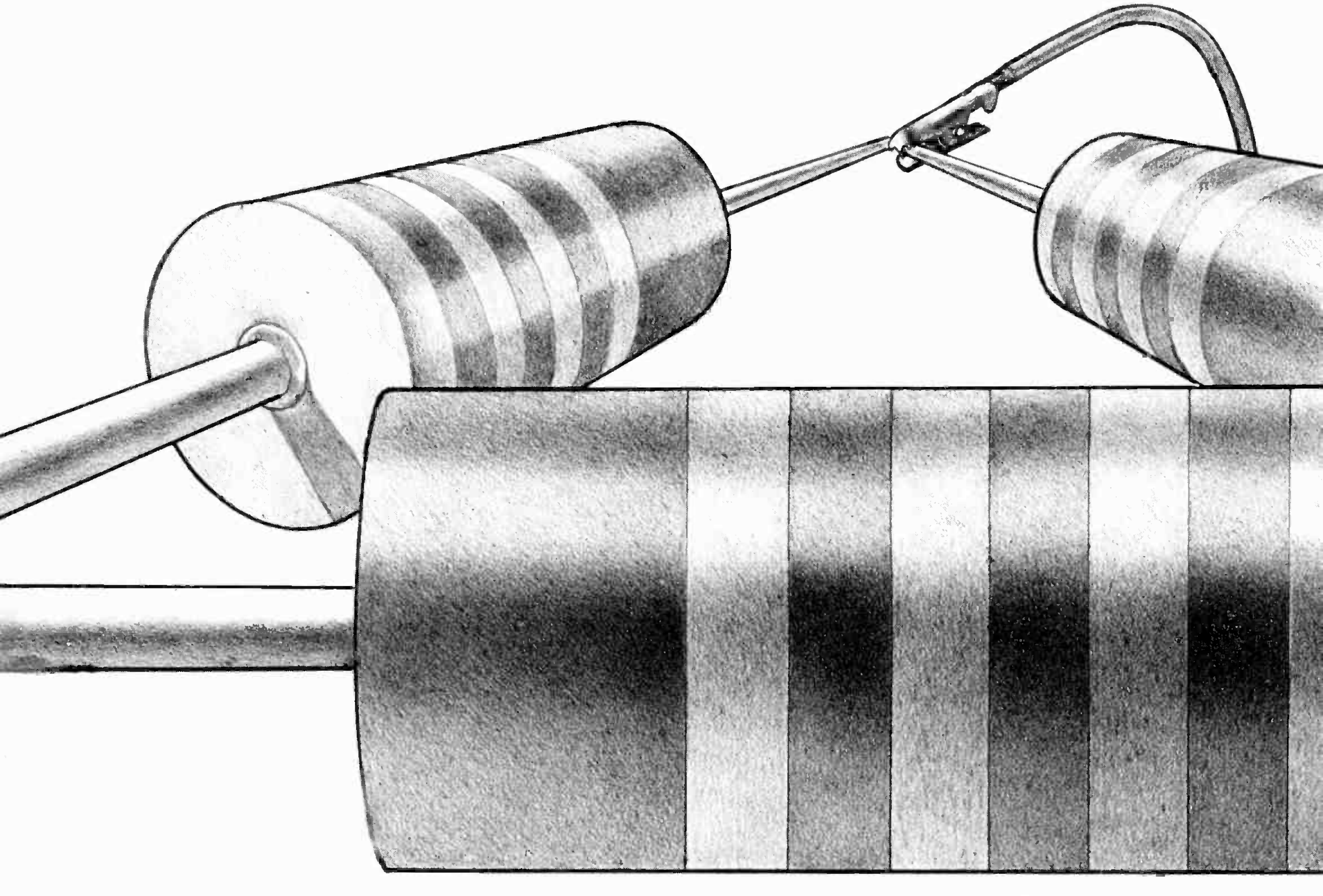
PARTS LIST

B1—9-volt battery (see text)
C1—150-pF capacitor
C2—360-pF capacitor
C3—0.001-μF capacitor
C4,C5—0.01-μF capacitor
C6,C14,C19—0.05-μF capacitor
C7,C15,C20,C23—0.1-μF capacitor
C8,C16,C21,C24—0.47-μF capacitor
C9,C17,C25—1-μF capacitor
C10,C11,C22,C26—10-μF, 15-volt electrolytic
C12—100-pF capacitor
C13,C18—500-pF capacitor
C27—50-μF, 15-volt electrolytic
IC1—SN76477N complex sound generator (Radio Shack 276-1765 or similar)
J1,J2—RCA phono jacks
J3 through J12—pin or banana jacks
Q1—2N3703 transistor
Q2—2N3704 transistor
The following are ½-watt, 10% resistors unless otherwise noted:
R1—3900 ohms
R2,R10,R14—47,000 ohms
R3,R5,R7,R17,R24,R26—2700 ohms
R4,R6,R8,R18,R25,R27—1-megohm linear-taper potentiometer
R9—22,000 ohms
R11,R19—100,000 ohms
R12—220,000 ohms
R13—330,000 ohms
R15,R23—50,000-ohm linear-taper potentiometer
R16,R22—50,000 ohms
R20—1 megohm
R21—10 megohms
S1 through S4,S6,S7,S10,S12 through S19,S21,S23 through S25—Spst slide or toggle switch
S5,S20,S22—Single-pole, 5-position nonshorting rotary switch
S8—Normally open, momentary-contact pushbutton switch
S9,S27—Single-pole, 5-position nonshorting rotary switch
S11,S26—Single-pole, 4-position nonshorting rotary switch
S28—Spdt slide or toggle switch
Misc.—Battery holder; 28-pin DIP socket for IC1; dry-transfer lettering kit; suitable enclosure; control knobs and dial plates (7); etc.

BY FRANK WITNER AND DIANE JASINSKI

Save time and avoid possible circuit damage with little-known techniques of component testing.

ACCURATE WAYS TO MEASURE IN-CIRCUIT RESISTANCES



IN-CIRCUIT measurement of a resistance offers several advantages compared to the alternative method of unsoldering one lead of the component to be measured. For example, it saves time and does not pose the risk of damage to printed-circuit boards and the components mounted on them. Presented in this article are techniques that provide accurate in-circuit resistance measurements. These are not to be confused with the use of so-called "low-power" ohmmeters that measure in-circuit resistance if the only shunting components are semiconductors. Rather, these techniques give accurate in-circuit resistance measurements even if the component to be measured is shunted by other resistors!

Measurement Basics. If an ohmmeter is used to measure the resistance of a component wired in a circuit, an inaccurate result will be obtained if there is any resistance in parallel with the resistance to be measured. Obviously, the parallel resistance causes a decrease in the overall resistance. The amount of error depends upon the ratio of the shunting circuit resistance to the value of the resistance to be measured. It is shown graphically in Fig. 1.

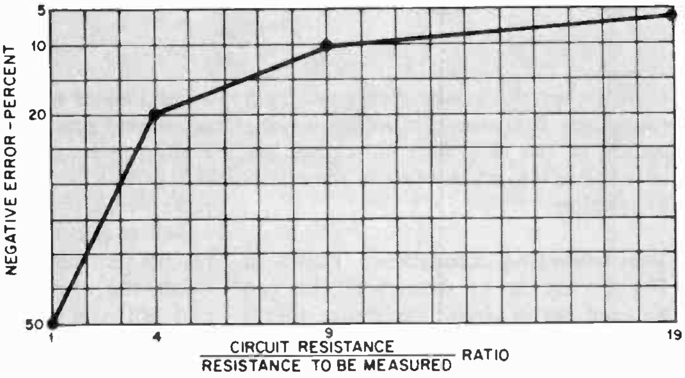


Fig. 1 Graphical analysis of the error in a resistance measurement caused by uncompensated shunting circuit resistances.

Seldom is a resistor in a given circuit placed directly in parallel with another resistor. Rather, any resistors connected to either side of it usually run to other circuit nodes. The delta-network model of a typical circuit shown in Fig. 2 reflects this. The resistor whose value is to be determined is designated *R1*, and the shunting circuit paths are embodied in *R2* and *R3*.

The node at the junction of *R2* and *R3* makes it possible to electrically isolate the resistor to be measured without physically disconnecting one end of it. This is accomplished by placing each end of part of the shunt path at the same voltage. Because there is no voltage drop across part of the shunt path, the entire shunt path behaves like an open circuit and will not affect an in-circuit resistance measurement of the component under test. This technique can be used even in a complex circuit because any number of shunt paths can be reduced to an equivalent of a single path by connecting together their junction points (homologous to the node *R2R3*).

There are several circuits, most of them designed around the operational amplifier, that can perform the required isolating function. Two of the qualities of the ideal operational amplifier make it well suited for this application. Firstly, no current flows into either the inverting or noninverting input terminals. Secondly, in a noninverting amplifier with 100% feedback, there is no voltage difference between the inverting and noninverting inputs. These statements are true of ideal, not practical, operational amplifiers. However, contemporary practical op amps can, within certain limits, offer levels of performance closely approaching those of ideal amplifiers. The differences are then slight enough that they can be ignored.

The Voltage Follower shown in Fig. 3 can electrically isolate the resistance to be measured from the shunting circuit resistances in the following manner. This stage has unity voltage gain and sets up at its output terminal the same voltage that appears at its noninverting input. When the ohmmeter is connected to the delta network as shown, a positive voltage appears at the HIGH TERMINAL and the follower's noninverting input. The follower then sources current into *R2* so that the node *R2R3* is at the same voltage as the HIGH TERMINAL. Therefore, no voltage drop appears across *R3*, and effectively no resistance is in parallel with *R1*, the component whose resistance is to be measured. This isolation causes the ohmmeter to provide an accurate resistance reading.

Two factors determine how much current the follower must source through *R2*—the measuring potential impressed across the network by the ohmmeter and the value of the shunt resistance driven by the follower (in this case, *R2*). If the voltage impressed across the network by the ohmmeter is too high, the necessary current level might exceed the maximum amount of current the follower can safely provide or the heat generated by the driven shunt resistance might exceed the component's dissipation capability.

Reversing the follower leads might prove helpful if either of the problems just mentioned is expected to be encountered. This will cause the follower to source current into the other shunt element (*R3*), which might have a higher resistance. The best solution, however, is to use an ohmmeter that employs a low measuring potential. A moment's reflection on the familiar equation $P = E^2/R$

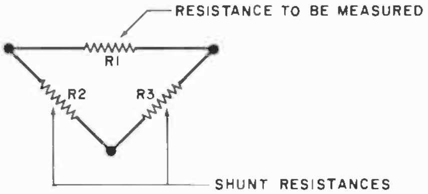
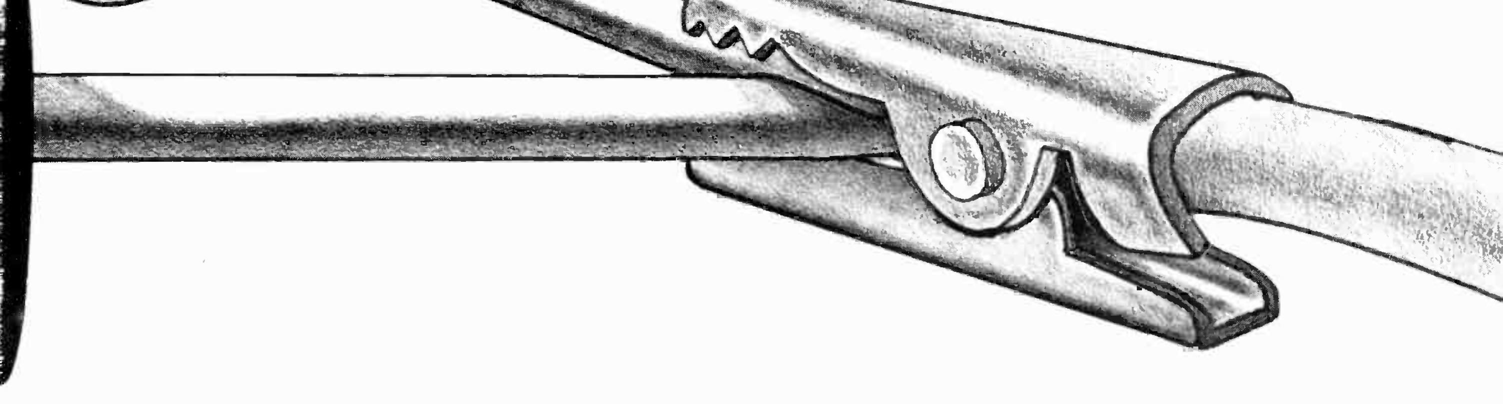


Fig. 2. Generalized model of a circuit containing a resistance to be measured and shunting components.



reveals that the power dissipated by a resistance decreases according to the square of the reduction in voltage but only linearly to an increase in the resistance value.

The Inverting Amplifier shown in Fig. 4 is another op-amp circuit that can be used for in-circuit resistance meas-

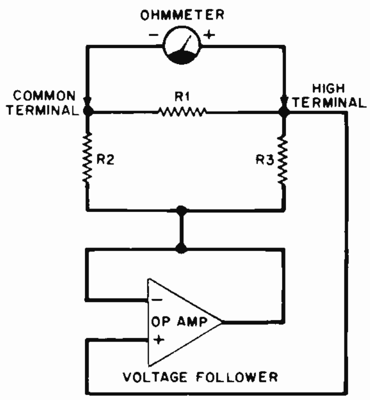


Fig. 3. Here, the voltage follower prevents shunting components from influencing theohmmeter reading.

urement. One well-known property of the inverting amplifier is that its voltage gain equals the ratio of the feedback resistance to the input resistance. In the in-circuit measurement application shown in Fig. 4, the component whose resistance is to be determined (*R1*) functions as the feedback resistance. Resistor *R4* behaves as the stage's input resistance. If the input resistance is a stable, known value, the op amp's output voltage is proportional to the feedback resistance.

The inverting op amp can be used to measure an in-circuit resistance if the junction of the two shunt components (the node *R2R3*) is connected to ground. A constant-current source drives the input resistance, and the op amp sources current into *R3* so that the same voltage appears across it as appears across *R1*, the resistance to be measured. Because of the feedback provided by *R1*, the HIGH TERMINAL is forced to virtually ground potential. Therefore, no voltage difference appears across shunt component *R2*, and the desired isolation of *R1* is achieved.

If the amplitude of the driving constant-current source is accurately known, the voltmeter reading can be converted to a resistance measurement by simple arithmetic. Alternatively, if an analog meter is used along with a constant-current source of known output, the meter's scale can be redrawn so that it reads directly in ohms. For resistance measurements over a wide range, it will probably be necessary to employ several meter scales and either a number of current sources with different output ratings or a single current source whose output can be varied in fixed, accurate increments.

Miller-effect analysis of this circuit reveals that resistances are reflected between the HIGH TERMINAL and ground and between the LOW TERMINAL and ground. These reflected resistances parallel shunt components *R2* and *R3* such that *R2* is in parallel with a resistance equivalent to $R1/(1-(1/A))$ and *R3* is in parallel with a resistance equivalent to $R1/(1-A)$, where A is the voltage gain of the stage. The effective resistances of the shunt paths thus depend upon both the value of the component to be measured and the values of the shunt components—not upon the values of the shunt components alone. Because of the Miller effect, in a practical circuit, the operational amplifier can work with a lower value of shunt resistance between the LOW TERMINAL and ground than between the HIGH TERMINAL and ground.

Another inverting op-amp circuit that can be used for in-circuit resistance measurement appears in Fig. 5. Here, the resistance to be measured (*R1*) functions as the stage's input resistance and a constant-voltage source drives the network. The output voltage generated by the op amp is *inversely* proportional to the value of the component to be measured, and is monitored by a voltmeter placed across the feedback resistor. As was the case in the previous circuit, feedback forces the HIGH TERMINAL to virtually ground potential. No voltage drop exists across *R2*, so the desired isolation of *R1* is achieved. Shunt component *R3* has no effect on the resistance measurement because it is connected directly across the constant-voltage source.

There are advantages that this inverting op-amp circuit has over the one previously presented. For example, the possibility exists in the constant-current case that the driven shunt resistance will be called upon to dissipate more heat than it is rated to do. This tends to be less of a problem when the constant-voltage circuit is employed. Also, the constant-voltage measuring circuit provides a faster response time when the resistance to be measured is shunted by one or more capacitors. The reason for this is simple. When a constant-current source is connected to a capacitive circuit, the voltage across the capacitor increases linearly to its maximum value. However, when a constant-voltage source is connected to an uncharged capacitor, the voltage across the capacitor increases exponentially until the capacitor is fully charged. This causes the capacitor to attain its ultimate voltage considerably faster than is the case when a constant-current source charges it, and allows for much shorter settling times during in-circuit resistance tests.

Bridge Measurements. A form of the classic Wagner bridge that can be used for in-circuit resistance measurements appears in Fig. 6. It can be thought of as two resistive bridges sharing common elements *R7* and *R1*, which is the component whose value is to be measured. As was the case in the circuits presented earlier, *R2* and *R3* are the in-circuit shunting components. Shunt resistor *R3* is placed across the null meter when *S1* is switched to its WAGNER position. This reduces the sensitivity of the null indicator for the Wagner adjustment but does not affect the balance of either bridge. Successive balancing of the bridge by means of potentiometers *R4* and *R6* (with *S1* switched alternately to each of its positions) results in no voltage drop across *R3*, the nondriven shunt resistance.

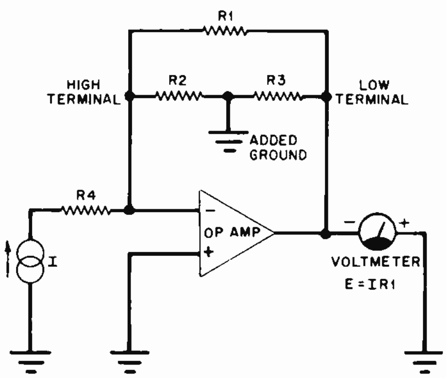


Fig. 4. An inverting op-amp circuit that can be used for in-circuit resistance measurements.

Measurement of the unknown value of *R1* now depends on the balancing out of shunt resistance *R3* such that the following relationship holds true:

$R1/R7 = R2/R4 = R5/R6$.

Note that this statement includes the standard balance equation of a four-arm resistive bridge.

An alternative bridge configuration has the side of potentiometer *R4* that was formerly connected to the node *R6R7B1*- shifted to the node *R5R6S1*. In effect, this is the same as interchanging the battery and the null detector in the bridge of Fig. 6. Measurement of *R1* now depends on the balancing out of shunt resistance *R2* so that:

$R1/R5 = R3/R4 = R7/R6$.

(Continued on page 81)

BUILD AN INFRA-RED Road Icing Alert

BY THOMAS R. FOX

Detects when conditions for ice on the road exist, even in the dark or if air temperature seems too warm

ROAD-SURFACE icing is one of the most dangerous hazards of winter driving. To warn drivers, ice-warning indicators for automobiles have indeed been developed. However, most of these indicators merely monitor air temperature a few inches from the road and alert the driver when that temperature falls to about 36°F. Unfortunately, this approach can deliver false alarms or, worse, fail to indicate danger when air and road temperatures are different.

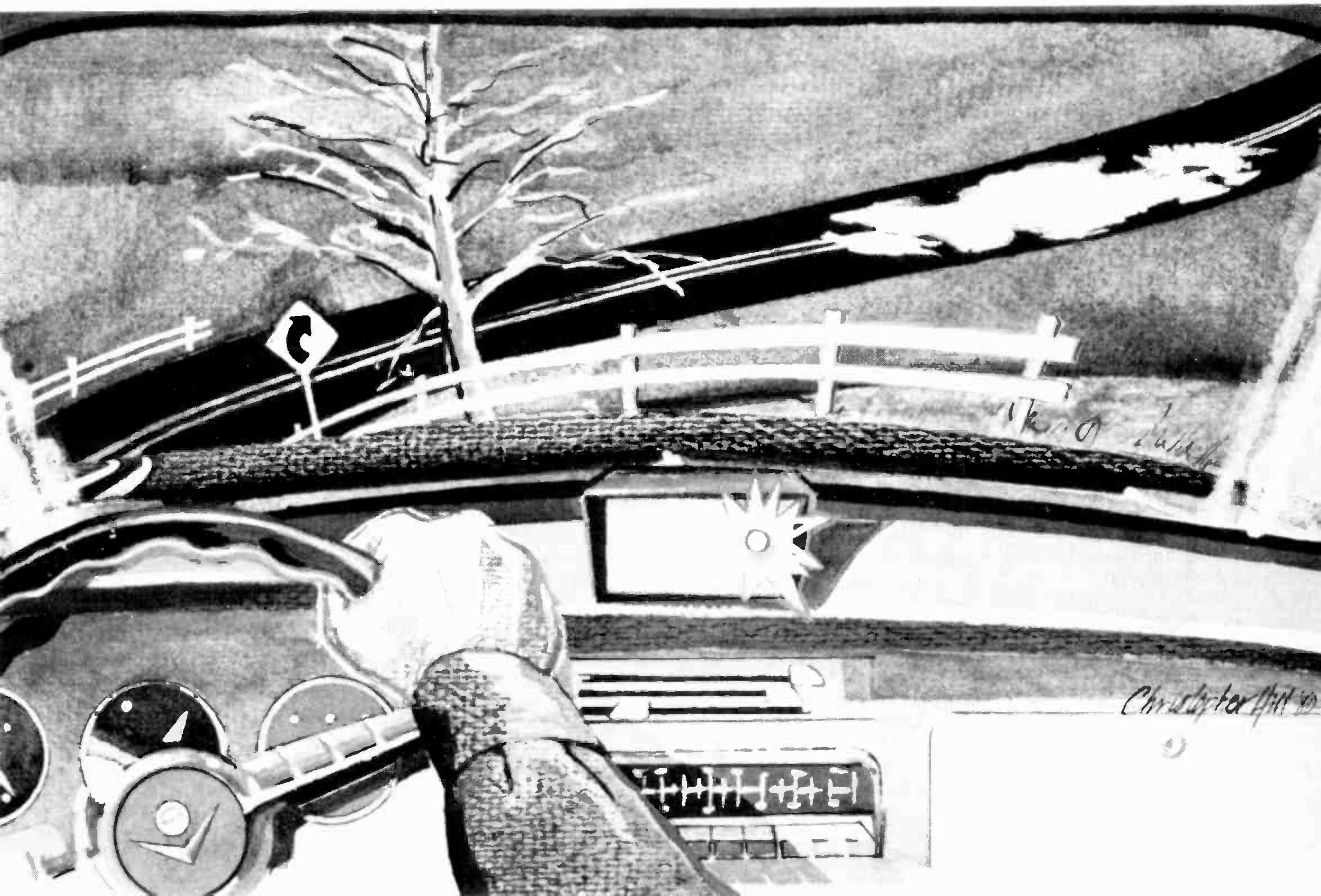
The infrared road icing alert (IRIA) system described here overcomes this problem by responding to both air and road temperatures. It senses infrared radiation emitted by the road and warns drivers both audibly and visually that the conditions for icing are present.

Sensor Operation. The sensor used in this project is a thermistor—a semiconductor device whose electrical resistance varies with temperature. Like any other material body, a thermistor can change temperature by conduction or radiation. As shown in Fig. 1, conduction is the exchange of heat between the air surrounding the thermistor and the thermistor, or the exchange of heat between the thermistor and any object making direct contact with it. In some remote cases, thermistor body temperature changes can occur by heat flowing along the thermistor leads. In all cases, the heat flow continues until the thermistor is at the temperature of the heat source and thermal equilibrium between the two is reached.

Temperature change through radiation occurs when the thermistor intercepts infrared radiation, that is electromagnetic radiation whose wavelength is just longer than visible light. When exposed to infrared radiation, the thermistor increases its internal temperature until it re-radiates energy at the same rate as it is being absorbed, and thus reaches equilibrium. Its electrical resistance, of course, changes accordingly.

A thermistor can also be heated by current flowing through it. However, in most applications, this current heating is small enough to be ignored.

While one does not usually consider ice or a road surface at or below freezing to be a source of infrared radiation, these objects like any in the universe that are above absolute zero (−273.16°C.), emit some electromagnetic energy. The magnitude and spectrum of the radiation vary with temper-



ature and the characteristics of the radiating body in a fairly complex way, but it is sufficient for our purposes to note that as temperature rises, the radiation increases in intensity and the peak of its spectrum moves to shorter and shorter wavelengths. Objects at normal temperatures (including the freezing point) radiate substantial infrared, to which a thermistor can respond.

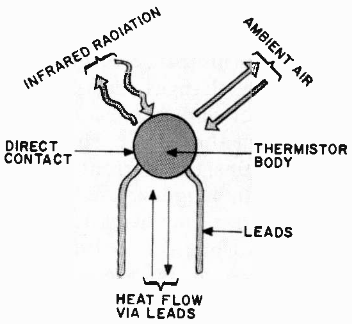


Fig. 1. How the temperature of a thermistor can change.

The Sensor Head. If a thermistor is mounted at the focal point of a parabolic reflector (a curved surface that has the property of focusing all incoming rays to a single point), and if the open end of the reflector is covered with a material that keeps air from circulating around the thermistor but allows infrared radiation to pass through, a sensor for infrared radiation is produced. This is shown in Fig. 2. Since the reflector and thermistor are not thermally insulated, the thermistor will have some response to ambient air temperature.

The reflector arrangement shown in Fig.2 is the approach used in the IRIA project. Such a sensor is mounted to the underside of the vehicle front bumper, with the open end facing the road underneath the vehicle. The temperature of the thermistor represents a weighted average of the road and air temperatures—with the road temperature predominating. If there were a perfect vacuum surrounding the thermistor, and the thermistor leads had the absolute minimum of support, the thermistor temperature would closely approximate that of the road.

The Sensor Assembly. The thermistor used in the author's prototype has a resistance of 1000 ohms at 25°C, is relatively small and inexpensive. It has a time constant of 10 seconds, and a diameter of 0.1 inch (see Parts List). The parabolic reflector used was a 4" type salvaged from a discarded lantern flashlight. Other sizes of reflectors can be used, but experiments show that a 2½" diameter is the smallest that can be used efficiently.

To determine the focal point of your reflector, remove the bulb and holder and temporarily attach a piece of styrofoam or balsa wood to the back of the reflector so that it covers the bulb holder hole. Stick a thin wood toothpick into the exact center of the holder hole so that it is supported by the styrofoam or balsa. On a clear, sunny day, aim the open end of the reflector to the midday sun until the toothpick begins to smoke. Remove the reflector from the sunlight and note that the charred part is at the reflector's focal point. Carefully measure and record the distance from the bottom of the reflector to this focal point as this is where the thermistor will be placed for maximum effect.

The reflector is mounted on a short length of 1" x 2" wood board, which in turn, is affixed to the car underside, far enough from the front so that direct sunlight will not strike the sensor. Once you determine where the wood element is to be mounted, you can then determine its length and method of mounting.

After the wood has been cut to length, the reflector is mounted to it using a pair of wood screws or epoxy as shown in Fig. 3A. After securing the reflector, carefully drill two 1/16-inch holes, ¼ inch apart and straddling the center point, through reflector and wood support. Cut two pieces of small-diameter insulated sleeving, about ⅛ inch shorter than the "focal length" previously determined. Mix a small batch of quick-setting epoxy and place some on each thermistor lead from the body to about 1¼ inches down. Slip the sleeving over each thermistor lead as shown in Fig. 3B. Insert the bare (unsleeved) thermistor leads through the two 1/16-inch holes drilled through the wooden support. As shown in Fig. 3C, adjust the height of the thermistor body so that it is centered at the "focal point" previously recorded. Use a dab of epoxy at each lead to secure the two leads to the board. Make sure bare leads do not make contact with the metal reflector.

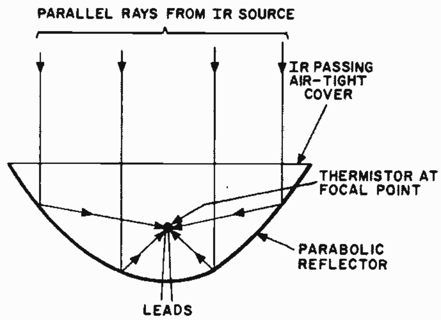


Fig. 2. A parabolic reflector focuses infrared rays onto the thermistor.

On the underside of the board, mount a two-lug terminal strip and connect both the two thermistor leads and a small two-conductor cable to the two terminals as shown in Fig. 3C. After the epoxy is cured, paint a thin coat of flat-

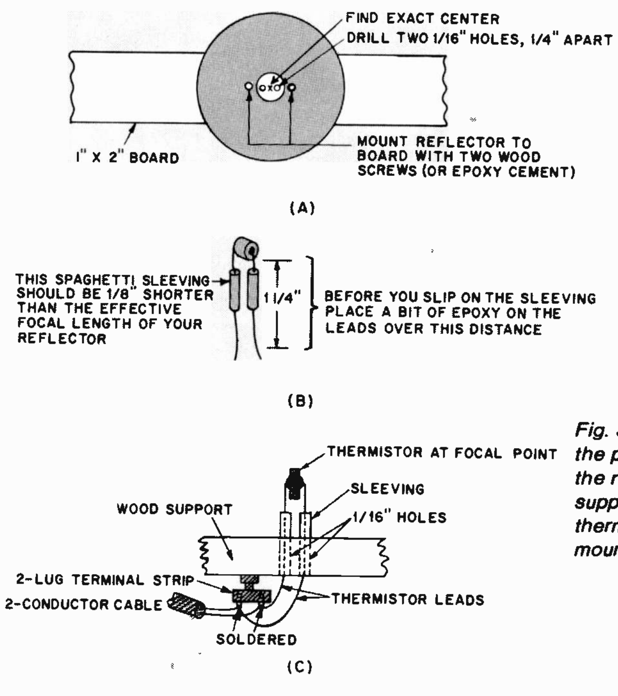


Fig. 3. Diagrams showing the procedures for mounting the reflector on its support (A), preparing the thermistor (B), and mounting the thermistor (C).

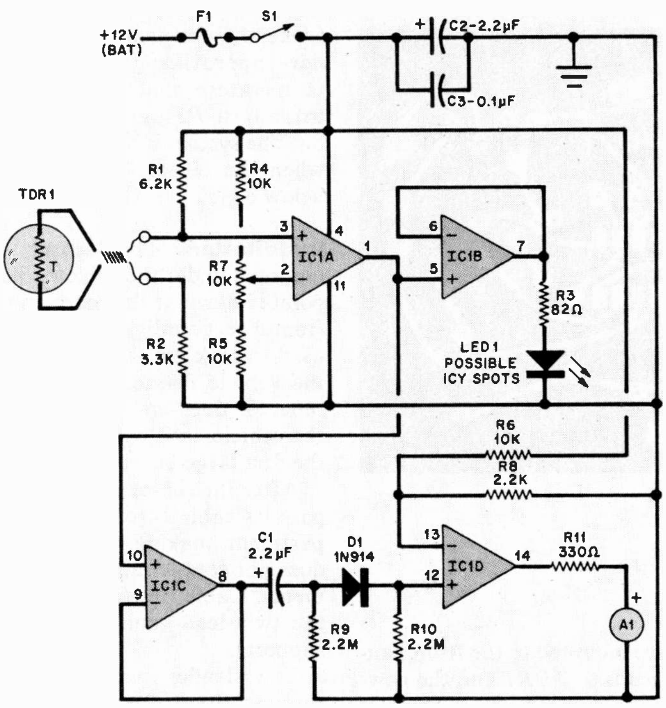


Fig. 4. The thermistor is part of a bridge that drives comparator IC1A. When this comparator turns on (detected temperature below preset), it activates a LED and an audible alarm.

PARTS LIST

A1—6- or 12-volt alarm (Sonalert or similar)
C1,C2—2.2-μF, 25-volt tantalum capacitor
C3—0.1-μF, 25-volt ceramic capacitor
D1—1N914 or similar diode
F1—¼-ampere fuse and holder
IC1—LM324N quad op amp
LED1—orange or red LED
The following are ¼-watt composition resistors unless otherwise specified:
R1—6.2 kΩ, 5%, film
R2—3.3 kΩ, 5%, film
R3—82 Ω
R4,R5,R6—10 kΩ, 5%, film
R7—10 kΩ, 10-turn pc mount potentiometer
R8—2.2 kΩ
R9,R10—2.2 MΩ
R11—330 Ω
S1—Spst switch
TDR1—1 kΩ @ 25°C thermistor, (Fenwall JB31J1 or similar)
Misc.—2½" or larger parabolic reflector (lantern or flashlight component), spaghetti sleeving, epoxy cement, 1" x 2" wood board, wood screws, machine screw, two-lug terminal strip, two-conductor cable, cable ties, etc.

Note: The following are available from Magicland Electronics, 4380 South Gordon Ave., Fremont, MI 49412: Fenwall JB31J1 thermistor at $2.95; thermistor and LM324N at $4.25 (kit IRIA1).

black, oil-based paint on the thermistor body. Cover the open end of the reflector with a thin transparent plastic shield (transparent food packaging material or other thin flexible plastic is fine). Transparent plastics pass more infrared energy than does glass.

Circuit Operation. The circuit is shown in Fig. 4. At a temperature of 32°F (0°C), the thermistor called for in the Parts List has a resistance of approximately 2.8 kΩ. Thus, at 32°F, pin 3 of op amp *IC1A* is just under 6.8 volts (assuming the vehicle's electrical system is delivering about 13.6 volts when the generator is operating).

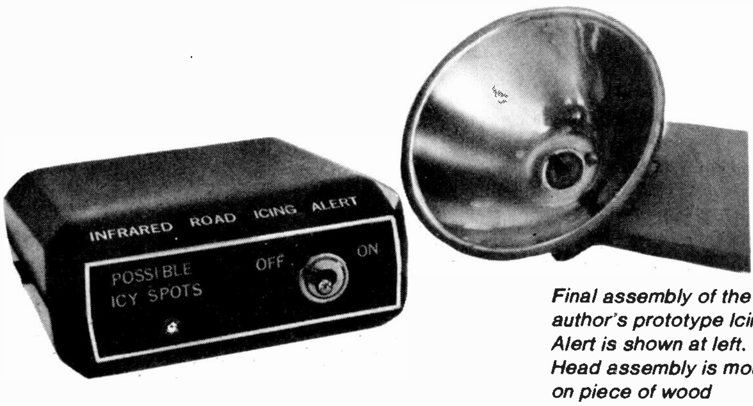
The output of *IC1A* is coupled to follower *IC1B* which in turn drives *LED1* through current-limiting resistor *R3*.

Reference voltage control *R7* is adjusted so that the LED is just below the point of glowing at the user-selected "critical point" (this is usually between 32 and 36°F). Once *R7* has been adjusted, the reference voltage at pin 2 of *IC1A* is just a fraction of a volt below that at its noninverting input (pin 3).

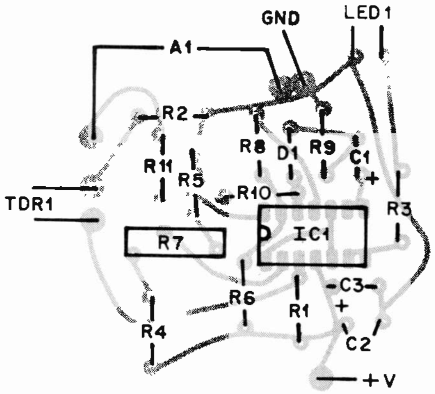
The noninverting input of *IC1A* is connected to the junction of *R1* and *TDR1* in series with *R2*. As the temperature of *TDR1* drops, its resistance increases, and the voltage at *IC1A* pin 3 increases above the reference voltage applied at pin 2. This causes *IC1A* to switch "on" which, in turn, forces buffer *IC1B* to supply current to *LED1* causing it to glow. This visually indicates that there is the possibility of an icy spot in the road.

The output (pin 1) of *IC1A* is also coupled to buffer *IC1C*, which drives a differentiator consisting of *C1* and *R9*. The output of this differentiator consists of a positive-going pulse when *IC1A* switches off. Diode *D1* allows only the positive-going pulse to pass to the noninverting input (pin 12) of *IC1D*. The inverting input (pin 13) is referenced to about 2.5 volts developed by network *R6* and *R8*. Therefore, *IC1D* will switch on only when its noninverting input is greater than the reference voltage (2.5 volts). When *IC1D* is activated, it supplies current to alarm *A1* via current-limiting resistor *R11*. This alarm turns on a fraction of a second after *IC1A* operates. After a time period determined by the values of *R6*, *R8*, *R9*, and *C1*, the alarm goes off. When the thermistor "sees" a higher temperature, its resistance drops, turning off *IC1A* and *IC1B*, and the LED goes dark.

The circuit is protected by fuse *F1*,



Final assembly of the author's prototype Icing Alert is shown at left. Head assembly is mounted on piece of wood with the thermistor at the focal point.



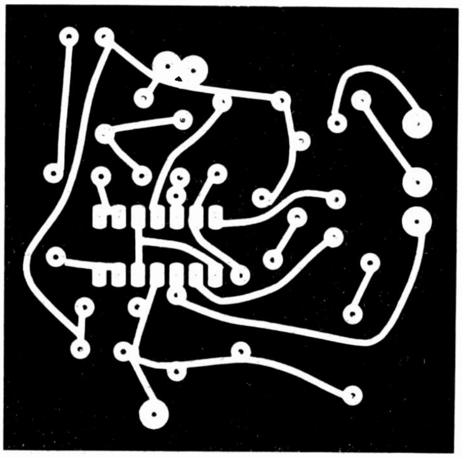


Fig. 5. Actual-size etching and drilling guide for a printed circuit board for the Infrared Road Icing Alert is shown above right. Component layout above left.

and capacitors *C2* and *C3* remove voltage transients that might produce a false alarm.

Circuit Construction. Although the circuit is simple enough to use direct point-to-point wiring on conventional perforated board, an actual-size foil pattern is shown in Fig. 5 along with the component installation. Note that *TDR1*, *F1*, *S1* and *A1* are not mounted on the small board. Though a single-turn potentiometer can be used for *R7*, a 10-turn type is recommended. If your alarm (*A1*) is a 6-volt version, use *R11*. If *A1* is a 12-volt type, *R11* can be eliminated. Resistor *R8* determines the "on" time for the alarm. Making this resistor smaller in value increases the *A1* "on" time. Conversely, for a shorter "beep," increase the value of *R8* to 3.3 kΩ.

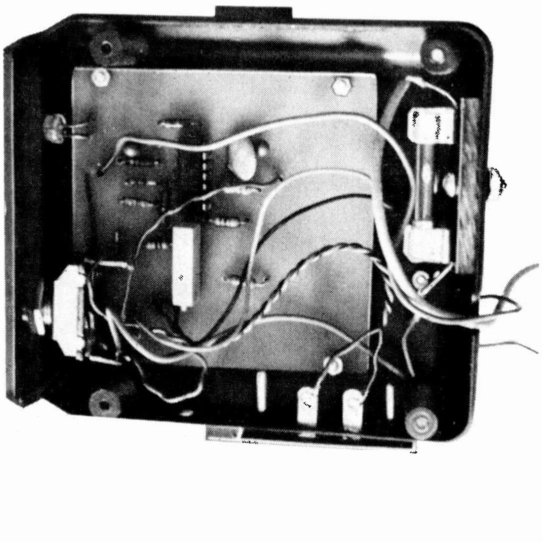
The circuit board can be mounted in almost any type of small (usually plastic) container. Power on-off switch *S1* and *LED1* are mounted to the front panel. The two leads to *TDR1* and the power-ground leads exit via small holes at the rear.

Initial Test. Connect a source of 12 to 15 volts dc to the pc board, and turn power switch *S1* on. Adjust trimmer potentiometer *R7* until the alarm sounds and *LED1* glows. Carefully back down on *R7* to the point where the LED just turns on.

Place the palm of your hand near the open end of the reflector for a brief period of time and note that the LED goes dark. Remove your hand, and note that after a few seconds, the LED glows and the alarm sounds off.

To create a "home-made" 37°F day, place the detector-reflector assembly in a common brown-paper bag and lay it on a shelf in the middle of your refrigerator (not the freezer!). Leave the sensor in this position for about 15 minutes. Since the temperature of the sensor is now approximately 37°F (the usual temperature that a refrigerator is set to), adjust *R7* until the LED just turns on. The system is now set up to sound off when the sensor "sees" a temperature below 37°F.

Internal view of the author's prototype shows circuit board in container with LED and switch on front and power leads exiting through back. Terminal strip on side is for leads to the thermistor.



Installation. The sensor must be mounted under the vehicle, the open end pointed down at the road, and protected from direct sunlight. Any means can be used to affix the wood sensor support to the vehicle frame. Make sure that the reflector does not extend too far below the vehicle, or it will be knocked loose at the first large bump.

After the sensor is mounted, carefully pass its cable through the engine compartment making sure that the cable does not contact any hot or moving elements. Cable ties can be used to secure the twin-lead conductor to appropriate supports.

The slender sensor cable is passed through the firewall and snaked to the upper part of the dashboard where it is connected to the electronics. The ground can be made to any metal part of the chassis, and the +12-volts should be obtained from any source that is "live" when the ignition key is used.

If the sensor has been calibrated at 37°F, you will have to wait until the ambient temperature drops into the 30's. A nearly perfect day would be one with cloudy skies and a temperature well below freezing in the morning, and an afternoon temperature over 38°F.

Park the car in the shade so that the reflector is positioned over an accurate thermometer placed on the ground. If you are on the cautious side, adjust *R7* until the LED barely lights with a ground temperature of 36°F. If desired, you can make the calibration at lower temperatures of about 32 or 33°F. If the weather is too warm, you can always use a pan of ice under the reflector to simulate 32°F.

The only maintenance required is keeping the reflector clean. You should wipe the reflector transparent cover at regular intervals. Contingent on the amount of road tar, sand, pebbles, etc., on the roads you use, you might have to replace the reflector cover when it becomes damaged.

Note that the IRIA does *not* detect road ice per se. Like conventional alarms, it responds to conditions under which icing may occur. The special characteristic of this system is that it assesses such conditions more accurately and offers a greater margin of safety when air and road temperatures are different, as they often are at dawn or early evening. ◇

ACTIVE FILTER

IMPROVES MORSE CODE READABILITY

BY LOU DEZETTEL

Outboard filter for low-cost rigs improves selectivity and reduces interference.

FOR learning or brushing up on Morse Code skills, it's hard to beat listening to and trying to "read" CW transmissions right off the air. Even though high transmission speeds and, sometimes, sloppy keying may make these signals frustrating for beginners, machine-perfect code at calibrated speeds is sent by W1AW, home station of the American Radio Relay League. The schedule of transmissions is given in the table; all you need to listen in is a general-coverage receiver with a bfo—providing that it is selective enough.

If your receiver is not selective enough, the Code Filter described in this article should help. It is meant to be connected between a receiver's audio output and a user's headphones (or audio amplifier) to sharpen the apparent selectivity and eliminate the interference that would otherwise make CW hard to read. The design is active, with a bandpass centered on 600 Hz and narrow enough to greatly reduce the effect of interference at neighboring frequencies. The center frequency of 600 Hz was chosen to provide a pleasant, nonfatiguing tone for the user.

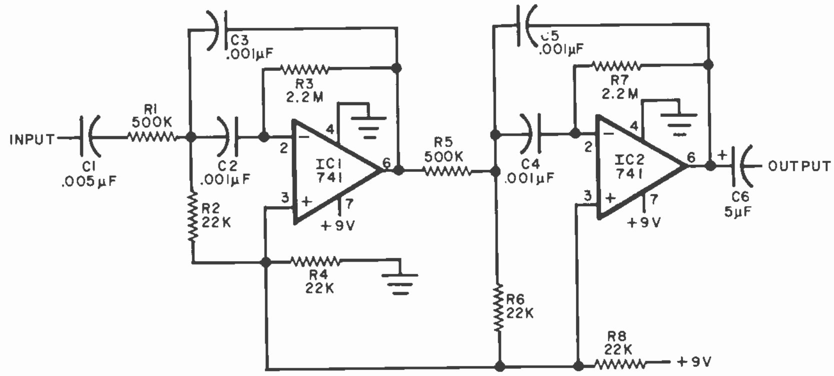


Fig. 1. Circuit for the Code Filter consists of cascaded pair of active stages formed by op amps IC1 and IC2.

PARTS LIST

C1—0.005-µF capacitor
C2,C3,C4,C5—0.001-µF capacitor (C3 and C5 must be closely matched)
C6—5-µF, 25-V electrolytic
IC1,IC2—741 op amp
R1,R5—500-kΩ, ¼-W resistor
R2,R4,R6,R8—22-kΩ, ¼-W resistor
R3,R7—2.2-MΩ resistor (must be closely matched)
Misc.—8-pin IC socket (2, optional), spst switch (optional), battery holder and connector, suitable connector for audio jack, small enclosure, mounting hardware, etc.

Circuit Operation. The circuit, shown in Fig. 1 consists of a cascaded pair of active stages formed by op amps *IC1* and *IC2*. With the component values shown, the bandpass peaks at about 600 Hz and is 100 Hz wide at the −6-dB points.

The frequency-determining components are *R2, R3, C2,* and *C3* connected to *IC1*, and *R6, R7, C4* and *C5* with *IC2*. Corresponding components of each stage should be closely matched to keep the two filters at the same peak frequency and bandpass. Components not affecting frequency may have ±20% tolerance in their values.

Because of its high input impedance,

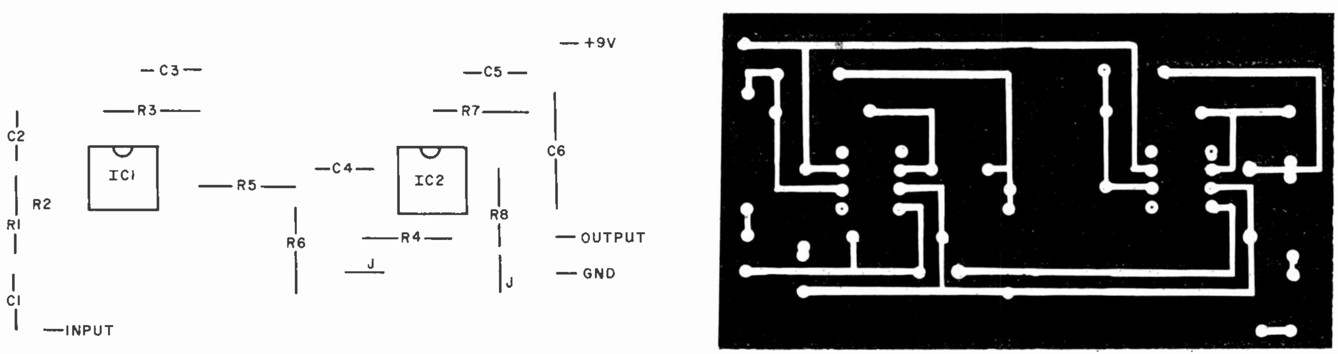


Fig. 2. Component placement guide for the Code Filter is shown at left, and actual-size pc board foil pattern is at right.

the filter will not appreciably load any circuit to which it is connected. The audio output can feed loads as low as 300 ohms without degrading the filter performance. (Most hi-fi phones have lower impedances and will not work.)

Construction. Although a pc board is not a necessity, an actual-size foil pattern and component installation is shown in Fig. 2. If desired, the circuit can be created using Wire-Wrap or any other assembly technique.

Since the circuit requires only 1.2 mA when operating, a conventional 9-volt battery will have a reasonably long life. If the receiver being used for code reception has a power supply between 5 and 30 volts, this voltage can be used to power the filter. Keep in mind, that if more than 20 volts or so is used, the rating of *C6* will have to be increased accordingly. Maximum supply voltage for the op amps is 30 V. An optional power switch may be used to remove the voltage from the filter when not in use.

The filter can be mounted within the receiver case or in a small outboard enclosure. Audio input can be taken from the earphone jack, if provided with the receiver, from the loadspeaker connections, or from a low-level audio circuit.

W1AW CODE PRACTICE SESSIONS

	EST	PST
Speeds: 5, 7½, 10, 13, and 15 wpm		
Mon.	9 a.m., 7 p.m.	6 a.m., 4 p.m.
Tues.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Wed.	9 a.m., 7 p.m.	6 a.m., 4 p.m.
Thur.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Fri.	9 a.m., 7 p.m.	6 a.m., 4 p.m.
Sat.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Sun.	4 p.m. 10 p.m.	1 p.m., 7 p.m.
Speeds: 10, 13, 15, 20, 25, 30, and 35 wpm		
Mon.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Tues.	9 a.m., 7 p.m.	6 a.m., 4 p.m.
Wed.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Thur.	9 a.m., 7 p.m.	6 a.m., 4 p.m.
Fri.	4 p.m., 10 p.m.	1 p.m., 7 p.m.
Sat.	7 p.m.	4 p.m.
Sun.	7 p.m.	4 p.m.

Frequencies: 1.835, 3.58, 7.08, 14.08, 21.08, 28.08, 50.08, 147.555 MHz.

Use. With the filter connected to the receiver audio, and a suitable amplifier or headphones connected to the filter output, tune in the desired CW transmission, and note the very sharp "peak" that occurs with filter use. It becomes very easy to "fine tune" the receiver, or its bfo, to produce a clean CW signal at the filter output. A dramatic falloff of interfering signals indicates that the filter is working properly. ◇

"Truth Analyzer... (Continued from page 38)

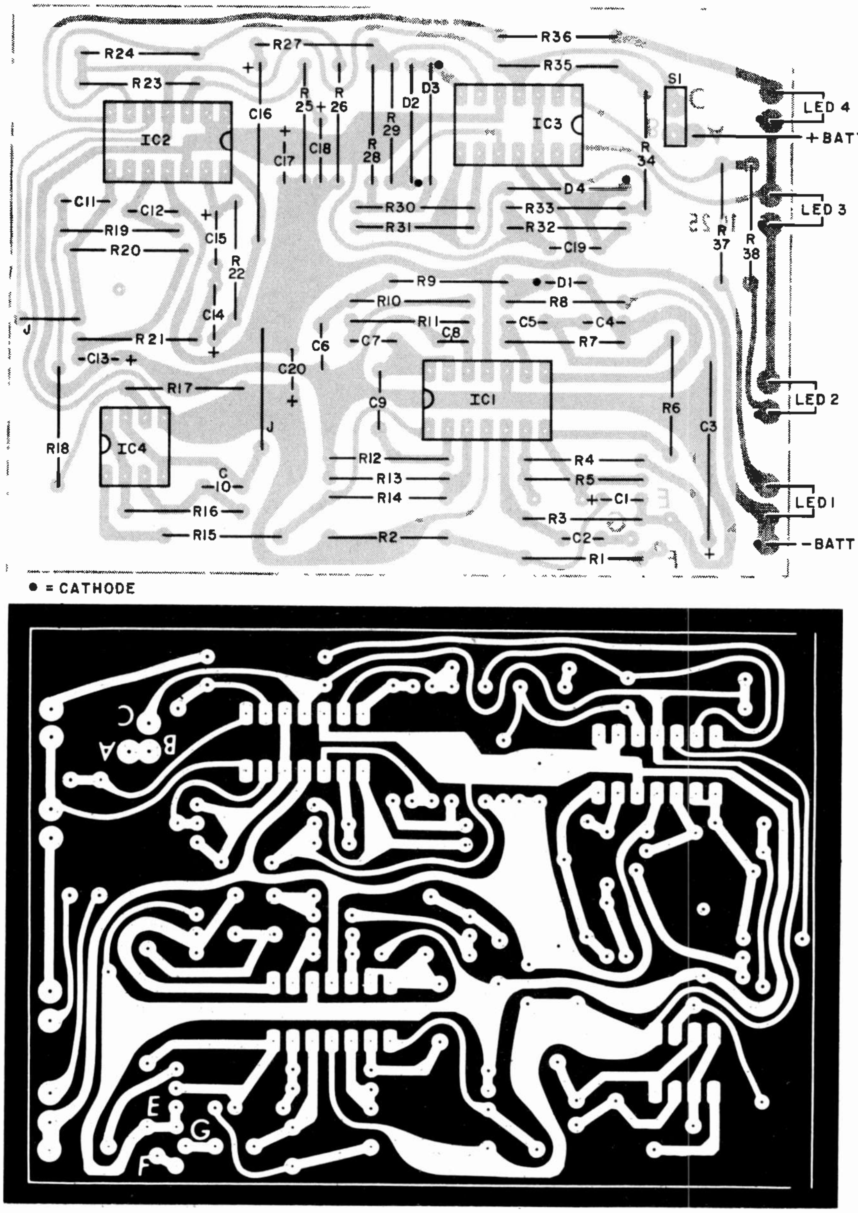
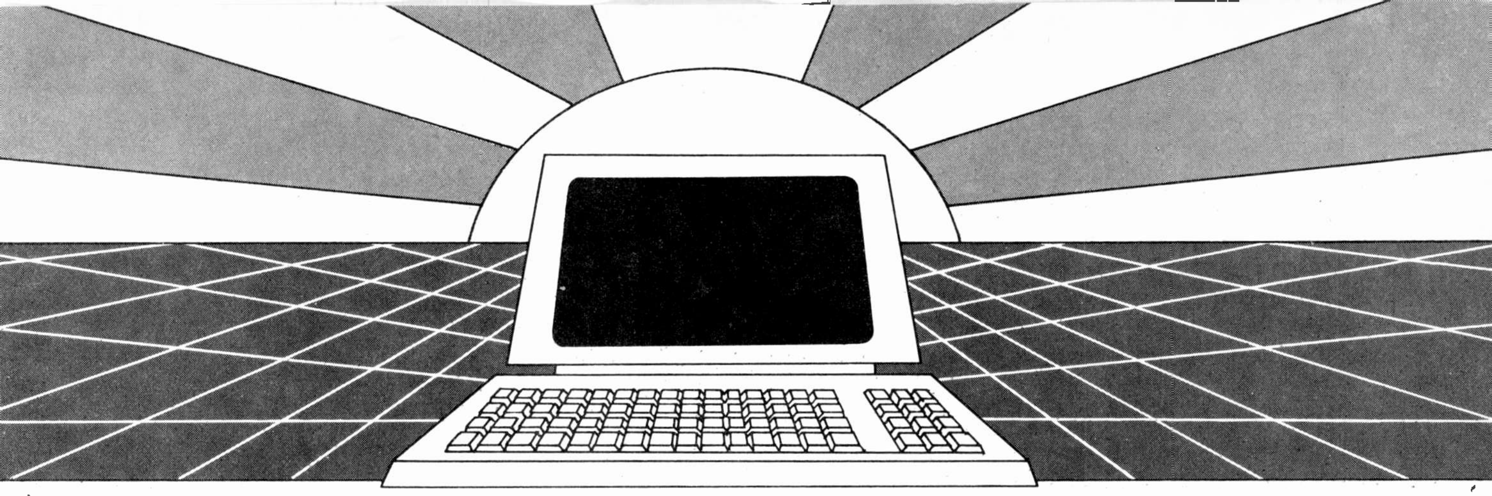


Fig. 6. Actual-size foil pattern and component placement guide for the voice analyzer. Be sure to observe polarities of electrolytic capacitors and diodes and orientation of ICs.

various advertising announcers' voices were monitored, it was interesting to note that the other LEDs had a tendency to flicker on, with the STRESS LED coming on quite often. The same was true when monitoring a number of phone-in radio programs. Finally, a number of situations were rigged, using various people as test subjects, all instructed to lie in answer to certain questions. The results were inconclusive. The results might have been pointedly different if the subjects being monitored were not aware that vocal stress tests were being conducted. Too, it should be kept in mind that voice characteristics differ among different people and even with the same person over a short period of time.

