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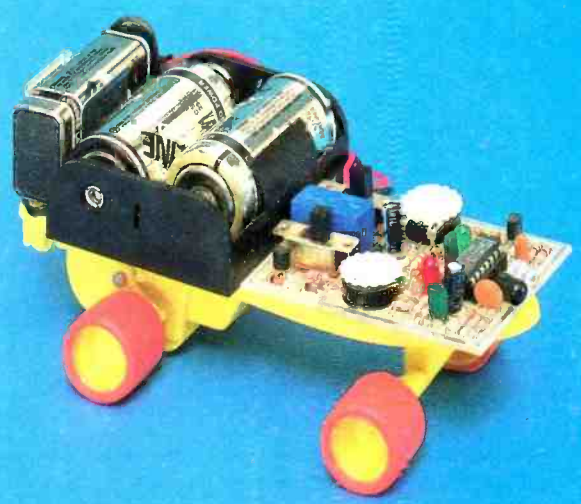

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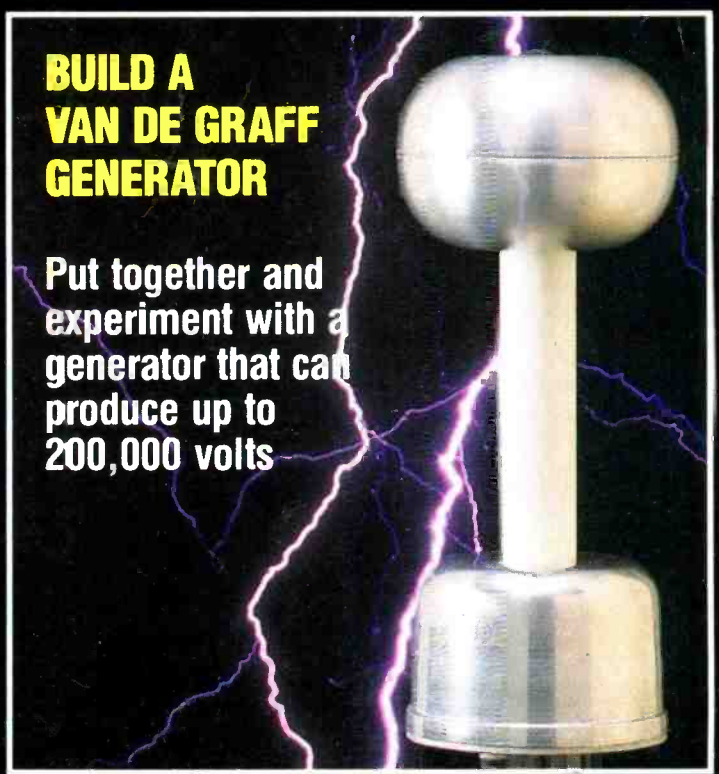

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Editorial

OFF WE GO

In this, the latest issue of the **Popular Electronics Hobbyists Handbook,** we have assembled another great collection of fascinating construction projects. There is something here for every electronics hobbyist, no matter what your interest. If you've already scanned the contents page you won't be surprised. If you haven't look now, and be sure to note that from as exciting a project as building a Van de Graff Generator, to finding out how you can Design Your Own Speaker Enclosures, to as simple yet useful a project as our Electronic Fishing Lure; they are all here. And every story contains all the information you need to complete these adventures in electronics.

On the how-to side there's a story on VCR Repairs You Can Tackle and a look at Techniques and Equipment for Stop-Action Photography.

Those are merely the highlights. There's a lot more for you in these pages. So sit back, get comfortable and start looking for the project you want to tackle. Then clean off your bench, warm up your soldering iron and dig in. Dig into the excitement of watching your own electronics creation come to life.

And if there's something special that we haven't covered in this issue, take a moment or two and drop me a line. Tell me about the equipment or the how-to story you'd like to read and I'll see to getting one of our authors to put that story together for you and your fellow readers in our next issue.