Psychologists at one U.S. university have stated that there is no conclusive evidence that microtremors actually exist in the vocal chords. One report, prepared by a psychologist on behalf of the U.S. Army's Land Warfare Laboratory at Aberdeen Proving Ground, concluded that results obtained with voice stress devices are "no better than chance." Moreover, American Civil Liberties Union suits have been presented alleging such devices constitute invasion of privacy.

Whether or not voice stress analyzers do what is claimed of them is a debatable point. However, they are interesting devices with which to experiment. ◇



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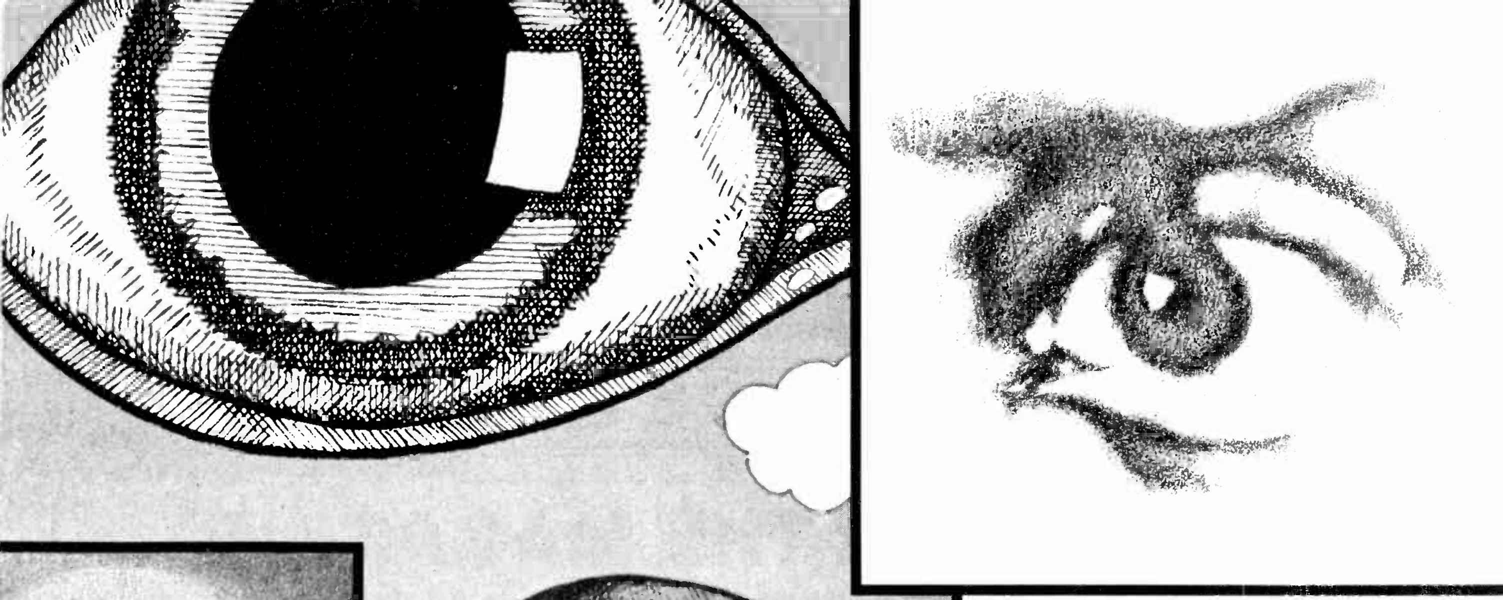
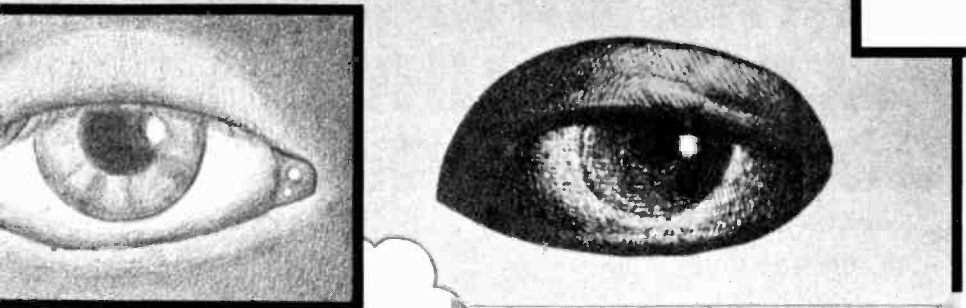
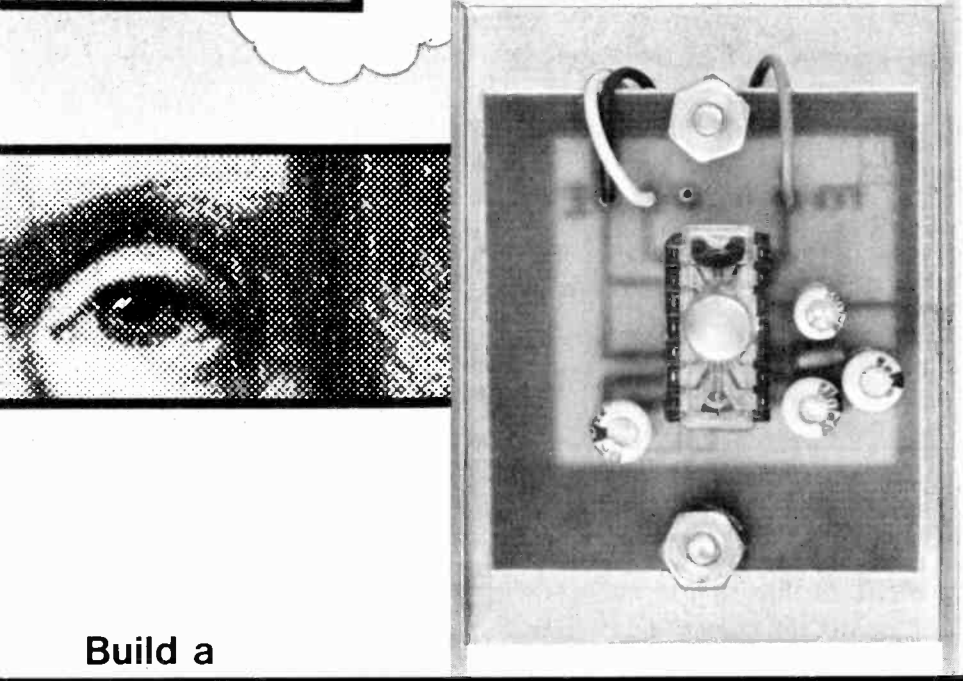






BY WALTER GONTOWSKI, JR.

Build a

MOTION-DETECTOR ALARM

Many-Eyed Modular System

Low-Cost IC

Responds to Light Changes

INTRUSION alarm systems are increasingly popular today owing to the growing incidence of crime. A new security system based on an IC motion detector developed by the Sprague Electric Company doesn't have the limitations of other types while sharing some of their advantages. Called the Optical Detector Modular alarm system (Opdec), the system presented here may be likened to a many-eyed optical device that detects movements through light changes, but is much lower in cost than an ultrasonic-type alarm and is resistant to false alarms.

Other characteristics of the Opdec include modular construction, provisions for timed exit and entry, and input terminals for optional closed-loop wiring that can yield added protection. Finally, Opdec can also function as a fire/smoke detector at the same time that it is on the lookout for intruders.

The Motion Sensor. The heart of the Opdec system is Sprague's ULN-2232A Integrated Optical Motion Detector. Un-

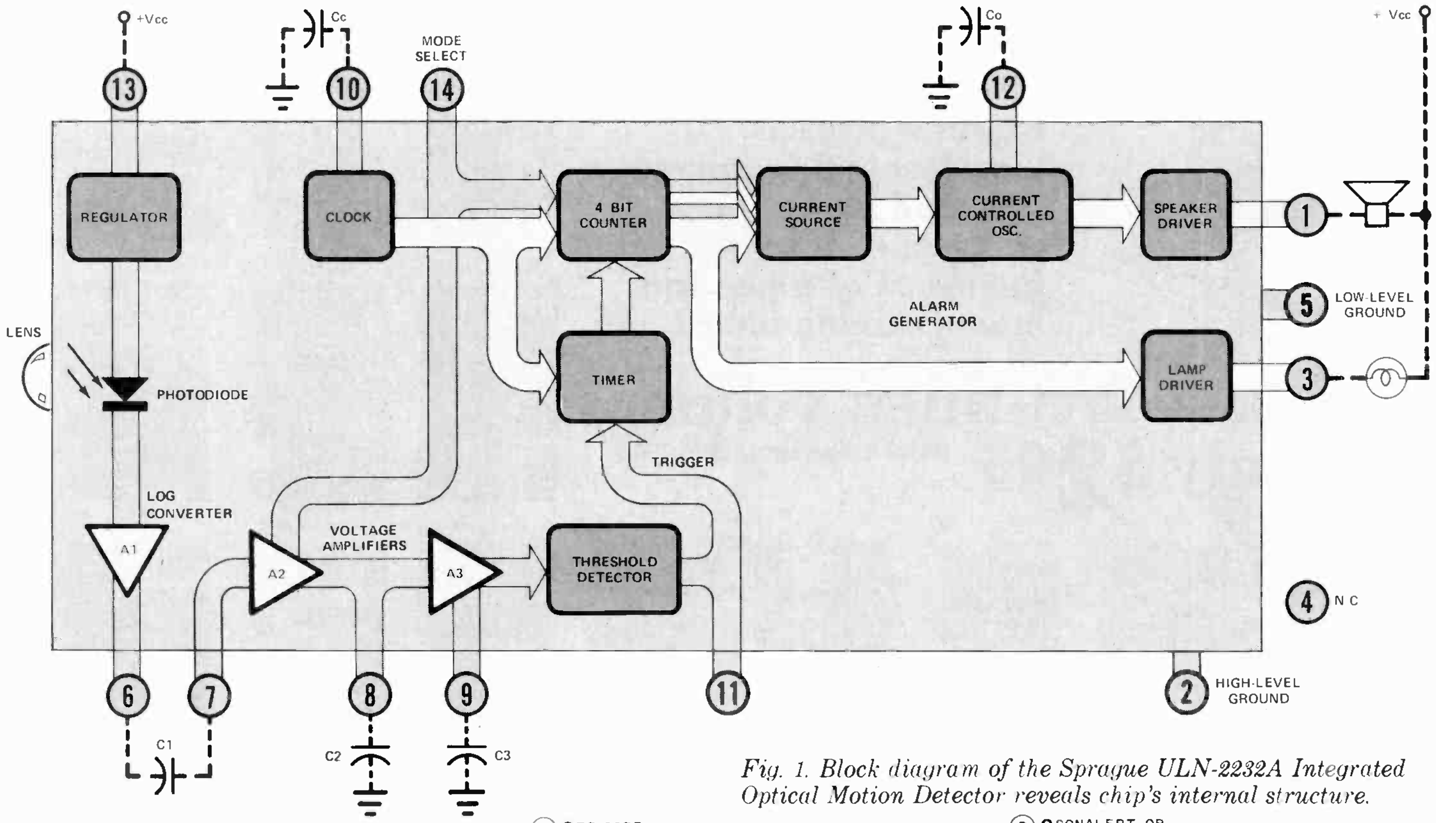


Fig. 1. Block diagram of the Sprague ULN-2232A Integrated Optical Motion Detector reveals chip's internal structure.

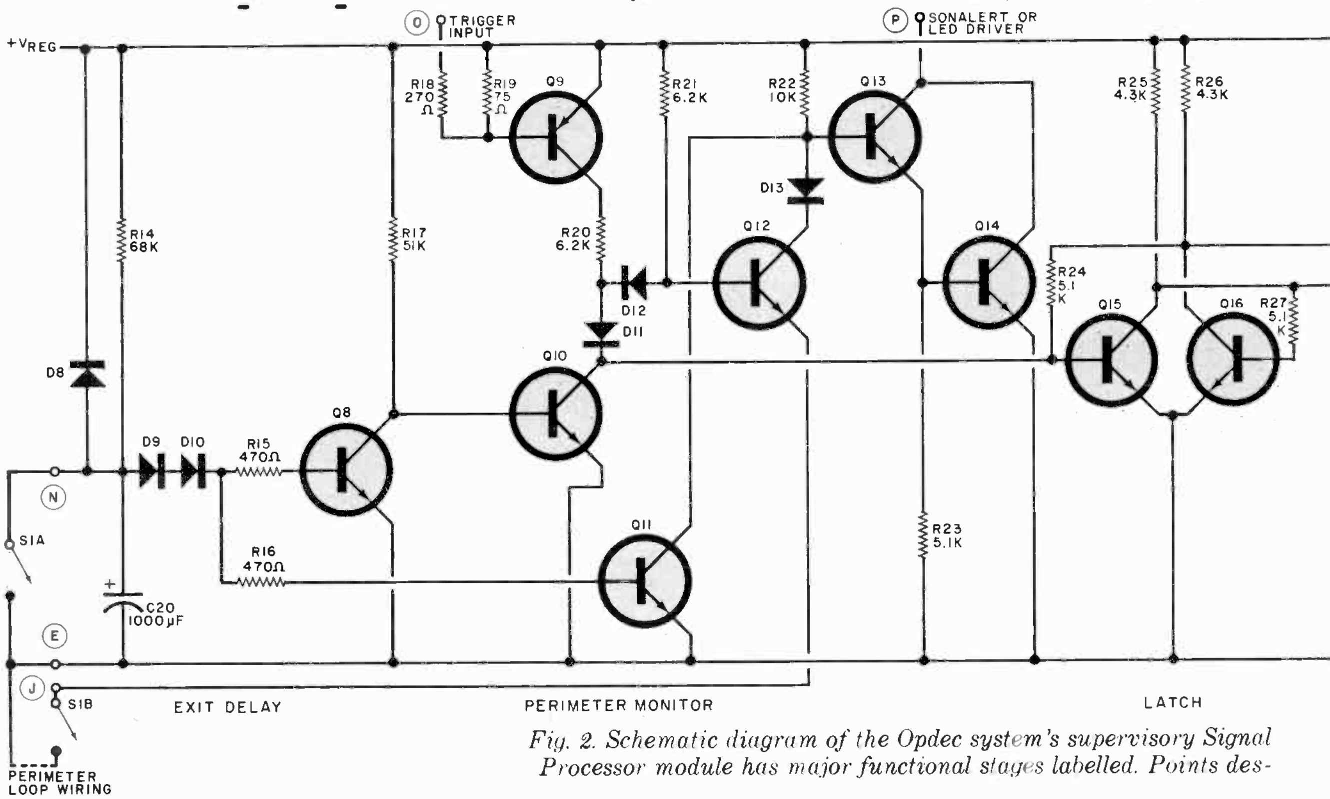


Fig. 2. Schematic diagram of the Opdec system's supervisory Signal Processor module has major functional stages labelled. Points des-

like a conventional optoelectronic alarm sensor (usually a CdS photocell) that triggers the alarm when the path between a light source and the sensor is interrupted, this novel IC senses the presence of an intruder by detecting changes in the amount of ambient light reaching it. As the intruder enters the room or moves around in it, the amount of light reflected to the sensor IC will vary. The sensor has been designed to respond to this change in light level.

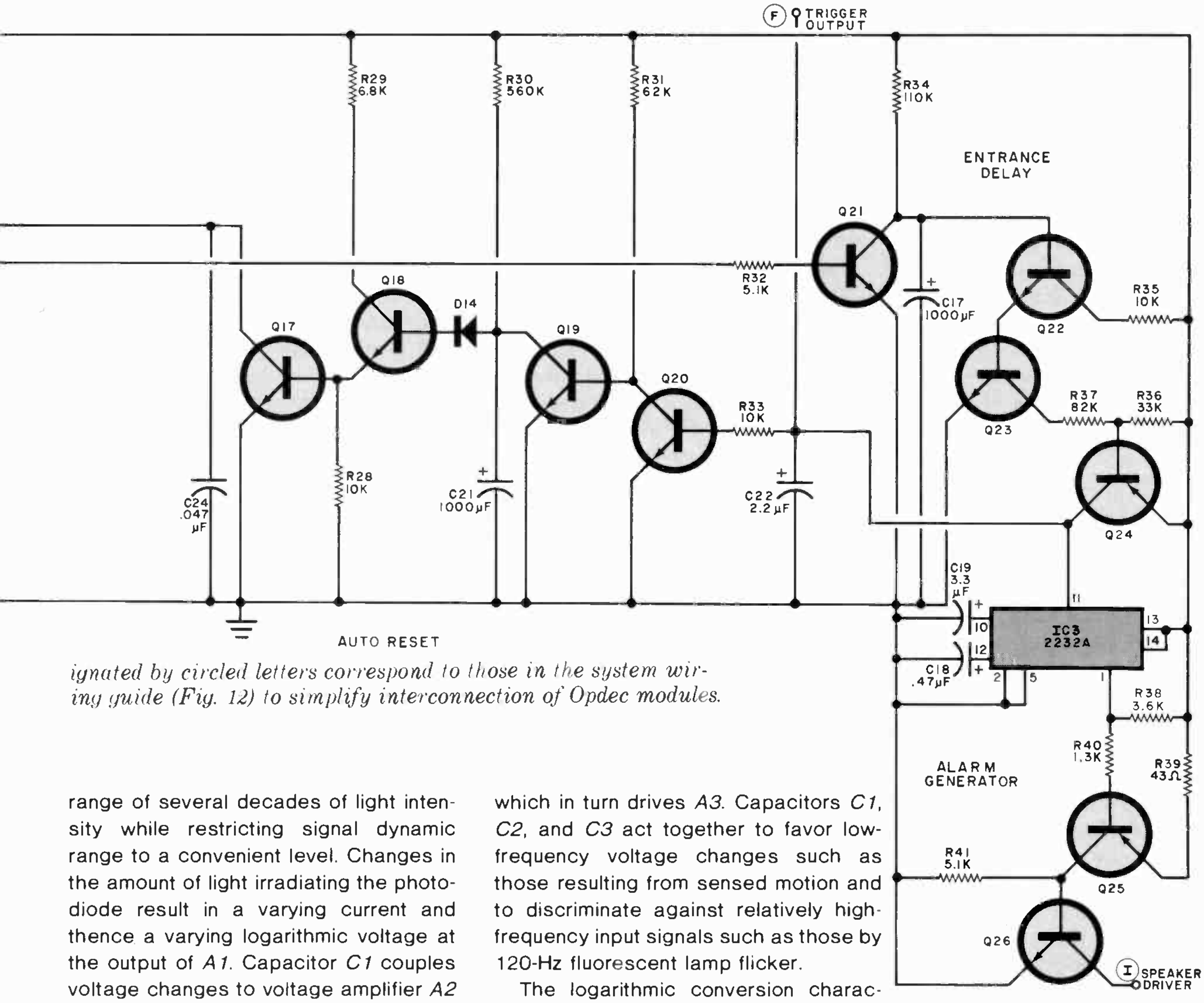
A block diagram of the ULN-2232A IC sensor is shown in Fig. 1. The chip contains, among other things, a photodiode, a logarithmic converter, a voltage amplifier, a threshold detector and an alarm generator. Sensor operation is as follows.

The photodiode generates a small electric current when it is irradiated by light energy. This photocurrent is processed into a voltage by logarithmic converter *A1*. Taking the log of the current allows sensor operation over a

PARTS LIST FOR SIGNAL PROCESSOR MODULE (including System Power Supply)

C1—10,000-μF, 25-volt electrolytic
C17,C20,C21—1000-μF, 6-volt electrolytic
C18—0.47-μF, 6-volt tantalum
C19—3.3-μF, 6-volt tantalum
C22—2.2-μF, 6-volt tantalum
C24—0.047-μF, disc ceramic
D1,D2—3-ampere, 100-PIV rectifier
D8 through D14—1N4001 rectifier
D15—4.7-volt, 1-watt zener diode (1N3825 or equivalent)
F1—½-ampere fast-blow fuse
IC3—ULN-2232A Sprague Integrated Motion Detector
Q1,Q26—2N4921 npn silicon transistor (or equivalent)
Q8,Q10 through Q23—Sprague RT108 npn silicon transistor (or equivalent)
Q9,Q24,Q25—Sprague RT106 pnp silicon transistor (or equivalent)
The following are 5%-tolerance, ¼-watt carbon-composition resistors, unless otherwise specified.
R1—100 ohms, 2 watts, 10% tolerance
R13—43 ohms, 4 watts, 10% tolerance
R14—68,000 ohms
R15,R16—470 ohms
R17—51,000 ohms
R18—270 ohms
R19—75 ohms
R20,R21—6200 ohms
R22,R28,R33,R35—10,000 ohms
R23,R24,R27,R32,R41—5100 ohms
R25,R26—4300 ohms
R29—6800 ohms
R30—560,000 ohms
R31—62,000 ohms
R34—110,000 ohms
R36—33,000 ohms
R37—82,000 ohms
R38—3600 ohms
R39—43 ohms
R40—1300 ohms
S1—Dpst switch
T1—24-volt, 2-ampere center-tapped transformer (Stancor P-8662 or similar)
Misc.—Mallory SC-628 Sonalert or LED, 8-ohm dynamic speaker (if Siren Driver module is omitted), printed circuit board, standoff insulators, snap-on heat sinks for *Q1* and *Q26* (Wakefield 291-80ABC2 or similar), silicone thermal compound, suitable enclosure measuring approximately 10" × 5" × 3¼" or 25.4 cm × 12.7 cm × 8.3 cm (Bud RC11100 or similar), barrier block terminal strip, hookup wire, solder, hardware, etc.

NOTE-*The Sprague ULN-2232A Integrated Optical Motion Detector can be purchased for $3.71 (plus postage and handling) from Poly Paks, P.O. Box 942, So. Lynnfield, MA 01940. Specify part No. K5870.*



ignated by circled letters correspond to those in the system wiring guide (Fig. 12) to simplify interconnection of Opdec modules.

range of several decades of light intensity while restricting signal dynamic range to a convenient level. Changes in the amount of light irradiating the photodiode result in a varying current and thence a varying logarithmic voltage at the output of *A1*. Capacitor *C1* couples voltage changes to voltage amplifier *A2* which in turn drives *A3*. Capacitors *C1*, *C2*, and *C3* act together to favor low-frequency voltage changes such as those resulting from sensed motion and to discriminate against relatively high-frequency input signals such as those by 120-Hz fluorescent lamp flicker.

The logarithmic conversion charac-

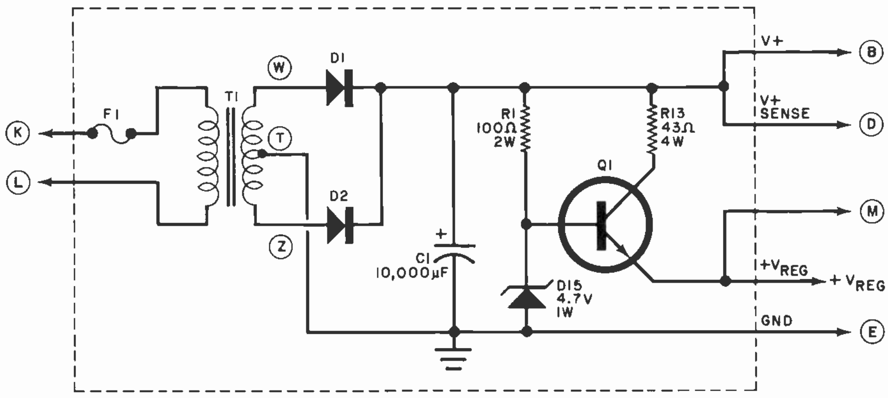


Fig. 3. This power supply can satisfy current demand of a complete Opdec system. Most of it fits on the Signal Processor's pc board.

teristic of *A1* and the gains of *A2* and *A3* are chosen so that the threshold detector is triggered when the change in light level exceeds ±5% during a relatively short period of time (about one second). When the threshold detector is triggered, a pulse is routed to pin 11 of the IC and to a four-bit counter that is part of the chip's timing and alarm-generating circuit. An on-chip transistor is capable of driving a small loudspeaker, but it is not used in the Opdec system. Rather, the pulse appearing at pin 11 of the IC sensor is applied to the Signal Processor, the central, supervisory module of the Opdec system.

The Signal Processor is shown schematically in Fig. 2. Among other things, it detects trigger signals from any of several motion sensors, decides if the sensor has in fact detected the movement of an intruder (rather than being triggered by lightning, a car passing in the night, or some similar phenomenon), generates exit and entry delays, automatically resets the system a few minutes after it has sounded the alarm, and provides optional closed-loop perimeter protection. Also included in the signal processor module is a power supply for the complete system. This supply is shown schematically in Fig. 3.

When the system is armed, *S1* is opened. This allows *C20* to charge through *R14*. In the meantime, *Q8* is cut off and allows *Q10* to conduct. Transistor *Q10* ensures that the latch consisting of *Q15*, *Q16* and their associated resistors is reset. While *C20* is charging (approximately one minute), the occupant can move about the premises freely and leave through a protected exit without setting off the alarm. Trigger pulses from the motion detectors he passes cause *Q9* to conduct, but while *C20* is charging, the pulses appearing at the collector of *Q9* are shunted to ground by *Q10*. When the voltage across *C20* increases to approximately 2.1 volts, *Q8* conducts and cuts off *Q10*. The Opdec system is now armed.

If light-level changes such as those caused by motion are detected, pulses are sent to *Q9*, which sets latch *Q15Q16*. The latch cuts off *Q21* enabling *C17* to charge through *R34*. During the interval that *C17* is charging (approximately 30 seconds), the alarm is not activated. This delay gives the occupant time to enter the house and disarm the system. When the voltage across *C17* equals approximately 1.3 volts, *Q22*, *Q23*, and *Q24* conduct and actuate the alarm generator comprising *IC3* and drivers *Q25* and *Q26*. The sound produced by *IC3* is similar to the "yelping" sound made by police sirens.

Once the alarm generator has been activated, it will continue to oscillate for 10 minutes. After that time, it turns off and the Opdec system automatically rearms itself. This feature is included in case the alarm is triggered while the occupants are away for an extended period and no one is able to turn off the alarm. This 10-minute reset function is generated in the following manner. When *Q24* begins to conduct, it provides base drive for *Q20*. This transistor cuts off *Q19*, which allows *C21* to charge through *R30*. It takes this capacitor approximately 10 minutes to charge up to a voltage which causes *Q18* and *Q17* to conduct. When *Q17* turns on, it resets the latch, which turns off the alarm. Opdec is again armed and awaits any further trigger signals.

Special precautions must be taken to prevent Opdec from generating false alarms due to lightning, passing cars with glowing headlights, etc. One specially constructed detector module (more on this later) should be mounted in a window and aimed at the sky. When a lightning flash occurs, this detector will momentarily disarm the system and then automatically rearm it. This module should not be mounted in such a way that any swaying trees, moving cars, or similar objects are in its field of view.

If you would like to incorporate the additional protection of a closed-loop system, magnetic reed door switches (normally closed) and metallic foil tape for glass can be connected to the signal processor. These items can be purchased at most electronics stores and are simple to install. The switches and tape are all wired in series and connected to point J and ground (point E). If any of the protected doors are opened or a foiled window is broken, the closed-loop circuit is opened. This cuts off *Q12*, which in turn allows the latch to be set by means of *R21*, *D11*, and *D12*. After the 30-second entry delay interval, the alarm is activated.

An additional feature of the Opdec Signal Processor module is either a visual or audible indication if any of the doors or windows are inadvertently left open upon exiting. If, for example, a window were left open, *Q12* would be cut off and *Q13* and *Q14* would conduct. Either a Mallory Sonalert or a light emitting diode can be employed to indicate that the Opdec system has been ordered to arm itself. The indicator can be connected to the collectors of *Q13* and *Q14* (point P). If you decide to use a LED, make sure you insert a 560-ohm resistor between the cathode of the LED and the collectors of the transistors (point P). Once the system has been armed, the warning circuit is disabled by *Q11*, which begins to conduct and cuts off *Q13* when *C20* has charged sufficiently.

The Siren Driver. There are several different means of signalling that the Signal Processor has been triggered. In the author's installation, the collector of *Q26* (point I) was connected to an existing intercom system and to two exterior paging horns. In addition, a 12-volt, battery-operated electronic siren was incorporated as a back-up alarm in case there was a power failure, or the power lines were cut. An 8-ohm horn speaker can be connected to the collector of *Q26*. The resulting *loud* alarm sound should be sufficient to scare away any intruder.

The electronic siren driver is shown

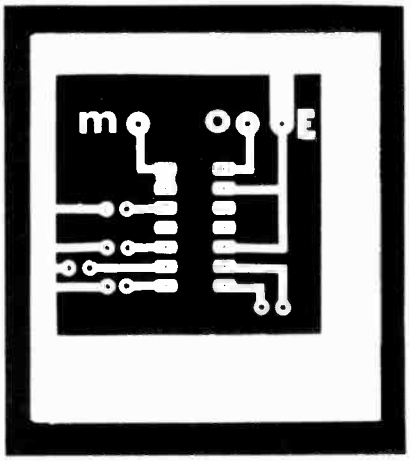


Fig. 4. Etching and drilling guide for motion and lightning sensor pc boards (shown above.)

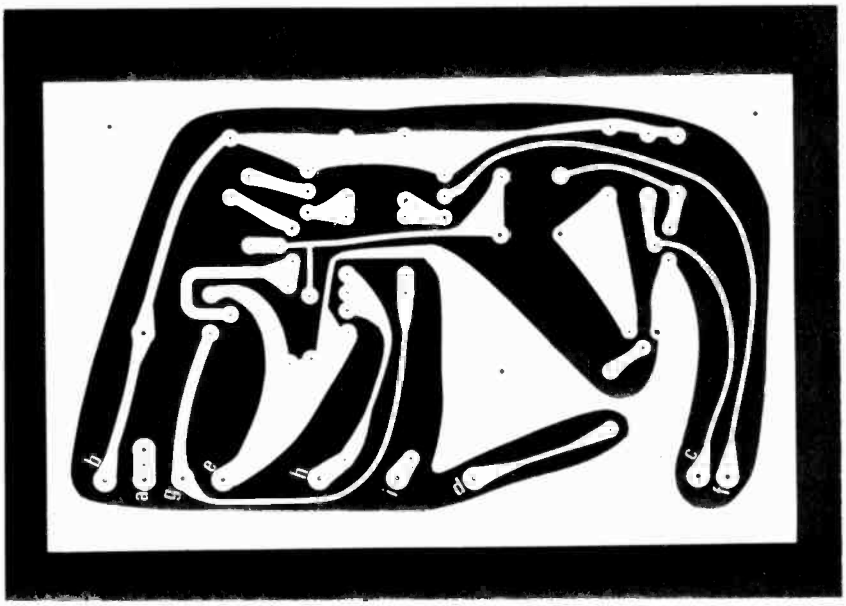
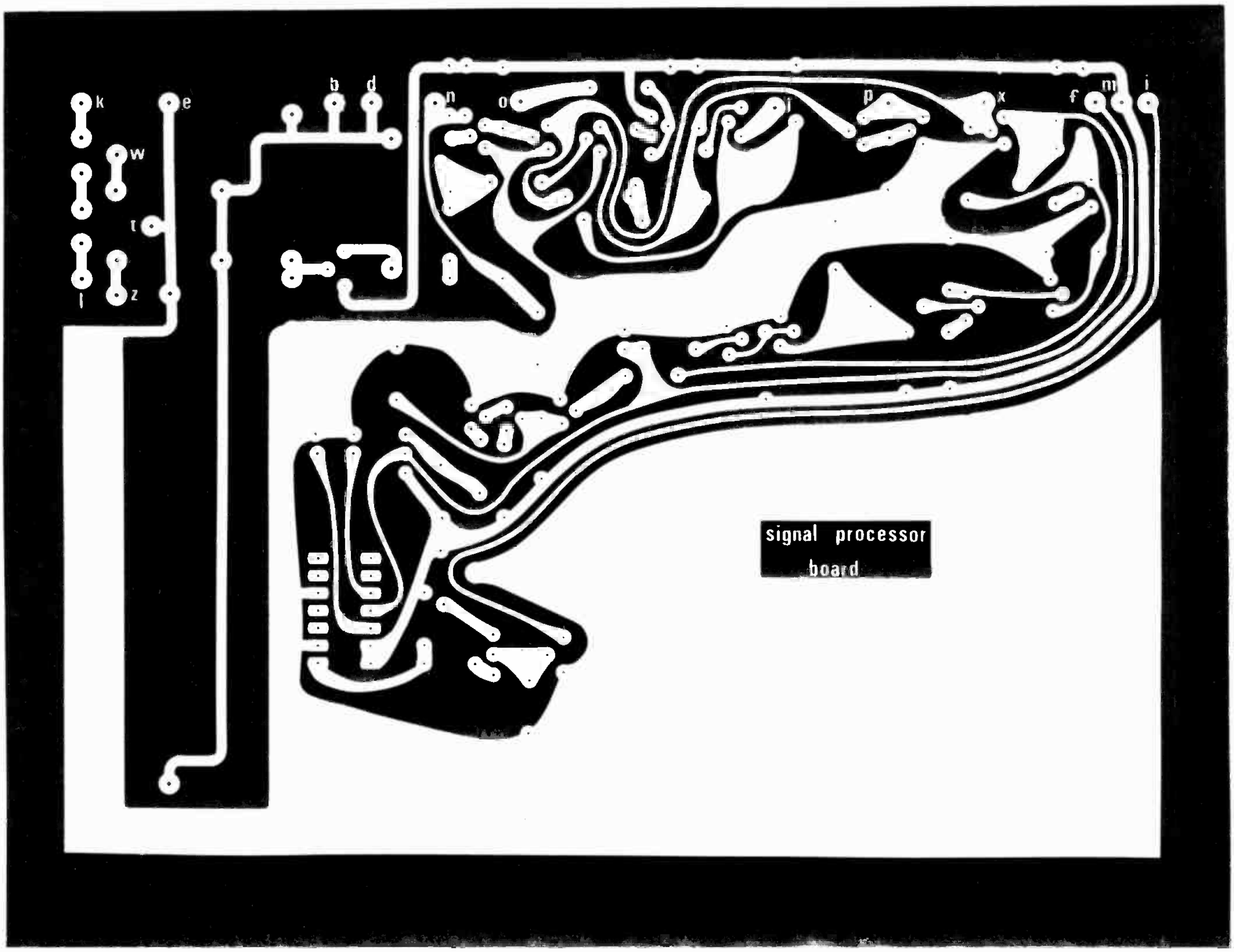


Fig. 6. Etching and drilling guide for the Siren Driver module's printed circuit board is shown above. Artwork for this and the other two pc boards on this page appears full-size.

Fig. 5. Etching and drilling guide for Signal Processor module pc board (shown below).



schematically in Fig. 7. Signals appearing at the collector of *Q26* are coupled to *Q5* by means of *D6* and *R8*. Capacitor *C23* filters the pulses produced by *Q26*. Transistor *Q5* provides base current for *Q6* which in turn supplies base current to siren driver *Q7*.

If the line-derived positive supply voltage V+ is lost because of a power-line failure or intentional disabling by the intruder, the system will be powered automatically by a 12-volt lantern battery. In the event that the intruder locates the Signal Processor module and cuts all the wires leading to it, *Q3* will sense a loss of voltage and activate the siren driver by means of *R5* and *D5*.

Finally, if because of some emergency you want to instantly activate the siren, close the optional, PANIC switch, assuming that it has been installed.

Smoke and Fire Detection. Although the motion detector will detect smoke and fire (because both cause changes in ambient light), it is advisable to install one or more commercially available, self-contained smoke detectors because the Opdec system has to be armed if it is to detect smoke and fire. Thus, the occupants of the premises will be protected while they are there even though Opdec will not ordinarily be armed.

PARTS LIST FOR MOTION SENSOR MODULE

C2,C5,C6—47-µF, 6-volt electrolytic
C3—0.22-µF, 6-volt tantalum
C4—0.01-µF, 50-volt disc ceramic
IC1—ULN-2232A Sprague Integrated Motion Detector
Misc.—Printed circuit board, standoff insulators, suitable enclosure measuring approximately 2¾" × 2⅛" × 1⅝" or 7 cm × 5.4 cm × 4.1 cm (Bud CU-2100-A or similar), barrier block terminal strip, hookup wire, solder, hardware, etc.

PARTS LIST FOR LIGHTNING SENSOR MODULE

C7,C10—47-µF, 6-volt electrolytic
C8—0.22-µF, 6-volt tantalum
C9,C11—4.7-µF, 6-volt tantalum
IC2—ULN-2232A Sprague Integrated Motion Detector
Misc.—Printed circuit board, standoff insulators, suitable enclosure measuring approximately 2¾" × 2⅛" × 1⅝" or 7 cm × 5.4 cm × 4.1 cm (Bud CU-2100-A or similar), barrier block terminal strip, hookup wire, solder, hardware, etc.

PARTS LIST FOR SIREN DRIVER MODULE

C23—1-µF, 25-volt electrolytic
D3—3-ampere, 100-PIV rectifier
D4 through D7—1N4001 rectifier
Q2,Q3,Q6—Sprague RT108 npn silicon transistor or equivalent
Q4,Q5—Sprague RT106 pnp silicon transistor or equivalent
Q7—Sprague RT114 npn silicon transistor or equivalent
The following are 5%-tolerance, ¼-watt, carbon-composition resistors.
R2—10,000 ohms
R3,R5,R9—20,000 ohms
R4—200,000 ohms
R6,R7—75,000 ohms
R8,R10—51,000 ohms
R11—30,000 ohms
R12—470 ohms
R42—360 ohms
Misc.—Siren (Vexon 160, Radio Shack 275-488 or equivalent), printed circuit board, standoff insulators, snap-on heat sink for Q7 (Wakefield 296040AB or similar), silicone thermal compound, suitable enclosure, 12-volt battery, barrier block terminal strip, etc.

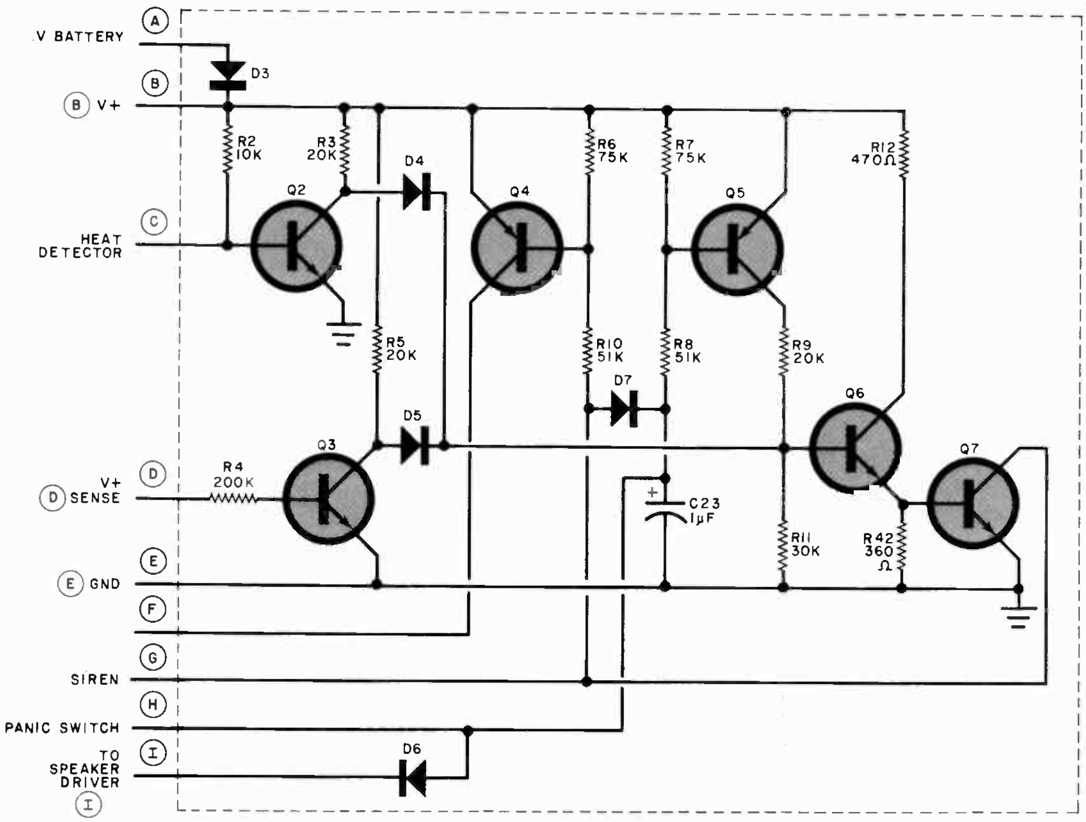
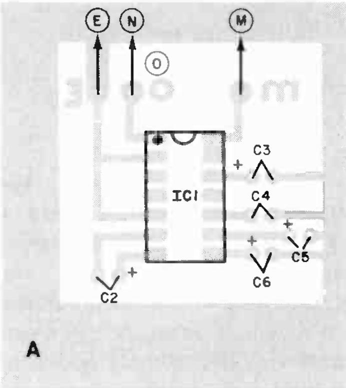
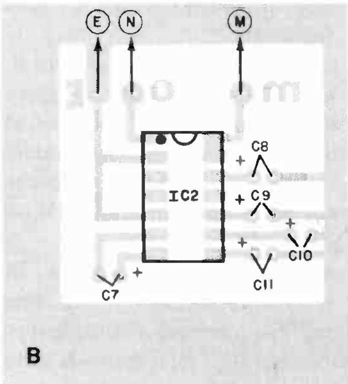


Fig. 7. Schematic diagram of Siren Driver module appears at left.





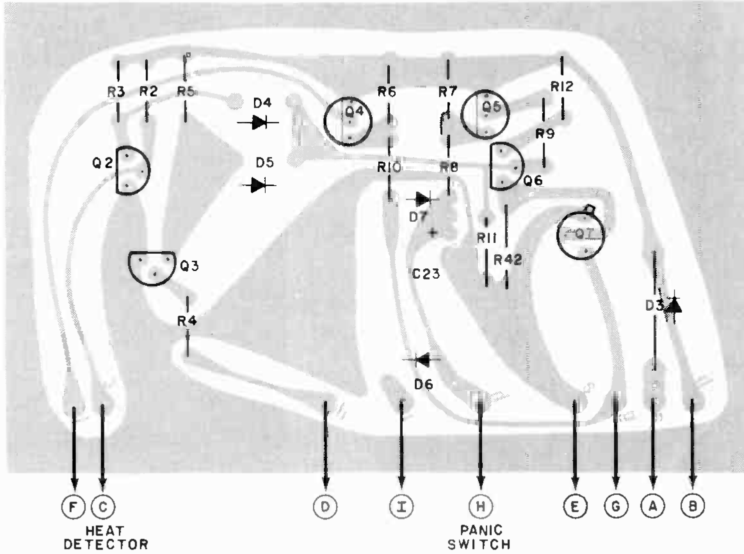
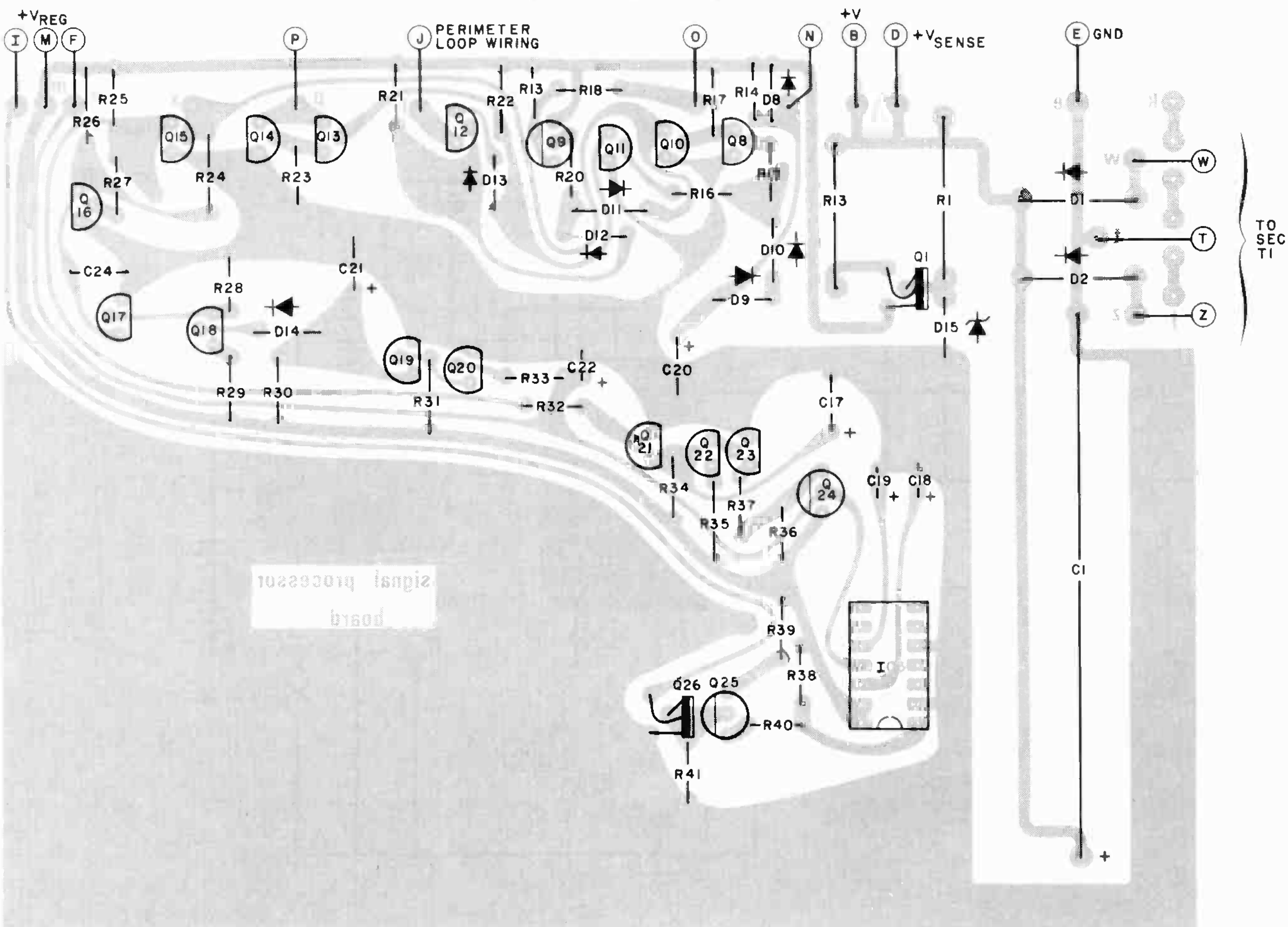


Fig. 10. Shown above is the component placement guide for Opdec system's Siren Driver module printed circuit board.

Fig. 8. Component placement guides for motion (A) and lightning sensor modules (B) appear above left. Also see Fig. 11.

Fig. 9. Component placement guide for the Signal Processor pc board, which includes power supply, is below.



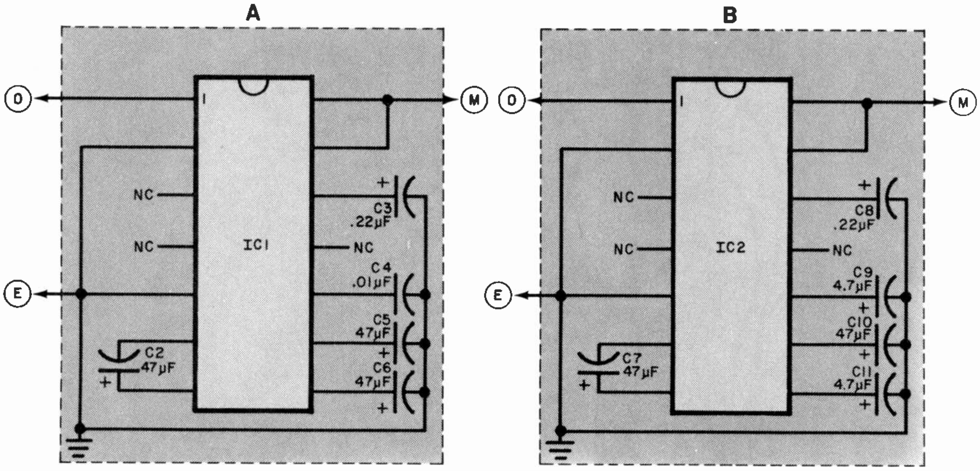


Fig. 11. Wiring diagrams for motion sensor (at far left) and special lightning sensor (left).

Because most smoke detectors do not detect fire, it is also wise to install heat detectors (available at most electrical supply houses) in areas where instant flare-ups could occur (i.e. furnace rooms, areas where paint and thinner are stored, etc.). These detectors, which behave like normally open switches, can be wired in parallel to point C of the Siren Driver module and ground. Whenever a heat detector attains a certain temperature, it behaves like a closed switch. It will then cut off *Q2*, which enables the siren driver via *R3* and *D4*. The Opdec system need *not* be armed for this to occur.

Construction. Printed circuit construction techniques are recommended for the assembly of the Motion Detector, Signal Processor, and Siren Driver modules. Full-size etching and drilling guides for printed-circuit boards for these modules are shown in Figs. 4, 5, and 6. The corresponding component placement guides appear in Figs. 8, 9, and 10. Note that there are two component placement guides in Fig. 8. The first (Fig. 8A) is the guide for the standard motion sensor, and the second (Fig. 8B) is for the lightning sensor that momentarily disarms the system and prevents false alarms.

Mount all resistors first, then the semiconductors. The capacitors should be mounted last. Take care to apply the minimum amounts of heat and solder consistent with the formation of good solder joints. Each module should be housed in a suitable enclosure. The lightning and motion detectors should be mounted in an enclosure measuring approximately 2¾" × 2⅛" × 1⅝" (7cm × 5.4cm × 4.1cm). Each printed circuit is mounted using ¼" (6.4-mm) spacers. A 5/16" (8-mm) hole should be drilled in the front of each sensor enclosure directly in line with the center of the ULN-2232A integrated circuit to allow light to reach the IC.

The circuits and circuit boards of the motion and lightning sensors are identical except for part number designations and component (capacitor) values. These are given in both the component placement guides of Fig. 8 and the wiring diagrams of Fig. 11.

A master wiring diagram for the Opdec system appears in Fig. 12. Interconnecting the modules will be greatly simplified if barrier block terminal strips are installed on the module enclosures and connected to the appropriate circuit board foil pads. The strips should be letter-coded to agree with the scheme used in Fig. 12 and the component-placement guides, and the wires used to interconnect modules should be color-coded. Because the cost of the ULN-2322A IC sensor is comparable to that

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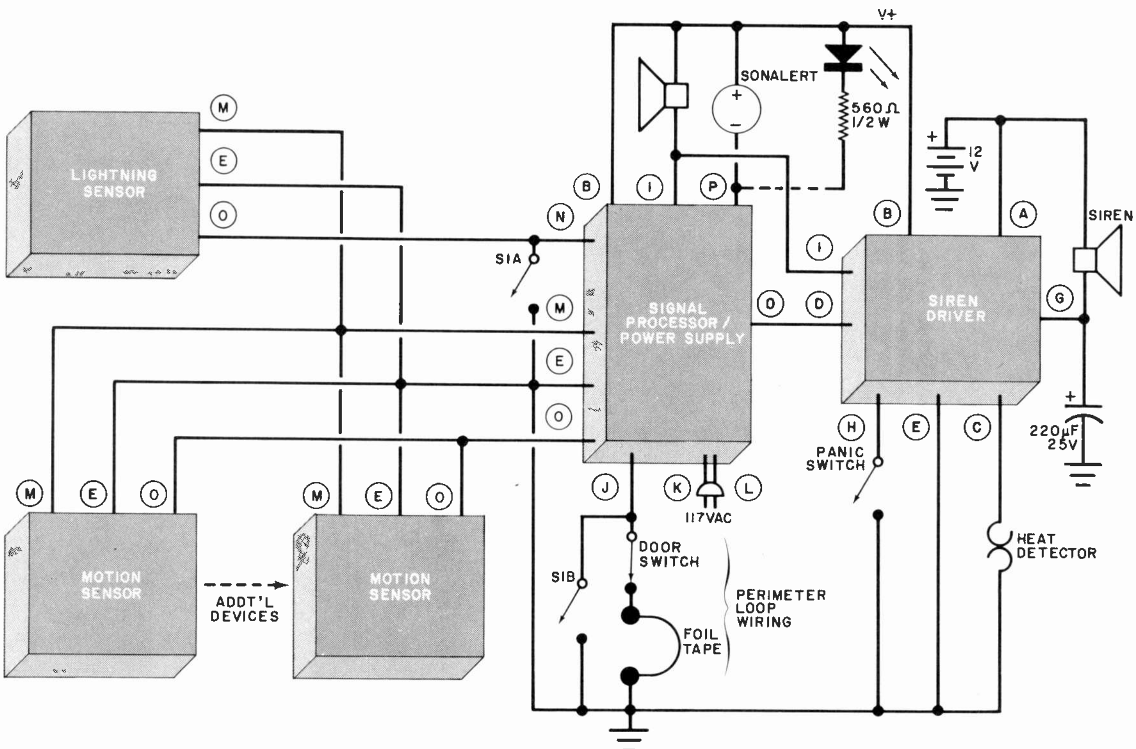


Fig. 12. Master wiring guide for complete Opdec system with optional closed loop and heat detector.

ADD A "KEY-DOWN" AUDIBLE SIGNAL TO YOUR COMPUTER KEYBOARD

BY ROY AUER, Jr.

Simple circuit provides audible confirmation that a key has been struck properly

THE action of some modern computer keyboards is extremely "light." As a result, even an attentive user may press a key but not cause generation of the desired character. Presented here is a simple circuit that produces a brief audible tone every time a key contact is actuated and a character is generated. It gives the user audible reassurance that the selected key has been properly pressed, and thus improves his efficiency. The circuit can be assembled on a compact circuit board and tucked into a small, free space inside the keyboard enclosure. Its modest power requirement can be easily satisfied by the host keyboard's power supply.

About the Circuit. The tone generator is shown schematically in the Figure. It employs the two timer circuits contained in the readily available NE556 dual timer chip. One section is used as a monostable multivibrator, the other as an astable multivibrator.

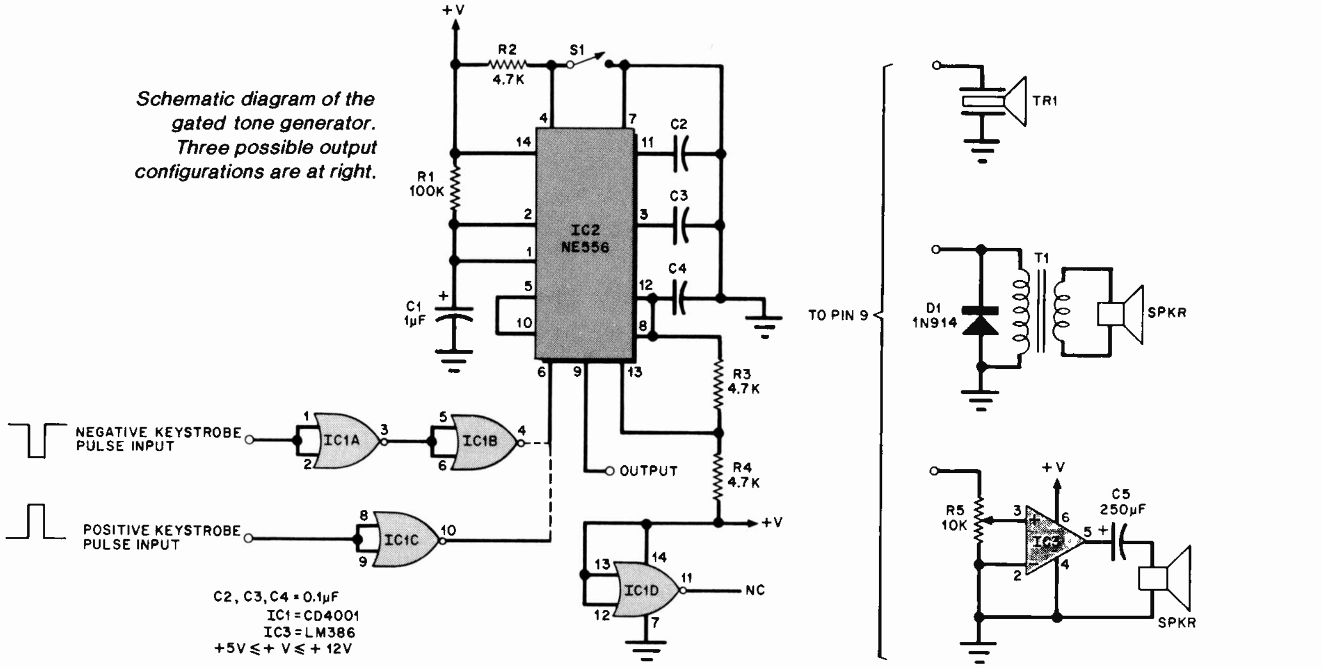
The monostable generates a 100-millisecond pulse upon the receipt of a "keystrobe" pulse from the keyboard. Such a pulse is generated every time a key contact is actuated and the corresponding character is generated. Duration of the monostable multivibrator's output pulse, which appears at pin 5, is determined by the values of *R1* and *C1*. When pin 5 switches from ground potential to +V, the astable multivibrator begins to oscillate and produces an audio-frequency pulse train at pin 9. The frequency of the pulse train is determined by the values of *R3*, *R4*, and *C4*, and the duty cycle by the relative values of *R3* and *R4*. For the values specified, the frequency of the pulse train is about 1 kHz with 67% duty cycle.

Note that three CMOS NOR gates are employed in the circuit. Actually, either *IC1A* and *IC1B* or *IC1C* will be used. If the keyboard with which the circuit will be used generates a positive keystrobe pulse, *IC1C* must be employed to invert it into the negative pulse that the monostable multivibrator requires for triggering. In that case, pins 8 and 9 of *IC1C* should be connected to the keyboard's keystrobe pulse line and pin 10 of *IC1C* to pin 6 of *IC2*. Pins 1 and 2 of *IC1A* should be connected to either +V or ground and pin 4 of *IC1B* should be left unconnected.

If the keyboard generates a negative keystrobe pulse, no inversion is necessary. In this case, however, *IC1A* and *IC1B* should be used as a noninverting buffer between the keystrobe pulse line and the trigger input of the monostable multivibrator. Pins 1 and 2 of *IC1A* should be connected to the keystrobe pulse line, pin 4 of *IC1B* to pin 6 of *IC2*, pins 8 and 9 of *IC1C* to either +V or ground, and pin 10 of *IC1C* should be left unconnected.

Three possible output configurations are shown in the Figure. At the top is a high-impedance crystal transducer. This transducer (*TR1*) can be driven directly by the circuit and can be either a conventional crystal earphone or one of the recently developed piezoelectric "wafer"

Schematic diagram of the gated tone generator. Three possible output configurations are at right.



PARTS LIST

C1—1-µF, 25-volt electrolytic
C2, C3, C4—0.1-µF disc ceramic capacitor
C5—250-µF, 25-volt electrolytic
D1*—1N914 signal diode
IC1—CD4001 quad NOR gate
IC2—NE556 dual timer
IC3*—LM386 audio amplifier

The following, unless otherwise specified, are ¼-watt, 10% tolerance fixed carbon-composition resistors.
R1—100 kΩ
R2, R3, R4—4.7 kΩ
R5—10-kΩ logarithmic-taper trimmer potentiometer
S1—Spst switch

SPKR*—8-Ω dynamic speaker
T1*—10-kΩ to 8-Ω audio transformer
TR1*—High-impedance crystal transducer
Misc.—Printed circuit or perforated board, IC sockets or Molex Soldercons, suitable power source and enclosure, hookup wire, solder, hardware, etc.
*—Optional; see text.

transducers. If an earphone with a screw-in earplug is employed, best results will be obtained with the earplug removed. The author reports that a suitable crystal earphone can generate sound levels audible at distances of up to ten feet.

The middle alternative is to have the circuit drive a low-impedance dynamic loudspeaker. Here, a small audio output transformer (*T1*) couples the output of the astable multivibrator to the speaker. Diode *D1* protects the astable multivibrator's output transistor from inductive spikes that can appear across the transformer primary.

The output configuration appearing at the lower right can provide a considerable sound pressure level. The output signal at pin 9 of *IC2* is applied to potentiometer *R5*, which functions as a level control. Audio amplifier chip *IC3* boosts the signal present at its noninverting input and drives a low-impedance dynamic loudspeaker via coupling capacitor *C5*. As shown, *IC3* has a voltage gain of 20. This is adequate for most applications but can be increased to 200 by connecting a 10-µF electrolytic capacitor between pins 1 and 8 of *IC3*. The IC can be powered from the same source as the rest of the circuit because its current demand is modest.

Toggle switch *S1* controls the action of the monostable timer section of *IC2*. When the switch is open, the positive supply voltage is applied to the monostable multivibrator's RESET input (pin 4). This allows the timer to function normally. However, when the switch is closed, the monostable's RESET input is grounded and that timer's output (pin 5) is frozen at ground potential. When this happens, the astable multivibrator is disabled and no tone can be produced. Therefore, if the user does not want a tone to be generated each time a key contact is actuated, *S1* should be closed.

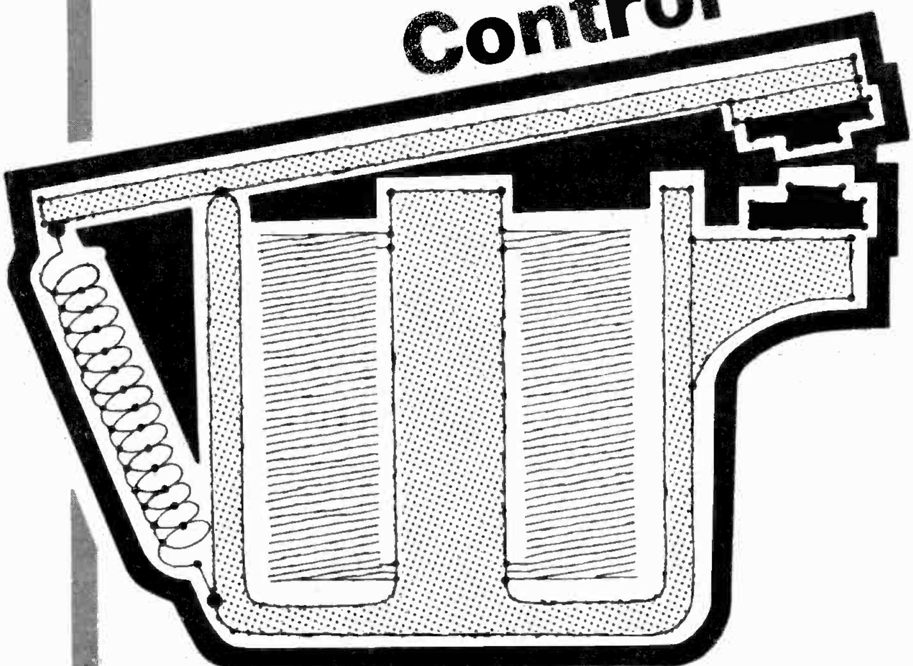
Construction. Because the project is relatively simple, it can be assembled on a small perforated or printed-circuit board. The use of IC sockets or Molex Soldercons is recommended. Be sure to observe the polarities of power supply leads, semiconductors, and electrolytic capacitors. Employ the minimum amount of heat and solder consistent with the formation of good solder joints. The project can be connected to the keyboard by suitable lengths of insulated, stranded hookup wire. If space permits, the project can be mounted inside the keyboard enclosure. Alternatively, it can be installed in a small enclosure of its own.

In Conclusion. Auditory confirmation of a proper key-contact actuation can speed and simplify the use of an ASCII or similar keyboard. The circuit that has been presented here will provide such confirmation and make the time spent at a keyboard more productive and enjoyable. If desired, the values of the resistors and capacitors associated with the two timer sections of *IC2* can be changed to suit the taste of an individual user. Increasing the time constant of *R1C1* will result in a longer "beep." Decreasing it will shorten the time that the astable multivibrator oscillates. The frequency and duty cycle of the audio output can be modified by appropriate changes in the values of *R3*, *R4*, and *C4*. Consult a 556 data sheet for the appropriate design equations. ◇

BY AL SYDNOR

How to use solid-state circuits to obtain predictable performance from electromechanical relays

An Experimenter's Guide to Relay Control



BECAUSE OF their simplicity and low cost, electromagnetic relays are widely used in control applications. Unfortunately, some experimenters and designers do not fully understand how to interface relays with electronic circuitry. As a result, their circuits frequently operate erratically, and outright failure of either the relay or the components associated with it is far more common than necessary. Moreover, many possible functions that relays can perform with appropriate drive circuitry are often overlooked. A knowledgeable approach, such as that presented here, should enable one to use relays with confidence and without hesitation.

What is a Relay. An electromagnetic relay, regardless of details of construction, is basically a mechanical switch operated by electric power. Its contacts are coupled to an armature of magnetic material held in proximity to a coil. When current passes through the coil, the resulting magnetic field attracts the armature toward the coil to close or open one or more sets of contacts. When the current stops, the magnetic attraction ceases, and a spring returns the contacts to their former positions.

Available in both ac and dc versions, relays have rated coil energizing potentials usually ranging from 1 to 250 volts with 6-, 12-, 24-, 48-, 117-, and 240-volt designs the most common. There are also relays that operate at energizing potentials as low as 25 millivolts for special applications. You should keep the voltages within ±20% of ratings. Too much voltage may burn out the coil; too little may cause erratic operation. Operating power ranges from a few milliwatts to about 20 watts, which should be borne in mind when you are designing the drive circuits. Operating current can be determined by measuring or looking up coil resistance.

Looked at from the point of view of the drive circuit, a relay has the following parameters:

Operating voltage (current). The value that closes the contacts reliably.

Pull-in voltage (current). The value that just barely closes (opens) the contacts.

Drop-out voltage (current). The value that barely lets the contacts open (close).

The limits on current or voltage the relay can switch are also important. Contacts are commonly rated either according to current capacity or by a maximum number of volt-amperes (VA), the product of current and voltage. If a relay that must handle heavy current cannot be driven from a low-power circuit, it can, in turn, be driven by a relay the circuit can handle.

Contact Protection. When a switch in series with an inductive circuit (such as a relay coil) is opened, the magnetic field in the coil collapses and a voltage proportional to the rate of change of current is generated. This high voltage across the switch contacts can eventually cause damage or failure.

Semiconductors can be used to suppress these voltage transients, as in Fig. 1A, where a diode is connected across the load as shown. When a positive spike appears across the switch contacts, the diode clamps it to the positive power-supply voltage. The diode's reverse-voltage rating must exceed the power-supply voltage, and its current rating must be at least 25 times the load operating current. A varistor, or voltage-dependent resistor, can be substituted for the diode. Its resistance should be more than 10 times the dc resistance of the coil at 20°C.

Sometimes, when a relay coil appears to have shorted for no reason, an inductive spike that exceeds its insulation ratings may be at fault. A diode can be used as in Fig. 1B to protect a relay coil if a longer release time can be tolerated. An improvement over this method is to use a transistor circuit as in Fig. 1C. When the switch in Fig. 1C is closed, the capacitor discharges. Opening the switch causes the capacitor to keep the transistor conducting until the capacitor has charged up through the base-emitter junction and resistor enough to cut off the transistor. This is equivalent to opening the switch slowly to lengthen the decay rate of the current and keep the induced voltage smaller.

Linear-Amplifier Driver. To drive high-current relays from low-current sources you can use a transistor amplifier such as that shown in Fig. 2A. When *S1* is set to OFF (ground), no base current is supplied, the transistor is cut off, and the relay is deenergized. Setting *S1* to its ON position sends the transistor into saturation and energizes the relay.

More sensitivity can be had simply by adding amplifier stages, as shown in Fig. 2B. If no input is applied to *Q1*, it is cut off and *Q2* is saturated energizing the relay. Application of bias to *Q1* saturates it, and *Q2* cuts off, deenergizing the relay.

Another two-stage transistor relay driver is shown in Fig. 2C. In this case, the circuit is noninverting and is controlled by a photocell. The photocell controls *Q1*, which in turn controls *Q2*, whose collector current energizes the relay. The potentiometer permits adjustment of threshold voltage for the particular photocell being used and prevents leakage current from operating the relay under high-temperature conditions.

A single-power-supply, three-stage driving amplifier is shown in Fig. 2D. Once again, illuminating the photocell energizes the relay, with the potentio-

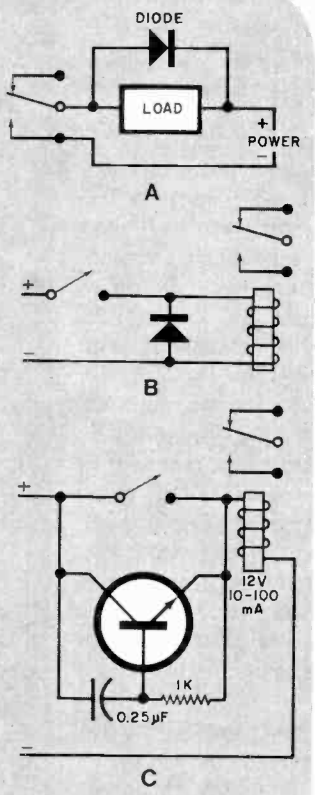


Fig. 1. Switching-transient suppression: diode across inductive load (A) or relay coil (B); transistor circuit across switch contacts (C).

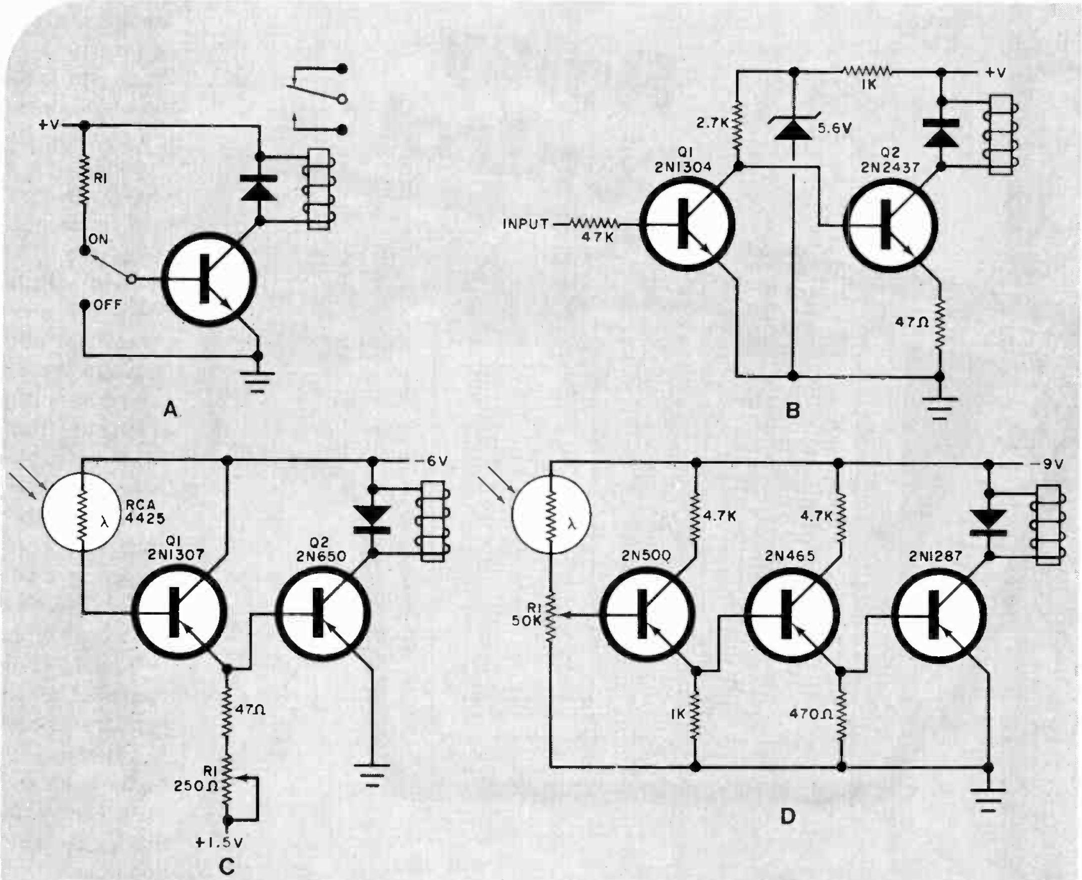


Fig. 2. Linear amplifiers as relay drivers: (A) single-stage; (B) two-stage inverting; (C) two-stage noninverting; (D) three-stage noninverting.

meter permitting adjustment of the relay's operating threshold. In the off state, all transistors are cut off and current consumption is negligible, which makes this circuit suitable for operation from a battery.

Regenerative-Amplifier Driver. The relay drivers discussed above have a serious disadvantage in that a borderline threshold input can cause the relay to alternate rapidly between on and off, producing "chatter." Also, the energizing threshold can vary with temperature. A regenerative amplifier can be used to keep the relay energized or deenergized with no in-between state.

A Schmitt trigger with a relay coil as the load is shown in Fig. 3A. As long as the input level is less than 6 volts, *Q1* is cut off, *Q2* is saturated, and the relay is energized. When the input exceeds 6 volts, *Q1* rapidly saturates and cuts off *Q2* to positively deenergize the relay. The potentiometer permits precise setting of the operating threshold.

Another regenerative-amplifier circuit is shown in Fig. 3B. Here, the relay's coil is the load for one side of an Eccles-Jordan bistable multivibrator. This is a conventional design except for *C1* and *R1*, which are used to ensure that *Q1* will be driven into saturation and *Q2* will be cut off when power is first turned on to prevent the relay from energizing on power-up.

A positive signal on the RESET line to the base of *Q2* activates the relay solidly, while a positive signal on the SET line to the base of *Q1* deactivates the relay just as solidly.

When using high-power relays, it is usually necessary to add a buffer stage between the relay and regenerative circuit. A typical arrangement is illustrated in Fig. 3C. Here, Schmitt trigger *Q1/Q2* is coupled to *Q3* via 12-volt zener diode *D1*. When a negative control signal of sufficient amplitude is applied to the input of this circuit, *Q1* conducts and *Q2* cuts off. Current through the *Q2* collector load resistor and *D1* to the base of *Q3* causes it to conduct and energize the relay.

Because *Q3*'s bottom potential at 1.5 amperes is less than 0.5 volt and this transistor's rated free-air dissipation is less than 1 watt, *Q3* can be operated without a heat sink. If *Q3* is to be operated at high ambient temperatures, however, it should be mounted on a 2" (50.8-mm) square sheet of No. 16 aluminum.

A regenerative relay driver that uses an SCR is shown in Fig. 3D. Initially, *S1* and *S2* are both open and no trigger voltage is applied to the gate of the SCR, which remains cut off. Closing *S1* applies a positive voltage to the SCR's gate, triggering the SCR and energizing the relay.

Opening *S1* does not turn off the SCR. It does, however, allow the voltage across capacitor *C1* to approach that of the supply. Then, closing *S2* applies a negative pulse to the anode of the SCR to stop conduction. An alternative to using *S2* to turn off the SCR is to connect a transistor from the anode to the cathode, as shown by the phantomed circuit in Fig. 3D. When the transistor turns on, it diverts current from the SCR. As soon as the SCR's current falls below its holding value, the device turns off. The relay coil is deenergized when the voltage to the base of the transistor is removed

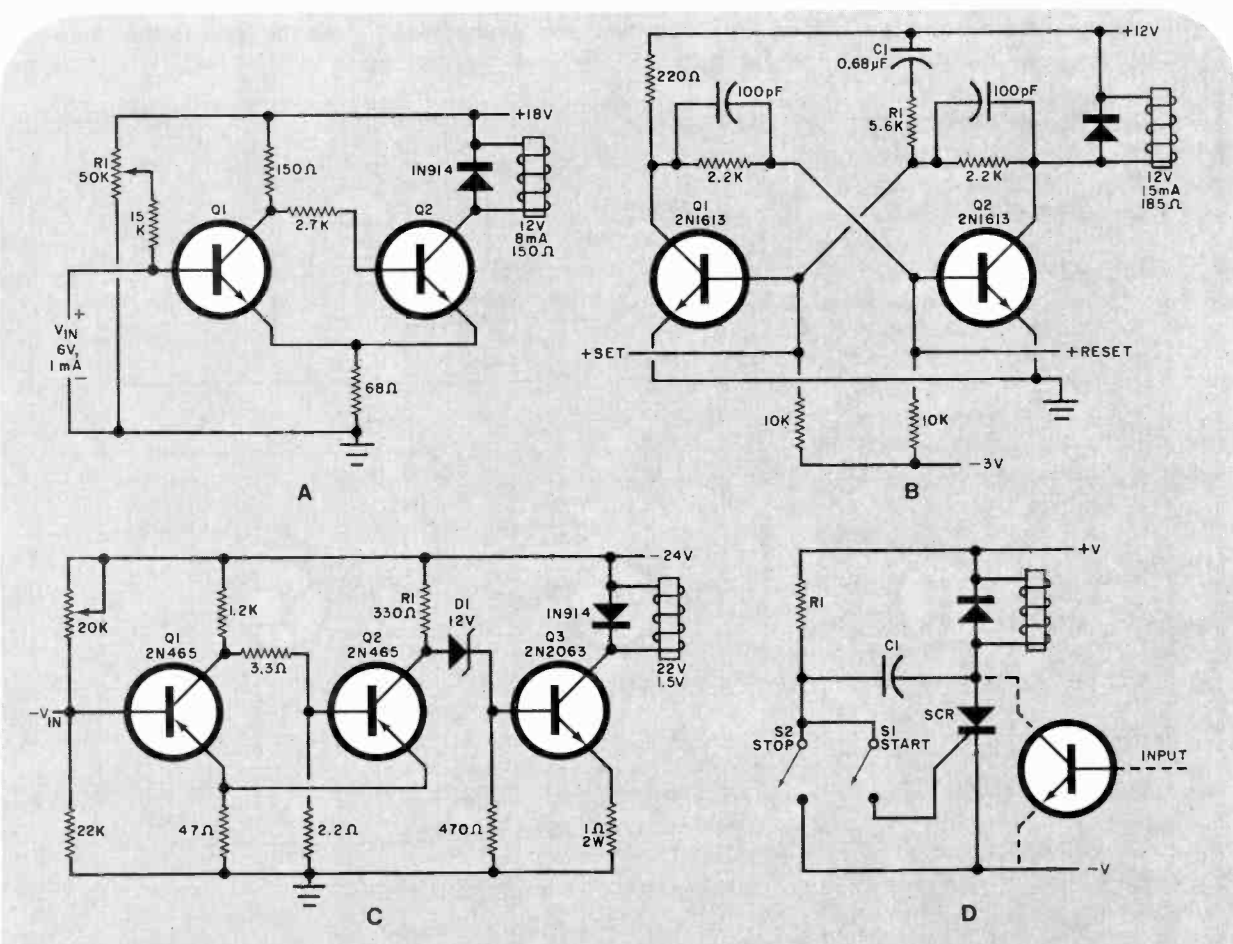


Fig. 3. Relay-driver regenerative amplifiers: (A) single-stage Schmitt trigger; (B) single-stage bistable; (C) Schmitt trigger with relay driver; (D) latching SCR control.

Time-Delay Circuits. Semiconductors are commonly used to provide time-delay periods for operating electromagnetic relays. An example of this is the delayed application of supply voltage to the power stages in a hi-fi amplifier to prevent the power-on transient from being heard in and possibly damaging the speaker systems. One simple way to delay energizing a relay is to place a thermistor in series with the coil, as shown in Fig. 4A. When the switch is closed, current flowing through the thermistor causes it to heat up, resulting in a decrease in resistance from its normally high cold resistance. As resistance drops, more current flows until the current through the relay coil is sufficient for energization. A series potentiometer can be used to permit adjustment of delay time.

At room temperature, the thermistor should have a resistance three to five times that of the relay's dc coil. For example, a thermistor with a cold resistance of about 400 ohms that drops to 25 ohms at 400 mA can be used with a conventional 12-volt, 80-mA relay.

The circuit in Fig. 4A is for slow energization and fast deenergization. For applications where fast turn-on and a slightly delayed turn-off are required, a shunt thermistor can be used, as illustrated in Fig. 4B. Again, the thermistor's cold resistance should be 3 to 5 times the relay's dc coil resistance.

Another circuit that gives slow turn-on and fast turn-off relay operation is shown in Fig. 4C. When *S1* is closed, the base of the transistor is grounded and *Q1* is cut off, resulting in a deenergized relay. Opening *S1* allows *C1* to be charged at a rate determined by the *C1* (*R1* + *R2*) time constant until the base potential of *Q1* is sufficient to turn on the transistor and energize the relay. Closing *S1* causes *C1* to discharge rapidly and cut off *Q1* practically at once.

A rearrangement of the Fig. 4C circuit, shown in Fig. 4D, gives a fast turn-on and slow turn-off action. With the switch closed, the capacitor discharges and base current through the resistors from the supply line sends the transistor into saturation and rapidly energizes the relay. Reopening *S1* allows the capacitor to continue to supply base current until it is charged up enough to cut off the transistor. The result is a slow turn-off for the relay.

Many variations of the above circuits are possible, such as the very slow turn-on circuit shown in Fig. 4E. With *S1* open, all capacitors are discharged. Closing *S1* allows *C1* to be charged up via *R1* until the voltage on the gate of *Q1* rises above firing potential. At this time, *Q1* becomes a low resistance and applies a firing pulse to the gate of the SCR, which energizes the relay.

When *S1* is opened, supply voltage is removed, the SCR stops conducting, and the relay deenergizes. This circuit has been used to provide a 40-second (±1 second) delay over a −25° to +75°C temperature range.

Differential Drivers. Many of the relay-driver circuits shown above are limited by the fact that control-signal operation is uncertain and may have considerable backlash. (The relay may not deenergize until the voltage across its coil is well below the energizing potential.) One way to obtain close differential operation with the deenergizing and energizing voltages roughly equal is to use a Schmitt-trigger circuit with a small hysteresis (backlash), such as shown in Figs. 3A and 3C. Simply replace the common-emitter resistor of the Schmitt trigger with a zener diode whose voltage rating is the same as the potential required at the emitters to energize the relay.

As the input to the close-differential

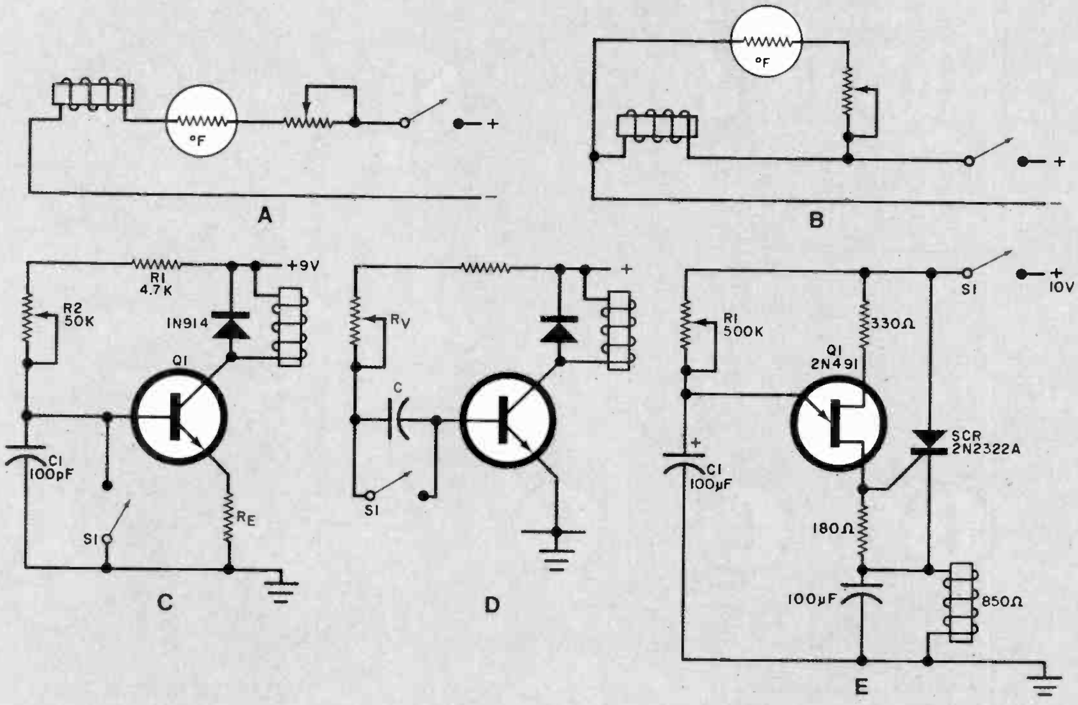


Fig. 4. Relay time-delay circuits: (A) thermistor-controlled slow-on/fast-off; (B) thermistor fast-on/slow-off; (C) transistor-controlled slow-on/fast-off; (D) transistor fast-on/slow-off; (E) unijunction transistor circuit with very slow on.

circuit shown in Fig. 5A is increased in the negative direction, no base current flows through *Q1* until V_{IN} exceeds the 10-volt breakdown potential of the zener diode plus the base-emitter forward voltage drop required for *Q1* to conduct (about 0.3 to 0.5 volt). When V_{IN} reaches about 11 volts, *Q1* saturates and collector current energizes the relay.

The silicon diode across the base-emitter junction of *Q1* prevents it from being overdriven. With up to 0.6 volt on the transistor's base, the diode does not conduct. Beyond this point, it conducts and shunts excess current away from the transistor's base. Because of the sharp breakdown characteristics of the zener diode, drop-out signal potential of this circuit is within a few hundred millivolts of relay energizing voltage.

Use of a p-channel MOSFET with a threshold potential of about 5 volts to yield close differential relay operation is shown in Fig. 5B. When V_{IN} is greater than 6 volts, the zener diode conducts through *R1*, but as long as the input is less than 11 volts, the drop across *R1* is less than 5 volts and *Q1* is off.

As long as *Q1* is cut off, *Q2* is also cut off and the relay is deenergized. When the input exceeds 11 volts, *Q1* conducts and current through *R2* to *Q2*'s base causes the relay to energize. When V_{IN} is less than 11 volts, the relay is deenergized, while it energizes with positive action when V_{IN} exceeds 12 volts. By cascading a second FET after the first, it is possible to reduce the difference between energizing and deenergizing potentials to 0.1 volt.

AC Drive Circuits. Any dc relay can be adapted to work from an ac source by combining it with rectifiers. In Fig. 6A, *D1* permits only positive current to pass through the relay and should have a current-carrying capacity several times the operating current of the relay. Clamping diode *D2* is optional and is used for surge suppression. It not only protects the relay contacts, but prevents high reverse voltage on *D1*.

Another diode arrangement is shown in Fig. 6B. Here, four diodes are used in a full-wave bridge circuit. Note that the bridge circuit inherently provides protection from inductive spikes.

The circuit in Fig. 6C allows a true ac relay to be operated electronically through an SCR. When *S1* is open, the SCR has no potential applied to its gate and does not conduct. Meanwhile, current from *T1* is rectified by *D1* and generates a dc voltage that is stored in *C1*. When *S1* is closed, the positive voltage across *C1* is applied to the gate, causing the SCR to conduct and remain on as long as *S1* is closed. Opening *S1* causes the SCR to cut off when the ac cycle passes through zero, causing the relay to be deenergized.

Op Amp Relay Drivers. Contingent on the type and level of the input signal, relay amplifiers can be built up with op amps whose extremely high (open-loop) gain is sufficient to allow operation with minute input levels. The op amp also allows for differential operation where an input signal can be compared with a known reference so that the relay pulls in (or drops out) only when the desired voltage differential exists.

In addition, the op amp, with its very high gain, can be used with reactive feedback to form filters that produce relay operation only at certain input frequencies (assuming an ac input). A phase-locked-loop (PLL) using a 567 for instance, can also be a frequency-sensitive driver for a relay amplifier. Since many op amps do not have sufficient output current to drive a relay directly, a transistor power stage will often be required between the op amp and the relay. ◇

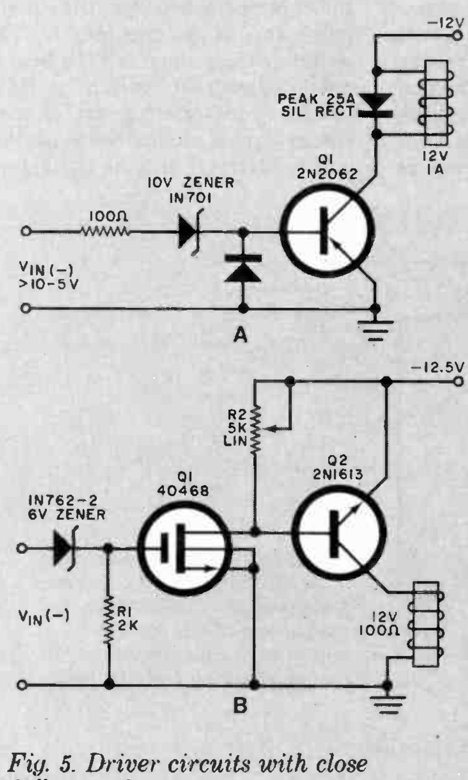


Fig. 5. *Driver circuits with close differential operation:*
(A) single-stage transistor with zener;
(B) two-stage FET and bipolar transistor.

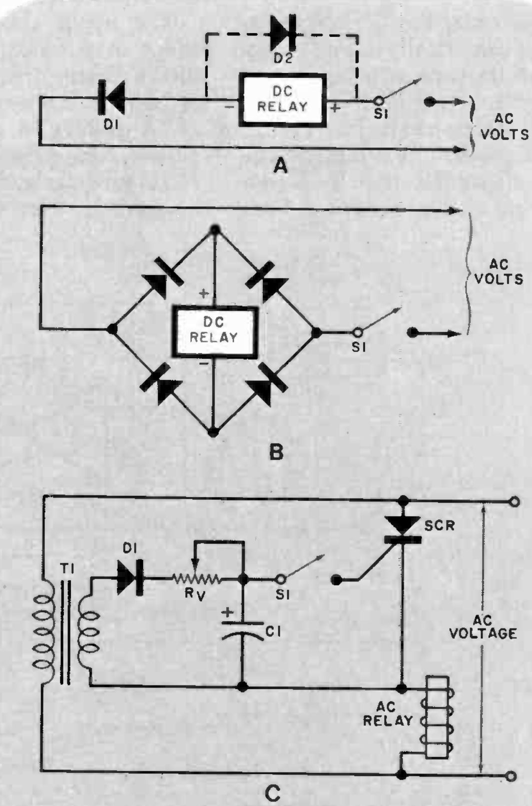


Fig. 6. Ac drive circuits: (A) single diode;
(B) diode bridge; (C) thyristor.

Wah-Wah Foot Pedal

Liven up your music with this easily operated low-cost add-on circuit

BY FRED PUCCETTI

"WAH-WAH" is one of several interesting effects used by electric guitarists to "spice up" the sounds generated by their instruments. This effect, named in imitation of its sound, is commonly employed by synthesists and electric pianists as well. It is achieved by sweeping the center frequency of a bandpass filter while the output of the instrument is fed through it. Typically, the filter is controlled by means of a foot pedal.

Presented here is a Wah-Wah pedal designed with the performing artist in mind. It employs a high-performance quad operational amplifier and a battery power source, making it well-suited to stage or studio work. Parts count is low, so the Wah-Wah Pedal is easy to build. A kit including a rugged foot-pedal mechanism is available for $55.

About the Circuit. The Wah-Wah pedal is shown schematically in Fig. 1. Signals from the instrument being played are presented to input jack *J1A*, one portion of a three-conductor, double closed-circuit, ¼-inch (6.3-mm) phone jack. The input signals drive a second-order, two-pole active bandpass filter comprising operational amplifiers *IC1A*, *IC1B*, *IC1C*, and their associated passive components. The center frequency of this filter can be varied by means of potentiometer *R7*.

When this potentiometer is adjusted for minimum resistance, the center frequency of the filter is approximately 2500 Hz. When the potentiometer's effective resistance is increased to its maximum value of 500,000 ohms, the filter's center frequency decreases to approximately 1050 Hz. These filter responses are shown in Fig. 2, a photo of the CRT traces generated by a spectrum analyzer. The analyzer was driven by a signal generator with the project inserted in series between the generator and the analyzer, and the project's frequency-control potentiometer (*R7*) was alternately set to provide for minimum and maximum resistance.

The upper and lower limits of the range over which the active bandpass filter's center frequency can be swept are determined by the stages comprising *IC1A* and *IC1B* and their associated passive components. Inverting amplifier *IC1C* provides a slight amount of voltage gain so that signals appearing at output jack *J2* are at a suitable level. That sets this project apart from older, discrete Wah-Wah designs that did not compensate for any insertion loss introduced by the bandpass filter. An additional benefit provided by *IC1C* is buffering, which prevents the load from interacting with the filter and affecting its frequency response.

The remaining op amp, *IC1D*, is not used. In accord with good design practice, its inputs are grounded. Power for the circuit is provided by a bipolar supply consisting of two 9-volt batteries in series. Diodes *D1* and *D2* protect against the inadvertent application of reverse supply voltages. Tantalum capacitors *C3* and *C4* function as power-supply bypassing components. Note that there is no separate power switch. This is because the switching contacts of *J1B* (part of input jack *J1*) automatically connect the battery supply to the rest of the project whenever the instrument patch cord is inserted into *J1*. The only switch in the project is *S1*, a heavy-duty, push-on/push-off switch activated by the foot-pedal mechanism. It either bypasses signals around the Wah-Wah circuit or inserts it into the signal path.

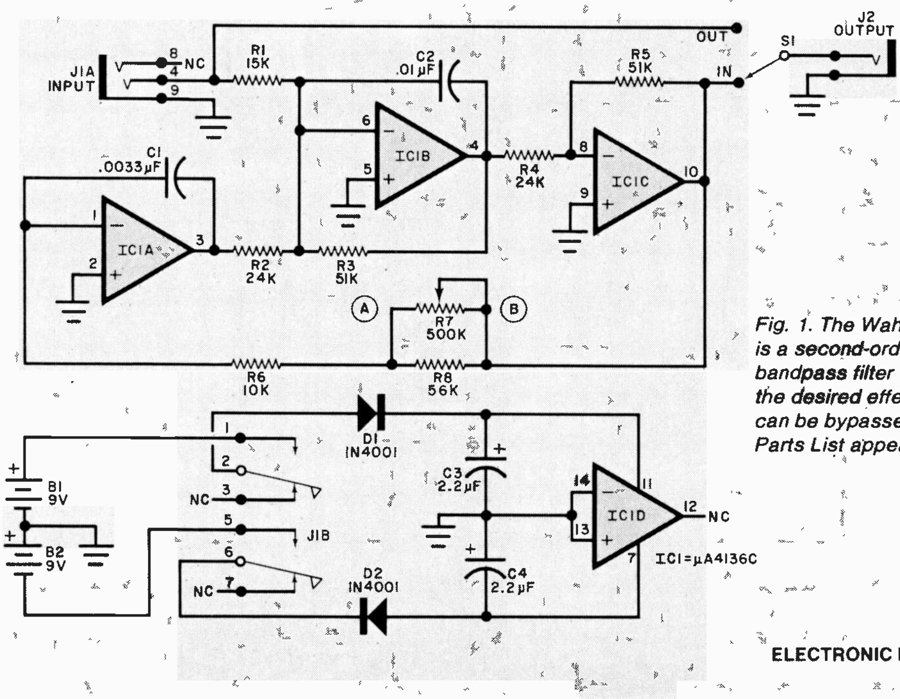


Fig. 1. The Wah-Wah Pedal circuit is a second-order, two-pole active bandpass filter that provides the desired effect. The filter can be bypassed by means of S1. Parts List appears on next page.

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50076	.062	25	4	2.39
50077	.062	50	8	4.25
50078	.032	33	1.5	1.31
50079	.032	88.5	4	2.47
50080	.032	175	8	4.57

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11301	8	$ .45	$ .40	$ .36
11302	14	.66	.59	.54
11303	16	.72	.64	.58
11304	18	.82	.73	.66
11305	20	1.11	.99	.90
11306	22	1.26	1.12	1.02
11307	24	1.41	1.25	1.14
11308	28	1.71	1.52	1.38
11309	40	2.31	2.05	1.86

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Tin plated phosphor bronze contact pins with gas tight seal

Stock No.	No Pins	1-24	25	100
11201	8	$.15	$.13	$.12
11202	14	.18	.15	.14
11203	16	.21	.18	.16
11204	18	.24	.21	.19
11205	20	.27	.24	.21
11206	22	.30	.26	.23
11207	24	.33	.30	.25
11208	28	.38	.34	.29
11209	40	.53	.45	.40

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13826	CB3811	3.0-7.0	12±0.6	0-25	.48×.51×3.05	7.95
13827	CB3802	3.0-7.0	15±0.7	0-20	.48×.51×3.05	7.95
13828	CB3812	3.0-7.0	15±0.7	0-20	.48×.51×3.05	7.95
13829	CB3804	3.0-7.0	28±0.7	0-10	.48×.51×3.05	7.95
13830	CB3814	3.0-7.0	28±0.7	0-10	.48×.51×3.05	7.95
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13831	CL3801	4.0-7.0	12±0.6	125	.651×1.2×1.77	$24.95
13832	CL3811	4.0-7.0	12±0.6	125	.651×1.2×1.77	24.95
13833	CL3802	4.0-7.0	15±0.7	100	.651×1.2×1.77	24.95
13834	CL3812	4.0-7.0	15±0.7	100	.651×1.2×1.77	24.95
13835	CL3804	4.0-7.0	28±1.4	50	.651×1.2×1.77	24.95
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13803	SOLV15-12	12	1.5A	4.7.16×4×2	Fixed included	39.95
13804	SOLV15-15	15	1.2A	4.7.16×4×2	Fixed included	39.95
13806	SOLV15-24	24	0.75A	4.7.16×4×2	Fixed included	39.95
13808	SOLV30-5	5	6.0A	5.5/8×4.7/8×3.3/16	OVP-4	59.95
13809	SOLV30-12	12	4.0A	5.5/8×4.7/8×3.3/16	OVP-4	59.95
13810	SOLV30-15	15	3.3A	5.5/8×4.7/8×3.3/16	OVP-4	59.95
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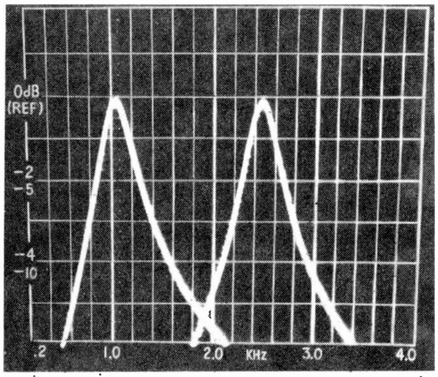


Fig. 2. Bandpass filter's frequency response when the foot pedal is fully up (left) and down (right).

PARTS LIST

B1, B2—9-volt transistor battery
C1—0.0033-μF, 5%-tolerance polystyrene
C2—0.01-μF, 5%-tolerance polystyrene
C3,C4—2.2-μF, 16-volt tantalum
D1,D2—1N4001
IC1—μA4136C quad operational amplifier or equivalent
J1—Three-conductor, double closed-circuit ¼-inch (6.3-mm) phone jack (Radio Shack No. 274-277 or equivalent)
J2—Monaural, open-circuit ¼-inch (6.3-mm) phone jack
The following are ¼-watt, 5%-tolerance, fixed carbon-composition resistors, unless specified otherwise.
R1—15,000 ohms
R2,R4—24,000 ohms
R3,R5—51,000 ohms
R6—10,000 ohms
R7—500,000-ohm, linear-taper potentiometer (see text and note below)
R8—56,000 ohms (see text)
S1—Spdt, heavy-duty, push-on/push-off switch (Alcoswitch MPG-106D or equiv.)
Misc.—Foot-pedal potentiometer drive mechanism and enclosure (DeArmond Model 1600 or equivalent), printed-circuit or perforated board, IC socket or Molex Soldercons (if desired), battery holder, battery clips, hookup wire, solder, hardware, etc.

NOTE-*The following is available from PAIA Electronics, Inc., Box 14359, Oklahoma City, OK 73114: DeArmond Model 1600 foot pedal No. 1230PED (includes 500,000-ohm potentiometer R7) for $39.95 plus $3.00 postage and handling (U.S.); etched and drilled printed-circuit board No. 1230PCB for $9.95 postpaid (U.S.). Oklahoma residents, add sales tax.*

Construction. The Wah-Wah circuit is simple, so either printed-circuit or point-to-point wiring techniques can be employed to reproduce it. The full-size etching and drilling guide for a suitable printed-circuit board appears in Fig. 3 together with the corresponding full size component placement guide.

Use of a socket or Molex Soldercons with *IC1* will simplify replacement of that component should it later become defective. Be sure to observe polarities and pin basing when mounting the IC, diodes, and tantalum capacitors on the circuit board. Employ the minimum amount of heat and solder consistent with the formation of good connections. When all components have been mounted on the board, examine your work for solder bridges, cold solder joints, etc.

A number of components (*B1, B2, J1, J2, R7* and *S1*) are not mounted on the circuit board. Rather, they are secured to the enclosure associated with the foot-pedal mechanism that drives potentiometer *R7*. This makes for a compact, convenient package. You can either construct an enclosure and foot-pedal mechanism from scratch or use a commercial product that has been specially designed for musical applications. The author recommends the DeArmond Model 1600 foot-pedal assembly, which contains a 500,000-ohm potentiometer and a worm-gear mechanism to drive the potentiometer. This is the foot pedal that he used in the construction of his prototype.

Figure 4 is a bottom view of the prototype with its bottom cover removed to show the worm-gear drive, the potentiometer, circuit board and other components mounted in the foot-pedal enclosure. A hole has been drilled along the long axis of the enclosure near the top below the pedal to accommodate bypass switch *S1*. This heavy-duty, push-on/push-off switch required a large mounting hole. Extreme care was taken when drilling this hole so that the rubber-topped metal pedal plate was not damaged by the drill bit. Figure 5 is a side view showing how *S1* was mounted so

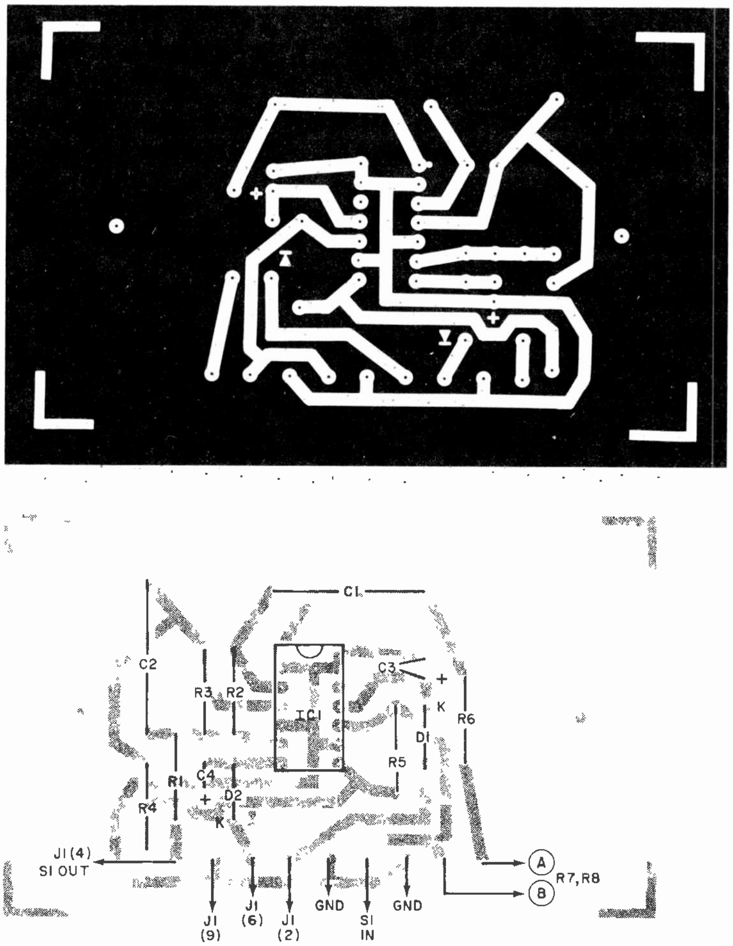


Fig. 3. Full-size etching and drilling guide (above) with corresponding parts placement guide below.

that it could be actuated by a full depression of the foot pedal.

The DeArmond Model 1600 foot pedal includes two monaural, open-circuit phone jacks. Its output jack (labelled AMPLIFIER) can be used as *J2*, but the input jack (INSTRUMENT) should be removed and replaced with a three-conductor, double closed-circuit 1/4-inch (6.3-mm) phone jack. This jack will fit in the space formerly occupied by the monaural, open-circuit input jack and will function as *J1*.

To mount the circuit board in the foot-pedal enclosure, a hole must be drilled in each of the mounting studs on the underside of the enclosure. Drill these holes 3/16" (4.8 mm) deep, taking care not to penetrate all the way through the enclosure. If a tap-set drill is available, it can be used to tap out the holes to the appropriate tap size. In the prototype, 10-32 tap-set holes were drilled and tapped to accommodate the screws that were used to hold the printed-circuit board in place. Spacers were inserted between the circuit board and the mounting studs to ensure that there is sufficient clearance for the board. If a tap-set drill is not available, holes should be drilled 3/16" (4.8 mm) deep using a No. 35 drill, and the board secured to the mounting studs using 6-32 self-tapping screws and circuit board standoffs.

Figure 4 shows how the battery holder that retains the two 9-volt batteries is mounted in the foot-pedal enclosure. It is secured in place using one of the two retaining screws of the worm-gear assembly. The photograph also shows how the circuit board, switch, jacks, batteries, and potentiometer are interconnected using battery clips and hookup wire. A close inspection of the photo reveals the installation of a fixed resistor (*R8*) across the 500,000-ohm potentiometer. It is placed in parallel with potentiometer *R7* to reduce the maximum effective resistance of the potentiometer, which is built into the DeArmond Model 1600 foot pedal, to 50,000 ohms. If a home-brew or some other foot pedal is used, *R8* can be omitted and a 50,000-ohm linear-taper potentiometer installed as *R7*. Note that the center lug (the wiper) of the potentiometer and the lug furthest away from the input and output jacks should be connected together.

Checkout and Use. Install fresh 9-volt transistor batteries in the holder and attach the battery clips to them. Then plug one end of a patch cord into the output jack of an electric guitar or similar signal source and the other end into jack *J1*. Use a second patch cord to route signals from output jack *J2* to the input jack of an instrument amplifier. Strike a note or chord and listen to the output of the amplifier while you pump the foot pedal up and down. If you hear no variation in timbre, depress the foot pedal fully until you hear the click of *S1*. Then repeat the process by striking a note or chord and rapidly pumping the foot pedal up and down. You should then hear the output of the guitar modified by the "wah-wah" sound.

Back the pedal off to its fully up position by pressing down with your heel and strike a chord. Bass notes should predominate over treble notes in the output of the amplifier. Next, move the pedal to its (almost) fully down position by applying pressure with your toes. Do not press the pedal with so much force that *S1* latches into its OUT position. Then strike the same chord that was struck previously and monitor the ouput of the amplifier. You should hear a predominance of treble notes over bass notes. If the opposite response is heard, potentiometer *R7* has been reverse-wired and the leads running to it from the circuit board should be transposed.

You can combine the Wah-Wah pedal with other signal processors, such as a fuzz-box, sustain, and a flanger, to create your own special sounds. Experiment with each of the signal processors you have to determine how much of any one effect should be added to the sound of your instrument at any given time. Keep in mind that too much of any sound effect can disturb your audience and that too little of it can bore them. The best bet is to apply judicious amounts of the sound effects available to you in a sequence dictated by your interpretation of the music you are going to play. This will not only entertain your audience, but also leave in their minds the impression that you are truly a creative musician. ◇

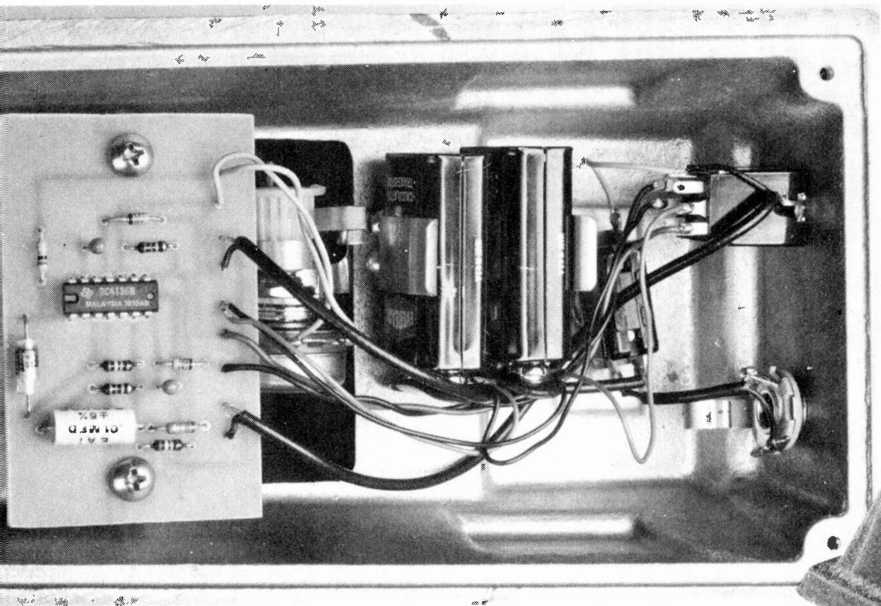


Fig. 4. Bottom view of prototype shows how the pc board and other components fit inside the foot-pedal enclosure.

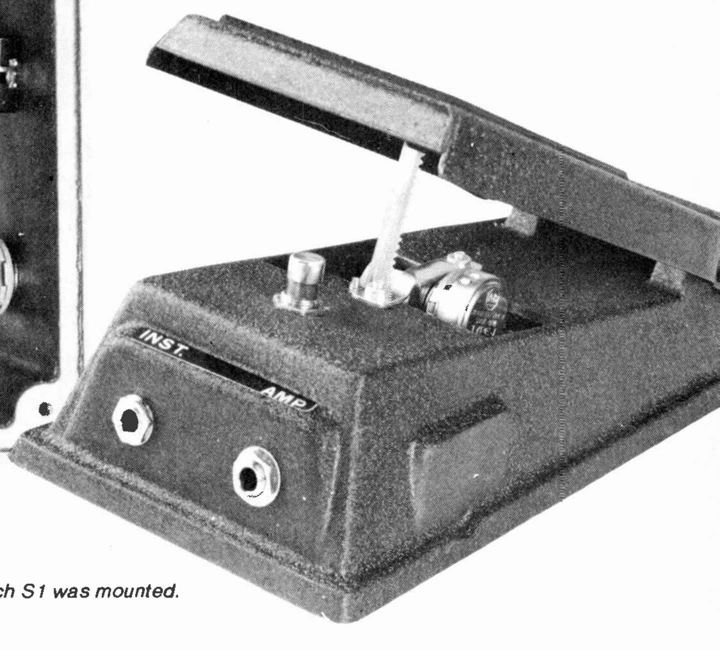


Fig. 5. View of pedal showing how switch S1 was mounted.

by Fritz Mueller

Digitally Programmed Varmint Zapper

Delivers a penetrating yet harmless electric shock to intruding animals

IF dogs and other small animals wreak havoc with your flowerbeds, or small "varmints" strew the contents of your trash cans over the area, this project is for you.

The Varmint Zapper described here uses a single strand of bare wire to create an "electric" fence. This wire is fed with a sequence of digitally programmed high-voltage pulses to create a penetrating but harmless electrical shock to anything making contact with the bare wire. You can also attach the wire to your garbage can (insulated from ground) or any other metallic enclosure that you want to protect.

Circuit Operation. The operation of the circuit, shown in Fig. 1, is similar to that of the capacitor-discharge ignition systems used in many vehicles.

The 117-volt ac developed across 1:1 isolation transformer *T1* is half-wave rectified by *D3* and charges *C6* via the primary of TV flyback transformer *T2*. The primary should be electrically separated from the high-voltage secondary.

When electronic switch *SCR1*, connected across the *C6-T2* network, is on, it forms a short circuit across the network. Then *C6* rapidly discharges through the transformer primary. The sudden change in current flow produces a high voltage at the secondary of *T2*. In a typical installation, about 15 or 16 kV will be developed. It is this voltage that is applied between the bare wire fence and ground.

The *C6-T2* network forms a resonant circuit. When it bursts into oscillation, the first half cycle of reverse voltage back biases the SCR, thus opening the electronic switch. The positive-going transient is bypassed via *D4*. Capacitor *C5*, damped by the low value of *R9*, attenuates any r-f transients generated by the sudden turn-off of *D4*. Neon lamp *NE1* glows to indicate the presence of the high dc voltage across the *C6-T2* network. Resistor *R10* provides current limiting for *NE1*.

The 10-volt dc required by binary counter *IC1* is developed by dropping resistor *R1*, rectifier *D1*, and filter capacitor C1. It is maintained at 10 volts by zener diode *D5*. Further filtering is added by *R2* and *C2*.

The clock pulses to be counted by *IC1* are developed from the half-wave rectified line voltage from *D2*. Noise is reduced by filter *R3* and *C3* before the pulses are applied to the IC.

The *SCR* is triggered into conduction by the positive-going pulses generated across *R8* each time unijunction transistor *Q2* fires. This occurs when *C4*, charged toward the 10-volt line via *R6*, reaches the UJT trigger level. When *Q1*, connected across *C4*, conducts, the trigger pulses are inhibited. Transistor *Q1* is kept in conduction during each positive half of the supply by bias across *R4*. During the negative half cycles, *Q1* is not biased by *R4*. Binary counter *IC1* is continuously counting line pulses applied to pin 1. Its outputs are connected so that four of its stages provide positive-going pulses through diodes *D6* through *D9* and *R5* to turn *Q1* on and off during the negative half cycles. This results in a rapid sequence of four SCR turn-on pulses followed by a 1.5-second space. The sequence is then repeated.

Each individual shock exceeds about 50 mA for a very short time, and currents of such intensity produce effects best described as "bite" or "sting." What renders the shock harmless without losing effectiveness is timing. Small, nervous animals will be instantly swayed by the first shock. The 2-second program is aimed to impress larger, more stubborn creatures. After the first four shocks, the varmint has time to move away from the unpleasant sensation.

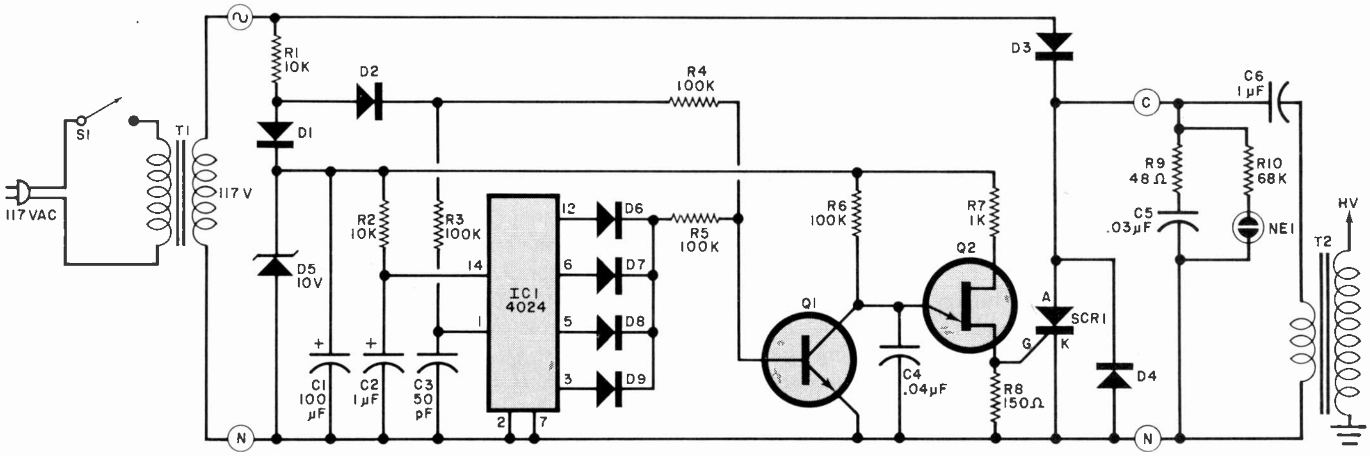


Fig. 1. Digital pulses from IC1 cause SCR1 to discharge C6 through primary of T2 to produce high voltage. Circled letters and symbol refer to foil pattern.

PARTS LIST

C1—100-µF, 10-volt electrolytic 20.55
C2—1-µF, 10-volt tantalum
C3—50-pF disc .15
C4—0.04-µF disc .15
C5—0.03-µF disc .15
C6—1-µF, 200-volt paper
D1,D2,D3,D4—200-volt PIV rectifier (1N4001 or similar)
D5—10-volt zener
D6,D7,D8,D9—1N914
IC1—4024 CMOS binary counter
NE1—Neon lamp assembly
Q1—General-purpose npn silicon transistor
Q2—Any UJT
R1—10,000-ohm, 1/2-watt resistor
R2—10,000-ohm, 1/4-watt resistor
R3,R4,R5,R6—100,000-ohm, 1/4-watt resistor
R7—1000-ohm, 1/4-watt resistor
R8—150-ohm, 1/4-watt resistor
R9—48-ohm, 1/4-watt resistor
R10—68,000-ohm, 1/4-watt resistor
S1—Spst switch
SCR1—200-PIV, 1-ampere SCR
T1—117:117-volt isolation transformer
T2—TV flyback transformer (see text)
Misc.—Suitable enclosure, high-voltage feedthrough, press-on type, bare wire for fence, insulators, mounting hardware.

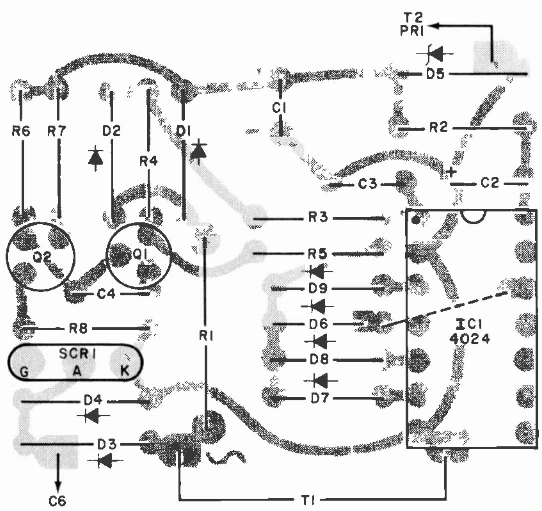
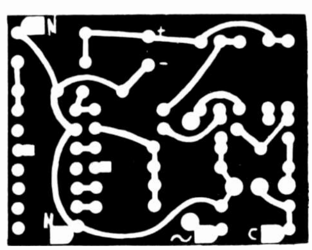


Fig. 2. Actual-size foil pattern for the printed-circuit board is shown below. Component installation diagram at left



Construction. The circuit can be assembled on a small pc board using the foil pattern shown in Fig. 2. It can also be Wire-Wrapped using conventional techniques. Note that *C5, C6, R9, R10,* the neon lamp, and both transformers are not mounted on the board.

The output transformer, *T2*, can be salvaged from a discarded small-screen TV receiver. You must be able to locate the two primary leads (between 2 and 8 ohms dc resistance), and both sides of the high-voltage winding, one end of which is the CRT anode connecter.

The use of a very high-voltage flyback transformer is not recommended. Corona discharge and possible flashover at the fence insulators may make the system inoperative after a short while. However, you can try using an automotive ignition coil.

Select an enclosure capable of holding the small pc board, the selected flyback transformer, the line isolation transformer and the associated off-board components.

Power switch *S1* and the neon lamp assembly can be mounted on the front side, while the high-voltage lead from *T2* is coupled to a high-voltage feedthrough located on the top of the enclosure. Place a "HIGH VOLTAGE" warning at the feedthrough.

Use. The fence can be formed from a length of bare wire (#17 galvanized steel is recommended) strung between insulators. Plastic rods, or small plastic or glass bottles affixed to wood stakes, can be used as a substitute. Make sure that no part of the bare wire "fence" touches, or comes close to, the actual ground.

To use the fence, connect the bottom end of the *T2* secondary to a good earth ground, then connect the fence to the high-voltage feedthrough. When the power is turned on, the neon lamp should glow indicating the presence of the operating dc voltage across the *C6-T2* network. If the fence is contacted, the neon lamp will blink on and off with each pulse.

The electrified fence can be installed so as to surround the area you want kept free from marauding animals, or, you can connect it directly to an insulated garbage can or other metallic container or enclosure. ◇

A Low-cost A/D Converter

BY SAMI A. SHAKIR

This simple, useful circuit employs "current mirrors" instead of conventional op amps

MORE and more digital techniques are finding applications in formerly exclusive domains of analog electronics—tests and measurements, communications, and the recording and reproduction of speech and music, to name a few. One necessary stage in any digital system that processes information originating in analog form is the analog-to-digital or A/D converter. In this article, we will present a low-cost A/D converter that you can build using readily available parts. The circuit can be used to experiment with the conversion of voltages, currents, and transduced physical quantities from analog into digital form.

About the Circuit. The A/D converter circuit, as shown in the schematic, employs a 12-bit CMOS counter and an LM3900 quad operational amplifier. Each of the op amps in an LM3900 IC employs the concept of a "current mirror" to amplify differential signals. They are known as Norton current-differencing amplifiers (CDAs) and are shown schematically as containing current sources to distinguish them from conventional operational amplifiers. Among the advantages of Norton CDAs are circuit simplicity, low cost, and the requirement of only a single-ended power supply from which each amplifier sinks a constant current independent of the supply voltage.

Stage *IC1A* generates a train of pulses whose duration is determined by the values of *R5* and *C1*. The frequency of the pulse train can be varied by adjusting potentiometer *R1*. Pulses generated by *IC1A* are applied to the noninverting input of *IC1B*. This Norton CDA is employed as an integrator which generates a staircase waveform. The staircase increases in amplitude as pulses are received from *IC1A*. It is applied to the inverting input of comparator *IC1C*.

The analog input signal is applied to the noninverting input of this comparator. As long as the staircase amplitude is less than that of the input signal, the output of comparator *IC1C* remains at +V, the positive supply voltage. The staircase continues to increase in amplitude until it just exceeds the input signal's amplitude, at which point the differential input current at *IC1C* becomes negative. This causes the output of the comparator to go to ground potential, and the resulting negative transition is capacitively coupled to the inverting input of comparator *IC1D*.

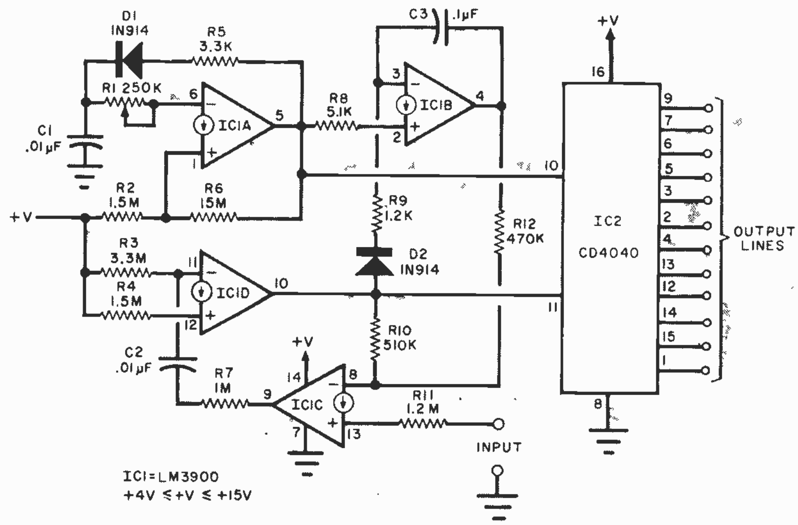
The negative pulse momentarily toggles the output of *IC1D* from its normal (ground) state to the positive supply voltage. The resulting positive pulse resets both integrator *IC1B* and counter *IC2*, causing the output lines of the counter and the output of the integrator (that is, the staircase waveform) to go to ground potential. The process begins all over again as new pulses are generated by *IC1A* and applied to the integrator and counter.

In operation, the amplitude of the staircase waveform is continuously compared to the analog input signal. If the input is a constant dc level, the staircase increases to a certain amplitude during each cycle until integrator *IC1B* is reset by *IC1D*. Similarly, *IC2* will count up to a certain binary number and then be reset. If the input waveform changes with time, the amplitude attained by the staircase and the magnitude of the binary count generated by *IC2* just before the reset pulse is applied will vary. Accordingly, the larger the input signal, the greater the amplitude of the staircase and the count at the output lines of *IC2* at the instant before the reset pulse causes the outputs of *IC1B* and *IC2* to go to ground. The smaller the input signal, the lower the amplitude of the staircase and count of *IC2* at the instant before the reset command takes effect. The highest count attained by *IC2* before the output lines are reset to zero describes the amplitude of the analog input signal at the instant that comparator *IC1C* changes states.

Because Norton CDAs are employed, only a single-ended power supply is needed. National Semiconductor, the manufacturer of the LM3900, states in its data sheet that a supply delivering from +4 to +36 volts can be used to power the chip. The power supply rating

project. Also, use the minimum amount of heat and solder consistent with the formation of good connections. Before applying any supply voltages, double check your wiring for errors that might cause damage to the ICs.

To calibrate the circuit, connect its input to the positive supply voltage. Then monitor the output lines of *IC2* and adjust *R1* for the desired weighting factor. This factor *n* will equal N_C di-



Schematic of the converter. The Norton CDAs are shown as containing current sources to distinguish them from standard op amps.

PARTS LIST

C1,C2—0.01-µF disc ceramic, silver mica or polystyrene capacitor
C3—0.1-µF disc ceramic, silver mica or polystyrene capacitor
D1,D2—1N914 diode
IC1—LM3900 quad Norton CDA
IC2—CD4040 counter
R1—250,000-ohm, linear-taper trimmer potentiometer
The following are ¼-watt, 5% tolerance, carbon-composition resistors.
R2,R4—1.5 megohms
R3—3.3 megohms
R5—3300 ohms
R6—15 megohms
R7—1 megohm
R8—5100 ohms
R9—1200 ohms
R10—510,000 ohms
R11—1.2 megohms
R12—470,000 ohms
Misc.—Printed circuit or perforated board, IC sockets, suitable power supply and enclosure, hookup wire, hardware, etc.

of the CD4040 CMOS counter is +1 to +15 volts. Accordingly, a supply furnishing a voltage greater than or equal to +4 volts and less than or equal to +15 volts can be used to power the entire circuit. Current demand is modest, so either a battery or small, well-filtered, line-powered supply is suitable.

Construction. Printed-circuit, point-to-point wiring, or wrapped-wire assembly techniques can be used to reproduce the analog-to-digital converter circuit. The use of IC sockets is recommended, and the standard precautions for the handling of CMOS devices should be employed with respect to *IC2*. Be sure to observe the polarities and pin basings of the semiconductors employed in this

vided by $+V$ where $+V$ is the positive supply voltage, N_C is the highest count attained by *IC2* before it is reset, and *n* is the number of counts per volt.

This low-cost A/D converter can be used to gain hands-on experience with one type of A/D conversion. It can also form the nucleus of some useful projects. For instance, a latch, decoder, driver and display network can be added to provide a seven-segment readout of the digital numbers generated by *IC2*. One interesting application would be a digital current meter that can be made by adding such a display network and by eliminating *R11*. This can then in turn be converted into a high-impedance (as much as 10 megohms) digital voltmeter. ◇

Sound Effects *(continued from page 42)*

Since the circuit can generate a very wide variety of sounds, let us give an example of how you might go about "tailoring" a specific sound with the bread-

TABLE II—SWITCH IDENTIFICATION

S1	Power switch for 7.5-to-9-volt dc supply
S2	Power switch for 5-volt dc supply
S3	Output
S4	Feedback
S5	Amplitude resistance selector
S6	Attack resistance
S7	One-shot, constant when closed
S8	One-shot momentary
S9	Attack-decay timing capacitor selector
S10	Decay resistance
S11	Noise filter capacitor selector
S12	Noise filter resistance
S13	Noise oscillator resistor
S14	Envelope select 1: logic 0, logic 1
S15	Envelope select 2: logic 0, logic 1
S16	Mixer C: logic 0, logic 1
S17	Mixer A: logic 0, logic 1
S18	Mixer B: logic 0, logic 1
S19	One-shot resistance
S20	One-shot capacitor selector
S21	Voltage-controlled oscillator (vco): logic 0, logic 1
S22	SLF oscillator control capacitor selector
S23	SLF oscillator control resistance
S24	Pitch control resistance
S25	Vco control resistance
S26	Vco control resistance selector
S27	Vco control capacitor selector
S28	Internal/external vco selector

TABLE III—CONTROL IDENTIFICATION

R4	Noise filter control
R6	Decay control
R8	Attack control
R15	Vco control
R18	Vco control
R23	Pitch control
R25	SLF control
R27	One-shot multivibrator control

TABLE IV—CONTROL GROUPING

One-Shot	J11,R27,S7,S8,S19,S20
Noise Filter	J3,R4,S11,S12
VCO Control	J7,J8,J9,R15,R18,R23,S21, S24,S25,S26,S27,S28
SLF Control	J10,R25,S22,S23
Noise Clock	S13
Mixer Select	S16,S17,S18
Envelope	J4,J5,R6,R8,S6,S9,S10, S14,S15
Amplitude	S5
Audio Output	J6,S3,S4
Power On/Off	S1
+5 volts	S2
Ground	J12

board. In this example, we will use the sound of a gunshot.

First, close FEEDBACK switch *S3* and OUTPUT switch *S4* to place the audio amplifier in the circuit. Then close +5V switch *S2* to activate the +5-volt line. Main POWER switch *S1* can now be closed when you are ready to experiment with the controls.

Since a gunshot has fast attack and relatively brief decay times, close ATTACK and DECAY switches *S6* and *S10*, respectively, to permit you to adjust attack and decay times via ATTACK and DECAY pots *R8* and *R6*. As you experiment with various settings of these controls, close main POWER switch *S1* and press and release ONE SHOT switch *S8* to hear the gunshot sound for each combination of settings. Adjust *R6* and *R8* and press and release *S8* until the sound obtained is "just right." (Calibrated index scales behind each potentiometer control knob will simplify recording of settings.)

If desired, required values of attack and decay time resistances can be measured and recorded by opening the ATTACK and DECAY switches and measuring with an ohmmeter between DECAY jack *J4* and ground and between ATTACK jack *J5* and ground. ENVELOPE SELECT 1 and 2 switches *S14* and *S15* can also be preset for the required envelope.

To produce an explosion instead of a gunshot sound, close NOISE FILTER switch *S12* and adjust NOISE FILTER control *R4* for the desired effect.

In Conclusion. The sound-effects generator breadboard presented here can be used in either or both of two ways. For the designer, it is a "tool" that simplifies designing a circuit from scratch. One can "design" a circuit with the breadboard, measure resistances of the controls and read off capacitor and logic-state (+5V or 0) settings from the panel, and assemble the circuit around a separate 76477 generator chip. The other way to use the breadboard is to simply experiment with control and switch setting combinations until you hear a sound you like. Used in this manner, you can record a whole series of sound effects that can be used with home movies and slide shows, for theatrical events, etc.

Whichever way you use the breadboard, it is a good idea to log parameter values for given sounds for future reference. Then, any time you want to reproduce a sound arrived at experimentally, you can, simply by setting the controls and switches as detailed in your log. ◇

in-circuit resistances...

(continued from page 46)

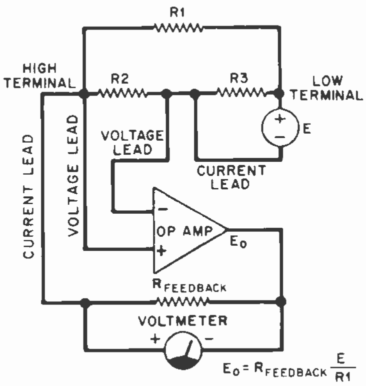


Fig. 5. Another inverting op-amp circuit where unknown resistance forms amplifier's input resistor.

In this latter configuration, a voltage drop will appear across each shunt resistor when the bridge is balanced.

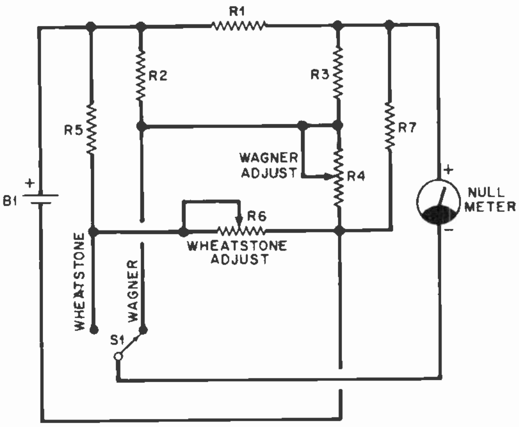
Practical Tips. A number of in-circuit measurement techniques have been presented in this article. However, there are several practical effects that should be considered before these techniques are implemented. These will now be summarized.

Thermoelectric voltages can be set up at the junctions of dissimilar conductors, as well as between points on the same conductor across which a thermal gradient exists. Although they are very small for ordinary working temperatures and materials commonly fabricated into probes and leads, these voltages can cause significant error if they are amplified as part of the measuring process. They can also be troublesome if the test potential of the ohmmeter is kept low to prevent semiconductor junctions from becoming forward-biased and influencing the reading. This type of error can be reduced by certain design techniques or by determining its magnitude and then subtracting it from the overall reading. The latter technique is commonly employed in precision, computerized procedures that are used to measure resistance.

If the measured resistance is of low value, test-lead resistance can be a source of significant error. The standard remedy for this is to use separate current-carrying and voltage-measuring leads. This avoids measurement of the IR drop in each current-carrying lead and is known as the *Kelvin* technique.

The in-circuit measurement techniques that have been presented can also eliminate the effects of semiconductors upon the resistance reading. However, any semiconductor present in the circuit might be called upon to dissipate power if it is part of the driven shunt path. Two practices are advised if this is the case. In a constant-voltage circuit, employ a measuring voltage that is less than the conduction threshold of the pn junction. In a constant-current circuit, reverse the polarity of the meter probes. These steps will effectively turn the semiconductor junction into an open circuit for the purposes of the resistance measurement and eliminate a source of potential error.

Fig. 6. A Wagner bridge circuit such as that shown here can be used to measure resistance of an in-circuit component.



In measuring circuits containing an operational amplifier, certain precautions should be observed. It is wise to install 0.01-μF disc ceramic bypass capacitors close to the IC package from the positive and negative power-supply leads to ground. This will enhance circuit stability. Input overvoltage and output short-circuit protection must also be considered. Many contemporary op amps, such as the Motorola MC1456, provide such protection internally. In those measurement situations which call upon the op amp to source more current into the driven shunt resistance than is available from the op amp, a current booster such as the Motorola MC1438R can be employed. Details on the use of the latter chip can be found in the manufacturer's *Applications Handbook* and its *Linear Circuits Manual*. ◇

BUILD A
Metal Locator

BY ROBERT KRIEGER

Low-cost, high-sensitivity unit for searching out metal objects

WHETHER it is put to work in searching for buried treasure, locating sunken pipes, or combing the Australian outback for fragments of a fallen space station, a metal locator can be a useful instrument. The locator described here uses a highly sensitive superheterodyne circuit. It is a true "from-scratch" project in which you even fabricate the search-head pickup-coil assembly. Assuming all parts and materials are bought new for this project, total cost should run about $20.

Circuit Operation. The metal locator, shown in block-diagram form in Fig. 1, functions on the beat-frequency (heterodyning) principle. Here, two high-frequency r-f signals are combined, or "beat" together, in the FET mixer to produce a difference frequency. (Actually, the mixer output contains the original frequencies along with their sum and difference, but it is the difference frequency that interests us because it is the only one that lies in the audio range.)

The original signals are produced by a pair of FET oscillators operating at 650 kHz. The frequency was chosen on the basis of tests showing that, up to 350 kHz, sensitivity and depth of penetration are fairly low and constant for moderately small objects. At 400 kHz, there is a sharp increase in performance that persists up to 1.3 MHz, where the copper-

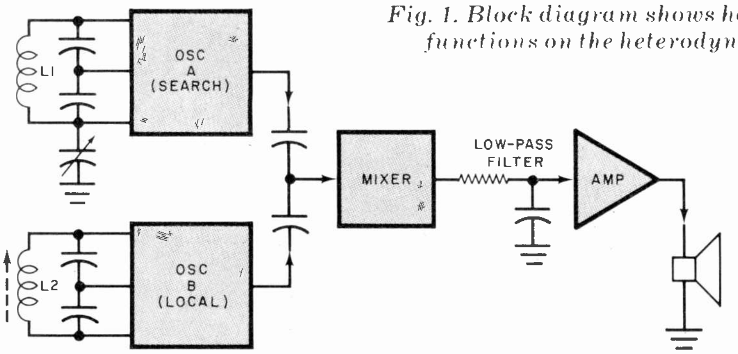


Fig. 1. Block diagram shows how the locator functions on the heterodyning principle.

braid Faraday shield (more about the shield later) loses its effectiveness. A frequency of 650 kHz gives excellent sensitivity and offers convenience in final adjustment. As designed, the metal locator can detect a nickel in free air at a distance of 6" (152 mm) or buried at a depth of 3" (76 mm) or more.

Assume that oscillators A and B in Fig. 1 are set to 650.454 and 650.400 kHz, respectively. Combining these in the FET mixer, we obtain signals at 650.454 kHz, 650.400 kHz, 1300.854 kHz and 54 Hz in the output. Since all we wish to pass on to the amplifier is the audible 54-Hz signal, the low-pass filter removes all higher frequencies. After amplification, the 54-Hz signal is heard from the loudspeaker.

When *L1*, the inductor that forms the search head, is brought near a metallic object (on the surface or buried), its inductance changes slightly. The deeper the object is buried, the less the change. With *L1* acting as one of the frequency-determining components of oscillator A, the variation in *L1* causes a frequency shift, say, to 650.440 kHz. Now, the difference between 650.440 kHz and the 650.400-kHz frequency of fixed oscillator B is 40 Hz. This means that the audible tone has shifted from 54 to 40 Hz to indicate the proximity to *L1* of a metallic object.

The metal locator contains two stable Colpitts oscillators (*Q1* and *Q2* circuits in Fig. 2) that are both tuned to operate in the 650-kHz range. The oscillators are essentially identical, except that one employs search-head coil *L1* as the inductive element and the other has small tunable inductor *L2*.

For operation, *C1* is set at its midpoint and then *L2* is adjusted so that both oscillators are at zerobeat (same frequency). Varying *C1* will then tune oscillator *Q1* out of zerobeat and cause an audio tone to be heard. Note that source resistor *R4* in the *Q2* circuit is greater in value than *R3* in the *Q1* circuit. Since the *Q1* circuit produces a low level of oscillation, it is necessary to damp the *Q2* oscillator

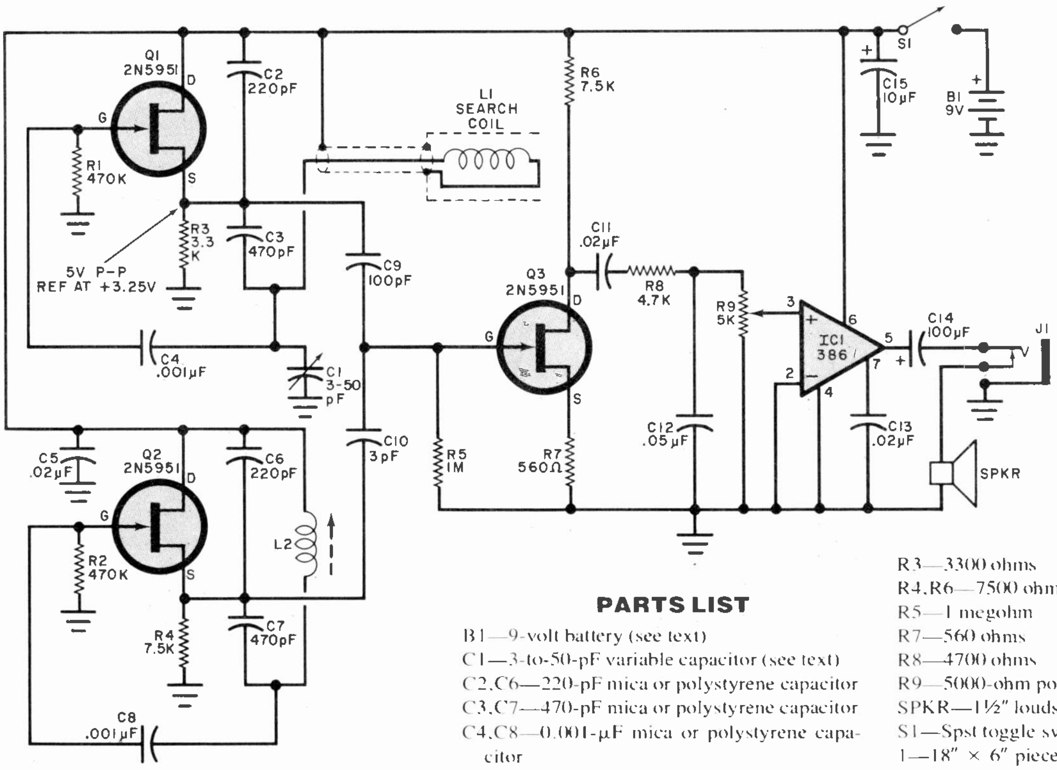


Fig. 2. Two stable Colpitts oscillators (Q1 and Q2) are tuned to operate in the 650-kHz range. They are essentially identical except for the two inductors.

PARTS LIST

B1—9-volt battery (see text)
C1—3-to-50-pF variable capacitor (see text)
C2,C6—220-pF mica or polystyrene capacitor
C3,C7—470-pF mica or polystyrene capacitor
C4,C8—0.001-μF mica or polystyrene capacitor
C5,C11,C13—0.02-μF capacitor
C9—100-pF mica or polystyrene capacitor
C10—3-pF capacitor
C12—0.05-μF capacitor
C14—100-μF, 16-volt electrolytic
C15—10-μF, 16-volt electrolytic
IC1—LM386 ½-watt audio amplifier IC
J1—Miniature transfer-type phone jack
L1—Search coil (see text)
L2—AM loopstick antenna with tunable slug
Q1,Q2,Q3—2N5951 n-channel FET
The following are ¼-watt, 10% tolerance resistors unless otherwise noted:
R1,R2—470,000 ohms
R3—3300 ohms
R4,R6—7500 ohms
R5—1 megohm
R7—560 ohms
R8—4700 ohms
R9—5000-ohm potentiometer
SPKR—1½" loudspeaker
S1—Spst toggle switch
1—18" × 6" piece of ¼" plywood for search-head coil form
1—36" length of ¾" diameter aluminum tubing
1—5' length of RG-58U coaxial cable
1—2' length of RG-8U coaxial cable
Misc.—Perforated board (or printed-circuit board—see text); socket for IC1; 9-volt battery clip; Bud No. CU234 or similar aluminum case; 40' No. 28 enamel- or Mylar-coated magnet wire; control knobs (2); white glue; epoxy cement; plastic tape; ½" foam insulation tape; plastic cement; two small brass screws; machine hardware; spacers; hookup wire; solder; etc.

to match the *Q1* oscillator. This is the reason for the greater value for *R4*.

The key to operation of a Colpitts oscillator is the pair of capacitors that form a voltage divider across the inductor (*C2* and *C3* for *Q1* and *C6* and *C7* for *Q2*). The capacitors and inductor in each circuit determine the frequency of operation for that circuit. In the *Q1* and *Q2* circuits, the FET's source is at signal ground. Therefore, because of the split capacitor action, the signal at the bottom of the inductor is 180° out-of-phase with that at the drain. Since the transistor inverts the signal by 180° and the split tank circuit inverts another 180°, an in-phase signal is fed back to the gate and sustains oscillations.

Increasing the value of *C3* or *C7* decreases the amount of feedback to the gate. If the value of this capacitor is made too large, there will not be enough feedback to sustain oscillation. Lowering its value to, say, 300 pF increases feedback and virtually guarantees oscillation, but the sine wave will not be as "clean" as it would be with a 560-pF capacitor value. The ratio of *C2* to *C3* or *C6* to *C7* should be about 1:3 for best overall operation. Although *Q1* and *Q2* appear to be arranged in a unity-gain source-follower configuration, *R3* and *R4* are actually working off the drains, since the sources are at feedback ground.

Mixer *Q3* heterodynes the r-f signals and provides some degree of preamplification for amplifier *IC1*. Resistor *R8* and capacitor *C12* make up the low-pass filter that prevents r-f from entering *IC1*.

Construction. There is nothing particularly difficult in assembling the metal detector. The only conceivable problem area might be in fabricating the search-head assembly, which requires relatively simple woodworking. Several hours are required for allowing the glue to set in the search-head assembly. Therefore, it is best to start construction by fabricating this assembly and, while the glue is setting, assemble the electronics package.

Cut two 5¾" (146-mm) and one 5" (127-mm) disks from a sheet of ¼" (6.4-mm) thick plywood. Lightly sand the cut edges to remove all splinters. Locate and mark the center of each disk and drill a 1/16" (1.6-mm) hole through each. Liberally coat both sides of the smaller disk with white glue and temporarily assemble the three disks with the smaller in the middle, using a nail to align the holes. Press lightly and then disassem-

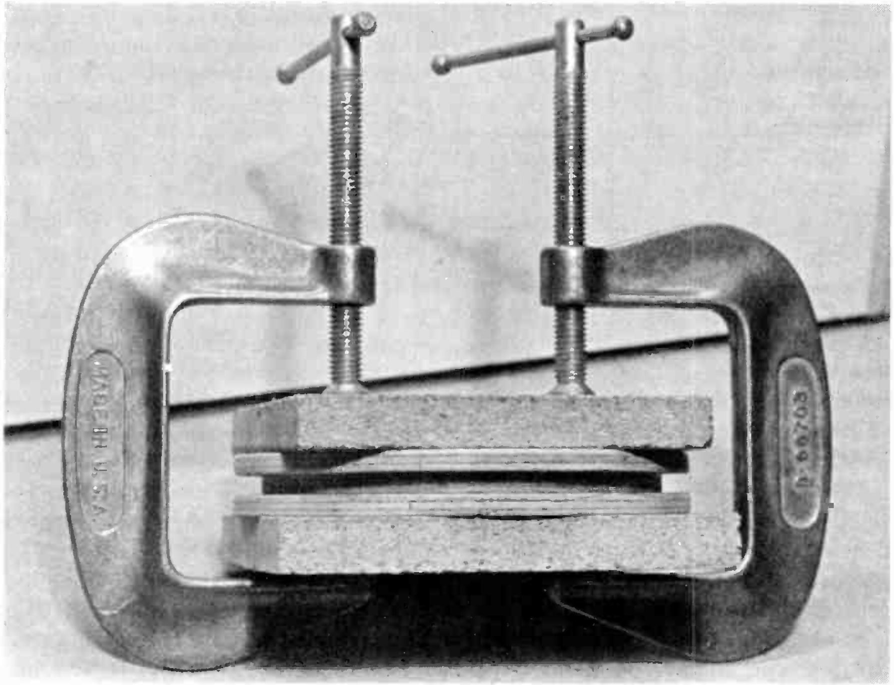


Fig. 3. Glue three plywood discs together with the smaller one in the middle. Use clamps or weights to ensure proper bonding.

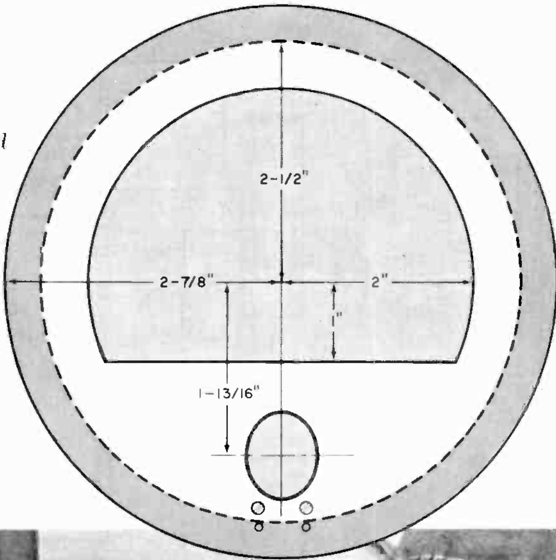


Fig. 4. When glue has had time to set thoroughly, draw a D-shaped form on the assembly as shown.

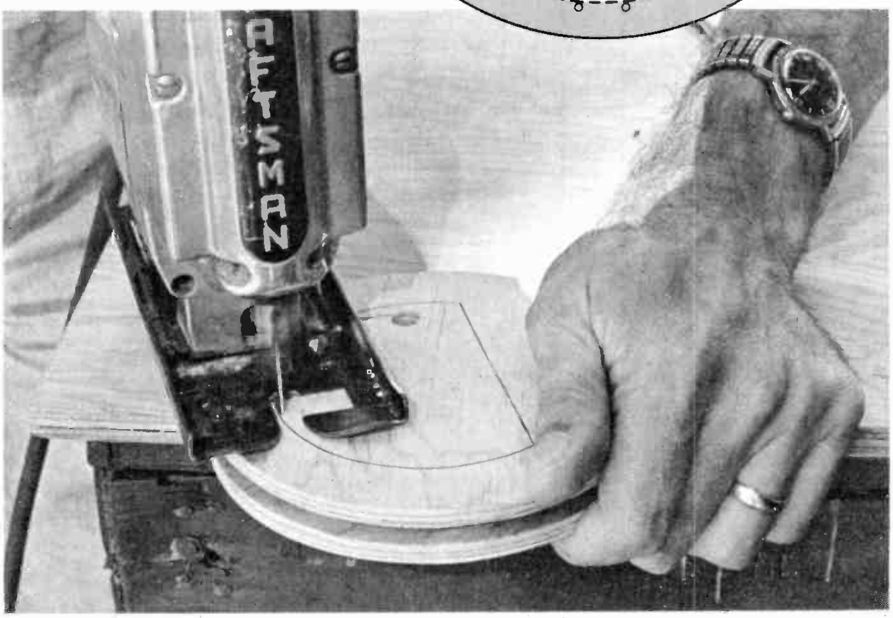


Fig. 5. Use a coping or sabre saw to cut out the form drawn on disc in Fig. 4.

Fig. 6. Drill shaft hole with wood bit, tilting it away from D cutout by about 18 degrees.

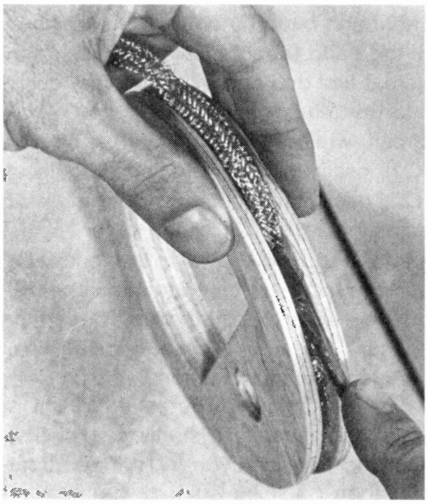


Fig. 7. The 20-turn coil is shielded with the braid from RG-8U coaxial cable.

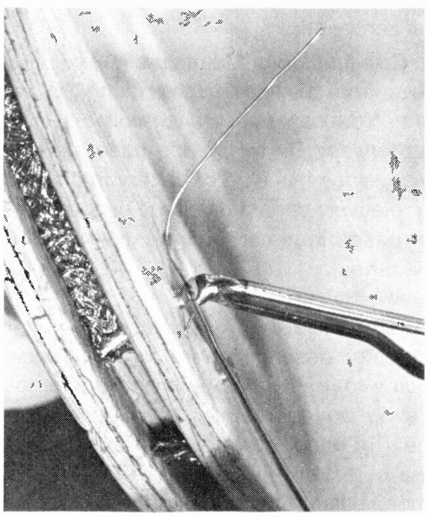


Fig. 8. Bring free end of braid up through plywood sandwich and solder to an adjacent screw.

ble. Allow the glue to air dry until the surfaces are just tacky. Then reassemble with the nail to assure proper alignment and clamp or weight the "sandwich" until the glue sets (Fig.3). Alternatively, you can use epoxy cement as the binder, aligning the disks with the nail and clamping or weighting immediately upon application. Set the assembly aside for at least 6 hours to allow the glue or cement to set solidly.

Meanwhile, referring back to Fig. 2, assemble the electronics package on a piece of perforated board, using either point-to-point or Wire Wrap techniques. If you are particularly ambitious, you can design and fabricate your own printed circuit board for the project. In any event, use a socket for *IC1* and, if possible, sockets for *Q1* and *Q2*.

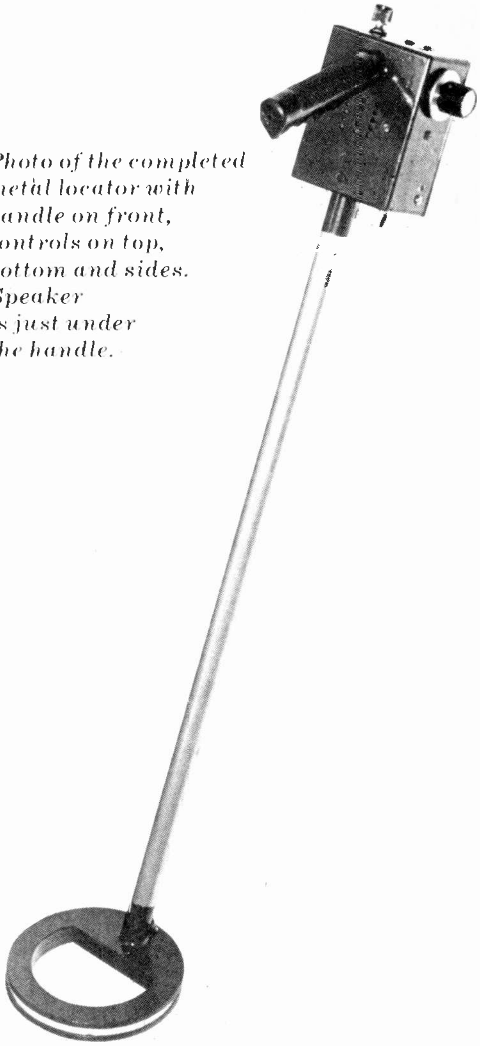
Do not wire *L1* or *C2* into the circuit just yet or mount the circuit board assembly into the case until directed to do so. Note that *C1* specified in the Parts List is a standard 365-pF capacitor. To reduce it to 50 pF, carefully remove all but one of its rotor plates, taking care to avoid bending the remaining plate.

Once the glue or cement has thoroughly set in the search-head assembly, remove the clamps or weights. Pry out and discard the nail. Then, referring to Fig. 4, draw a D-shaped form on the assembly as shown. Use a sabre or coping saw to cut out this form (Fig. 5). Lightly sand the cut edges to remove all splinters and rough spots. Referring back to Fig. 4, locate the centers of the shaft and wire-exit holes. Drill the latter with a 1/16" bit. Use a ¾" (19.1-mm) wood bit to drill the shaft hole, tilting it away from the D cutout by about 18° (Fig. 6). The angle is not critical, but it should be between 15° and 20° from perpendicular to permit convenient handling of the metal detector.

The 20-turn coil to be wound in the groove formed in the search-head sandwich must be shielded to reduce ground capacitance effects. The shield is a length of copper braid removed from RG-8U coaxial cable. Carefully slit the outer plastic jacket from about a 24" (61-cm) length of coax. Then slide the inner conductor out of the braid. With your fingers, flatten the braid and press one turn into the groove. Use a Phillips screwdriver to force the braid in place as shown in Fig. 7. Be sure to leave a gap of ⅜" (9.5 mm) between the braid ends.

Drive two small brass screws into the top of the plywood sandwich near the shaft hole. Solder a length of hook-up wire to one end of the braid. Pass the

Photo of the completed metal locator with handle on front, controls on top, bottom and sides. Speaker is just under the handle.



free end up through one of the 1/16" holes, and solder to the head of the adjacent screw. (Fig. 8). Cover the braid with a single layer of plastic tape, as shown in Fig. 9.

Use No. 28 enamel- or Mylar-coated magnet wire to wind the search coil. Scrape away about ½" (12.7 mm) of the insulation and pass the wire up through the same hole as the wire to the shield is routed to the brass screw. Solder to the same screw. Then wind 20 turns of the magnet wire into the groove. Pass the free end up through the other 1/16" hole and solder to the screw adjacent to the hole. Coat the windings completely with plastic cement to prevent them from shifting and affecting frequency stability.

When the cement sets, cover the winding with a single layer of plastic tape. Lay in another turn of the wire braid, again leaving a ⅜" gap between the ends and connecting one end, via a length of hookup wire, to the screw to which the inner braid and one end of the search coil is connected. Note, when you are finished with this part of construction there should be three wires soldered to one screw and only one to the other. For thermal protection, cover the outer braid with a single layer of ¼" wide polyfoam weather stripping.

Several inches up on the aluminum shaft, drill a ¼" hole through which to pass the coaxial cable that interconnects electronics package with search coil. On the other end of the shaft, measure down ½" and 1½" and drill ⅛" holes directly in line with the ¼" hole. Place the search-head assembly on a flat, level surface, top side up. Run a liberal bead of epoxy cement inside the shaft hole and around the head end of the shaft. Slide the shaft into the hole, orienting it so that the ¼" hole faces toward the screws in the search-head assembly. Prop the assembly up and let stand undisturbed until the epoxy cement sets.

When the cement sets, pass a 36" (914-mm) length of RG-58U coax through the ¼" hole and route through the shaft. Prepare the end of the coax and connect and solder it to the heads of the screws to which the search coil and shield are connected. The shield goes to the screw head to which the coil's two shield and one coil wires are connected, while the inner conductor goes to the other screw, as shown in Fig. 10.

Now, referring to Fig. 11, machine the cabinet for mounting *L2, SPKR, S1, J1, C1, R9, B1*'s bracket, the handle and shaft, and the circuit-board assembly. Carefully deburr all holes. Then mount the handle, shaft, and battery bracket, in that order, with appropriate machine hardware. (Note that the shaft fits through a ¾" hole at one end of the box and is held in place with two sets of 6-32 × 1¼" machine screws, nuts, and lockwashers through one wall of the box.)

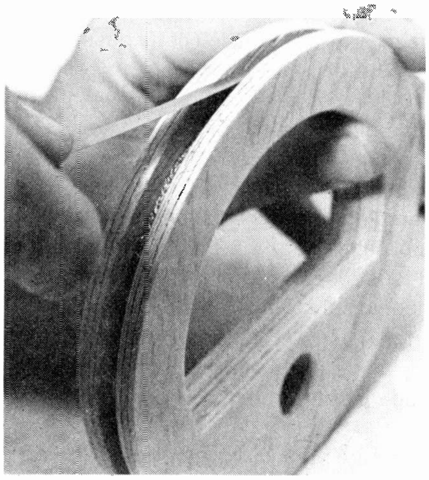


Fig. 9. Cover the coax shield braid with a single layer of plastic electrical tape.

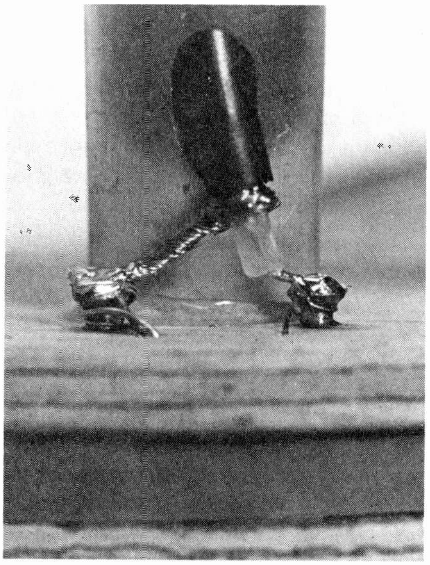


Fig. 10. Coax is routed to search coil through the shaft with ends soldered to the proper screws.

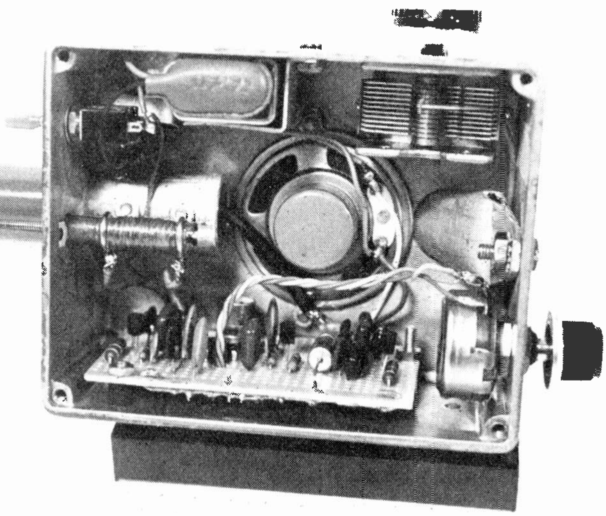


Fig. 11. Photo showing inside of author's prototype. The shaft fits through hole at left. Handle and speaker are shown on the back of enclosure here.

Next, mount the speaker, *C1, J1, S1, R9,* and *L1* in their respective locations. Mount these components in the order given and connect and solder lengths of hookup wires to their lugs. Referring back to Fig. 2, connect and solder the free ends of the wires to the appropriate points in the circuit. Then mount the circuit board assembly inside the box, using spacers and 6-32 hardware. Snap the connector onto the battery terminals and slip the battery into its bracket.

Operation and Use. The critical factor in a metal detector is in the adjustment of both its oscillators to function on the same frequency. If possible, each oscillator should be tested separately with a frequency counter. If a counter is not available, use a standard AM broadcast-band radio tuned near the low end of the band (about 650 on the dial) and defeat first one and then the other oscillator by temporarily opening the source circuit while tuning. Tune the search (*Q1*) oscillator first and then the local (*Q2*) oscillator to the same frequency, adjusting *L2* to bring the latter to the same frequency. When the oscillator and the radio are tuned to the same frequency, you will hear a "dead-air space," a band of silence resulting from the presence of an unmodulated carrier.

To use the metal detector, give it a couple of minutes to stabilize after first applying power. Adjust *C1* for zerobeat and then back off so that you hear a low-frequency tone from the speaker or earphone. Pass the search head over a metal object, and the tone should shift upward or downward in frequency, depending on the side to which you tuned off zerobeat.

One final note: Maintain a low volume level from the speaker to prolong battery life. You can use an 8.4-volt mercury battery for *B1* to provide superior service, since this type of battery maintains a relatively constant voltage over a longer period than can ordinary carbon-zinc batteries.

In Conclusion. As you use the metal detector described here, you will soon come to realize how well it works for locating buried metallic objects. Always bear in mind, however, that the smaller the object or the deeper it is buried, the more difficult it will be to locate. When working in noisy environments, such as at a beach with a pounding surf, use an earphone for best results. ◇

BUILD A Personal Radiation Monitor

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

BY JOHN STEIDLEY
MARTIN NAKASHIAN and
GERALD ENTINE

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

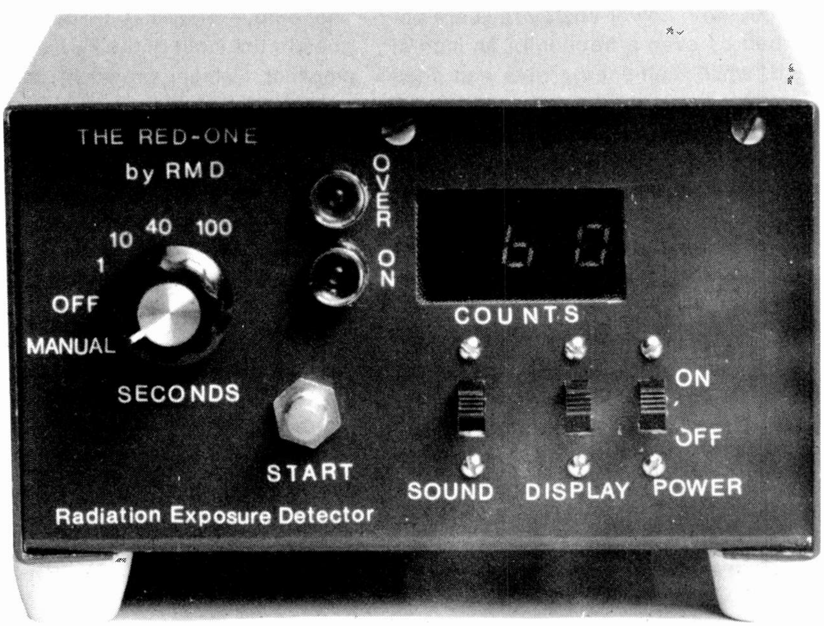
The RED-ONE battery-powered radiation monitor project described here detects local radiation levels from man-made and natural sources. It indicates relative radiation, which is perfectly satisfactory for alerting one to excess radiation levels.

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

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

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

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



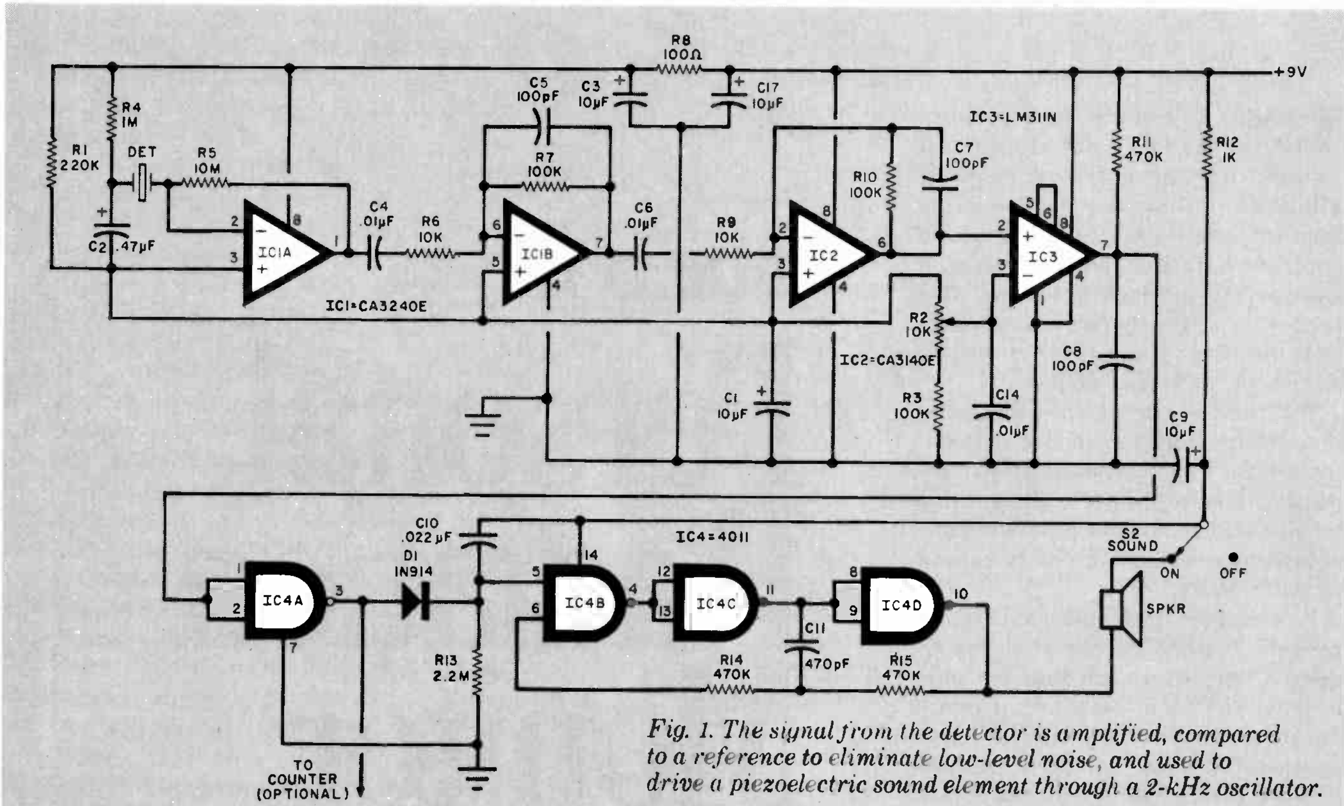


Fig. 1. The signal from the detector is amplified, compared to a reference to eliminate low-level noise, and used to drive a piezoelectric sound element through a 2-kHz oscillator.

PARTS LIST—FIG. 1

C1, C3, C17—10-µF, 16-V tantalum
C2—0.47-µF, 35-V tantalum
C4,C6,C14—0.01-µF disc ceramic
C5,C7,C8—100-pF disc ceramic
C10—0.022-µF disc ceramic
C11—470-pF disc ceramic
D1—1N914 diode
DET—CdTe radiation detector (see text and Note below)
IC1—CA3240E dual FET op amp (RCA)
IC2—CA3140E op amp (RCA)
IC3—LM311N comparator (National)
IC4—4011 quad NAND gate
The following are ¼-watt, 10% resistors unless otherwise specified:
R1—220,000 ohms
R2—10,000-ohm pc potentiometer
R3,R7,R10—100,000 ohms
R4—1 megohm
R5—10 megohms
R6,R9—10,000 ohms
R8—100 ohms
R11,R14,R15—470,000 ohms
R12—1000 ohms
R13—2.2 megohms
SPKR—Piezoelectric sound element (Kyocera KBS 27DB-3A or similar)
S2—Spst switch
Misc.—Suitable enclosure, 9-volt battery including holder and power on/off switch, 0.005" brass foil for shield, machine hardware, etc.
Note—For availability of kit and parts, see Parts List for Fig. 2.

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

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

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

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

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

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

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

PARTS LIST—FIG. 2

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

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

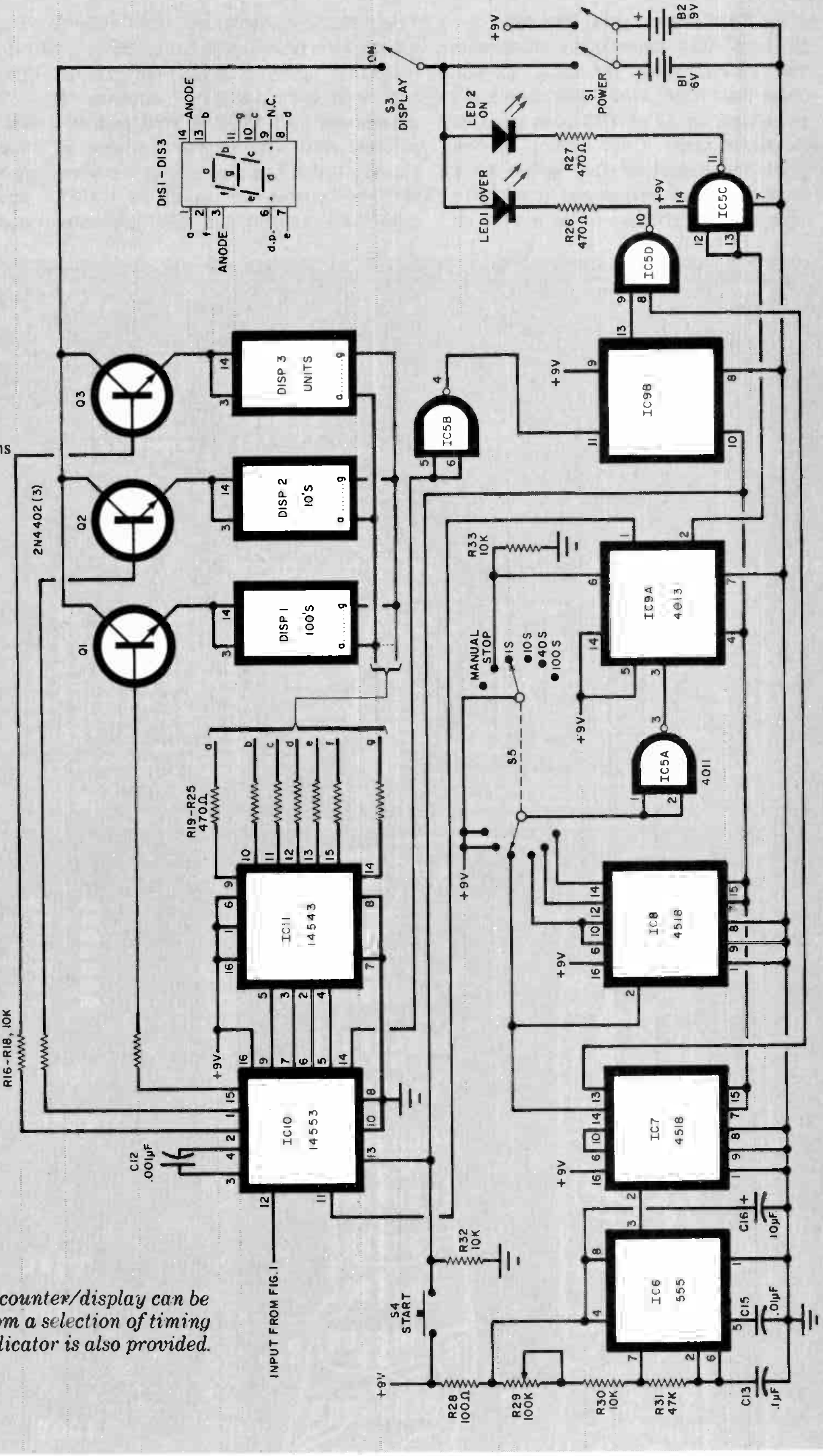


Fig. 2. The conventional 3-digit counter/display can be enabled either manually or from a selection of timing signals. A blinking overrange indicator is also provided.

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

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

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

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

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

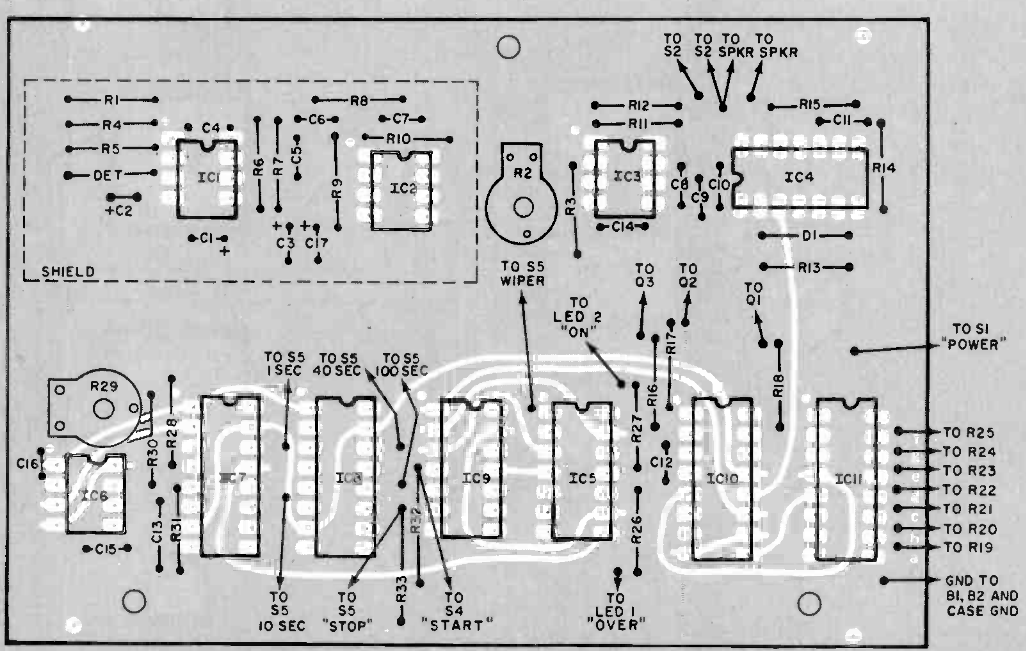
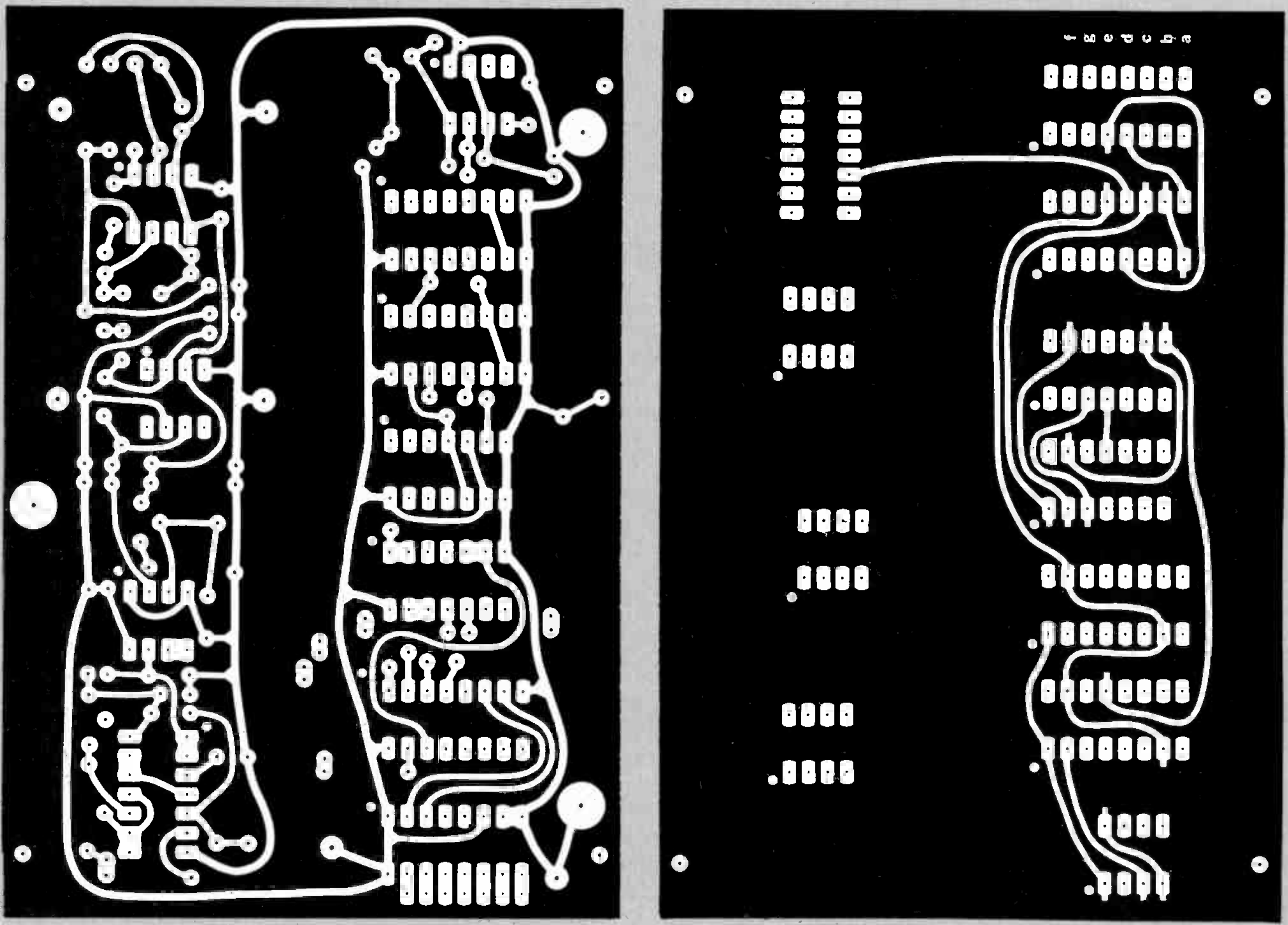


Fig. 3. Actual-size etching and drilling guides for the two-sided pc board are shown below. Component mounting on the top is at left. Note that the upper portion of the board (containing the audible circuit shown in Fig. 1) can be detached if only that circuit is to be used.



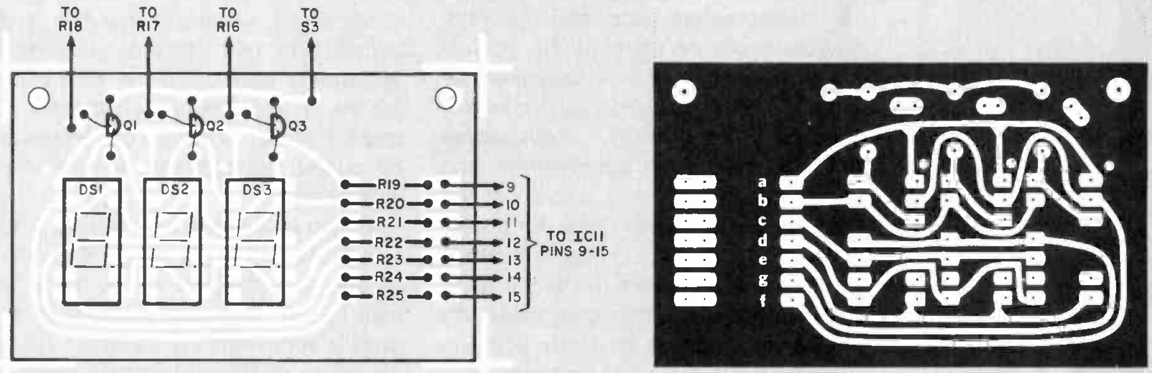


Fig. 4. Actual-size etching and drilling guide and component layout for the display board.

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

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

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

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

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

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

(Continued on page 97)

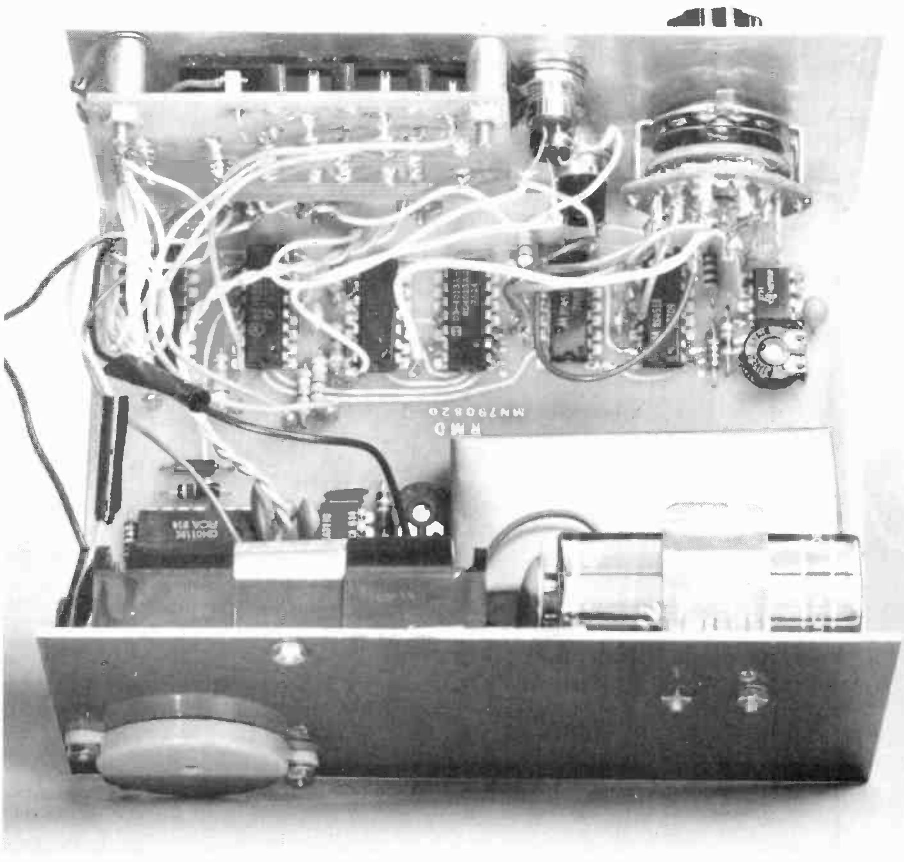


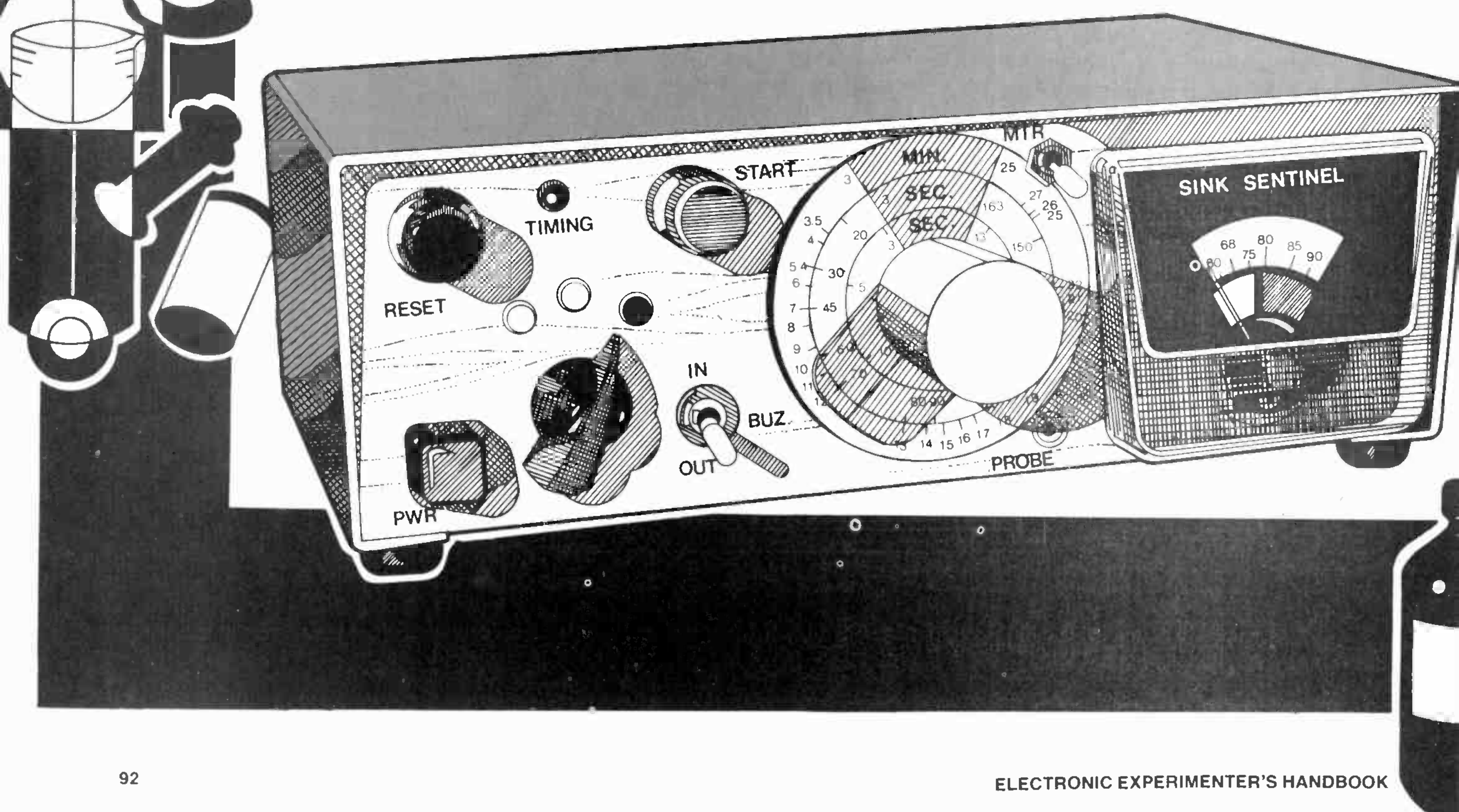
Photo of the author's prototype shows the main pc board mounted on chassis bottom with sound element on back and display on front.

BUILD A PHOTO SINK

THERE are many reliable timers, thermometers, and quality-control devices to aid the photographer. Unfortunately, most of these commercial devices are expensive. You can, however, build the "Sink Sentinel," which serves as a photo-lab timer, thermometer, and conductivity tester, at a fraction of the cost you would expect to pay for a similar commercial device. The Sink Sentinel accurately monitors the temperature of film-processing chemicals, times film processing, and tells you when your film or paper can come out of the hypo.

About the Circuit. The timer portion of the Sink Sentinel is shown in Fig. 1. It is based on a conventional 555 timing circuit (*IC1*). TIME SET potentiometer *R2* and RANGE switch *S3*, the latter selecting the appropriate range capacitor (*C1* and *C2* shown, but more capacitors can be added, as desired), determine the timing range.

Timing is initiated by pressing START switch *S4*, which places pin 2 of *IC1* at ground potential. Pin 2 is normally held high by *R3*. The timing interval in seconds is approximately equal to 1.5 times the value of *R2* in megohms times the value of the capacitor (selected by *S3*) in microfarads. The timing values for the R



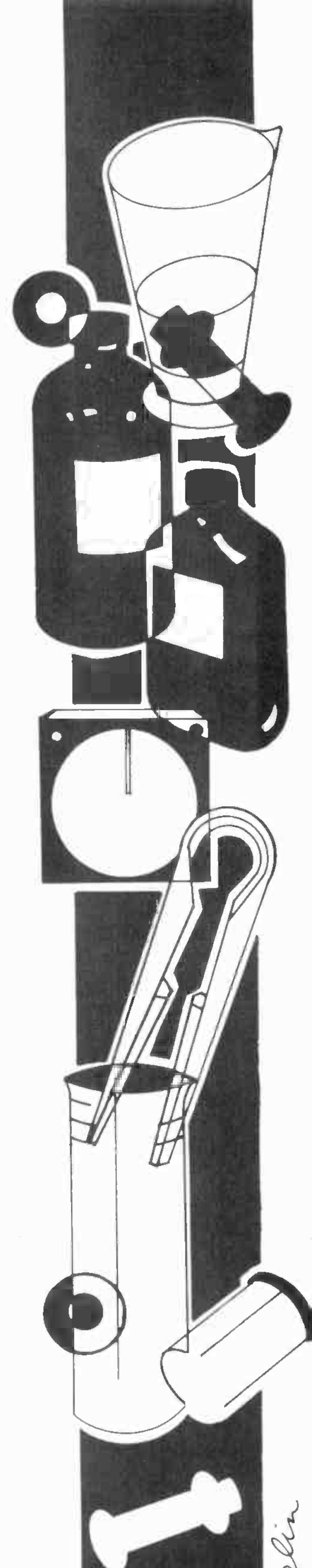
and C values shown in Fig. 1 were set in three ranges. The first and most commonly used for photographic printing and enlarging is from about 3 to 23 seconds; the second from 20 seconds to nearly 3 minutes; and the last from 3 to almost 30 minutes. If desired, the R and C values can be changed to produce any desired timing interval.

During the timing interval, the output of *IC1* at pin 3 is high and lamp *I1 and* alarm *A1* (if the latter is switched in via *S5*) will not operate, but *LED1* will be on. At the end of the timing cycle, the output of *IC1* goes low to allow *A1* and *I1* to operate. At this point, *LED1* extinguishes.

If at any time you wish to terminate the timing cycle, you simply press RESET switch *S2*.

An optional enlarger/safelight powering arrangement is provided by sockets *SO1* and *SO2* and relay *K1*, as shown in Fig. 1. If you prefer not to have this option, you can eliminate *K1* and *SO1* and *SO2*. Assuming you decide to keep this option, when *K1* is not energized at the end of a timing cycle, *SO2* is powered and can be used to power your safelight. During the timing cycle, *K1* is energized, connecting *SO1* to the power line for powering an enlarger.

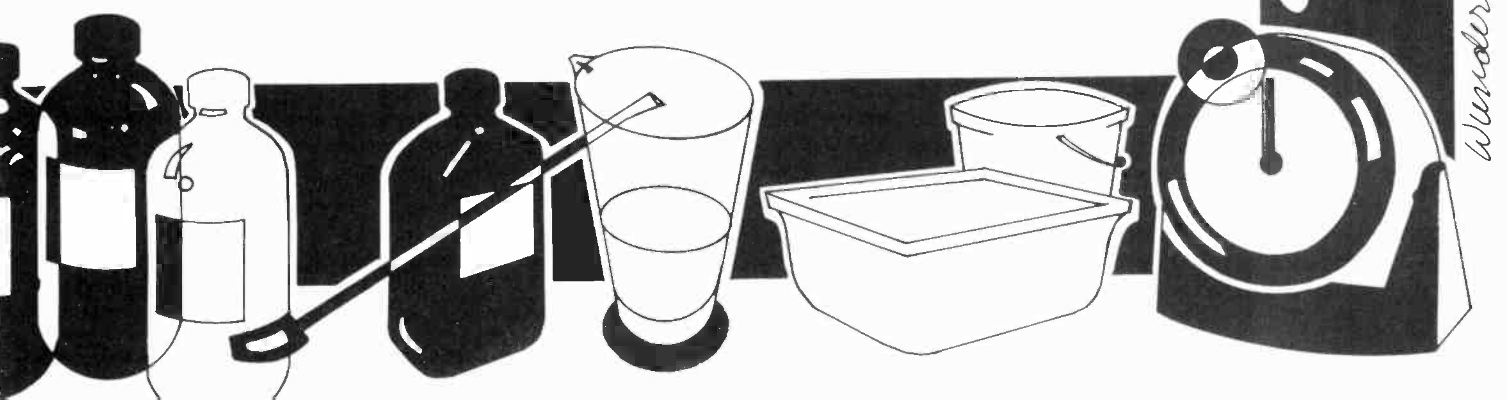
The temperature/conductivity section



DARKROOM SENTINEL

Moderately priced system monitors temperatures and film process time of photographic chemicals, and alerts user when film or paper processing is completed

BY FRANK I. GILPIN



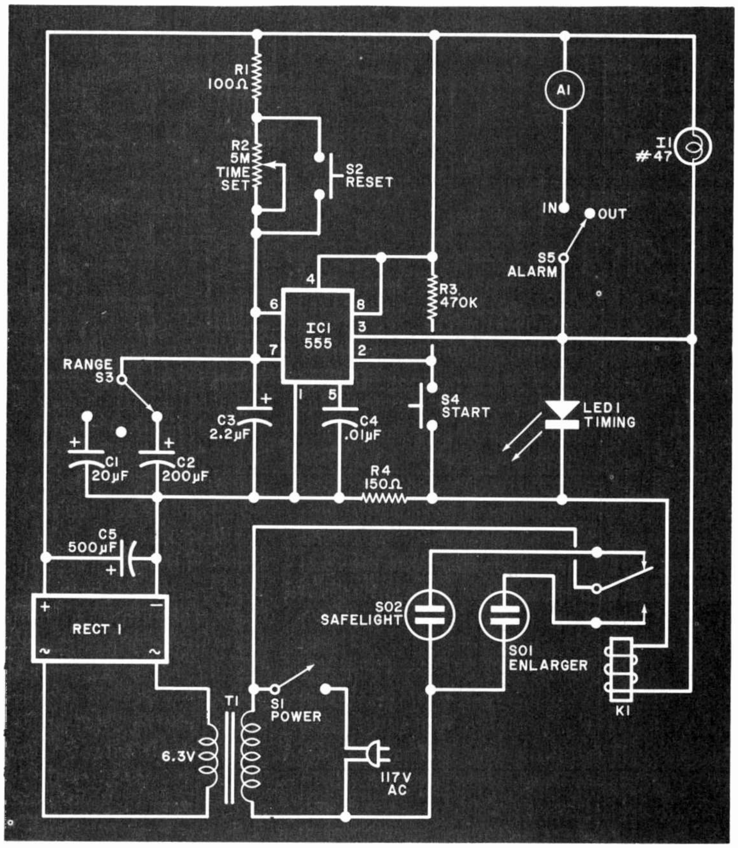


Fig. 1. Basic 555 timer can be adjusted for almost any desired timing ranges. The relay circuit allows timing an enlarger then turning on safelight.

PARTS LIST

A1—6-volt dc alarm or buzzer (Mallory Sonalert No. SC628, Radio Shack No. 273-049, or similar)
B1—9-volt battery
C1—20-µF, 20-volt electrolytic
C2—200-µF, 20-volt electrolytic
C3—2.2-µF, 20-volt electrolytic
C4—0.01-µF disc
C5—500-µF, 20-volt electrolytic
I1—6-volt lamp (No. 47 or similar)
J1—Subminiature phone jack
K1—6-volt, low-current relay (Radio Shack No. 275-004 or similar)
LED1—Red discrete light-emitting diode
M1—0-to-50-µA dc meter movement (Radio Shack No. 22-051 or similar)
P1, P2—Subminiature phone plug
Q1—Pnp germanium transistor in TO1 or TO4 metal case (see text)
The following resistors are ½ - watt, 10%:
R1—100 ohms
R3—470,000 ohms
R4—150 ohms
R5,R6—3000 ohms
R8—3600 ohms
R2—5-megohm linear-taper potentiometer
R7—100,000-ohm miniature potentiometer
RECT1—Rectifier (Radio Shack No. 276-1626)
S1—Spst switch
S2,S4—Normally open spst pushbutton switch
S3—Single-pole, three-position nonshorting rotary switch
S5,S6—Spdt switch
SO1,SO2—Chassis-mounting ac receptacle
T1—6.3-volt, 300-mA transformer
Misc—9" × 6" × 3½" (22.9 × 15.2 × 8.9 cm) aluminum cabinet; holder for B1; ac line cord with plug; pointer knob; plain pressfit control knob; 2" × 2" (10.8 × 10.8 cm) perforated board; 36" (about 1 m) stranded two-conductor speaker cable; 1/16" clear plastic sheet; quick-set epoxy; plastic cement; silicone-rubber cement; 4" (21.6 cm) chrome or stainless-steel wire (see text); dry-transfer lettering kit; rubber grommets (2); hookup wire; machine hardware; etc.

of the Sink Sentinel is shown in Fig. 2. It is based on the Wheatstone bridge principle. The circuit measures the relative resistance of either a plug-in temperature or conductivity probe.

The temperature probe is made up of an ordinary pnp germanium transistor with a metal TO1 or TO4 case. Sensing is performed in the emitter-collector junctions. Although such a temperature probe is limited in range, it will suffice for the 60° to 90° F (15.6° to 20° C) range required in most photographic developing situations.

Construction. The timer circuit can be assembled on a small perforated board, or you can use a printed-circuit board of your own design. A socket is recommended for *IC1* in either case.

Mount the various switches, control, indicators, and meter on the front panel of the enclosure in which the system is to be housed. This done, secure the power supply in place on the bottom of the enclosure. Pass the prepared end of the line cord into the box through a rubber-grommet-lined hole in the rear panel. Then, before connecting and soldering the line cord to the appropriate points in the circuit, tie a knot about 4" (10.2 cm) from the prepared end on the inside of the box to prevent the cord from being torn loose.

Light-emitting diode *LED1 mounts* on the front panel via a rubber-grommet-lined hole. Note that a separate lamp and switch can be used for *I1* and *S1*, or you can use a switch with built-in lamp.

Use a dry-transfer lettering kit to label the front panel with the appropriate legends. With an ink compass, draw four concentric circles on medium-weight white cardboard. Make the circles ⅝", 2", 2½", and 3" (15.9, 51, 63.5, and 76.2 mm) in diameter. Cut a disc from the cardboard, using the 3" circle as a guide. Next, cut a hole in the center of the disc, using the ⅝" circle as a guide. Rubber cement the disc to the front panel, with the shaft of *R2* centered in the hole. (This "dial plate" will be inscribed later during the timer calibration procedure.)

Slip a pointer knob onto the shaft of *S3*. Properly index the pointer and tighten the setscrew.

Next, cut a 3" disc from 1/16" (1.6-mm) thick sheet of clear plastic. Using a metal straightedge and a sharp needle, firmly scribe a line from the center to the edge of the disc. Fill the scribed line with india ink and wipe off the excess, leaving behind a fine scribed cursor. Drill a ⅜" (9.5-mm) hole through the center of the plastic disc.

Temporarily place a knob with a pointer on the shaft of *R2* and rotate it to locate the two stops on the pot. Locate this angular gap at the top of the cardboard disc (lightly pencil marking the two points on the cardboard disc) equidistant to both sides of an invisible vertical axis with the pot's shaft. Remove the pointer knob.

Now place the plastic disc over the pot's shaft, scribed cursor line toward

SINK SENTINEL

(Continued from page 52)

the cardboard disc. Center the plastic disc over the cardboard disc and line up the cursor line with the *right* pencilled stop mark on the cardboard disc. Temporarily tape the plastic disc in place. Rotate the pot's shaft fully counterclockwise. Apply a thin bead of plastic cement to the back of a plain plastic friction-fit control knob. Slide the knob onto *R2*'s shaft and gently press it against the plastic disc. Allow the cement to set for at least 8 hours before removing tape.

Meanwhile, fabricate the conductivity probe as follows. The probe itself (see Fig. 2) consists of a pair of closely-spaced conductors, with a limiting resistor, that can be plugged into *J1*. The probe elements can be made from two 2" (5.1-cm) lengths of chrome or stainless-steel 12-gauge rod. A bicycle spoke or a length of stainless-steel antenna rod will do.

Solder *R8* to one end of one of the rods. Then trim away 1" (25.4 mm) of one of the conductors at one end of a 36" (about 1-meter) length of speaker cable. Strip away the insulation from both conductors of this end of the cable, twist together the wires and tin them lightly with solder. Connect and solder the shorter conductor to the free end of *R8* and the other conductor to one end of the remaining rod.

Now, cut two 1" × ⅜" (25.4 × 9.5 mm) strips from a sheet of 1/16" thick sheet of plastic. Drill two ⅛" (3.2-mm) holes ⅛" apart in the center of both strips of plastic. Slip the free ends of the rods through one hole in each strip of plastic and apply a drop of fast-setting epoxy cement at each hole to secure the strips to the rods.

While the cement is setting, drill a ½" hole through the center of the bottom of a plastic film or pill container. Drill eight or more ⅛" holes around this hole and 25 or more ¼" holes through the body of the container. Assuming the epoxy cement has set, slightly bend the tops of the rods apart to obviate any possibility of the two touching each other.

Pass the free end of the speaker cord through the ½" hole from the *inside* of the container and pull it through until the tips of the rods are just slightly recessed from the open end of the container. Then liberally apply silicone-rubber cement over the resistor and the three soldered connections. Just fill the space around and between the tops of the rods to fill the ½" hole. This will provide a mechanically secure mount for the conductivity probe's elements and a seal against the caustic solutions into which it will be immersed. Allow the cement to set for at least 24 hours.

To one end of a 36" length of speaker twin-lead cord, connect and solder a subminiature phone plug. Separate the cord at the other end for a distance of about 4" (10.2 cm). Strip away about ⅜" of insulation, twist together the wires, and lightly tin the conductors with solder. Plug in and turn on the Sink Sentinel. Then, making sure to prevent the tinned conductors from contacting each other, insert the phone plug into *J1*.

Temporarily connect the collector and emitter leads of a pnp germanium transistor to the tinned conductors. Make sure that the emitter connects to the *R5* junction and the collector connects to the *R7/M1* junction. Note that the meter's pointer swings upscale. In a typical 68° F (20° C) ambient room, adjust *R7* for about a one-quarter-scale pointer swing.

Bring the transistor close to a turned-on light bulb; the meter's pointer should swing to full-scale. If this does not occur, repeat the procedure with a different germanium transistor until you locate one that is relatively heat sensitive. Put a kink or other identifying mark on the transistor lead connected to the speaker cable conductor with ribbed insulation. Then disconnect the cable from the circuit and turn off the power.

Once you have your heat sensitive transistor, clip away its base lead close to the metal case that houses it. Connect and solder the emitter and collector leads of the transistor to the cable's conductors, making sure that the identified transistor lead goes to the cable conductor with ribbed insulation. This done, pack silicone rubber cement over the exposed metal connections and down to the case of the transistor. Do *NOT* coat the sides or top of the transistor's case with the cement. Put this cable assembly aside to allow the cement to set for at least 24 hours.

Calibration. The timer section can be calibrated with the aid of a stopwatch, digital watch with seconds display, or an ordinary analog watch with a sweep second hand. Plug the Sink Sentinel into the power line and turn on the power. Lamp *I1* should come on and the alarm will sound if ALARM switch *S5* is on.

Set the RANGE switch to the maximum time (*C2* in Fig. 1) and the pointer knob for minimum resistance (fully counterclockwise). Carefully mark with an awl or the point of a pin, on the plastic disc over the potentiometer dial, the points where the cursor line crosses the circles on the cardboard disc. Remove the cursor knob and drill a 1/16" hole at the two points marked. Then slip the knob back on the pot's shaft.

With the knob fully counterclockwise, push the point of a pin through both holes in the cursor disc to lightly detent the cardboard disc. Turn the knob fully clockwise and repeat the procedure. Return the pot fully counterclockwise.

Now calibrate the minutes range on the inner circle of the dial plate as follows. Simultaneously start your stopwatch (or wait for your watch to reach the zero seconds mark) and press

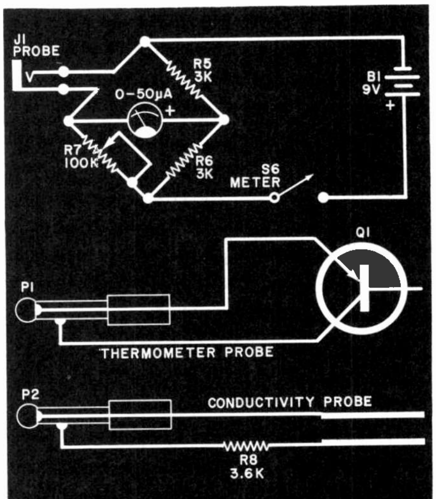


Fig. 2. Temperature/conductivity is measured on conventional Wheatstone bridge. Both probes are also shown. Temperature probe uses standard germanium transistor, while resistivity probe has stainless steel rods.

START switch *S4*. The LED should come on, *I1* should extinguish, and the alarm should cease to sound (assuming it is switched in). When the countdown is completed by the timer, *I1* will come on, the LED will extinguish, and the alarm will sound. Note how long this took on a sheet of paper under the heading "MIN." Adjust *R2*'s cursor slightly clockwise and repeat this procedure. At the end of the countdown, note the time elapsed and slightly detent the inner circle on the cardboard with a pin. Repeat this procedure until the pot is at its fully clockwise stop. Then repeat this procedure for the other two positions of the RANGE switch and the two SEC circles on the cardboard disc. (If you prefer, you can adjust the pot's setting to coincide with exact seconds and minutes to obtain a neater dial plate. This is time-consuming but well worth the effort.)

When you have completed calibration, turn off the Sink Sentinel and remove the cursor knob from the shaft of the pot. Mark three or four points on the perimeter of the cardboard disc and on the front panel exactly in line with them. Then lift off the cardboard disc. Using a dry-transfer lettering kit (or working with a pen), place tick marks at each detented point on the circles on the disc and label each with the appropriate time in your calibration listing. Then rubber cement the disc back in place, using the marks on it and the front panel as a guide. Slip back onto the shaft of the pot the cursor knob. (A typical finished dial is shown in the lead photo.)

The temperature probe can be calibrated with the aid of an accurate mercury-column thermometer. Since the most used range will be between 60° and 90° F, leave the probe in ambient room air (about 68° F) until the meter's pointer deflection stabilizes. Then adjust *R7* for a pointer deflection of about one-quarter scale. Carefully place a pencil mark on the scale at this point. Place both the mercury thermometer and temperature probe in water and adjust the temperature for an indicated reading of 95° F on the mercury thermometer. Again, place a pencil mark on the meter's scale at this point. Reduce the temperature of the bath by 2.5° F and again make a pencil mark on the scale. Repeat reducing the bath's temperature by 2.5° F and indicating each point on the scale until you reach 60° F. Turn off the power and remove the line cord from the ac power line.

Carefully remove the dial-scale card from the meter and relabel it with a dry-transfer lettering kit for each of the pencil marks. Start with 60° F and label only in 5° F increments, placing a small but easily legible tick at the 2.5° locations on the scale. Then replace the scale card. Plug in and turn on the Sink Sentinel and replace the temperature probe with the conductivity probe.

Calibration of the meter scale for conductivity is simple. Allow a cold water tap to run for awhile. Then fill a clean container with water. Place the conductivity probe in the water and mark the meter pointer's deflection on the scale with a pencil. Add some hypo to the water and wait a few seconds; the meter's pointer should swing upscale, the amount of deflection determined by the concentration of the hypo in the water. No further marks need be made on the meter's scale. Run cold water in the container while observing the pointer deflection. As the concentration of hypo diminishes and finally is all gone, the meter's pointer will swing down-scale and ultimately come to rest at the mark you made on the scale.

Turn off the power and, using a black felt marker, place an easily legible dot at the point pencilled in just below the arc of the scale. Then replace the protective cover on the meter and assemble the project's case.

Use. When you start your film-washing cycle, set the timer for a period of slightly less than the time recommended by the chemical manufacturer. Insert the conductivity probe into the wash water. Then when the timer's alarm sounds (or *I1* lights), note the position of the meter's pointer with respect to the mark made below the scale arc. If it is at the mark, it is safe to stop the wash cycle. However, if the pointer is above the mark, continue to wash until it gets there.

To operate the complete system, turn on the METER switch (*S6*), plug in the temperature probe, and place the probe in the chemical bath. When the proper temperature is reached, set RANGE switch *S3* to the appropriate range and TIME SET control *R2* to the desired interval. Start the developing cycle and press START switch *S4*. (If you desire visual signals only, switch off the alarm with *S5*.)

When the programmed-in developing time is completed, the timer will signal with both *I1* and the alarm (if the latter is switched in). Set the time for the correct fixing period and press START switch *S6* to start the timing cycle.

During the fixing cycle, you replace the temperature probe with the conductivity probe. When the timer's alarm sounds, end the fixing and start the washing cycle. Set the timer just short of the recommended period and, when the timer signals again, immerse the conductivity probe into the wash water. Continue washing until the meter's pointer drops to the mark on the scale.

You will find that, once you become familiar with its operation, the Sink Sentinel will take the guesswork out of your photographic lab processing. It will insure accuracy and let you turn out more professional negatives and prints. ◇

Alarm *(Continued from page 64)*

of a quality magnetic reed switch, it can be used liberally throughout the premises to be protected. Each sensor module should be connected to the Signal Processor module using three lengths of flexible, stranded hookup wire (No. 22 or larger). Heavier gauge hookup wire (No. 18 or larger) should be used for the rest of the connections.

Installation and Use. The siren and the Siren Driver module should be installed in the attic or some other area where the intruder will not be able to locate it readily. The Signal Processor module can be mounted in any convenient area such as an entrance closet. As was mentioned earlier, any attempt to tamper with the Signal Processor module will set off the siren. The ARM/DISARM switch, *S1*, should be located in a convenient spot but not easily detectable by an intruder.

The ideal number and location of Motion Sensor modules in your Opdec system depends on the size of your home or office and the number of areas that need protection. Sensor modules can be placed on kitchen counters, on TV receivers, or even mounted within a suspended ceiling into which a (5/16" or 8-mm) hole has been drilled. In deciding where modules are to be placed, keep in mind that they sense motion by detecting *changes* in light level. Therefore, do not aim a Motion Sensor module toward a window or any flashing lights. During the daytime, there should be suf-

DESIGN SPECIFICATIONS ULN-2232A SPRAGUE INTEGRATED MOTION DETECTOR

Supply voltage: +3.0 to +4.5 volts dc
Ambient temperature: +10°C to +40°C
Current demand: 20 mA maximum when V_{CC} equals +4.5 volts
Minimum sensing range: 8' (2.4 m)
Sensitivity: $\Delta L = \pm 5\%$ at 1 Hz
Ambient light: 0.1 fc to 100 fc (1.08 lux to 1076.4 lux or 1.08 lumens/m² to 1076.4 lumens/m²)
Alarm sweep: 200 to 1000 Hz
Alarm sweep rate: 5 Hz
Audio output: 100 mW continuous
Device fabrication: Monolithic IC containing linear amplifiers employing pnp and npn bipolar junction transistors; I^2L gates, counters, and D/A converter; low-leakage photodiode; and bipolar junction power transistors.

ficient natural illumination to permit operation of the sensors. At night, however, some source of artificial light will have to be used. Readily available photoelectric or electromechanically timed devices can be employed to automatically turn on such lights at dusk. Make sure that the artificial light sources are *simultaneously* activated and that one of them is placed near the lightning detector. This module will momentarily disarm the system, thus preventing the Motion Sensor modules from triggering the Signal Processor when power is applied to the lamps.

Options. Depending on factors peculiar to each site at which an Opdec system is to be installed, there are several optional changes that can be made. For example, if you think that lightning or some similar phenomenon is not a problem in the area to be protected, simply eliminate the lightning detector. Also, you can mount a key-operated dpst switch outside the premises to be protected for use as *S1*. If this is done, the exit and entry delays will no longer be needed. Accordingly, the following Signal Processor components can be eliminated: transistors *Q8*, *Q10*, and *Q11*; diodes *D8*, *D9* and *D10*; resistors *R14*, *R15*, and *R16*; and capacitors *C17* and *C20*. If this is done, connect the position lug of both portions of the dpst switch to point E. Connect one switch pole to the base of *Q13* and the other pole to that of *Q15*.

If you prefer to have the alarm remain on indefinitely after the system has been triggered, eliminate the automatic timeout feature. This is done by omitting the following Signal Processor components: transistors *Q17* through *Q20*; diode *D14*; resistors *R28* through *R31*, and *R33*; and capacitors *C21* and *C22*. Finally, if a back-up battery power source is not needed, the Siren Driver module, the siren, and the battery can be eliminated. If this is done, the collector of *Q26* (point I) can be used to sink current from the positive supply through a dynamic loudspeaker to ground.

In Conclusion. Opdec is an inexpensive but sophisticated alarm system that can enhance the security of business or residential premises. Its optical sensors can detect not only intruders but also smoke of fire. The system is thoughtfully designed and is readily expanded to include heat detectors, closed-loop sense wiring, and a large number of optical Motion Sensor modules. ◇

Radiation Detector

(Continued from page 91)

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

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

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

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

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

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

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

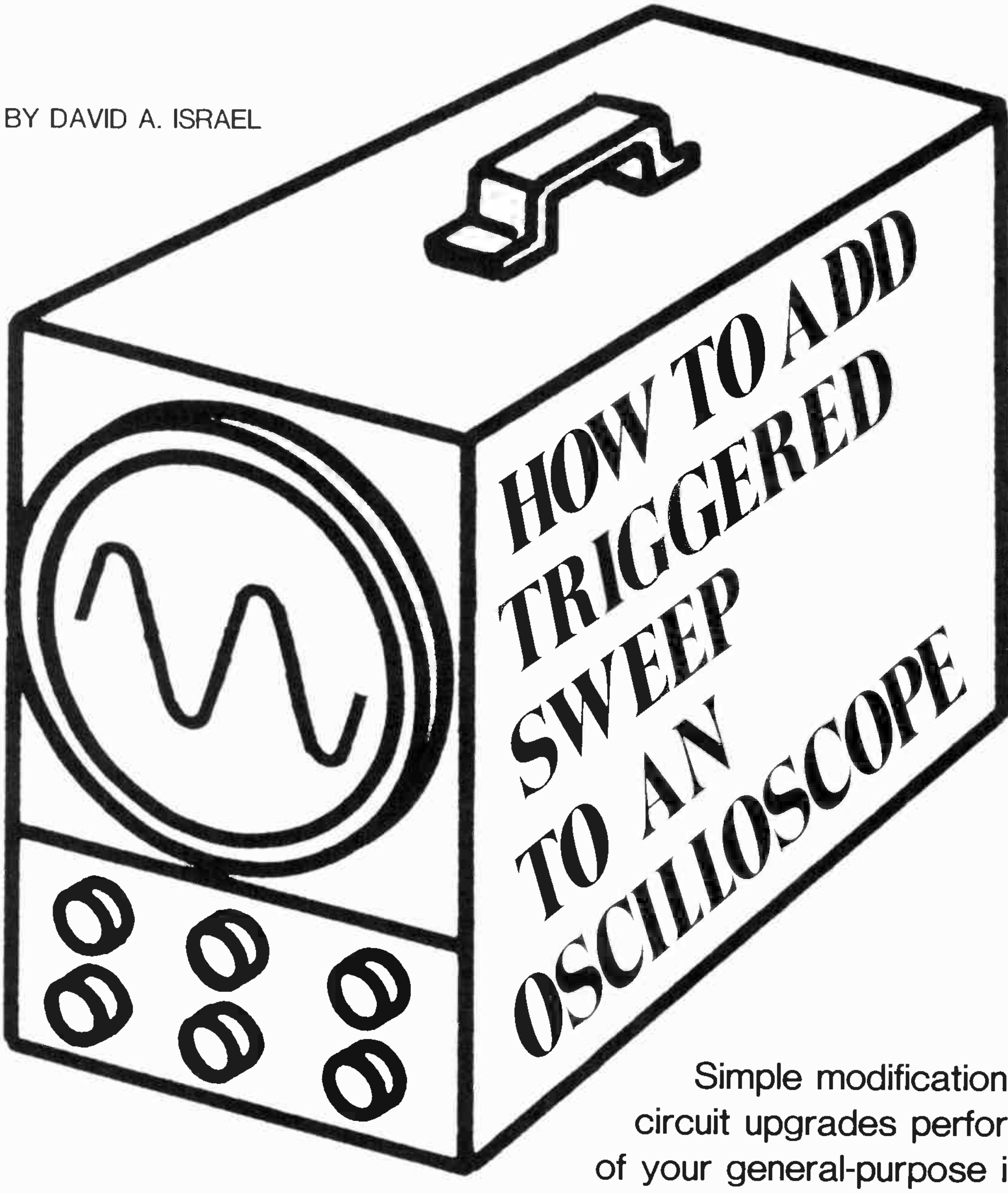
Natural background radiation levels can vary by as much as a factor of two, depending on where you live, the materials from which your house is built, and your altitude above sea level (the last due to cosmic rays). In addition, variables in detector construction and electronic components influence noise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

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

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

BY DAVID A. ISRAEL

HOW TO ADD TRIGGERED SWEEP TO AN OSCILLOSCOPE



Simple modification circuit upgrades performance of your general-purpose instrument

IF YOU ARE still struggling along with an old, service-type recurrent-sweep oscilloscope, your instrument is woefully inadequate for modern needs. However, one can upgrade such a general-purpose scope's performance at relatively little cost simply by adding the high-performance triggered-sweep circuit described here. In comparison with an earlier triggered-sweep add-on (POPULAR ELECTRONICS, May 1978), the new circuit is much faster and triggering sensitivity does not interact with output amplitude among other benefits.

This circuit can be added to most scopes to produce calibrated triggered sweeps at speeds from 0.5 s to 0.5 μs/division in the standard 1-2-5 format. In addition to manual trigger-level selection, it features free-run capability with automatic triggering, and adjustable input-stage gain and frequency response for easy triggering on low-level and noisy signals. A LED tells you when a sweep is being generated. Cost is about $35.

About the Circuit. The heart of the circuit, shown in Fig. 1, is field-effect current regulator *CR1*. This device adjusts its resistance to provide a constant current with only slight regard (within limits) to the voltage applied across it.

Since the rate of change in voltage across timing capacitor C_T is directly proportional to the current flow, keeping the charging current constant causes the capacitor voltage to rise linearly. Applying this linear ramp waveform to the horizontal axis of the scope makes the electronic beam move equal distances across the CRT screen in equal time increments. The sweep rate is also inversely proportional to the value of C_T. Therefore, to obtain varying sweep rates, the charging current is kept constant, while the value of C_T is changed.

The input of *IC1* is isolated from dc by *C1*, while *D1* and *D2* clamp excessive-amplitude signals. Resistors *R4* and *R5* provide biasing for *IC1* so that the output can symmetrically vary within the supply range. Stage gain for *IC1* is either ×10 through *R2* or ×1 through *R3*. When *S2* switches in *C3*, stage bandwidth is limited to allow reliable triggering on slow input signals on which high-frequency noise is superimposed.

Comparator *IC2* determines the actual trigger point on the input waveform. Two modes of operation are selectable via *S4*. In NORM, the *IC1* signal is compared with a dc voltage set by TRIG LEVEL control *R7*. When the voltage at the + input of *IC2* exceeds that at its − input, *IC2*'s output swings positive, and vice versa. Resistor *R10* adds positive feedback to the circuit, and the approximately 0.5-volt hysteresis prevents generation of multiple outputs with noisy input signals.

In AUTO, *R7* is switched out of the circuit and is replaced by *R11* and *C4*. Now, *IC2* operates as an astable multivibrator at approximately 50 Hz in the absence of an input signal. This provides a constant scope trace base line for operator convenience and allows dc input levels to be measured.

When a greater than 50-Hz signal is applied to the input, *IC2* automatically synchronizes to the input signal. With *S4* set to NORM, *S3* selects triggering on either the positive or the negative slope of the input waveform. When *S4* is set to AUTO, *S3* has no effect.

The remainder of the circuit controls the charging and discharging of C_T to produce the sweep waveform. When the circuit is quiescent (not triggered), the not-Q output of *IC3* is high and *Q1* conducts to discharge C_T and prevent recharging as long as not-Q is high. Note that not-Q also sets the J input of *IC3* to high. Since the K input is tied to ground, the flip-flop must change states on the next clock input.

When the positive-going edge of the trigger pulse is applied to the CK input of *IC3*, the flip-flop changes states. Now, *Q1* cuts off and allows C_T to charge through *CR1* to produce a linear sweep.

When not-Q goes low, Q goes high and TRIGGERED *LED1* comes on to signal that triggering has occurred. The J and K inputs of *IC3* are now both low, and the flip-flop is immune to any trigger pulses that might occur in the sweep.

The selected C_T capacitor charges until the voltage across it just exceeds the voltage at the *R15/R16* junction. When this occurs, comparator *IC4*, whose output has been at near ground potential, generates a positive reset pulse for *IC3*. This forces *IC3* back into quiescence, turning off *LED1* and turning on *Q1* to rapidly discharge C_T. As C_T rapidly discharges, the scope's electron beam rapidly retraces to the starting position on the left side of the scope CRT screen.

Construction. With the exception of *S1* through *S5*, *R7*, and *LED1*, which mount

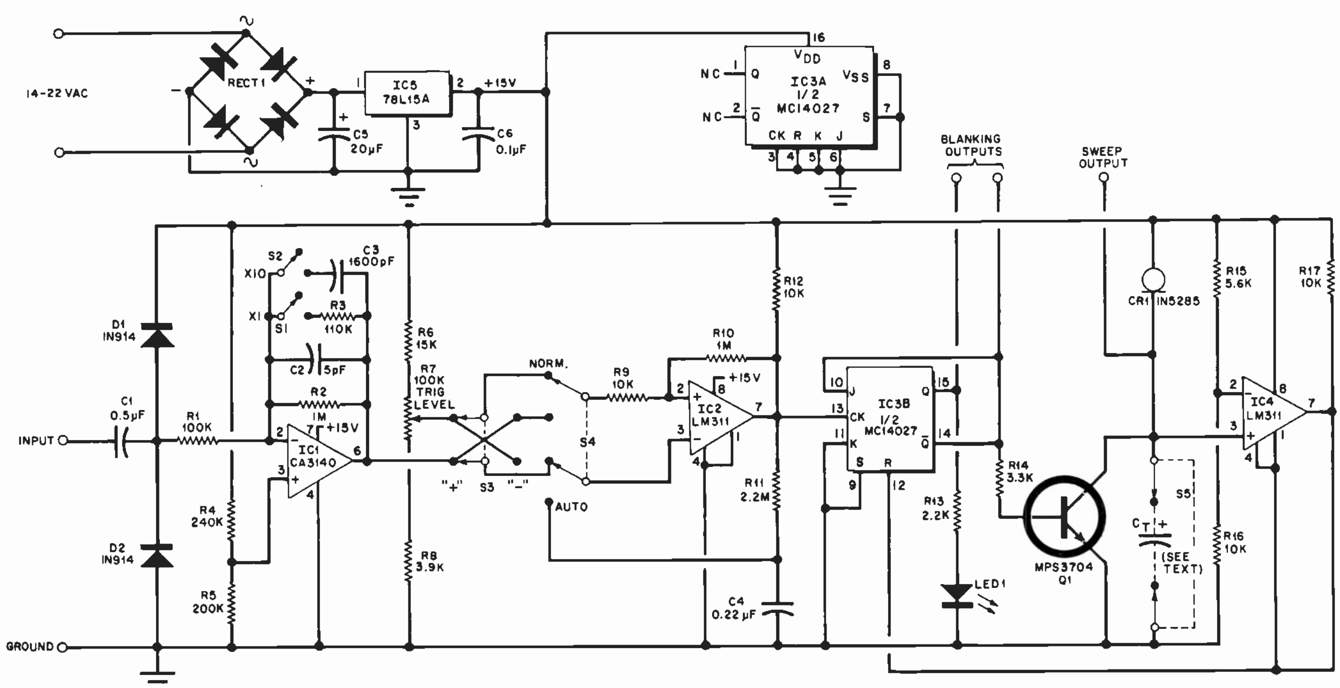


Fig. 1. A linear ramp is generated across the timing capacitor by the current regulator CR1.

PARTS LIST

C1—0.5-µF, 600-V
C2—5-pF ceramic
C3—1600-pF ceramic
C4—0.22-µF, 50-V miniature monolithic
C5—20-µF, 35-V electrolytic
C6—0.1-µF, 50-V miniature monolithic
C_T—Timing capacitor (see text)
CR1—1N5285 field-effect current-regulating diode, 0.27 mA (Motorola)
D1,D2—1N914
IC1—CA3140S MOS bipolar op amp
IC2,IC4—LM311N comparator
IC3—MC14027CP dual J-K flip-flop
IC5—78L15A 15-V voltage regulator
LED1—Discrete LED
Q1—MPS3704 general-purpose npn small-signal transistor (or similar)
RECT1-50-PIV, 1-ampere modular bridge rectifier
The following are ¼-watt, 5% fixed resistors unless otherwise noted:
R1—100,000 ohms
R2,R10—1 megohm
R3—110,000 ohms
R4—240,000 ohms
R5—200,000 ohms
R6—15,000 ohms
R7—100,000-ohm linear-taper potentiometer
R8—3900 ohms
R9,R12,R16,R17—10,000 ohms
R11—2.2 megohms
R13—2200 ohms
R14—3300 ohms
R15—5600 ohms
S1,S2—Miniature spst switch
S3,S4—Miniature dpdt switch
S5—2-pole, 2-23 position rotary selector switch (Centralab PA-4003 or similar)
Misc.—Pc board, mounting hardware, knobs, LED panel-mount adapter.

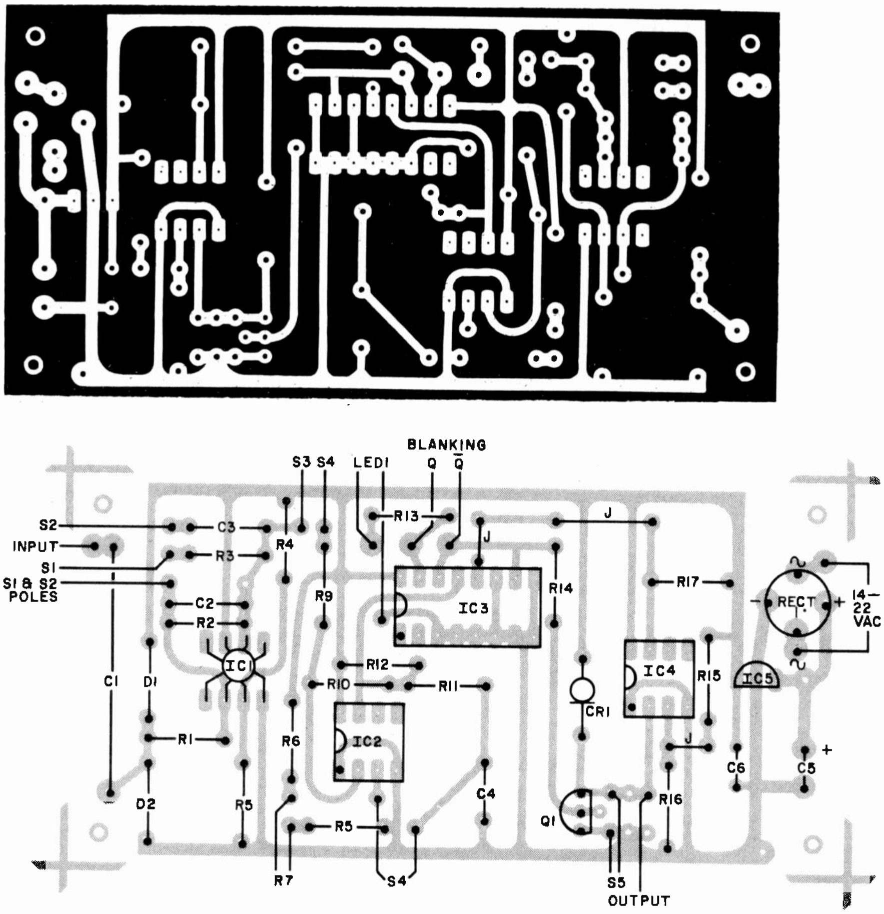


Fig. 2. An actual-size etching and drilling guide for a printed-circuit board is shown at top. Below it is guide for component placement.

on the scope's front panel, all components mount on a small printed-circuit board. An actual-size etching and drilling guide for the board is shown in Fig. 2. During installation of the components on the board, be sure to observe the proper polarities and orientations of the diodes, *CR1*, and ICs. Also, be sure to observe the safe handling procedures for *IC1* and *IC3*, which are MOS devices.

The C_T timing capacitors mount directly on SWEEP SPEED switch *S5*. No values are given for these capacitors in the Parts List since they are hand selected to minimize cost while providing the necessary accuracy. More about this under Calibration.

The circuit board is best mounted inside the scope, although a separate case can be used if desired. Inside the scope, try to locate the board as far as possible from heat-producing components. Unless you wish to retain the recurrent-sweep generator in the scope, disable this circuit and remove the associated controls from the front panel. When mounting the TRIG LEVEL control, switches, and *LED1* on the panel, it may be necessary to drill additional holes to accommodate them.

You may wish to use a rotary switch on TRIG LEVEL control *R7* for *S4* instead of a miniature toggle switch. This will allow you to turn *R7* to one end of its travel to switch the circuit to AUTO. Also, if you wish to avoid drilling holes in your scope, *S1* and *S2* can be replaced by a double-pole, four-position rotary switch.

If your scope has a +18- to +30-volt power supply, you can omit *RECT1* and connect the dc supply to the input of *IC5*. Alternatively, you can use a small filament transformer rated at 14 to 22 volts rms to supply power. The circuit draws typically 20 to 25 mA.

The pickoff point for the trigger signal depends on the scope being modified. Ideally, it should be at a point in the scope's vertical amplifier after the input attenuator and any gain controls so that the input voltage varies over a limited range, in the region of 0.5 to 20 volts peak-peak. (Refer to the schematic diagram of your scope.) In some cases, the scope manufacturer will make this easy for you by using such a point as a source of sync signal to the recurrent sweep.

Your scope may have a horizontal mode selector that provides sync from + and − slopes of input signals, as well as from the 60-Hz line and external sources. This type of selector is an ideal trigger pickoff point and provides switch-selectable trigger signals. If such a switch is present, *S3* in the project is redundant and can be eliminated. It is very useful to have the capability to connect the input of the trigger circuit directly to the external input jack because in some cases the poor response of the scope's vertical amplifier will severely limit trigger generator performance at high frequencies.

Connect the sweep output to the input of the scope's horizontal amplifier. Direct coupling works best. With capacitive coupling, you will have to keep recentering the trace as the average dc level of the sweep waveform varies with changing proportions of sweep period and repetition rate for different signals. In some cases, the coupling capacitor at the input of the scope's horizontal amplifier can be removed if it is not blocking a dc bias level that will be fed into the sweep circuit. The sweep output of the trigger circuit is designed to be connected to a typical horizontal amplifier that has a 1-megohm or greater input impedance. Lower impedances will shunt charging current from C_T and generate a nonlinear sweep waveform.

If the circuit you are driving has less than 1-megohm input impedance, use a buffer amplifier between it and the trigger sweep. A CA3130 op amp connected in a standard voltage-follower configuration, powered from the existing single 15-volt supply, will do.

The Q and not-Q outputs of *IC3* should go to pads for connection to the Z-axis circuit of the scope to provide retrace blanking. The not-Q output is at 0 volt during the sweep and switches to +15 volts during retrace, while the Q output is complementary to this. Choose the output that is correct for your scope. Again, dc coupling is preferred if available in your scope. Capacitive coupling will differentiate the blanking pulse. While you may get satisfactory retrace blanking, the beam can recover its brightness before beginning the next sweep, resulting in a vertical line at the left side of the trace. Also, when sweep begins, the blanking signal switches state rapidly, causing the coupling capacitor to charge in the opposite direction and resulting in undesirable intensification of the trace.

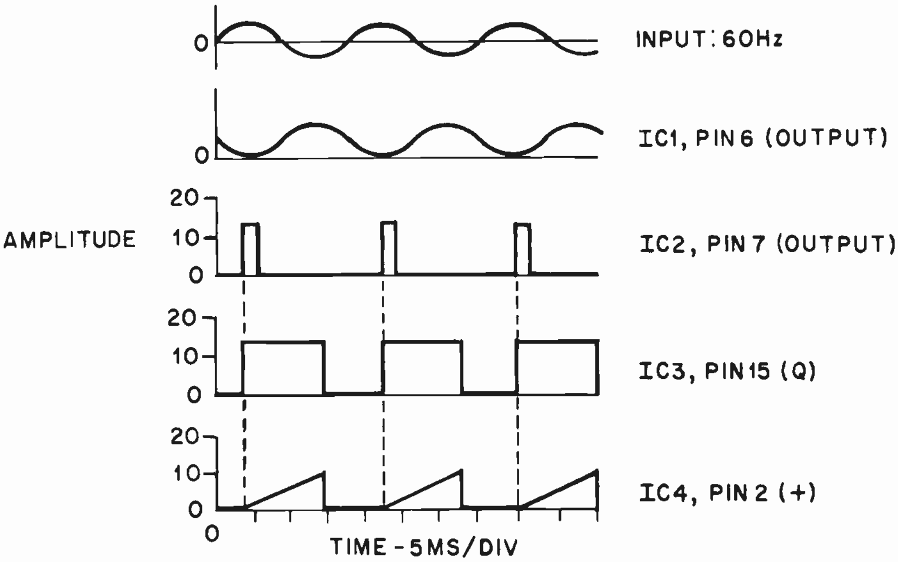


Fig. 3. Representative waveforms to be used in troubleshooting, with S1 on X1, S2 open, S3 on +, S4 on NORMAL, R7 three-quarters CCW and the timing capacitor selected for 1 ms/div.

The last problem can be reduced by first passing the blanking signal through one coupling capacitor to differentiate it and then diode clipping the unwanted half of the resulting waveform and finally connecting this signal to the Z-axis coupling capacitor.

A word of caution: In many scopes, the coupling capacitor is connected directly to the grid or cathode circuit of the CRT, which may be operating at 1000 or more volts. Do NOT attempt to bypass this capacitor or serious damage will result. A coupling capacitor can be removed from the circuit *only* if it is *not* blocking a dc bias voltage.

Test and Calibration. Temporarily connect a 1-μF tantalum capacitor across the C_T terminals, observing polarity. Turn on the scope and adjust for a moderate-intensity dot in the middle of the screen. Apply power to the sweep circuit. Set *S4* to AUTO; a horizontal baseline trace should appear on the CRT and the TRIGGERED LED should come on. With this value of capacitor, the trace and LED indicator should flicker rapidly at the same rate.

If a trace does not appear, check the scope's BRIGHTNESS control and for +15 volts on the trigger-sweep bus. Representative waveforms for trouble-shooting are shown in Fig. 3. In this test, *S1* is set to ×1, *S2* is open, *S3* is at +, *S4* is set to NORMAL, *R7* is three-quarters CCW, and C_T is selected for 1 ms/division. Using this setup, apply a 1-volt, 60-Hz sine-wave signal to the scope's vertical input. The sweep should automatically lock onto this signal and a steady display of three to four cycles should be seen on-screen. Check for any obvious nonlinearities. Rotate TRIG LEVEL control *R7*; the trace should disappear and reappear and the trigger level should vary up and down one side of the sine wave. Also note the change in the sensitivity of *R7* when ATTENUATOR *S1* is switched from ×1 to ×10.

Center the scope trace and note its length. Before you can calibrate the sweep for a given time per unit length, overall length of the sweep must be set to a given repeatable value. (To ensure that the sweep is not inadvertently adjusted after calibration, the horizontal-gain control can be mounted inside the scope, or it can be replaced with a pair of fixed resistors.)

Adjust the length of the trace to fill the screen. In some cases, the frequency response of the scope's horizontal amplifier may roll off at a lower frequency than those generated by this circuit at the highest sweep speeds, resulting in a shorter trace. You can compensate for this by setting the horizontal gain so that the trace is longer than the width of the screen at slow speeds. This will not affect accuracy at any speed, since each range is individually calibrated.

To calibrate the sweep, you need a source of reasonable-accuracy (1% will do) square waves. A crystal-controlled timebase is ideal. You can also use a signal generator and frequency counter.

Before starting, wire the pc board terminals to the rotor connections of SWEEP SPEED selector *S5*, using a length of two-conductor cable that will be appropriate for the physical layout of your scope. It is important that you do this before calibration because the capacitance of the cable will be in parallel with the selected timing capacitors and at the highest sweep speeds will comprise a large portion of the timing capacitance.

Begin calibration at the highest sweep speed and work down. With the capacitance of the cable serving as the timing capacitor, feed a 1-MHz square wave to the scope's input. Adjust the trigger and scope controls for a stable, centered display. To obtain a stable display with low-bandwidth scopes, the vertical amplifier may have to be bypassed with the sweep circuit input connected directly to the signal source. Experiment with several different capacitors connected to the switch until you find the value that produces a sweep speed closest to the desired 0.5 μs/division but not slower than this. That is, one cycle should occupy two divisions or slightly more. Unless you have a large number of capacitors on hand, you will find that the best way to obtain the exact capacitance value needed will be to parallel one capacitor with a lower-value capacitor until you obtain the desired display. Do your measuring between corresponding points in different cycles of the waveform. Do not, for example, measure between a rising and a falling edge of one cycle or of consecutive cycles. By following this rule, you will avoid errors introduced by assymmetry in the signal source and splaying or overshoot of the trace itself. For best results, choose two points separated by about six or eight divisions and equally spaced from the center line of the scope screen.

In the same manner, select the remaining timing capacitors, soldering them to the lugs of *S5* as you proceed. The next value should produce a 1-μs/division sweep speed, then 2 μs/division, 5 μs/division, etc., in the 1-2-5 format. For values larger than 0.5 μF or so, use high-quality tantalum capacitors and take care to observe polarity.

Operating Hints. The triggered-sweep circuit is very easy to use. For most applications, leave the input amplifier selector set to ×10 and set the mode

(continued on page 113)

A 3-Way Drive System for Speakers

Active crossover divides the audio spectrum for individual drivers before power amplification

BY J.F.P. MARCHAND

IN TRADITIONAL multiway loudspeaker systems, the division of the driving signal into frequency ranges suitable for the several drivers is performed after power amplification. The crossover or dividing network is composed of a set of passive components—inductors, capacitors, and resistors—interposed between the power amplifier output terminals and the input terminals of the individual transducers.

From the point of view of economy, this approach is advantageous, but it is not without difficulties. One is that the dividing network must handle appreciable power. This means that the passive components (the inductors are most problematic) must behave in a linear manner at high current levels if distortion products are not to be generated. Optimal design often raises the cost of the passive components and causes some of the economic advantage to evaporate.

Another drawback of particular concern to the home constructor is that a high-level network capable of performing well with the drivers to which it is added can be very difficult to design. The reason is that most tables and formulas for the filter-section design are based on the assumption that the network will be terminated by a purely resistive load, while the driver impedances usually contain significant, frequency-dependent reactive components.

Clearly, it would be advantageous to eliminate this problem. We can do this with no loss of performance by multiamping the system and taking advantage of the fact that the power amplifiers act as buffers between the filters and the drivers. Another benefit is that, with several power amplifiers sharing the load, the demands made on each of them are less stringent than when a single unit must do the whole job. For example, since bass frequencies cannot intermodulate with treble frequencies in loud passages, a particulary audible form of distortion is minimized. Also, the bass power amp can have a relatively low slew rate and cause no problems, as it will not see rapidly changing signals. A treble amp, on the other hand, can have a low damping factor, with less feedback and fewer problems.

The Filters. A schematic diagram of the active crossover for one audio channel appears in Fig. 1. While other types of filters can give good results in this application, the 18-dB/octave active Butterworth filters used here offer a desirable combination of steep slopes and good phase response. Rolling off the drivers rapidly helps to suppress any anomalous behavior they may exhibit as the extremes of their useful ranges are approached. Using as sharp a network as this between a power amplifier and the drivers is often avoided because of expense. In a design of this type, however, the extra cost is minimal.

Quad operational amplifiers *IC1* and *IC2* are the central elements of the filters. Integrated circuits *IC1A, IC1B, IC1D,* and their associated components and *IC1C, IC2A, IC2B,* and their associated components comprise two active filters with ultimate slopes of 12 dB/octave. The first filter separates the high frequencies from the low and middle frequencies. The second

(Continued on page 104)

PARTS LIST

C1—13,000-µF, 50-volt electrolytic
C2,C10,C12*,C15*,C17*,C18—1-µF, 50-volt radial-lead electrolytic
C3,C4,C9—1000-pF, 5% polystyrene
C5,C6,C7,C8,C16—10,000-pF, 5% polystyrene
C11,C14*,C20*—47-µF, 50-volt radial-lead electrolytic
C13*,C19,C21*—470-µF, 25-volt radial-lead electrolytic
C22 through C28—0.1-µF disc ceramic
D1,D2—6.8-volt, 1-watt zener diode
F1—1-ampere fast-blow fuse
IC1,IC2—LM324N, TL074CN, or similar quad operational amplifier
IC3*,IC4*—LM379S dual six-watt audio amplifier
J1—RCA phono jack
Q1*,Q3*—TIP31 npn power transistor
Q2*,Q4*—TIP30 pnp power transistor
The following, unless otherwise specified, are ¼-watt, 5%, carbon-film resistors.
R1,R32—1000 ohms
R2,R3,R4,R6,R8,R10,R12,R13,R24*, R25*,R31*—100,000 ohms
R5,R7,R11,R14,R15,R16,R17—68,000 ohms
R9—51,000 ohms
R18,R23*,R30*,R33—10,000 ohms
R19*,R22*,R28*,R29*—150,000 ohms
R20*,R21*—5.1 ohms, ½-watt, carbon-composition
R26—22,000 ohms
R27*—4700 ohms
R34,R35—10,000-ohm, pc-mount, linear-taper potentiometer
RECT1—6-ampere, 100-PIV modular bridge rectifier
S1—Spst toggle switch
T1—24-volt, 2-ampere transformer (Stancor No. P-8617 or equivalent)
Misc—Printed circuit board, heat sinks (four Thermalloy No. 6070 or equivalent, two Thermally No. 6072 or equivalent), line cord and strain relief, fuseholder, circuit board standoffs, hardware, hookup wire, shielded cable, etc.

Note—An etched and drilled glass-epoxy printed circuit board is available for $15.00 from Marchand Electronics, Inc., 1334 Robin Hood Lane, Webster, NY 14580. New York residents, please add 7% state sales tax.

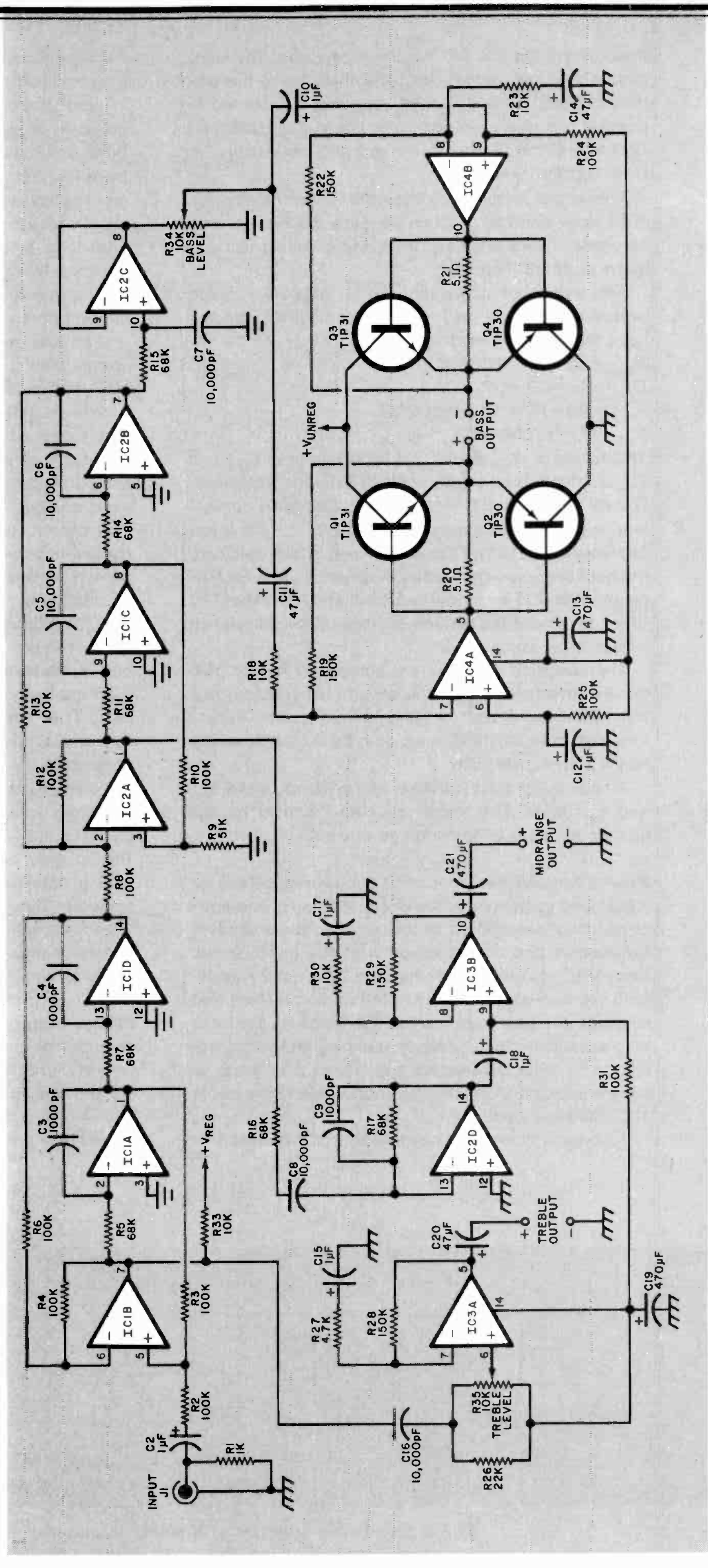


Fig. 1. Schematic diagram of the active crossover for one audio channel. Further power amplification may be added if desired.

then divides the low and middle frequencies. The high, middle, and low frequencies, which appear at the outputs of *IC1B, IC2A,* and *IC2B,* respectively, are fed to passive high-pass and low-pass filters *C16, R26,* and *R35* and *C7, R15* and to active band-pass filter *C8, R16, C9, R17,* and *IC2D.*

These last circuits are first-order filters having ultimate slopes of 6 dB/octave. Because the second- and first-order filters are cascaded, the resulting ultimate slope is 18 dB/octave.

The values of capacitance and resistance which determine the low and high crossover frequencies have the following relationships:

$C_{high} = C3 = C4 = C16/10$

$C_{low} = C5 = C6 = C7$

$R_{high} = R5 = R7 = 10\ (R26 \parallel R35)$

$R_{low} = R11 = R14 = R15$

The values of R_{high} and R_{low} in kilohms and of C_{high} and C_{low} in picofarads are determined from the equations: $R = 10^9/6.28fC$ and $C = 10^9/6.28fR$. Choose a convenient value of capacitance, say 100,000 pF for a low crossover, 10,000 pF for a high one. Then calculate the necessary resistor values. A negative value for *R26* means that *R35* is too low to allow it and *R26* in parallel to reach the desired resistance. Repeat the calculation with a larger value for *C.*

The specified op amps are sufficiently fast to give good performance. However, anyone concerned about transient intermodulation (TIM) distortion may substitute a pin-compatible IC, such as type TL074CN, which has a higher slew limit.

To use the project with two-way systems, make f_{high} and f_{low} equal. The bandbass output should be left floating as there is no midrange driver.

Power Amplifiers. The choice of power amplifiers for a triamped system depends on the efficiency and power-handling capabilities of the drivers, the crossover frequencies and how loud you want the music to be. Generally, you will want to use the best quality amplifiers you can afford; but, as noted earlier, factors that influence the high-frequency performance of the bass amp are unimportant. Similarly, damping factor, dc coupling, and other parameters or features that relate to low-frequency performance are not critical in the treble and midrange amps.

To decide how much power each of the amplifiers must have, start with the reasonably conservative assumption that music has equal power in each of the 10 audible octaves. With your chosen crossover frequencies in mind, determine how many octaves each driver will handle. The number of octaves is given by the relation $N = \log_{10}(f_2/f_1) / \log_{10} 2$, where f_1 and f_2 are the lower and upper limits, respectively, of the passband allocated to a particular driver. (This is a formidable looking calculation, but it can be performed easily on most scientific calculators.) A driver handling five octaves would get 50% of the system power; one handling three octaves would get 30%, etc.

If an appropriate calculator is not available, draw a chart, marking octave boundaries at 20, 40, 80, 160 Hz etc., and note which bands contain your crossover frequencies. Then you can get an approximate idea of how many octaves are reproduced by each driver. Obviously, this method is not exact, but you are not likely to find power amplifiers in exactly the sizes you need anyway.

A constructor who can be satisfied with a modest amount of power at distortion levels that are adequate but not state-of-the-art can build the power amplifiers included in Fig. 1. These are built around two National LM379s, dual 6-watt integrated power amplifiers, which require few additional components and have built-in thermal protection. Integrated circuits *IC3A* and *IC3B* are the amplifiers for the high and middle frequencies. They are connected as standard noninverting operational amplifiers and the outputs are capacitively coupled to the loudspeakers via *C20* and *C21.*

To satisfy the higher power requirement of the low-frequency channel, *IC4* is arranged as a balanced amplifier with booster transistors *Q1, Q2, Q3* and *Q4.* The op amps are arranged as an inverting and a noninverting amplifier, differentially driving the bass loudspeaker. This doubles the maximum voltage across the loudspeaker, yielding four times the power. The booster transistors handle the doubled output current. All three amplifiers are designed for 8-ohm drivers.

Power Supply. Power for the filters and power amplifiers can be provided by the supply shown schematically in Fig. 2. A simple bridge rectifier and filter capacitor provide 35 volts dc at no load. As the LM 379 is relatively insensitive to power-supply ripple, no additional filtering is required.

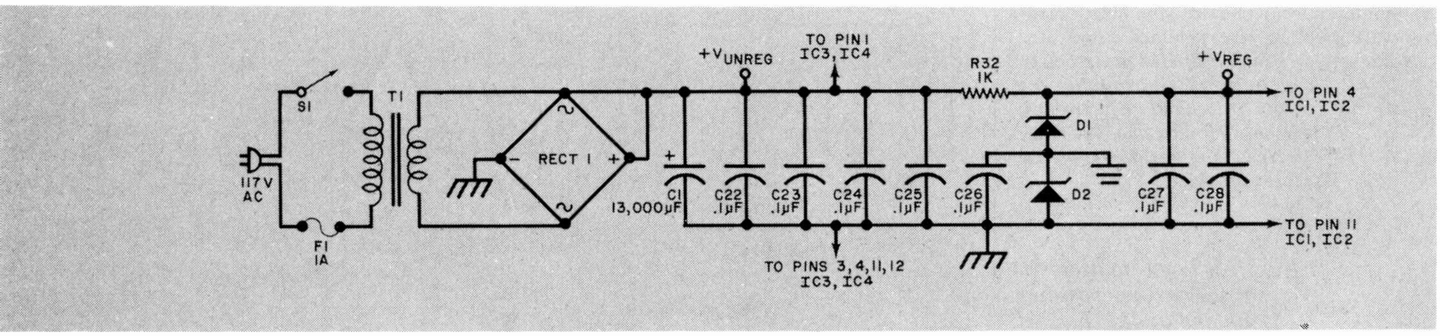


Fig. 2. Schematic diagram of a power supply for the filters and amplifiers. Capacitors supply filtering and zener diodes regulation for various voltages.

Supply voltages for *IC1* and *IC2* are provided by the 6.8-volt zener diodes, *D1* and *D2*. Capacitors *C22* through *C28* provide power-supply decoupling. Power amplifiers *IC3* and *IC4* require high-frequency power-supply decoupling to prevent ultrasonic oscillation. This decoupling is provided by *C22* through *C25*. These disc ceramic capacitors are mounted in pairs close to the LM379 integrated circuits.

Note that two distinct ground symbols are employed in the two schematic diagrams. This is so because the power supply is single-ended. The "earth ground" symbol is employed as the input and output signal ground and the negative supply line for the ICs. The "chassis ground" symbol signifies an artificial ground for operational amplifiers *IC1* and *IC2* that is at a dc level equal to one half the regulated supply voltage. It is derived by means of the voltage-dropping action of zener diodes *D1* and *D2*.

The gains of the low and high channels can be adjusted with potentiometers *R34* and *R35*. With the wipers of these controls at the center of their travel, the gains of all amplifiers are approximately 15. An input sine wave of 460 mV rms will then result in full power output.

Construction. The assembly of the project is relatively straightforward. All parts except the 24-volt power transformer are mounted on a single 5½-×-6½-inch printed circuit board. The full-size etching and drilling guide for this board appears in Fig. 3. A complementary parts placement guide is reproduced in Fig. 4. When inserting electrolytic capacitors, diodes, transistors and integrated circuits, be sure to observe proper polarity.

Resistors *R2* through *R17* and *R26* and capacitors *C3* through *C9* and *C16* determine the crossover frequencies. For best performance, these components should have a tolerance of no more than ±5%. Polystyrene capacitors are specified but other low-loss precision types, can be substituted.

Transistors *Q1* through *Q4* are mounted on Thermalloy No. 6070 or similar heatsinks with suitable mounting hardware. Cooling for the LM379 ICs is accomplished by mounting them directly on Thermalloy No. 6072 or similar heatsinks with two No. 4-40 machine screws. The holes in these heatsinks do not line up with the threads in the ICs, so two holes spaced 1 inch (2.54 cm) apart must be drilled in the heatsinks. Pin 1 of the power ICs is marked with a small white dot on the

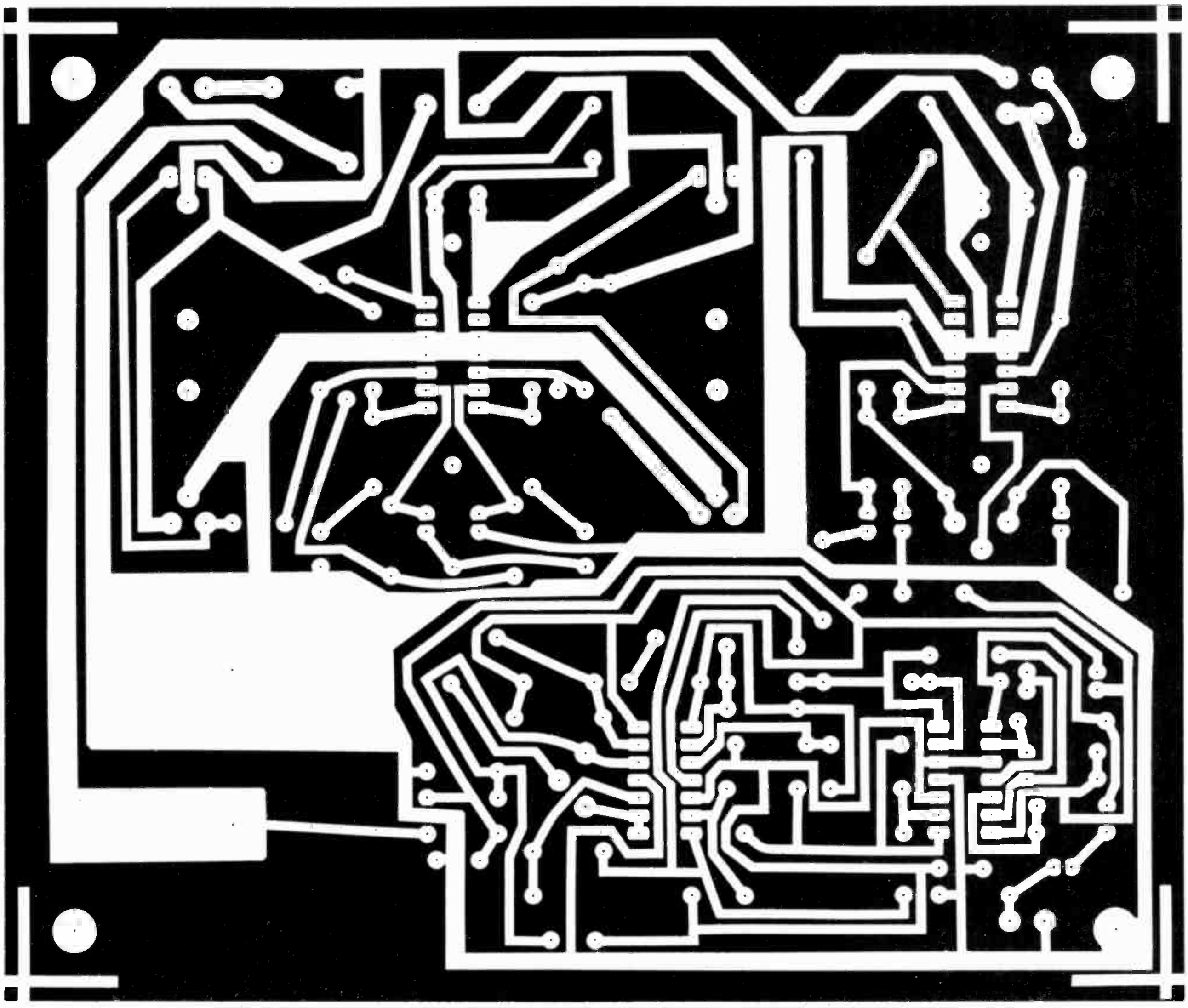


Fig. 3. Actual-size etching and drilling guide for printed circuit board.

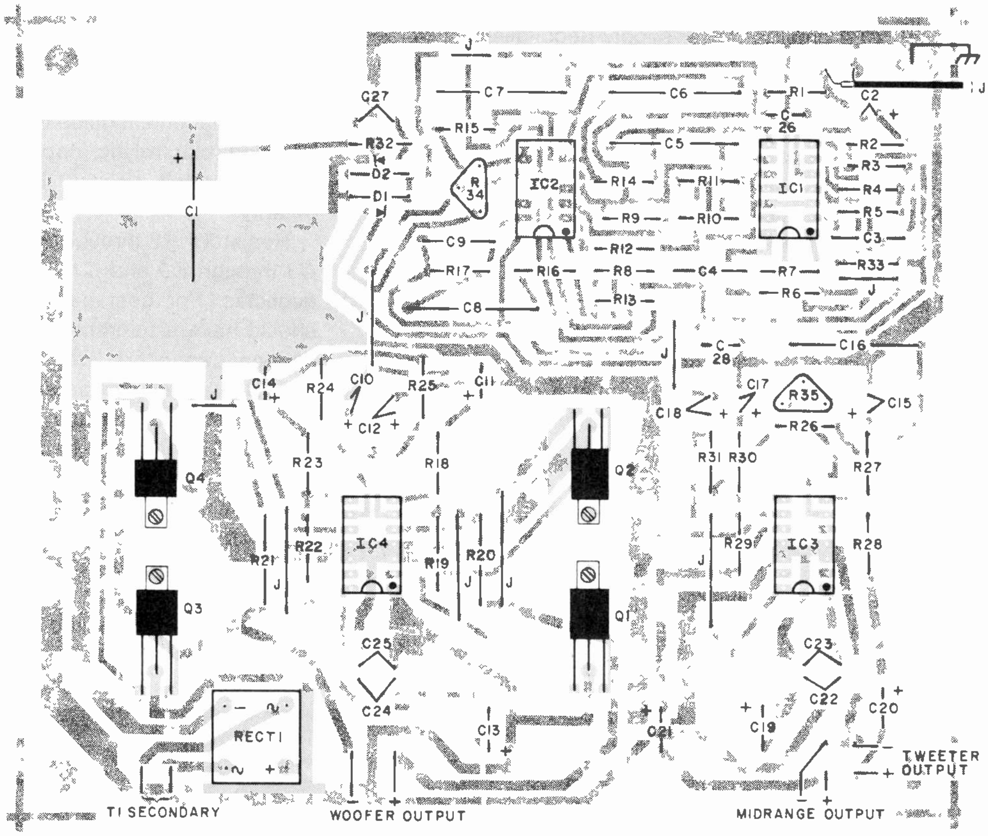


Fig. 4. Component layout diagram for the printed circuit board. Transistors Q1 through Q4 are mounted on heat sinks.

underside of the package. The large filter capacitor, *C1*, is mounted on the board with standard hardware.

Should you decide to use other power amplifiers, *IC3* and *IC4*, *Q1* through *Q4*, and their associated components (see parts list) can be omitted. Outputs for the external amplifiers can be taken from the solder pads intended to accommodate pins 6 and 9 of *IC3* (high and mid frequencies) and pin 7 or 9 of *IC4* (low frequencies). Use shielded cable with phono jacks and the shield grounded only at the jacks. Keep cables short, adding 100-ohm buffer resistors if needed to prevent oscillation.

If you use the on-board power amps, it will be convenient to mount the entire project inside the loudspeaker enclosure. Potentiometers *R34* and *R35* can be mounted in place of the original crossover controls, and the fuse holder, input connector, and on-off switch can be installed on the rear of the enclosure. To allow adequate ventilation, mount the circuit board as low in the box as possible, positioning it so that damping material does not interfere with air circulation. Leads to the pots and speakers should be twisted together.

To use the project with external power amps, it will be necessary to fabricate some form of enclosure. The controls, input and output connectors, fuse holder, and on-off switch can be mounted on one of its panels.

Power-supply components *T1*, *B1*, *C1* are more than adequate for two stereo channels of filtration. Decoupling capacitors *C22* through *C25* can be omitted, but a separate zener-diode regulator section should be used for each channel. The loudspeaker system will have to be fitted with a separate set of connectors for each driver. If desired, the drivers can be protected by individual fuses of appropriate ratings.

Setting it Up. Whichever arrangement you use, pay careful attention to the polarity of the drivers, sometimes indicated with a red dot meaning "plus" (+). Some authorities feel that, with 18-dB/octave crossovers, the best phase response near the crossover frequencies is achieved by connecting adjacent drivers out of phase. You may want to experiment to see which arrangement gives you the best results.

In some cases, coupling the amplifier directly to a woofer will increase damping to the point where a small amount of bass response is lost. This can be cured by connecting a small resistor, generally 1 ohm or less, in series with the driver. To protect the speaker drivers from transients, be sure that the power amps are turned on *after* the crossover is powered and turned off *before* crossover power is removed.

Once you are certain that the project is operating correctly, make all necessary corrections and set the level controls for flattest frequency response. The improvement in the sound of your speakers will not be earth-shaking but should be clearly audible. Many listeners who use tri-amping report clearer, tighter sound with reduced distortion. ◇

SPECIAL COUNTER CIRCUITS FOR EXPERIMENTERS

Various combinations of the basic J-K flip-flop circuits provide many useful digital counting schemes

BY PATRICK J. DELANEY

WHEN the need for counting events in an electronic system arises, the most common solution is to use an asynchronous digital ripple counter. This circuit, shown in Fig. 1, consists of a group of J-K flip-flops set to toggle with each applied Clock pulse. The flip-flops are connected in cascade so that each Clock input is driven by the Q output of the preceding stage. The circuit provides a sequential binary-up count ranging from zero to one less than 2^N where N is the number of flip-flops in the circuit. While this arrangement finds wide use, it is only one of many useful digital counting schemes.

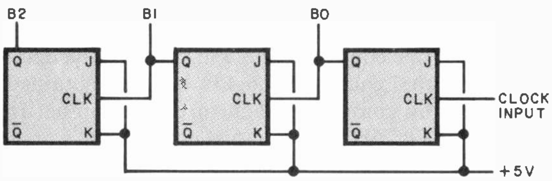
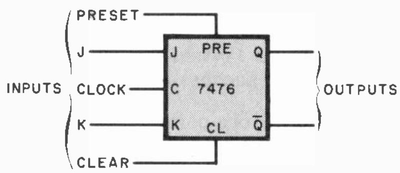


Fig. 1. Basic three-stage synchronous ripple counter.

Special counters make up a major class of flip-flop circuits. However, before these advanced configurations can be described in detail, a review of the J-K flip-flop is in order. A 7476 will be used as an example.

As shown in Fig. 2, a J-K flip-flop typically has five inputs and two outputs. The five inputs are Preset, Clear, Clock, J and K, while the two outputs are variously referred to as Q and not-Q, or some other alphabetic labels indicative of a variable and its complement. When a chain of flip-flops is used, the outputs are identified by a succession of alphabetic labels—A and not-A, B and not-B, etc.



INPUTS		OUTPUTS
PRESET	CLEAR	Q
0	0	Indeterminate (never used)
0	1	1 (SET)
1	0	0 (RESET)
1	1	Determined by J, K, and clock

Fig. 2. Details of the 7476 flip-flop and its truth table.

Preset and Clear inputs take precedence over all other inputs and are active low. This means that logic zero applied to the Preset input forces the Q output high (1). Alternately, Q would be forced low (0) by applying a logic zero to the Clear input. If both the Preset and Clear inputs are 1, the flip-flop's state will be determined by the J, K, and Clock inputs.

The last of the four possible combinations of these inputs is 0 for both Preset and Clear. This is contradictory in that it attempts to force Q high and low simultaneously (an impossible condition). The logic state of Q is thus indeterminate. The operation of the Preset and Clear inputs is summarized by the truth table shown in Fig. 2.

The J, K, and Clock inputs together form the second means by which the outputs may be changed. When these inputs are to be used, the Preset and Clear terminals are both tied high. When the J and K inputs are supplied signals as shown in Fig. 3, each time the Clock input is forced to switch from a logic 1 to a logic 0 (a negative edge), outputs take on the appropriate values. It should be noted that the J and K inputs alone have absolutely no effect on the flip-flop's output state. These two levels are clocked into the flip-flop by a one-to-zero transition at the Clock input. Figure 3 illustrates the effect of the four possible combinations of the J and K inputs on the Q output.

INPUTS			OUTPUT
CLOCK	J	K	Q
↓	0	0	Previous value
↓	0	1	0 (RESET)
↓	1	0	1 (SET)
↓	1	1	TOGGLE

Fig. 3. Effect of the J-K inputs on the Q output of the 7476.

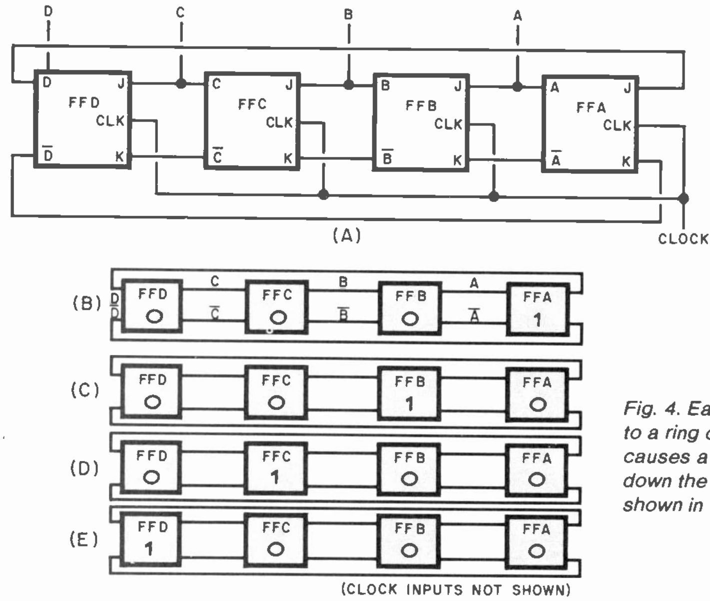


Fig. 4. Each clock pulse to a ring counter (A) causes a logic 1 to "walk" down the counter as shown in (B), (C), (D), and (E).

If both J and K equal 0, and a negative-going Clock pulse occurs, the Q output will remain unchanged. If J is equal to 1 and K equals 0 during the Clock edge, Q will become a logic 1 (set). When J equals 0 and K equals 1, a Clock pulse will force Q to equal 0 (reset). Finally, if J and K equal 1, the Clock will force Q to change its state or toggle. That is to say: if Q had been 0, it becomes 1 and if Q had been 1, it becomes 0.

Now that the operation of the J-K flip-flop is firmly within grasp, let us examine one of the special counters.

Ring Counter. A simple synchronous ring counter is shown in Fig. 4A. Note that the outputs of flip-flop D are fed back to the J and K inputs of flip-flop A, thus forming a "ring." The clock feeds all four clock inputs simultaneously. This circuit differs from most other counters in that its entire operation depends on the initial (power-up) states of its flip-flops. If, for example, output A equals 1 while outputs B, C and D equal 0 as in Fig. 4B, then the application of a single Clock pulse will set B, but Reset A, C and D because the J and K inputs of B were 1 and 0 (the condition for Set) the instant before the Clock pulse, but the J and K inputs of all of the other flip-flops were 0 and 1 respectively. The new condition is shown in Fig. 4C. The next Clock pulse will set C and reset A, B and D, as shown in Fig. 4D. Figure 4E shows how a third Clock pulse will Set D and Reset A, B and C. The final Clock pulse will cause A to set once again, and the cycle will repeat. Note that a lone 1 is shifted from right (A) to left (D) and then back around again. This changing pattern is responsible for the circuit's name. The 4-bit pattern shifted through the group of flip-flops, or register as they are collectively called, is not limited to a single 1, but can be any one of many patterns. These bit patterns can be forced into the register, before the application of Clock pulses, by the use of the Preset and Clear inputs. More complicated bit patterns can be generated by using more flip-flops.

CLOCK	D	C	B	A
1	0	0	0	1
2	0	0	1	0
3	0	1	0	0
4	1	0	0	0
5	0	0	0	1
6	0	0	1	0
7	0	1	0	0
8	1	0	0	0
9	0	0	0	1
10	0	0	1	0
11	0	1	0	0
12	1	0	0	0

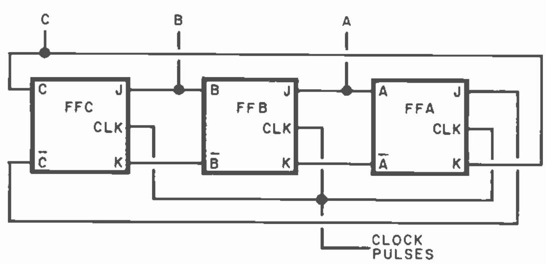
Fig. 5. Ring counter truth table shows how a 1 moves through the counter with successive clock pulses.

Ring counters are used primarily in the production of complex waveforms that generate timing pulses for computers, music synthesizers and similar systems. The voltage-versus-time waveform resulting from the truth table in Fig. 5 is easily obtained by simply turning the column on its side, and drawing a 5-volt waveform for each 1 and a zero-volt waveform for each 0. Note that the negative-going edge of the Clock triggers each transition of the outputs.

Shift Counters. A small change in the feedback from the last to the first flip-flop of a basic ring counter produces the shift counter shown in Fig. 6A. Unlike the ring counter, the shift counter is usually used as a synchronous event counter rather than as a waveform generator. Shift counters can easily produce any even modulus (number of states) count at extremely high rates of speed, with illegal states and high power consumption and component count being the only drawdacks. Another difference between the ring counter and the shift counter is that the latter does not have to be Preset to a specific pattern or starting state. The shift counter can naturally fall into the correct counting sequence.

A typical count sequence for a three-bit shift counter is shown in Fig. 6B. Whenver a Clock pulse occurs, the feedback connection between flip-flops C and A causes the inverse of the state of flip-flop C to be loaded into flip-flop A. This means that, when C = 0 before a Clock pulse, A will become the opposite of C (1) after the pulse ends. Conversely, if C is a 1 just before the Clock pulse, A will become a 0. This odd, but repetitive count scheme will produce the decimal count 1,3,7,6,4,0, which is obtained by converting each three-bit number in Fig. 6B to its decimal equivalent.

One question that often arises is: "What will happen if the state 010 or 101 occurs?" Since neither of these two states is part of the normal counting sequence, their effects should be determined. It has aready been established that the state of flip-flops A and B will ultimately be shifted to flip-flops B and C respectively, and that the inverted contents of C will be shifted into A after each Clock pulse. It is clear, then, that the state 010 (decimal 2) will force B to become the former state of A, C to become the former state of B, and A to become the inverse or opposite of C. It is



CLOCK	C	B	A	DECIMAL
↓	0	0	1	1
↓	0	1	1	3
↓	1	1	1	7
↓	1	1	0	6
↓	1	0	0	4
↓	0	0	0	0
↓	0	0	1	1

Sequence begins again

Fig. 6. Note the feedback from the last flip-flop to the first in a shift counter (left) with the truth table shown at right.

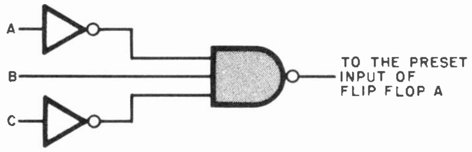


Fig. 7. Illegal state detector works in conjunction with the ring counter to avoid possible oscillation between 010 (decimal 2) and 101 (decimal 5).

as if all of the bits have shifted left by one position, while the most significant bit became complemented and replaced bit A. Thus, illegal state 010 (decimal 2) gives way to state 101 (decimal 5), while state 101 (decimal 5) gives way to the original state 010 (decimal 2). This means that either state, once entered, will cause an oscillation back and forth from decimal 2 to decimal 5, and the normal six-state count sequence will never be entered.

Since the initial application of power to a series of flip-flops creates a random state, it is possible that one of the two undesirable, illegal states will be entered at power-up. To prevent the 2-5-2-5 oscillation from persisting, a series of gates must be added to the basic shift counter. The purpose of this gating arrangement is to detect one of the illegal states and force legal counting to resume. Once the legal counting sequence begins, it continues to exclude the two undesired states.

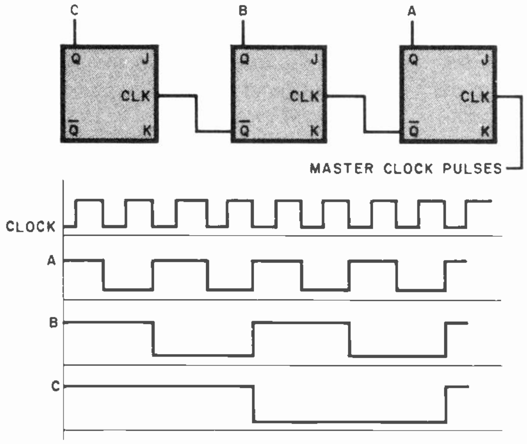
Logic state 010 can be detected by the arrangement shown in Fig. 7. The output of the NAND gate will become zero only when state 010 occurs at inputs A, B and C. This low level will instantly Preset flip-flop A, thus causing the state 011, or decimal-3 to be entered. From this point on, the shift counter will operate only in its legal six-state sequence.

Just as with the ring counter, a shift counter may employ any number of flip-flops. One or more count sequences containing a number of states equal to twice the number of flip-flops will always occur. Illegal states will also frequently exist and must be prohibited from occurring through the use of circuits similar to that of Fig. 7. It is left to the reader as an experiment to prove that a four-bit shift counter would produce two eight-bit sequences, one of which would generate very odd waveforms indeed!

Up/Down Counters. The last type of circuit falling into the category of special counters is the up/down counter. In its simplest form, the up/down counter is a variation of the basic ripple counter. In this circuit, each clock pulse causes a group of outputs to take on a binary value one larger than that existing previously. The primary reason for the ever-increasing count is the connection from the Q output of each flip-flop to the clock input of the next flip-flop. If the not-Q output of each flip-flop were used for this purpose, the count would decrease rather than increase. Occasionally, of course, the count would reach zero, at which point it would begin to decrease from the highest count again.

The logic and truth table for a down count are shown in Fig. 8. Note that all the flip-flops are wired so as to toggle with each input clock pulse. The toggle occurs on the negative-going trailing edge of the transition from 1 to zero. For example, the not-Q output of flip-flop A acts as a clock pulse for flip-flop B. Flip-flop B will not toggle (change state) each time the master clock input produces a negative edge, but rather when the not-Q output of flip-flop A switches from 1 to zero. In much the same fashion, flip-flop C responds only to the negative clock edges provided by the output of flip-flop B. The resulting count can clearly be seen to decrease rather than increase in the manner of a standard up ripple counter. A counting circuit that counts solely up or down can often be useful, but a circuit with the ability to count both up and down would in general, be even more useful. The previous discussion indicates that any ripple counter can be changed from count up to count down through simple rewiring.

However, true versatility can be achieved only by electronic control of the counting direction, using a circuit such as that shown in Fig. 9. This circuit makes use of the gating, or switching property of AND gates E and F. That property can best be summarized as follows whenever one input to the AND gate is a logic 1, the gate is said to be enabled, and the remaining gate input will be switched through to the output as if the gate were a piece of conducting wire. The inverter at the count up/down input will cause only the E pair of AND



CLOCK	C	B	A
1	1	1	1
2	1	1	0
3	1	0	1
4	1	0	0
5	0	1	1
6	0	1	0
7	0	0	1
8	0	0	0

Fig. 8. Three-stage down counter, its truth table and waveforms illustrating how counting takes place on the negative-going edge of the clock pulse.

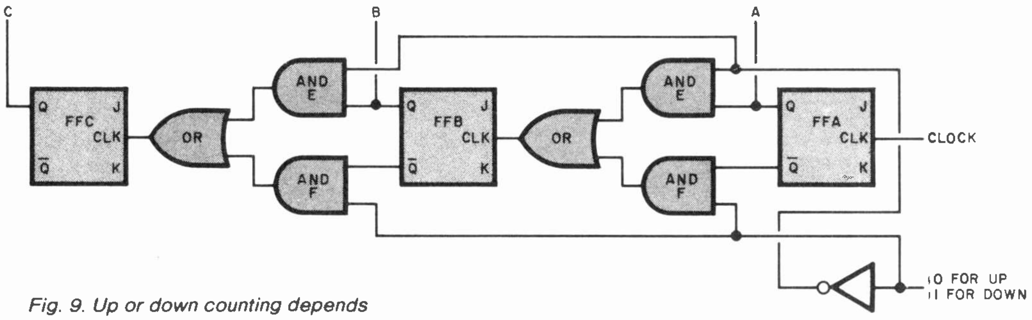


Fig. 9. Up or down counting depends on the signal applied to the inverter.

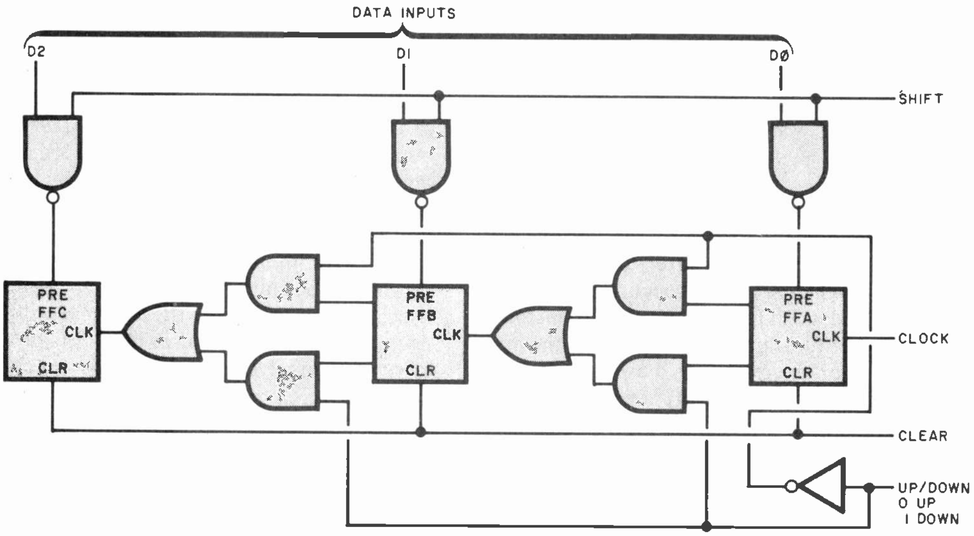


Fig. 10. One method of parallel data entry into an up/down counter. Data input can come from thumwheel or fixed switches, other digital logic, or even from a computer.

gates or the F pair of AND gates (but not both) to be enabled at any given instant. If the E pair is enabled, the Q output of each flip-flop serves as the clock input for the next flip-flop, since the F input to each OR gate will always be at logic 0, and the OR gate output will simply take on the value of the previous flip-flop Q output. This coupling of A to B clock and B to C clock will result in an up count.

If the count input is set to logic 1, the F-pair of AND gates will be enabled and each OR gate output will take on the value of the previous not-Q output. This is electrically similar to the circuit of Fig. 8. A down count will result because A is effectively gated to B clock, while B is effectively gated to C clock.

If the capability to load a given count into the up/down counter is provided, the utility of the circuit will be greatly enhanced. One approach which could be used to achieve parallel entry of data into an up/down counter is shown in Fig. 10. The application of a logic 0 to the normally high clear (CLR) line forces the Q output of all four flip-flops to a logic 0. This would be followed by a brief logic-1 shift pulse to load binary 1's into the appropriate flip-flops. The sequential application of clock pulses will now force the circuit to count up or down from this initial value. The operation of this circuit can essentially be duplicated by a conventional TTL 74193 IC with two small exceptions. The 74193 is an up/down decade counter and, as such, will count only to 1001 (decimal 9) before resetting to 0000. The second minor difference between the circuit of Fig. 10 and the 74193 is the method of parallel data entry. The IC abandons the cumbersome, two-step Clear-Shift approach for a simple one-pulse load technique.

The combination of a 74193 and a BCD-thumbwheel switch (for ease of entry of the initial count) can be used to produce a handy count down timer using the logic shown in Fig. 11. If the clock period is one minute, the circuit will require a number of minutes equal to the initial setting of the thumbwheel switch to reach the 0000 state. The BCD outputs of the 74193s are also used to activate a transistor (*Q1*) and alarm circuit. Thus, the parallel-loading down counter can be used as a presettable timer. Notice that the eight counter outputs are effectively NORed by diodes *D1* through *D8* and *Q1*. If any counter output is at logic 1, transistor *Q1* will be held on and will bypass the alarm. Only when all counter outputs are at logic 0 will *Q1* switch off and permit current to flow to the alarm. ◇

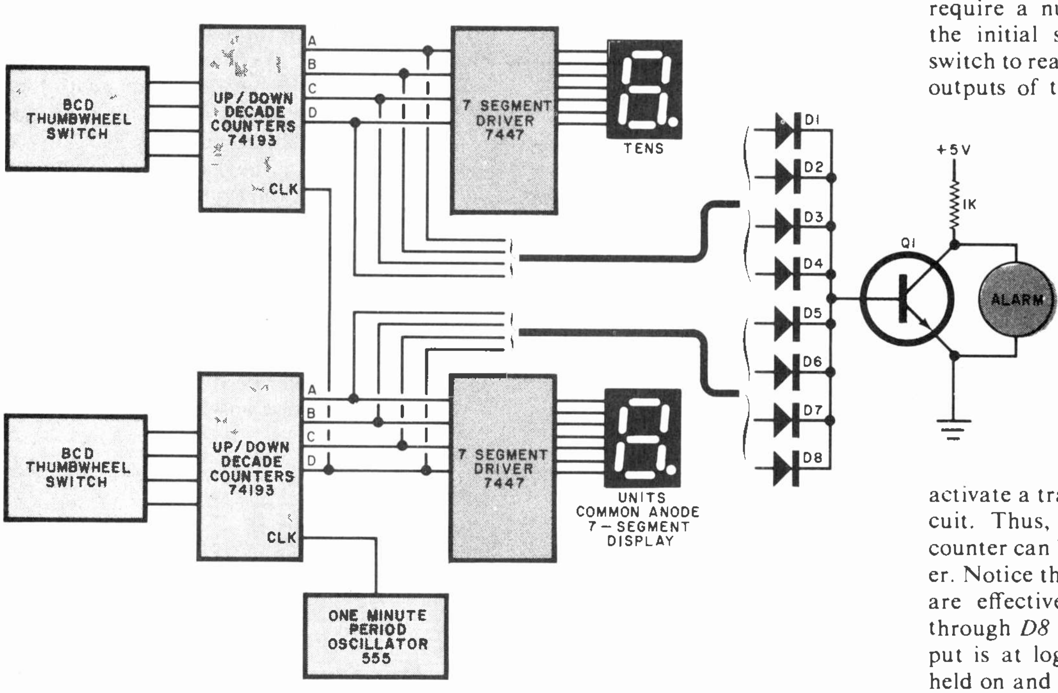
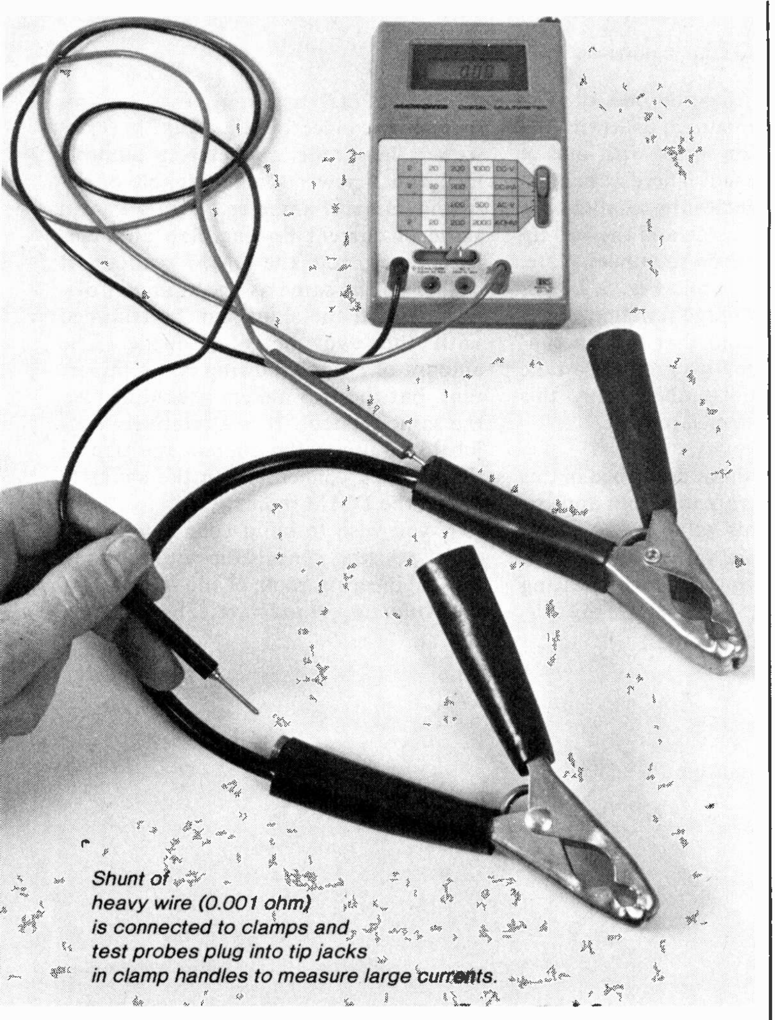


Fig. 11. Down counter sounds the alarm when the counters decrement to zero from the data inserted via the thumbwheel switches In this case, there will be one decrement per minute.



Measuring Large Currents with a DMM

By using the proper shunt, a DMM can measure up to hundreds of amperes

THE current-measuring function of digital multimeters (DMMs) is usually limited to 1 or 2 amperes at most. How then can one use a DMM to measure the tens or hundreds of amperes that may be associated with automotive starter and battery-charging systems, or heavy-duty appliances? The answer is: use a high-current shunt.

A DMM set to its current function really measures the voltage developed by a current in a known shunt resistance. Since all DMMs measure dc voltages, an internal rectifier is used to convert ac voltages to dc. Even though the DMM is operating as a voltmeter, the current function display is calibrated in milliamperes or amperes.

If the resistance of the shunt is low, a large current through it will develop only a small voltage drop. For example, as shown in Fig. 1, a shunt resistor of 0.001 Ω (one milliohm) will produce a drop of 0.001 volt for each ampere that flows through it. If a DMM is capable of displaying 0.001 volt at the least-significant digit (the one on the extreme right), this range can be interpreted directly in amperes. Thus, a display of 0.028 represents 28 amperes flowing through the 0.001-Ω shunt resistor.

Then there is the matter of wattage. Since the shunt is a resistor, a current flowing through it will develop heat that the resistor must dissipate. The power dissipated as heat can be calculated as $W=I^2R$, where I is the current and R the resistance of the shunt: thus a current of 50 amperes would develop 2500 milliwatts of heat.

Note that the shunt is, for all practical purposes, a short circuit and should not be connected directly across a power source. *Always place the shunt in* **series** *with the load!*

In all metallic elements including copper wire, resistance increases with temperature. Therefore, the thicker the wire the less the resistance change and the better the tolerance to I^2R heat build-up. Ambient temperature also affects conductor resistance. Commercial shunts often use manganin, an alloy that was specially developed to have very little resistance change with temperature. The typical experimenter may not have access to a manganin shunt, but he can use a heavy-duty cable specifically designed for very high current work—automotive jumper cables using multi-strand #10 wire.

Shunt Construction. Remove the clamps from one of the jumper cables and cut the cable to exactly 13.5 inches. Then, as shown in Fig. 2, remove 1.5 inches of the heavy plastic insulation from each end, being careful not to nick the wire strands. This leaves 10.5 inches of insulated wire. The electrical connections should be 11.0 inches apart, yielding a resistance of 0.001 ohm, taking into account the resistance of the clamps and soldered connections. Carefully separate one or two strands of wire from each end and cut them so that the ends are as close as possible to 11.0 inches apart. (Bear in mind that different samples of this wire may have slightly different resistances due to variations in manufacture.)

Carefully tape a tip-jack connector (see Figs. 2 and 3) to the end of the plastic insulation, then solder the loose wire strands to the electrical connector. Do the same at the other end.

Carefully solder together and mount the remaining bundle of wires to the hand clamp. Use a high-wattage soldering iron to make a secure electrical connection. Replace the heavy plastic sleeve over the connection. Do the same at the other end.

If desired, smaller clamps, or even banana plugs can be used at the ends of the shunt cable as shown in Fig. 4. Regardless of the termination used, make sure that the high current flows in the shunt and its end connectors and not through

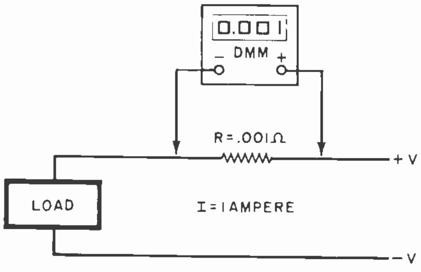


Fig. 1. Current can be read by measuring voltage drop across a known resistance.

PARTS NEEDED

Automotive jumper cables, tip jacks (Lafayette 32A65105, Allied 920-0292, Calectro F2-879 or 30-1080, or similar), or combination tip jack-and-banana connector (Lafayette 32A64850, Calectro F2-883, or similar), 50-ampere clamps (Mueller PK46A or similar), electrical tape, solder.

Note: A 0.001-Ω shunt is available for $5.95 plus $1 shipping and handling from R. H. Johns Scientific Instruments, 3379 Papermill Rd., Huntingdon Valley, PA 19006. Pennsylvania residents, please add 6% sales tax.

the jacks that feed the DMM.

If your DMM does not indicate to tenths of a millivolt, a 0.01-ohm shunt having a current sensitivity of 0.1 ampere per millivolt can be built. With this shunt, a DMM indication of 0.016 volt represents a current flow of 1.6 amperes. Use the same approach as previously described, but use 66 inches of #12 stranded copper wire with the tip jacks 65 inches apart.

To measure ac current, a conventional ac outlet box having one or two appliance sockets mounted on it with the 0.001-ohm shunt in series with one of the leads can be used. There is enough room within the enclosure to allow the shunt to be placed inside and the two tip jacks to be mounted on the upper plate. This approach is shown in Fig. 5. In this mode, use the ac voltage function of the DMM. Keep in mind that the tip connectors may be "hot" to ground so take all safety precautions when using this method of current measurement.

Accuracy. The shunt described in this article will be accurate to within approximately ± 3%. This value is dependent on the actual ohmic value of the shunt and resistance changes due to heating (I^2R losses).

The shunts' accuracy can be improved by connecting the shunt in series with a lab-grade ammeter, a suitable load and a power source capable of delivering several amperes. With a known value of current flowing (lab ammeter indication), note the DMM readout. It should be the same as the ammeter display. If not, the shunt can be trimmed until the two meters coincide. The amount of current flowing is not important, but the two meters should display the same readout. It is a relatively easy job to re-adjust the contact position of the tip jack connectors on the shunt to adjust the DMM indication.

If you wish to build your own "standard" resistor, consult the wire tables in any engineering book, or the ARRL *Radio Amateurs Handbook*. These list the

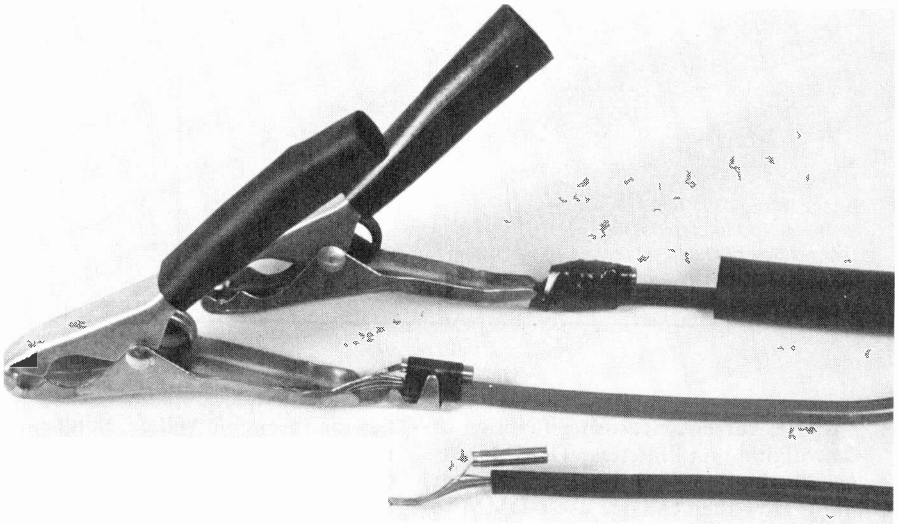


Fig. 3. Assembly of the tip jack and shunt cable to the clamp. After soldering, the large plastic sleeve is placed over the joint and clamp handle.

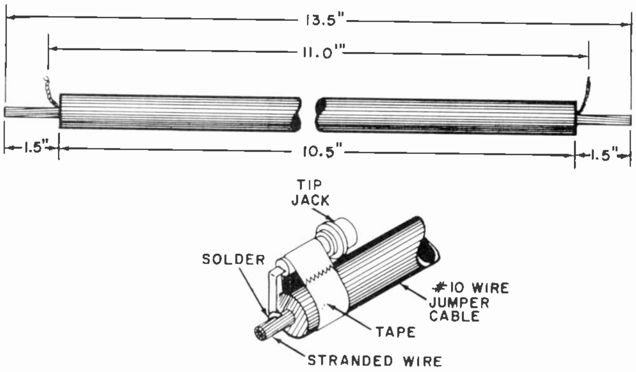


Fig. 2. As described in the text, a 0.001-ohm, high-power shunt can be constructed as shown here from a conventional battery jumper cable and a pair of standard tip jacks.

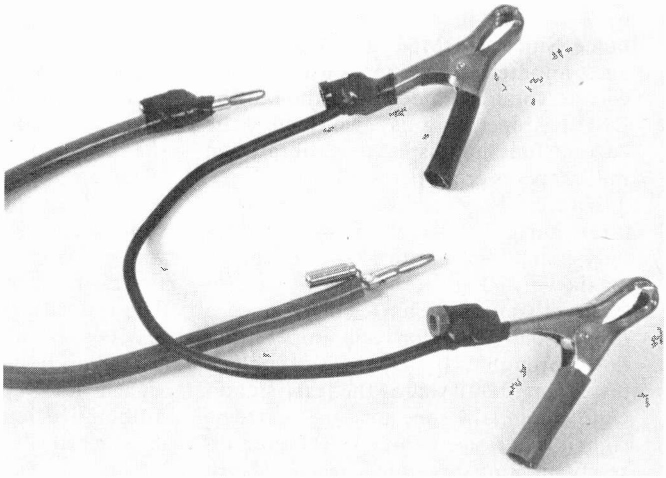


Fig. 4. Shunts can be terminated in banana plugs or small clips as shown here.

Fig. 5. To measure ac current, the shunt can be coiled inside a conventional ac outlet box and the two tip jacks mounted on the top plate.

resistance of solid copper wire to four significant digits. For example, a 0.001-ohm resistor can be fabricated from 10 parallel strands of #16 Formvar or enamel-insulated copper wire, each strand 30.6 inches long. Scrape about 1/4 inch of the insulation from each end and, after affixing a flexible bare wire to make the connections to the tip jacks, solder the bundle together. To calibrate other shunts, connect them in series with your "standard" and adjust the lengths of the meter connections until both resistors generate the same voltage. Although a DMM is accurate on dc, on the ac functions, signals that are not sine waves can produce measurement errors. One common source of error is the unfiltered dc output from an automotive battery charger. The current measured across a shunt from the 60-Hz rectified charger can be as much as 18% low. However, the high-frequency, 3-phase rectified output from an automotive alternator is only a few percent low, not enough to worry about.

Although readers are encouraged to build for their own use the shunt technique described, many features described here are covered in patent applications now pending. ◇

Triggered Sweep *(continued from page 101)*

switch to AUTO. Then set the number of cycles of the waveform you wish to view with SPEED selector *S5*. The period of any waveform can be obtained directly from the screen as the time it takes the beam to "write" one cycle, while the frequency is the reciprocal of this time.

Obtaining a stable display of a fraction of a repetitive waveform cycle is also easy. First, adjust the scope's vertical-gain, brightness, and centering controls for a stable display of several cycles. Set *S4* to NORM and adjust *R7* until the beginning of the portion of interest is at the left side of the screen.

Large-amplitude signals may drive *IC1* into saturation, causing clipping and an apparent reduction in the range of the TRIG LEVEL control. If you cannot position the waveform properly, close *S1* to reduce the gain of the input op amp stage to unity.

Once the waveform is positioned, increase sweep speed until desired magnification is reached. Advance the brightness as necessary. When using very high-speed sweeps with relatively low-repetition-rate triggers, the scope beam and TRIGGERED LED will be very dim or appear to be off even when a sweep is present. This is due to the very low duty cycles in these situations.

As mentioned previously, bandwidth and/or noise limitations of the vertical amplifiers of some low-cost scopes may make triggering on high-frequency signals jittery at best or even impossible. In some of these cases (CMOS or TTL logic running in the low megahertz-range, for example), where signal amplitudes are in the 1-to-20-volt range and circuit loading tolerance is not too critical, the trigger signal can be routed directly to the input of the scope sweep circuit.

Another situation in which the best choice of trigger source is not immediately obvious occurs when you are looking for 60-Hz line noise. For example, if you are checking the output of a dc power supply with 1 or 2 mV of ripple, there will often be insufficient gain in the scope's vertical amplifier to yield a clean trigger pulse and the sweep will run free. However, since the ripple will occur exactly at the power-line frequency or a whole-number multiple thereof, syncing the sweep to the 60-Hz line will provide a rock-steady trace.

Providing a trigger-source selector switch that can disconnect the input of the sweep circuit from the vertical amplifier and connect it to an internal line-voltage source simplifies sweep syncing. The pickoff point can be the secondary of any low-voltage transformer in your scope.

If you wish to gate an external device, such as an oscillator, in sync with the sweep generator, a CMOS-compatible signal is available at the Q output of *IC3*, which is at 0 volt during retrace and +15 volts during sweep. The inverse of this is present at not-Q. In some applications, you may wish to sweep an external oscillator directly, using the sweep output of the circuit. Use a buffer amplifier if necessary to prevent excessive loading by low-impedance inputs.

Summing Up. By substituting the high-performance triggered sweep described here for the recurrent sweep in an older scope, you can upgrade the instrument to permit better waveform analysis as needed for examining modern circuits. Cost is modest and installation is fairly simple. It will also enable you to hold off on purchase of a costly modern scope for a while longer. ◇

How a PLL circuit works, how it is used in communication equipment, and how to locate circuit defects

Troubleshooting Phase-Locked-Loop Circuits

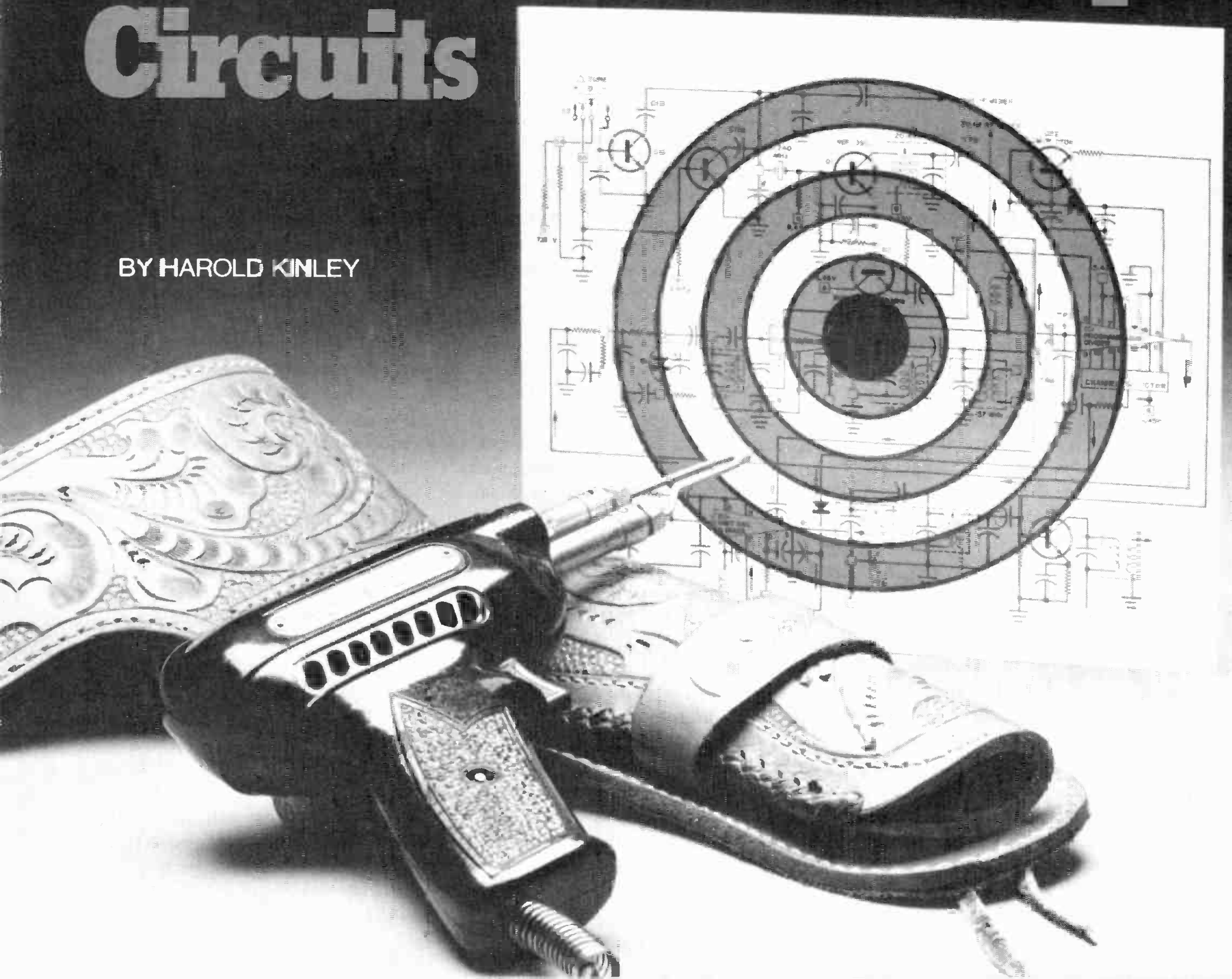
BY HAROLD KINLEY

THE phase-locked-loop (PLL) circuit has been around for many years now. It wasn't until it was introduced in integrated circuit form to 40-channel CB transceivers, however, that it truly came into prominence. Now it's conspicuously used in other electronic equipment, such as FM tuners and amateur radio gear.

Presented here is detailed information on how a PLL circuit works in CB applications, followed by step-by-step troubleshooting analysis of a typical PLL CB system. The principles are applicable to other equipment using PLLs.

Why Use PLLs? The switch to PLLs was necessitated by the CB move from 23 to 40 channels. The old system, in which a bank of crystals in a "Crystal-plexer" arrangement was used, would have been prohibitively expensive. By switching to the PLL, it was possible to synthesize all channel frequencies with just two or three crystals. Increased accuracy and stability were bonuses.

Another advantage of the PLL is that its digital circuitry is compatible with electronic numeric displays, which provide large, easy-to-read numerals.



Actual PLL Circuit. Shown in Fig. 1 is an actual circuit commonly used in many CB transceivers. The one shown here appears in the Boman Model CB-930 transceiver. The total system, including delta-tune and transmit-stop circuits, is composed of five transistors and three integrated circuits. The small boxes in Fig. 1 are used to indicate interconnections to other circuits within the overall system.

Divider *IC1* can be programmed to divide the input frequency present at pin 2 by a divisor selected via CHANNEL SELECTOR switch *S1* This switch provides either 5.36 volts (logic 1) or zero volts (logic 0) to programming pins 9 through 15 of *IC1*.

Each programming pin has a "weight" (value) that increases in binary fashion (each number is twice the previous one) as the pin numbers go down. For example, pin 15 is weighted 1, pin 14 is 2, pin 13 is 4, etc., proceeding down to pin 7 weighted 256. Since pin 7 is permanently connected to 5.45 volts, it is always a 1 hence 256 must be added to the divisor. Pin 8 (which should be 128) is permanently connected to ground, hence it has no weight and can be disregarded.

As shown in Table I, the truth table for the *IC1* programming pins, each channel has a unique array of 1's and 0's. In the case of channel 1, pins 9, 12 and 14 are selected high (1). Therefore, the divisor is 256 (pin 7) + 64 (pin 9) + 8 (pin 12) + 2 (pin 14) which equals 330, the divisor for channel 1.

Also contained in *IC1* is a phase comparator and a constant divider, the latter dividing the input at pin 3 by 1024. Both inputs of the phase comparator are fed with separate 10-kHz signals and the comparator's output frequency is determined by the relative frequency or phase differences between the two input signals. This output is then filtered to obtain a steady dc-level "error" signal that is used to control a voltage-controlled oscillator (vco).

Vco and Mixer. Contained in *IC2* are a vco and a mixer. When two different frequencies are fed to pins 2 and 4, their sum and difference appear at pins 6 and 9, respectively.

The heart of the vco is Varactor diode *D1*, whose capacitance varies with changes in bias voltage. The oscillator in *IC2* is controlled by the external components connected to pin 1. The LC network that parallels *D1* also has an effect on the nominal 17-MHz operating frequency of the vco.

Although *IC2* and *IC3* are identical, the oscillator in *IC3* is crystal controlled at 10.695 MHz. The outputs from pin 6 of *IC2* and the 10.695-MHz oscillator go to *IC3*'s mixer. Their difference appears at pin 9 of *IC3*.

The basic reference frequency is generated by oscillator *Q1*, which operates at 10.240 MHz. The secondary of *T1* is tuned to the 20.480-MHz second harmonic of the oscillator signal.

Detailed Analysis. Let us use channel 1 (throughout this article) to analyze system operation. Refer to both Fig. 1 and Table I. Since pin 7 (not listed) is always high, its weight of 256 must be added to the final tally to obtain the divisor on *all* channels.

Also shown in the chart is the divider input at *TP3* (3.300 MHz for channel 1) and the receiver and transmitter outputs at *TP4*.

The 3.300-MHz signal is obtained as follows. The *IC2* mixer is fed a 20.480-MHz signal from *T1* and another signal from the vco. The latter goes to the mixer at pin 2. The 20.480-MHz signal goes into the mixer via pin 4. The sum and difference of the two signals appear at pins 6 and 9, respectively, of *IC2*.

Calculate the vco frequency as follows. From Table I, the *IC2* sum output frequency is 37.660 MHz. Since the vco frequency is mixed with 20.480 MHz to obtain 37.660 MHz, F_{vco} = 37.660 MHz − 20.480 MHz = 17.180 MHz. The difference of the vco frequency and 20.480 MHz is 3.300 MHz, which is present at pin 9 of *IC2* and pin 2 of *IC1*. The programmable divider then divides the input by 330 to yield 10 kHz. This 10-kHz signal is fed, within *IC1*, to one of the inputs to the phase comparator.

The other 10-kHz signal used for the reference is derived as follows. A 10.240-MHz signal from the emitter of *Q1* is amplified by *Q2* and fed to pin 3 of *IC1*, where it is divided by 1024. This yields the 10-kHz reference signal required for the reference input to the phase comparator.

The comparator constantly compares the phases of the two 10-kHz signals fed to it, and its output varies with the differences. Since the reference oscillator is crystal controlled, its output is very stable. The frequency of the signal from the vco, on the other hand, is likely to drift. Any drift is interpreted by the comparator as a phase change, which results in an error voltage at pin 5 of *IC1*.

The error voltage is fed to *D1*, where it changes the bias (hence, capacitance) and, in turn, changes the vco frequency. The vco "hunts" for the correct frequency. When it finds it, the error voltage stabilizes to keep the voltage-controlled oscillator on frequency.

In the receive mode, the 37.660-MHz signal from pin 6 of *IC2* goes to the first r-f mixer, where it combines with the 26.965-MHz channel-1 signal to yield 10.695 MHz. This is the first i-f. In the second r-f mixer, the 10.695-MHz i-f combines with 10.240 MHz (from the reference oscillator) to yield the second i-f 455-kHz signal.

On transmit, the 37.660-MHz signal from pin 6 of *IC2* goes to pin 4 of transmit-oscillator/mixer *IC3*. The other mixer input at pin 2 is fed the 10.695-MHz oscillator signal. When 37.660 and 10.695 MHz are mixed, the result is 26.965 MHz. This is the channel-1 frequency, which is then fed to the following transmitter stages.

Delta Tune & Transmit-Stop. With delta TUNE switch *S2* set to 0, *Q17* conducts and grounds one end of *C132*, which is part of the frequency-determining circuit. This removes *C131* from the circuit. When *S2* is set to −, *Q17* cuts off and *Q16* conducts. Capacitor *C131* is now in and *C132* is out of the circuit. The larger capacitance of *C131* lowers the frequency and makes it possible for stations off-frequency to the low side to come in better.

The delta-tune circuit is designed so that when the transmitter is keyed on, *Q17* is forward biased. With *S2* set to − and the MODE switch set to RECEIVE, *Q16* conducts. Supply point 8 has 7.88 volts applied to it on transmit and 0 volt on receive. Similarly, point 9 is "live" only on transmit. So, when the transmitter is keyed, forward bias on *Q16* is removed because point 8 is dead. Simultaneously, point 9 is "hot" and *Q17* conducts, returning the oscillator to the proper frequency.

When *S2* is set to +, both *Q16* and *Q17* are cut off and remove *C131* and *C132* from the circuit. A decrease in circuit capacitance and an increase in oscillator frequency result.

The purpose of the transmit-stop circuit is to kill the transmitter if the PLL system should go out of lock to prevent off-frequency transmission. When an out-of-lock condition occurs, pin 6 of *IC1* goes low and forward biases *D22* and kills forward bias on *Q22*. Since forward bias to *Q3* is supplied through *Q22*, if the latter cuts off, forward bias on *Q3* is killed. This shuts down the transmitter until lock is restored to the PLL system.

Getting Acquainted. To properly troubleshoot a PLL system, you should get to know all its nuances through actual hands-on experience. Begin by monitoring the dc "command" voltage that keeps the vco on track at pin 5 of *IC1*. The actual measurement here is about 3.7 volts on channel 1. The reading will steadily decrease as you switch up-channel, until it is about 1.9 volts on channel 40.

An exception to the foregoing is that there will be an *in*crease in voltage as you go from channel 23 to channel 24 because the latter is actually *lower* in frequency. (See last column in Table I) When 17 new channels were added to the existing 23, channels 24 and 25 were sandwiched between channels 22 and 23. This is less confusing than it would have been if a new frequency had been assigned to channel 23 just to maintain consecutive order for the 40 channels that now make up the band.

You can determine what occurs at pin 6 of *IC2* if one input to the comparator is missing by temporarily connecting a 0.05-μF capacitor from pin 3 of *IC1* to ground. This kills the reference signal here and places about 5.5 volts on pin 5 of *IC1*. Connecting the capacitor from pin 2 of *IC2* to ground cuts off the other input to the comparator. Again, 5.5 volts appears at pin 5 of *IC1*. With either input missing, the voltage on pin 5 of *IC1* will remain at 5.5 volts as you tune through the channels. This can be an important clue to troubleshooting a PLL system.

Repeat the experiment while monitoring the potential at pin 6 of *IC1*. When the reference signal disappears, the potential on pin 6 drops to about 0.3 volt, reverse biasing *Q22* and killing transmitter output. Interrupting the signal at pin 2 of *IC2* causes the monitored potential to drop to practically 0, again triggering the transmit-stop circuit.

Substitute the output of a variable-frequency signal generator in the PLL system when you suspect vco failure as follows. Disconnect pin 2 of *IC2* to simulate a missing vco signal at mixer-input pin 2. The vco frequency on channel 1 is 37.660 MHz − 20.480 MHz = 17.180 MHz. Using a frequency counter, tune the generator to 17.180 MHz and set it for about a 100-mV output. Feed a signal from a CB generator to the input of the receiver so that you know when the PLL begins operating.

When the 17.180-MHz output of the signal generator is fed to pin 2 of *IC2*, the signal from the CB generator should come through loud and clear, indicating that the PLL is working. When the transmitter is keyed, there may be no output at first. Then there may be a brief output that comes and goes as if the PLL is attempting unsuccessfully to lock. Confirm this by monitoring the lock voltage at pin 6 of *IC1*, where there should be regular fluctuation. Whenever the voltage at pin 6 rises to a level sufficient to reverse bias *D22*, there will be an output from the transmitter. This output will not remain since the PLL cannot lock because it does not have the control over the signal generator it has over the vco.

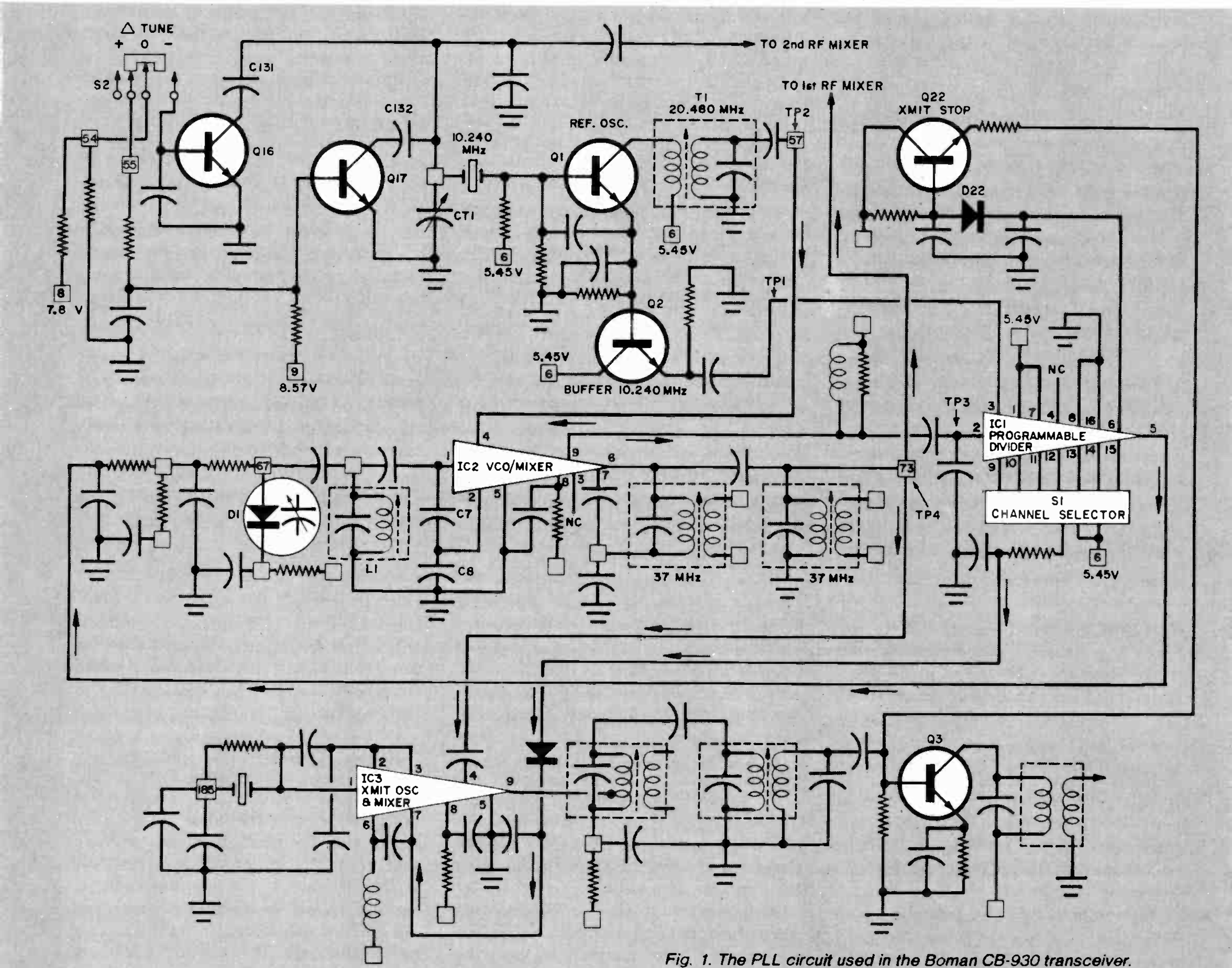


Fig. 1. The PLL circuit used in the Boman CB-930 transceiver.

Due to instrument loading effects, very few frequency-counter readings are possible around the PLL. When the test probe is touched to pins 1, 2, 4, and 6 of *IC2*, PLL operation will cease. The 3.300-MHz mixer output at pin 9 is the only frequency you will be able to measure on *IC2* (on channel 1). However, you can measure 10.240 MHz at the emitters of *Q1* and *Q2* and at pin 3 of *IC1*. You can also measure 3.300 MHz on pin 2 of *IC1*. On *IC3*, you can measure the signal frequency at pin 9 with the transmitter keyed, but the transmitter's output will cease every time the probe tip is touched to pin 9. If you use a frequency counter with a top end of 50 megahertz or greater, you can even measure 37.660 megahertz at *TP4* (point 73 in Fig. 1).

If any frequency obtained by mixing two other frequencies can be measured, the two mix frequencies must be present. For example, if you cannot measure the *IC2* vco signal nor the 20.480-MHz signal but are able to measure 3.300 MHz on pin 9, you automatically know the other two signals must be present.

Troubleshooting Examples. Many conditions can render a PLL system inoperative. Suppose, for example, that the reference oscillator stops working. Without a reference, the PLL would not operate and the voltage on pin 5 of *IC1* would be high and would not vary when switching through the channels. This is a clue that one of the inputs to the phase comparator is missing. Also the voltage on pin 6 of *IC1* would be near 0, another clue that one of the comparator's inputs is missing.

First, check for a 10.240-MHz signal at pin 3 of *IC1*. Finding nothing here, go directly to the oscillator. Check for the presence of r-f at the emitter of *Q1*; no r-f here pinpoints the trouble.

A missing vco signal will also cause one of the comparator's inputs to be absent. If the 1024 divider or the programmable divider is not working properly, it can cause one comparator input to be missing. A malfunctioning mixer in *IC2* can also cause a comparator input to be missing.

Now, suppose the PLL is dead. About 5.5 volts is on pin 5 of *IC1* and there is no output at pin 9 of *IC2*, but the reference oscillator is working. You must determine if the voltage at pin 5 of *IC1* is high because the vco stopped working or the vco stopped working because the voltage is so high as a result of some defect in *IC1*.

To determine where the fault lies, tune to channel 1 and feed a 3.300-MHz signal to the input of *IC1* via pin 2. Assuming *IC1* is working properly, there should be near 0 volt on pin 6 until the correct frequency is applied to pin 2, at which time, the voltage should rise and fall as the PLL tries to lock. Monitor the voltage at pin 5 as you vary the frequency above and below 3.300 MHz. There should be a voltage below but none above 3.300 MHz. These results are a good indication that *IC1* is okay.

Suspicion is now on the vco or mixer in *IC2*. Generator substitution for the vco output is called for. Remove all connections from pin 2 of *IC2* by cutting through the foil trace on the pc board. Feed a 17.180-MHz (on channel 1) signal through a coupling capacitor to pin 2. Have a modulated signal feeding the input of the receiver so you know when and if the PLL starts to work. If it does, the problem is in the vco.

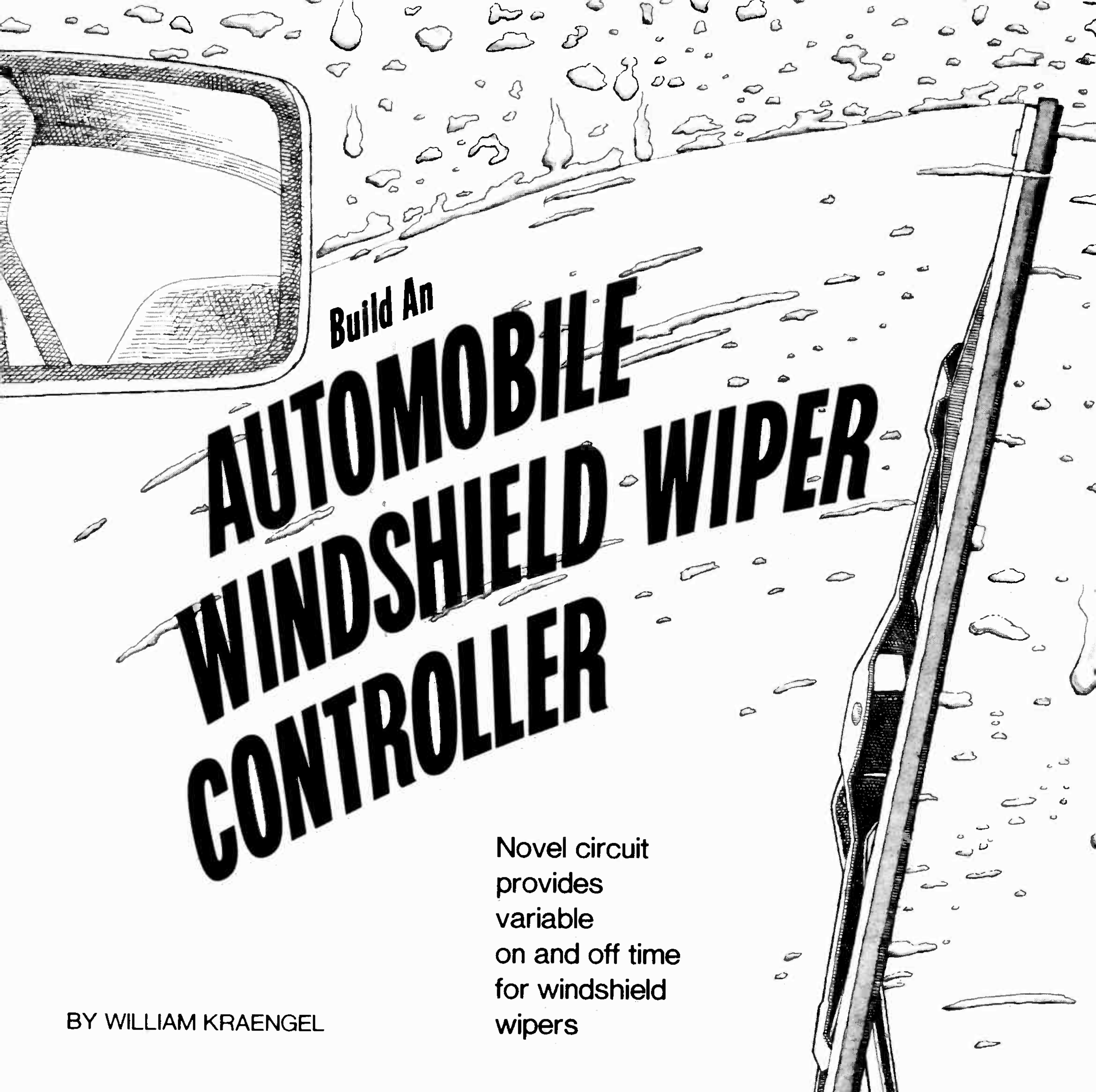
To determine if the trouble is within *IC2* or in the external circuitry, measure the voltages on the IC pins. If this fails to produce results, you may have to substitute another IC and/or check all external components.

Summing Up. The material presented here is the result of actual tests and measurements on a commonly used PLL system. Using the material presented here as a guide, you should be able to troubleshoot virtually any CB PLL system you encounter. Note, however, that FCC regulations require anyone repairing or adjusting the frequency-determining sections of a CB transceiver to have a First-Class Commercial license. However, a radio amateur who is modifying a CB PLL rig for 10-meter operation need not have the license. ◇

TABLE I—TRUTH TABLE FOR ICI PROGRAMMING PINS

Chan.	IC1 Program Divider Pins (64) 9	(32) 10	(16) 11	(8) 12	(4) 13	(2) 14	(1) 15	Divider Input in MHz at TP3	Rec. & Xmt. Synthesizer Output in MHz at TP4	Channel frequency
1	1	0	0	1	0	1	0	3.300	37.660	26.965
2	1	0	0	1	0	0	1	3.290	37.670	26.975
3	1	0	0	1	0	0	0	3.280	37.680	26.985
4	1	0	0	0	1	1	0	3.260	37.700	27.005
5	1	0	0	0	1	0	1	3.250	37.710	27.015
6	1	0	0	0	1	0	0	3.240	37.720	27.025
7	1	0	0	0	0	1	1	3.230	37.730	27.035
8	1	0	0	0	0	0	1	3.210	37.750	27.055
9	1	0	0	0	0	0	0	3.200	37.760	27.065
10	0	1	1	1	1	1	1	3.190	37.770	27.075
11	0	1	1	1	1	1	0	3.180	37.780	27.085
12	0	1	1	1	1	0	0	3.160	37.800	27.105
13	0	1	1	1	0	1	1	3.150	37.810	27.115
14	0	1	1	1	0	1	0	3.140	37.820	27.125
15	0	1	1	1	0	0	1	3.130	37.830	27.135
16	0	1	1	0	1	1	1	3.110	37.850	27.155
17	0	1	1	0	1	1	0	3.100	37.860	27.165
18	0	1	1	0	1	0	1	3.090	37.870	27.175
19	0	1	1	0	1	0	0	3.080	37.880	27.185
20	0	1	1	0	0	1	0	3.060	37.900	27.205
21	0	1	1	0	0	0	1	3.050	37.910	27.215
22	0	1	1	0	0	0	0	3.040	37.920	27.225
23	0	1	0	1	1	0	1	3.010	37.950	27.255
24	0	1	0	1	1	1	1	3.030	37.930	27.235*
25	0	1	0	1	1	1	0	3.020	37.940	27.245*
26	0	1	0	1	1	0	0	3.000	37.960	27.265
27	0	1	0	1	0	1	1	2.990	37.970	27.275
28	0	1	0	1	0	1	0	2.980	37.980	27.285
29	0	1	0	1	0	0	1	2.970	37.990	27.295
30	0	1	0	1	0	0	0	2,960	38.000	27.305
31	0	1	0	0	1	1	1	2.950	38.010	27.315
32	0	1	0	0	1	1	0	2.940	38.020	27.325
33	0	1	0	0	1	0	1	2.930	38.030	27.335
34	0	1	0	0	1	0	0	2.920	38.040	27.345
35	0	1	0	0	0	1	1	2.910	38.050	27.355
36	0	1	0	0	0	1	0	2.900	38.060	27.365
37	0	1	0	0	0	0	1	2.890	38.070	27.375
38	0	1	0	0	0	0	0	2.880	38.080	27.385
39	0	0	1	1	1	1	1	2.870	38.090	27.395
40	0	0	1	1	1	1	0	2.860	38.100	27.405

*Out of sequence—see text.



Build An AUTOMOBILE WINDSHIELD WIPER CONTROLLER

Novel circuit provides variable on and off time for windshield wipers

BY WILLIAM KRAENGEL

AUTO-WIPER, an add-on intermittent windshield-wiper controller, evolved as a solution to the shortcomings of conventional controllers. Built around the ubiquitous 555 timer and a handful of discrete components, it offers some unusual features not found in most commercial systems.

Conventional SCR controllers use the wiper motor internal cam switch to commute (turn off) the SCR as the wiper motor cam rotates out of its detent. The electrical power to complete the wipe cycle flows through the cam park switch and the wiper switch until the cam once more rotates into detent interrupting the power flow to the motor. After a pause, the SCR is again pulsed "on" to repeat its single cycle. This approach to control is called open-loop (no feedback), single-cycle operation.

In most SCR wiper controllers, the system continues to operate as long as the wiper switch is turned on and power is applied to the circuit. And, although most can be slowed down (for a very light rain), many cannot be made to automatically perform one "pass" and then "pause" for any appreciable amount of time. To create such a pause requires operation of the wiper switch. This may mean that the wipers stop at any place along the wiper arc and at the park position (where they do not hinder the drivers vision) only fortuitously.

Most modern wiper systems use dynamic braking to stop the wipers at the park position. To interface to these systems, the SCR controllers usually require additional relay switching, or the dismantling of the dynamic braking feature, both undesirable alternatives.

Auto-Wiper is designed to work with a modern wiper system through a simple interface. Bipolar power transistors eliminate the SCR and its need for external commutation, while providing the dynamic braking essential for proper wiper action. As shown in Fig. 1, by means of a pulse generated by the cam switch once each cycle, synchronization between Auto-Wiper and the windshield wipers is maintained. Furthermore, these feedback pulses allow varying the number of wipes between pauses to one, two, three, or more without resetting the PAUSE control.

How It Works. As shown in Fig. 2, the 555 timer, *IC1*, configured as a gated astable multivibrator with independently adjustable "on" and "off" times, derives its feedback from the voltage across the wiper motor. This voltage, governed by the park switch, pulses in synchronization with the wiper blades. Hence, the timer is controlled by the wipers themselves in addition to its "on" (WIPES, *R1*) and "off" (PAUSE, *R3*) time constants.

When *S1* (part of *R1*) is first closed, low voltage on pin 2 of *IC1* triggers the timer into its "on" state. Darlington power transistor *Q2* is cut-off but *Q1* is

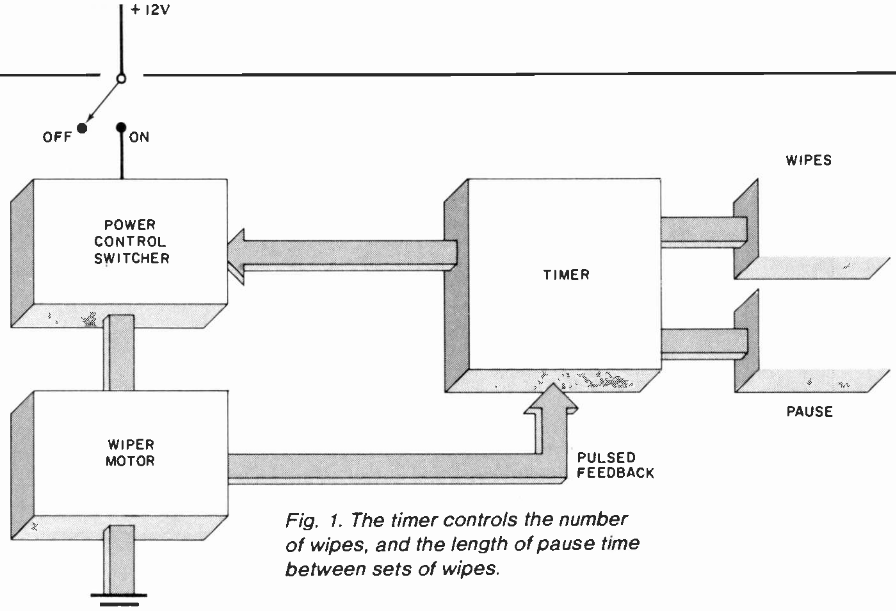


Fig. 1. The timer controls the number of wipes, and the length of pause time between sets of wipes.

PARTS LIST

C1—8.2-µF, 50-V, 10% solid tantalum capacitor (Sprague Q-Line #QDT1-61)
C2—0.01-µF, 50-V disc ceramic capacitor
C3,C5,C7—0.1-µF, 50-V disc ceramic capacitor
C4,C6,C8,C9—10-µF, 35-V upright (radial lead) electrolytic
D1,D2,D3—1N914 or similar diode
D4—1N4001 or similar diode
IC1—SE555 or MC1455 timer
Q1—2N6384 or MJ1000 transistor
Q2—2N6649 or MJ900 transistor
R1—1-megohm linear-taper potentiometer with push-pull switch (Mallory PP16L or similar)
R2—33,000-ohm, ¼-W, 10% resistor
R3—10-megohm linear-taper potentiometer
R4—1000-ohm, ¼-W, 10% resistor
R5,R6—120-ohm, ¼-W, 10% resistor
Misc.—Heat sink (2) (RCA SK-KH3423 or similar), plastic case (Radio Shack 270-233 or similar), 1-inch diam. knob (2), pc board, IC socket or socket pins (optional), 6-ampere in-line fuse (see text).

Note: The following is available from CM Circuits, 22 Maple Ave., Lackawanna, NY 14218: etched and drilled glass-epoxy pc board for $4.25 plus $.50 postage and handling. Residents of New York state, add sales tax.

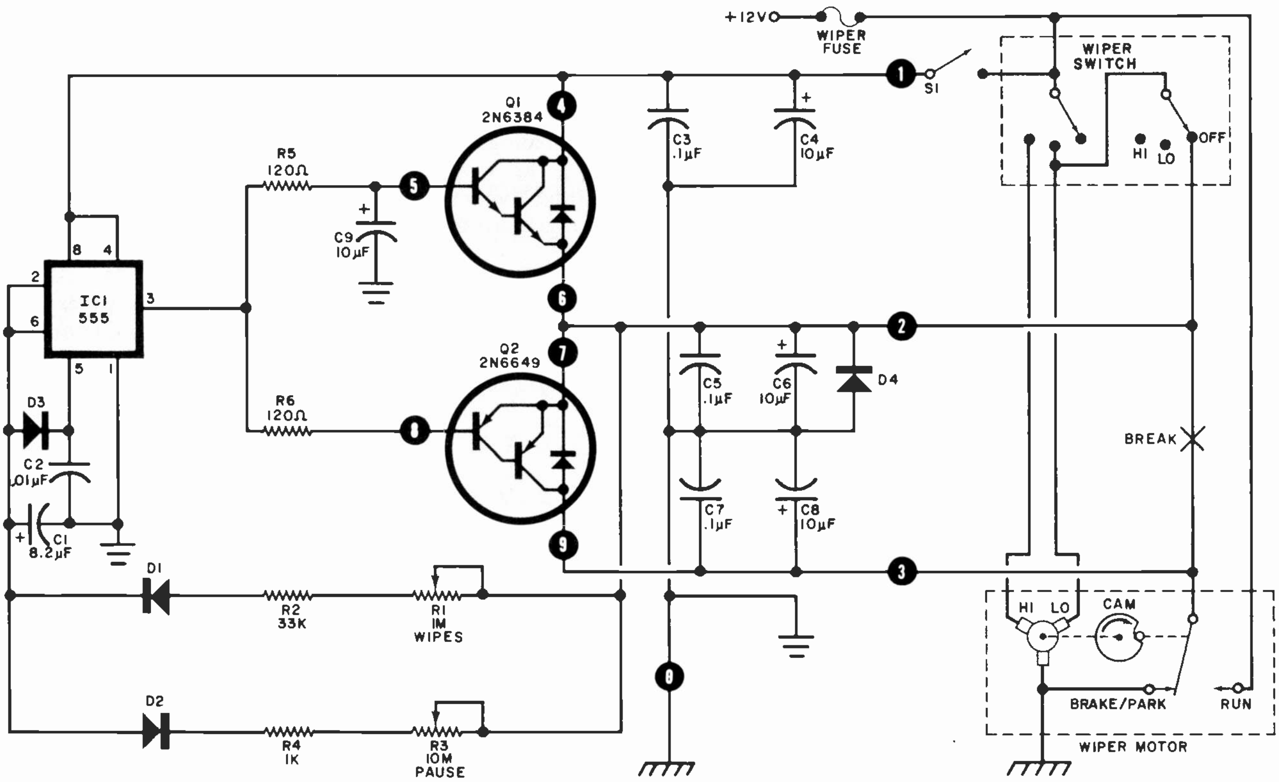


Fig. 2. The Auto-Wiper connects between the wiper switch and wiper motor after one lead is broken.

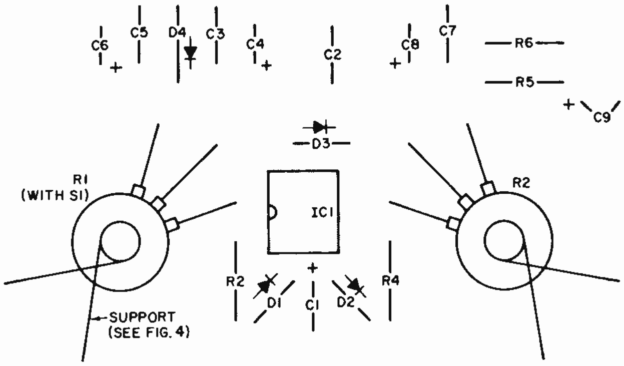
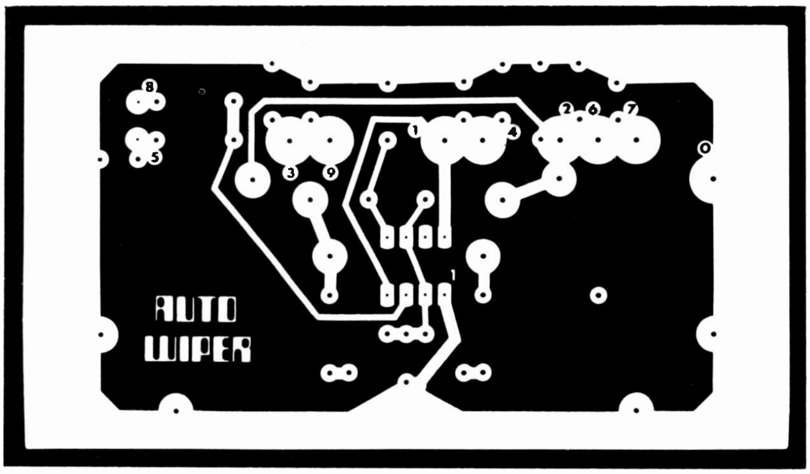


Fig. 3. The two transistors are mounted off the pc board with interconnections via the numbered pads.



turned on, allowing power to flow to the wiper motor. Power is also supplied to the motor through the internal diode of *Q2* as the park switch cam rotates out of detent. The feedback voltage across the motor charges *C1* through WIPES control *R1* until the voltage across *C1* is clamped by *D3* just above the upper threshold of *IC1*.

As the voltage on *C1* rises above the upper threshold of *IC1*, the timer turns "off", turning *Q2* on while cutting off *Q1*. The wiper motor, still powered through the internal diode of *Q2*, continues to operate until the park switch cam once more rotates into detent. The result is that the feedback voltage remains "high", thus preventing the discharge of *C1* until the cam rotates into detent. When this occurs, *C1* is freed to discharge through PAUSE control *R3* toward the zero feedback voltage across the wiper motor. The voltage on *C1* falls until it crosses the lower threshold of *IC1*, triggering it "on" to start the cycle over again. Also, as the cam rotates into detent, the wiper motor's windings are shorted to ground through the WIPER switch and *Q2*. The resulting dynamic braking halts the wiper blades in their proper park position.

During the interval in which *C1* is charging through *R1*, the park switch cam is free to make more than one revolution. Thus, time constant *R1C1* can be varied to allow 1, 2, 3 or more revolutions of the cam before the voltage on *C1* reaches the upper threshold of *IC1*. Similarly, as *C1* is discharged through PAUSE control *R3* toward the lower threshold of *IC1*, time constant *R3C1* varies the discharge time from zero to 60 seconds.

Construction. While there is nothing critical about the layout, construction is greatly facilitated if the pc board shown in Fig. 3 is used. The pc board is held in place by controls *R1* and *R3* which are fastened to the front panel of a small plastic case. If *S1* is attached to *R1*, it mounts through a suitable hole in the pc board. The controls are mounted to the board with short wire extensions from the terminals to the pertinent pc pads and with the bus wire straps shown in Fig. 4. The part specified for *R1* has a push-pull switch. Using this type of switch allows turning the Auto-Wiper on and off without changing the setting of *R1*.

It is suggested that a premium 18-volt 555 timer, such as an SE555 or MC1455 (RCA SK3564 or equal) be used rather than an ordinary 16-volt version since automobile primary voltages commonly exceed 15 volts. Transistors *Q1* and *Q2* are mounted on the rear of the case on individual heat sinks. If the heat sinks cannot be insulated from each other and/or ground, each transistor must be insulated from its heat sink.

Use 16-gauge or heavier wire from pc pads 0-4, 6,7 and 9 to the transistor collectors and emitters and to the wiper connections and automobile frame. If there is no separate fuse or circuit breaker for the wiper circuit, add a 6-ampere in-line fuse and holder to the *S1* input circuit.

Operation. To start a wipe cycle, it is only necessary to pulse *Q1* long enough for the park switch cam to rotate out of detent. Therefore, it is only necessary to advance the WIPES control clockwise until the desired number of wipes are reliably swept. Erratic operation may occur if the control is turned beyond this optimum point. When decreasing the number of wipes, always retard the WIPES control to less than the number of wipes you want, then advance it as above. Any desired pause, up to 60 seconds, is simply set by the PAUSE control.

When first turned on, the initial wipe duration will be somewhat longer than set by the WIPES control. This is caused by *C1* charging from zero volts rather than from the lower threshold voltage of *IC1* as in subsequent cycles. A useful purpose is served, however, in that the windshield is sure to be wiped clean at the start. The original wiper switch is normally not used, but can at any time override Auto-Wiper. ◇

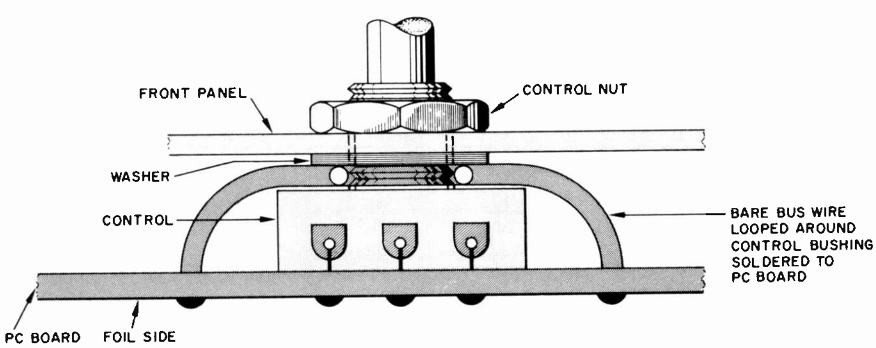


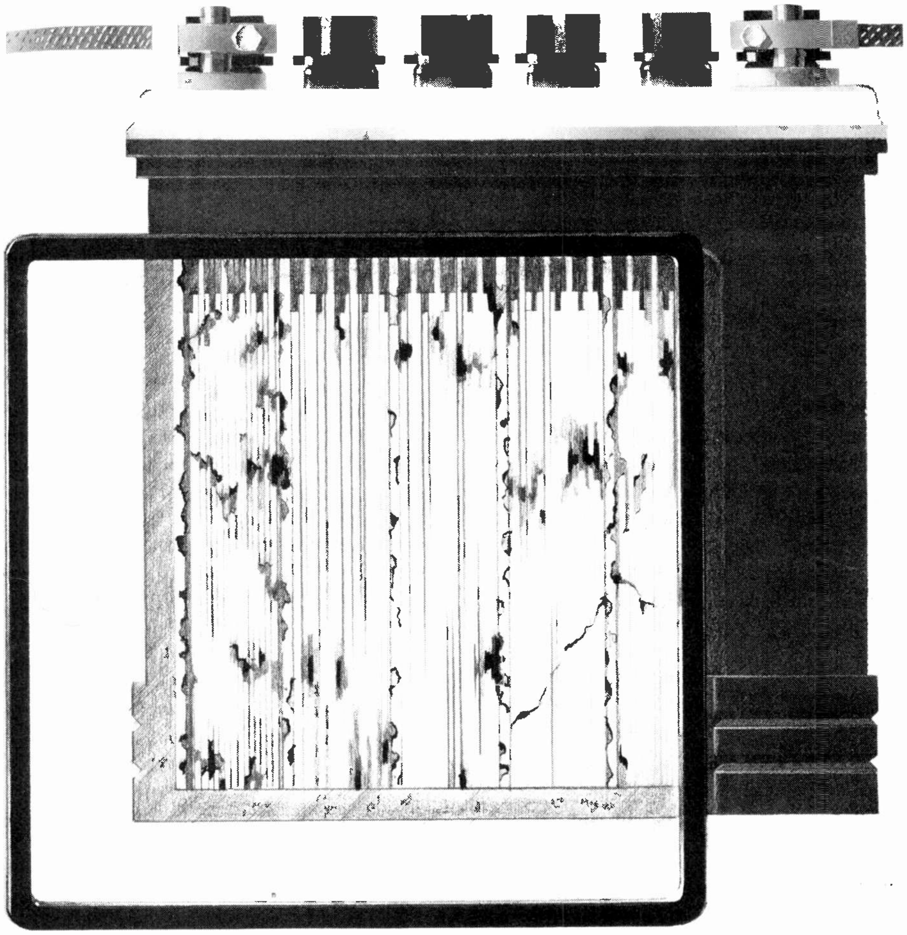
Fig. 4. How potentiometers are wired to board to provide support when mounted in case.

INEXPENSIVE

AUTO BATTERY TESTER

BY HANK OLSON

Simulates 200-ampere starter-motor load



AN AUTOMOTIVE battery works very hard, especially when cranking the engine, and if you have a plethora of electrically operated accessories that often draw more power than the unaided alternator can deliver, it may not have a full charge to work with. Even a battery that loafs most of the time may age to the point where it can no longer start the engine on a cold day, so it's a good idea to check your battery's health now and then.

Numerous tests can be made on a battery, and all of them give some indication of its condition. But none is as conclusive as checking its performance under load. To do that you need a professional battery tester, an inexpensive version of which you can build, as described in this article.

The Circuit. The battery tester, shown schematically in Fig. 1, assumes the test current to be 200 amperes at 12 volts. (To determine appropriate load current, refer to the box.) Using Ohm's Law and assuming a 12-volt battery, you can readily see that load resistor *R2*'s value would have to be a very low 0.06 ohm ($R = E/I$ = 12 volts/200 amperes = 0.06 ohm). Furthermore, its power rating would have to be a whopping 2400 watts ($P = IE$ = 200 amperes × 12 volts = 2400 watts). Clearly, you're not going to find a resistor with these ratings in your local electronics parts store. Fortunately, however, you can fabricate your own power resistor from available inexpensive materials.

Continuing with our example of 12 volts and 200 amperes, you'll need about 12 feet of ½-inch wide, 0.025-inch thick steel banding strap (used to cinch wooden packing cases) to fabricate *R2*. Connect the strap in series with an ammeter that can handle at least 2.5 amperes across a variable power supply capable of delivering up to 1 volt at more than 2 amperes. Adjust the power supply for a 2-A output and measure the voltage across the load. If it is over 0.12 volt, trim the strap until it equals 0.12 V.

Turn off the power supply and disconnect the test setup. You've now determined the length of steel strap to use for a 0.06-ohm load resistor. (You can use the same test setup to determine the length needed for any other battery voltage/power ratings simply by changing the voltage or/and current to the appropriate values in the formulas that are provided in the box.)

You're not likely to find a switch that can handle 200 amperes in an electronic parts store, but a conventional 12-volt automotive starter solenoid (*K1* in Fig. 1) will fill your need. Operating current for the solenoid is controlled by normally open pushbutton switch *S1*.

Meter *M1*, resistors *R3* through *R6*,

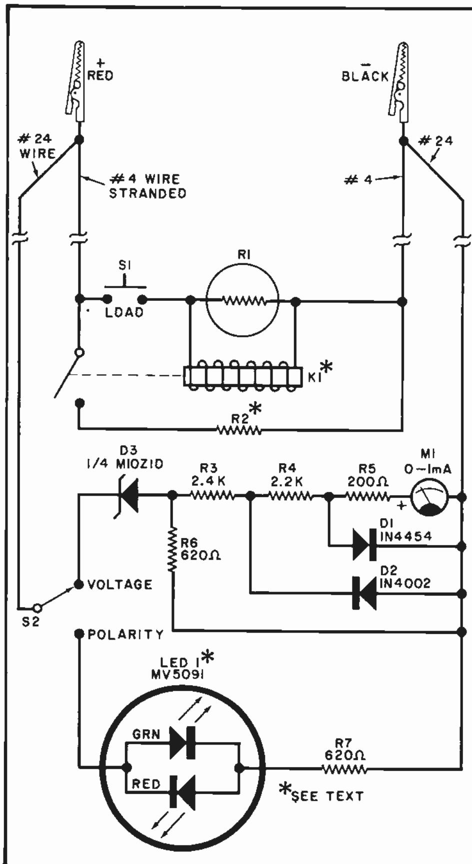


Fig. 1. In the circuit, a standard starter solenoid and contact are used instead of a switch.

PARTS LIST

D1—1N4454 diode
D2—1N4002 diode
D3—10-volt zener (Motorola 1/4 M10Z10 or similar)
K1—12-volt automotive starter solenoid
LED1—Two-color LED (Monsanto MV5091 or similar; see text)
M1—0-1-mA meter movement
R1—Thyrite varistor for solenoid
R2—See text
R3—2.4-kΩ, 1/2-W, 5% resistor
R4—2.2-kΩ, 1/2-W, 5% resistor
R5—200-Ω, 1/2-W, 5% resistor
R6, R7—620-Ω, 1/2-W, 10% resistor
S1—Normally open pushbutton switch
S2—Spdt switch
Misc.—#4 wire cables; suitable Mueller clips or jumper-cable clamps (2); 12 feet steel banding (for R2); 1/2" steel or aluminum spacers (13); 1" × 1/2" metal L brackets; 3/4" plywood board; 16-gauge sheet aluminum; 6-32 machine screws (1" and 1/4" long); large flat No. 6 washers; No. 6 × 1/2" metal spacers; 1/4" machine hardware; assorted terminal strips (see text); 3/4"-long round-head wood screws; #24 hookup wire; etc.

and diodes *D1* and *D2* make up a 0-to-6-volt dc voltmeter. When connected in series with 10-volt zener diode *D3*, this meter circuit becomes an expanded-scale 10-to-16-volt dc voltmeter. Diode *D2* protects the meter against reverse polarity, while diode *D1* protects against overvoltage when the meter is connected in proper polarity.

When selector switch *S2* is set to POLARITY, *LED1* glows green if the tester is connected to the battery in proper polarity, red when the connection's polarity is incorrect. Note that Fig. 1 shows and the Parts List specifies an integrated red/green LED assembly for *LED1*. If you wish, you can replace this with discrete red and green LEDs, connecting them into the circuit as shown for the integrated unit.

Construction Hints. As shown in Fig. 2, the best way to mount the steel strapping that makes up the load resistor, *R2*, is on a 3/4-inch plywood board, using No. 6 metal—*not* plastic—spacers and machine hardware. Start by drilling a 1/4-inch hole spaced 1/4-inch in from each end of the strapping.

Next, drill two rows of 1/8-inch holes through the board, spacing the rows about 8 inches apart and the holes within each row about 1 inch apart. Then mount a metal spacer at each hole location with a 6-32 × 1" machine screw, placing a large flat No. 6 washer under the head of each screw. Mount another large flat washer on top of each spacer with a 6-32 × 1/4" machine screw.

Mount the starter solenoid at the right rear of the plywood board and fasten one end of the steel strapping to one of its terminals. Then route the strapping back and forth from spacer to spacer. (The washers prevent the strapping from slipping off the spacers.)

Fasten a large L bracket to the free end of the strapping with 1/4-inch hardware. Then secure the L bracket and one- and two-lug terminal strips to the wood base with 3/4-inch round-head wood screws.

For the front panel, you will need a sheet of 16-gauge aluminum. Trim it to the width of the plywood base. Then, if possible, bend a 90° lip, about 1 inch wide, along the panel's bottom edge (alternatively, use three large L brackets) and drill three or four 1/8-inch holes along the length of the lip to permit mounting the panel to the plywood base.

Machine the panel and mount on it the meter movement, integrated LED assembly (or discrete LEDs), switches, and two three-lug terminal strips. This done, mount the panel to the top front of the plywood base with 3/4-inch-long roundhead wood screws.

Wire the circuit as shown in Fig. 1. Note that separate #24 wires are used as voltage sensors and are run in parallel with the large #4 cables that carry the actual current. The #24 wires are used to measure the voltage at the battery before any voltage drops in the cable resulting from the high-current flow through *R3*. When installing the #24 wires, route them along the #4 cables and use either lacing cord or tape to bind wire and cable together. Finish the assembly by attaching large Mueller clips or jumper-cable clamps to the free ends of the #4 cables.

Use. To use the tester, connect the two Mueller clips (or clamps) to the battery/charger system (at the battery's terminals) in the vehicle you wish to test and set *S2* to POLARITY. If the LED glows green, the tester is properly connected, but if the LED glows red, reverse the connections to the battery.

Continued on page 126

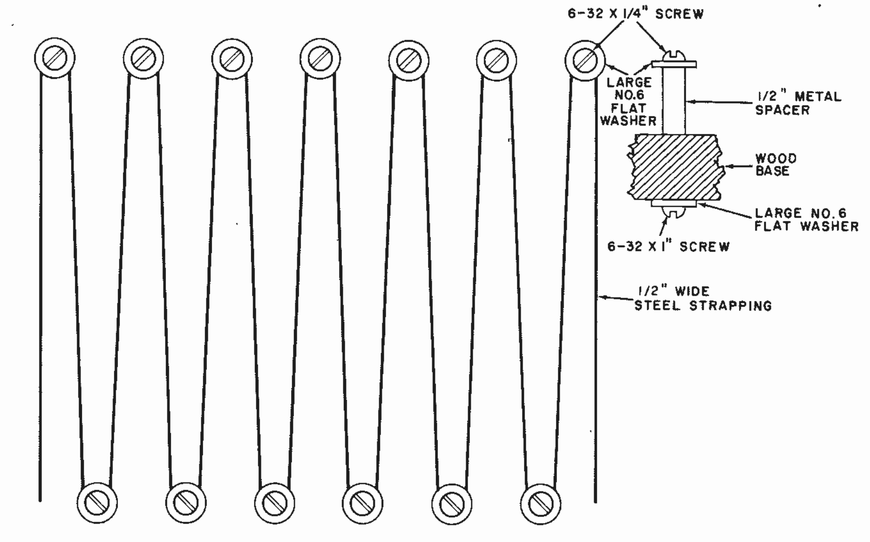
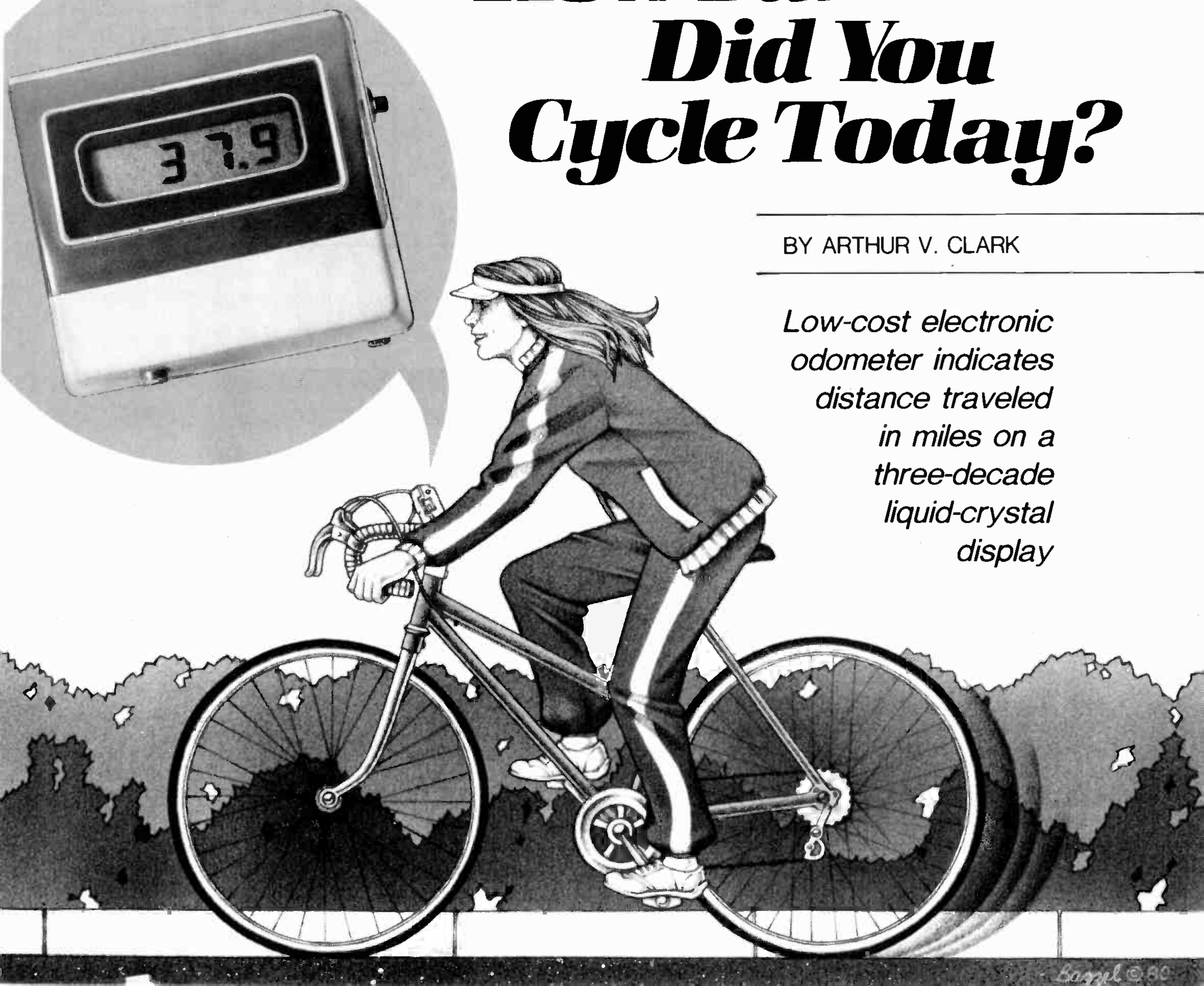


Fig. 2. Using this diagram as a guide and following instructions in the text, you can make up your own load resistor from 1/2-inch steel banding strap.

How Far Did You Cycle Today?

BY ARTHUR V. CLARK

Low-cost electronic odometer indicates distance traveled in miles on a three-decade liquid-crystal display



WHETHER you pedal according to a strict exercise regimen or just for fun, you probably want to know how far you travel on your bicycle. Presented here is an electronic odometer for cyclists that allows you to do just that. Its design provides advantages lacking in many commercially available odometers. Wheel motion is sensed magnetically, obviating drag, slippage, noise generation, and sensitivity to misalignment, one or more of which can characterize the mechanical sensing systems employed in many commercial products.

Digital counters tally the number of wheel revolutions sensed and convert this number into the total distance (in miles) travelled. The counters, which can be reset to zero at the push of a button, drive a liquid-crystal display that is highly legible in the brightest daylight. Accuracy of the odometer is limited by the tenth-of-a-mile resolution of the display. Parts count is low, and, thanks to the use of CMOS ICs and a liquid-crystal readout, the circuit draws very little current from its self-contained battery power source.

About the Circuit. The Electronic Odometer is shown schematically in Fig. 1. Travel is measured by means of *S1*, a magnetically actuated reed or LC2 mercury-film switch mounted on the bicycle frame. Each time a magnet on the rim of the front bicycle wheel passes near the switch (which occurs once each time the wheel makes a complete revolution), the switch closes. Thus, a series of momentary switch closures is generated when the bicycle is in motion.

The reed switch is connected to the rest of the project by a short length of two-conductor cable terminated with subminiature phone plug *P1*. This plug is inserted into matching jack *J1*. When *S1* is open, the CLOCK input (pin 10) of 12-stage binary counter is at V_{DD}. During the brief interval that *S1* is closed, the counter's CLOCK input is at V_{SS}. It is in this manner that the series of switch closures is converted into a train of clock pulses that counter *IC2* can process.

This counter is triggered by the negative transition of each clock pulse. When it has counted 74 of them (equalling a tenth of a mile traveled for a bike with

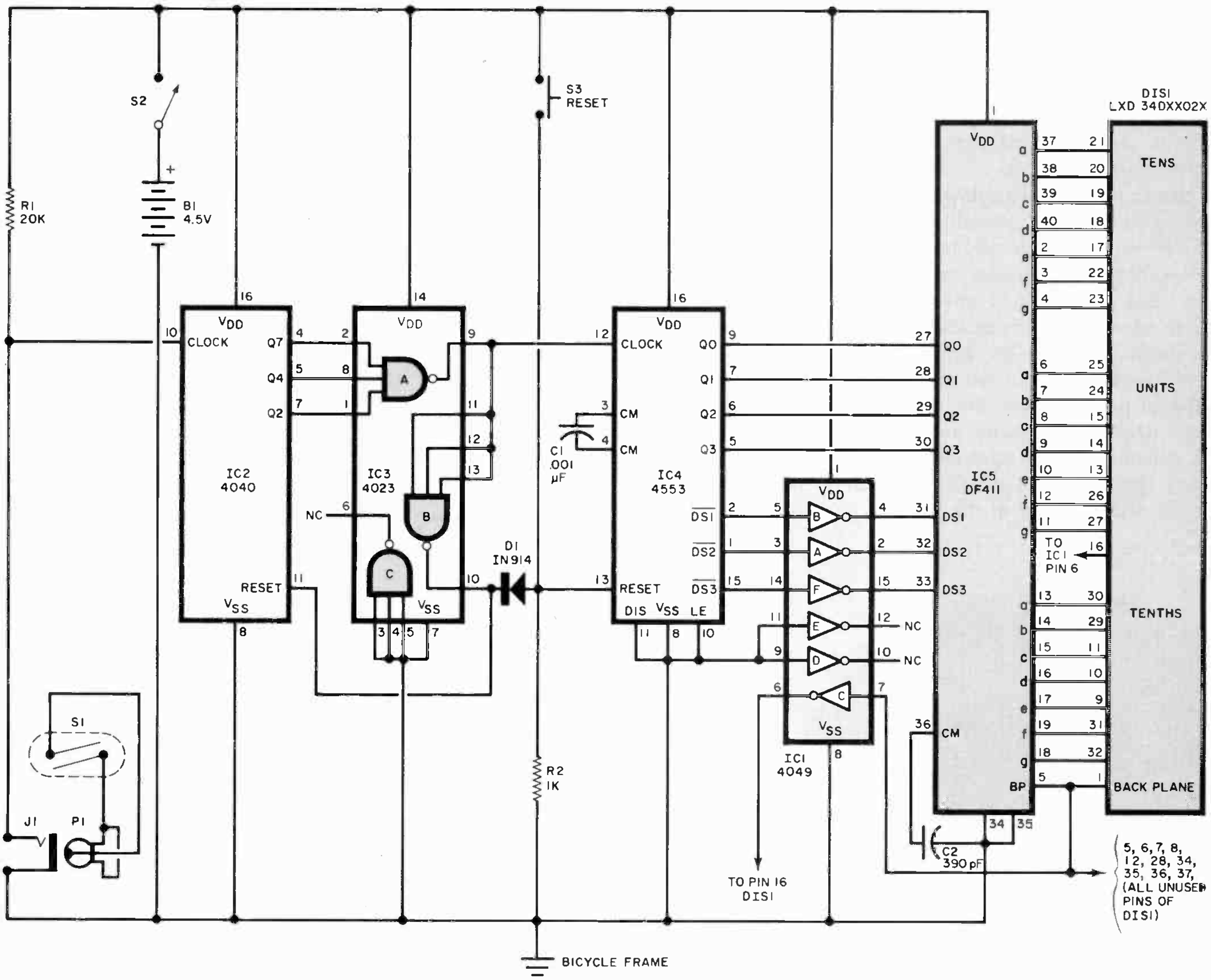


Fig. 1. Schematic diagram of the bicycle odometer. Counter IC2 converts closures of S1 into pulses representing distance traveled. These are tallied by IC3 and displayed by DIS1.

27-inch wheels), pins 4, 5, and 7 are at logic one (V_{DD}). These logic levels are applied to the three inputs (pins 1, 2, and 8) of NAND gate *IC3A* and cause its output (pin 9) to go to logic zero. This negative-going pulse clocks *IC4*, a three-decade counter/BCD decoder with multiplexed outputs. The pulse is also applied to NAND gate *IC3B*, which inverts it to provide a positive-going reset pulse for 12-stage binary counter *IC2*. The binary counter then starts to tally the clock pulses generated by *S1* during the next tenth of a mile.

Each clock pulse applied to pin 12 of *IC4* is counted and stored in the chip's latch, up to a maximum count of 999. Because each pulse corresponds to a tenth of a mile of travel, the maximum tally will signify a total distance of 99.9 miles. This stored information is time-division multiplexed and presented sequentially, one BCD digit at a time, at output pins 5, 6, 7, and 9.

PARTS LIST

B1—Three series-connected 1.5-volt alkaline or NiCd cells
C1—0.001-µF disc ceramic
C2—390-pF disc ceramic
D1—1N914 silicon switching diode
DIS1—LXD 34DXX02X liquid-crystal seven segment display
IC1—CD4049 hex inverter
IC2—CD4040 12-stage binary counter
IC3—CD4023 triple 3-input NAND gate
IC4—F4553 or MC14553 3-decade counter/BCD decoder with multiplexed outputs
IC5—DF411 multiplexed BCD-to-seven-segment decoder/liquid-crystal display driver
J1—Subminiature phone jack
P1—Subminiature phone plug
R1—20,000-ohm, ¼-watt, 10% carbon-composition resistor
R2—1000-ohm, ¼-watt, 10% carbon-composition resistor
S1—Normally open reed or LC2 mercury-film spst switch
S2—Spst toggle switch
S3—Normally open momentary pushbutton switch
Misc.—Printed circuit board, IC sockets or Molex Soldercons, suitable enclosure, No. 16 AWG brass wire, wood or aluminum block, two-conductor cable, hookup wire, battery holder, printed circuit board standoffs, solder, epoxy cement, permanent magnet, etc.

Note—The DF411 display driver is manufactured by Siliconix Inc., 2201 Laurelwood Road, Santa Clara, CA 95054. The LXD 34DXX02X liquid-crystal display is manufactured by Liquid Xtal Displays Inc., 24500 Highpoint Road, Cleveland, OH 44122. A suitable LC2 mercury-film normally open spst switch is manufactured by Fifth Dimension Inc., Box 483, Princeton, NJ 08540.

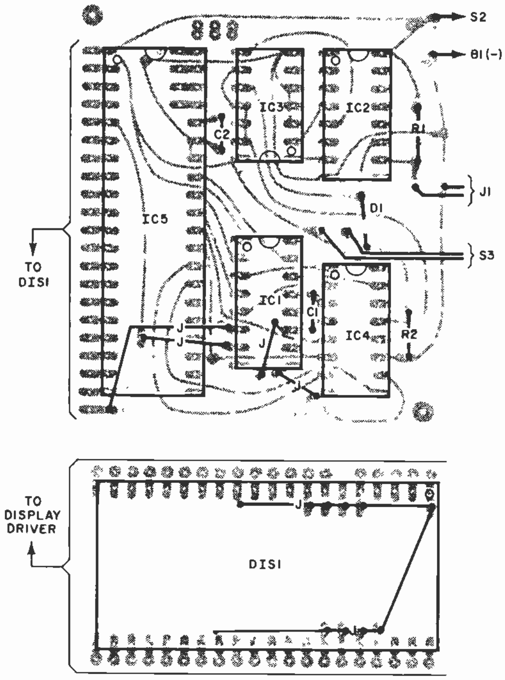


Fig. 2, Full-size etching and drilling guide for a suitable printed circuit board is at left.

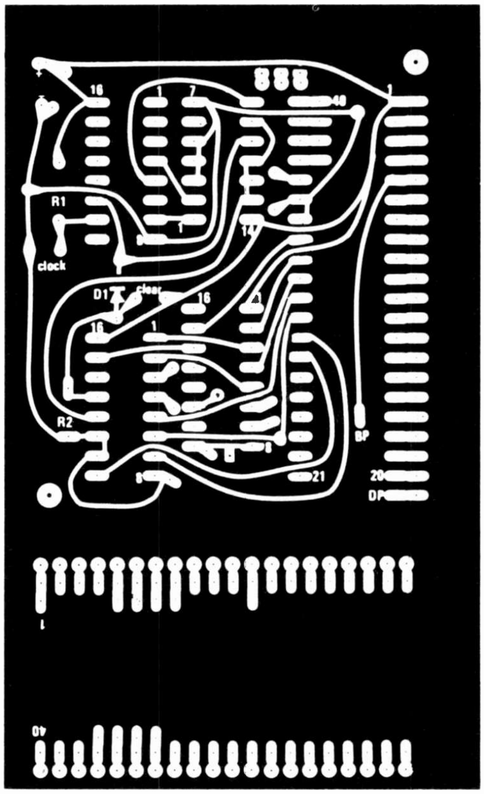


Fig. 3. Component layout for the printed circuit board is at right.

An on-chip oscillator, whose frequency is determined by the value of *C1*, governs the multiplexing of the BCD digits and provides DIGIT SELECT control pulses at pins 2, 1 and 15 of *IC4* for the multiplexed LCD driver. Logic levels appearing on these stobe lines are inverted by *IC1A, IC1B* and *IC1F* to be compatible with the levels required by *IC5*. The BCD numbers presented at pins 5, 6, 7, and 9 of *IC4* are applied to the input terminals (pins 27 through 30) of *IC5*, a BCD-to-seven-segment decoder/latch/multiplexed driver designed for use with a liquid-crystal display.

This complex chip's multiplexing function and the ac drive required by the liquid-crystal display are generated by an internal oscillator whose operating frequency is determined by the value of *C2*. The outputs of *IC5* drive directly the active segments of *DIS1*, a three-digit liquid-crystal display. At the same time, the common back plane of the display is driven by a voltage that is 180° out of phase with respect to the voltage applied to the activated segments of the display. In accord with good design practice, the unused inputs of CMOS logic chips *IC1* and *IC3* are committed to logic zero.

Power for the Odometer circuit is provided by *B1*, the series connection of three 1.5-volt alkaline or rechargeable NiCd cells. Because the circuit's current demand is very modest, long alkaline cell life (or, in the case of NiCd batteries, extended intervals between recharges) can be expected.

Construction. The use of a printed circuit board is recommended because it results in a compact, rugged assembly. A full-size etching and drilling guide for a suitable board is shown in Fig. 2. The corresponding component placement guide is shown in Fig. 3. This board calls for some close work, so be sure to use a fine-tipped soldering pencil and small-diameter solder. When soldering component leads to the board, apply the minimum amounts of heat and solder needed for good connections.

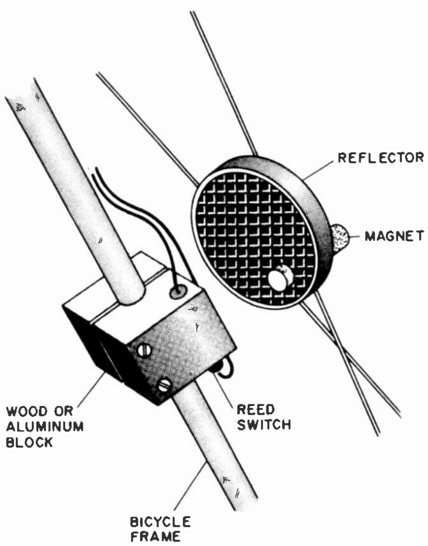


Fig. 4. Details of the author's actuating magnet/motion sensor switch assembly.

A single-sided printed circuit board is employed to simplify its fabrication. This means, however, that several insulated jumpers must be used. These jumpers must be installed first, because components will be mounted on top of them. Next, install the fixed resistors, capacitors and convenient lengths of flexible hookup wire that will be used to connect the circuit board to the battery holder, switches, and phone jack.

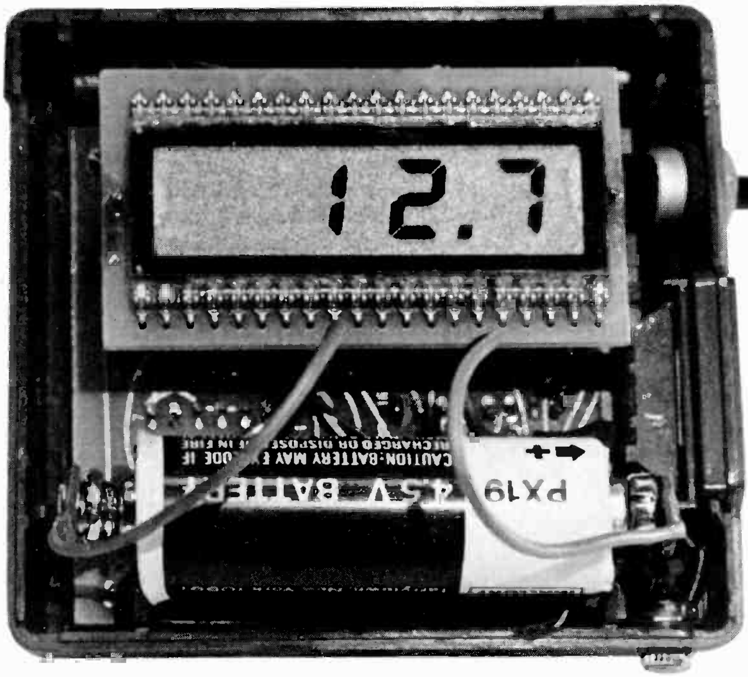
The last components to be installed are the semiconductors and the display. Be sure to orient each semiconductor carefully, observing its polarity and pin basing. Follow the standard procedure for handling MOS devices. The use of IC sockets or Molex Soldercons will minimize the risks posed to the chips by improper handling, the application of excessive heat during soldering, etc. Be sure to inspect your work carefully for solder bridges.

In the author's prototype, that portion of the circuit board containing the liquid-crystal display was sawed and separated from the rest of the board. It was then interconnected with the display driver using convenient lengths of flexible hookup wire (using Fig. 3 as a guide) and was stacked above the printed circuit board by two slender rods made from No. 16 AWG brass wire running through holes drilled in the board and through corresponding holes in the display board. This assembly was secured together by means of epoxy cement.

An enclosure for the project was made from the case of a defunct calculator by cutting it in half and cementing the end cap back on with epoxy. A threaded bolt was run through a hole drilled in the case and cemented to it with epoxy. This bolt and a matching wing nut permit quick, easy installation and removal of the project from the bicycle's front reflector bracket. Connection of the circuit common to the bicycle frame is accomplished by the mounting bolt, wing nut, a solder lug and the reflector bracket.

inserted into this hole and secured with epoxy cement. A drawing of the complete switch and magnet assembly devised by the author appears in Fig. 4. Note that the switch block was cut in half after drilling a hole in it corresponding to the diameter of the bicycle fork's tubing. This allows the block to be secured to the fork by means of retaining screws. Note also that the reed switch was installed in another hole drilled in the block.

Checkout and Use. Connect the probes of an ohmmeter to *P1* and lift the bicycle frame so that the wheel to which the actuating magnet has been attached can turn freely. Rotate the wheel and note the ohmmeter reading. It should indicate an open circuit until the actuating magnet passes near the reed switch, at which point a short-circuit reading



Internal view of the author's prototype odometer shows display, circuit board and battery fit in a compact plastic case.

The wheel-motion sensor switch is installed by securing a normally open reed switch to a block of wood or aluminum with epoxy. This block is then secured to one of the bicycle forks. Either the front or rear fork can be used, but installing it on the front fork permits the use of a shorter cable (terminated in subminiature phone plug *P1*) to connect the switch to the rest of the circuit.

The actuating magnet is installed by drilling a suitable hole in the plastic reflector of the appropriate wheel. A strong permanent magnet should be

should be seen. If this does not occur, adjust the position of the switch assembly until a switch closure is obtained each time the magnet passes the switch.

Now plug *P1* into *J1* and apply power to the project. The display should read 00.0. If it indicates some other number, momentarily depress *S3*. Rotate the wheel a total of 74 revolutions. The display should now register 00.1. If it does, the project is working properly, and you are now ready to take your first bicycle trip with an Electronic Odometer. ◇

battery tester

(Continued from page 122)

Now set *S2* to VOLTAGE; the meter should indicate between 10 and 13 volts. Press and hold LOAD switch *S1* for no longer than 5 seconds (the limit because as *R2* heats up, from the current flowing through it, its resistance increases) and note the meter indication. A fully charged battery should indicate 10 volts or more.

Release *S1* but leave *S2* set to VOLTAGE. Start the vehicle's engine. The meter's pointer should now swing up-scale to a point between 13 and 15 volts as the vehicle's charging system comes into play. If you obtain abnormally low readings at any time, try fully recharging the vehicle's battery and repeat the tests. If the condition still persists, the battery is most likely bad.

You should periodically "load test" your vehicle's battery, say, once a month. Regular testing will help you keep track of the battery's condition and can also indicate preventive maintenance steps to keep it delivering maximum current for as long as possible. Periodically clean the battery terminals and connectors and, unless yours is a sealed, "no-maintenance" type, check the liquid level in each cell often and add distilled water where necessary. ◇

SELECTING A LOAD

Battery testers used by professionals have built-in load resistors specifically selected for testing a range of typical automotive battery power-delivery capabilities. As a general rule, load-resistance values are calculated from a simple formula that states that the load resistor should draw half of the battery's maximum current during a voltage measurement. Since automotive batteries are usually rated in watts, rather than current-delivery capability, it is necessary to first convert to current before you can calculate the load resistance.

Using the standard power formula $P = IE$ (P is rated battery power, I is unknown battery current, and E is battery voltage), we obtain $I = E/P$. Now, let's assume the battery is rated at 12 volts and 4800 watts. First, we divide the power rating by 2, obtaining 2400 watts. Plugging these values into the formula, we get $I = P/E =$ 2400 watts/12 volts = 200 amperes.

Now, use Ohm's Law to calculate the resistance of the load: $R = E/I$, where R is load resistance, E is battery voltage, and I is test current (calculated above). Continuing our example, we obtain R = 12 volts/200 amperes, or 0.06 ohm. Therefore, for a typical 12-volt, 4800-watt automotive battery, the load resistance should be 0.06 ohm at 2400 watts.

Using the procedure described above, you can calculate the required load resistor's parameters for any battery voltage/power ratings.

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