Larry Steckler

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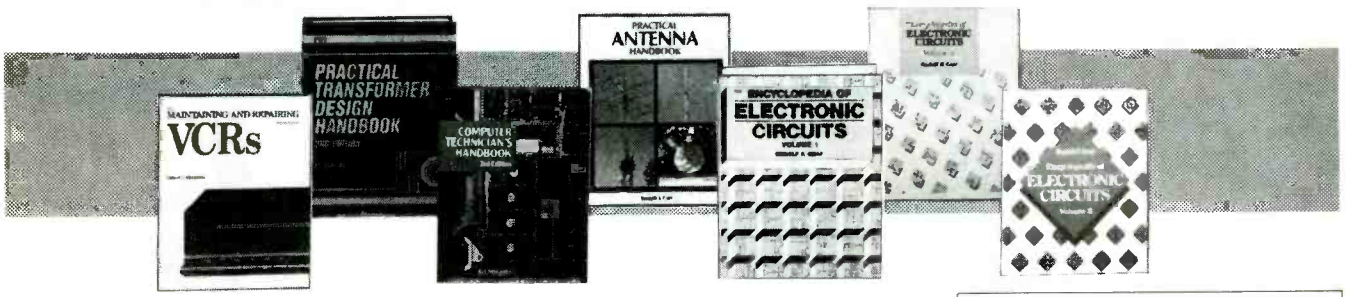

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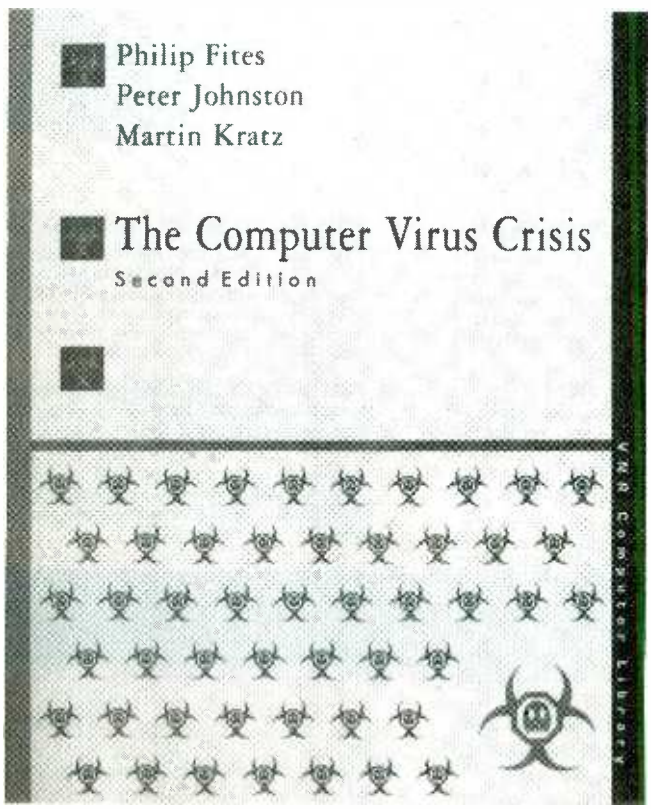

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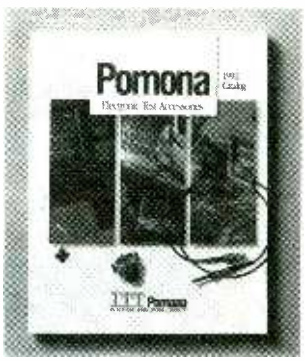

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edited by Robert A. Coburn

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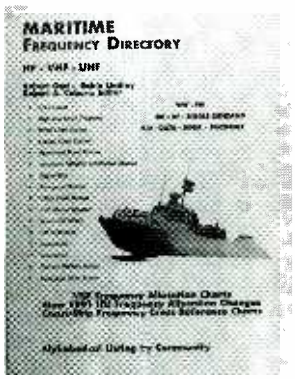

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Connect Muscle Wires™ to a battery or other power source and watch them *contract in length up to five percent!* Remove power, and they relax and are ready for millions more cycles.

Create direct linear action without heavy gears, coils, or motors. Use Muscle Wires in robots, models, planes, railroads – anywhere you need small, strong all-electric *motion*.

Q&A

What Are Muscle Wires?

Muscle Wires are highly processed strands of a nickel–titanium alloy called *nitinol*. At room temperature they are easily stretched by up to 5% of their length. When conducting an electric current they heat and return to their original "unstretched" shape with a force thousands of times their own weight.

How strong are Muscle Wires?

The force a wire pulls with varies with size, from 35 to 330 grams. For more strength, use several wires in parallel.

How fast can Muscle Wires activate?

They contract as fast as they are heated – as quickly as 1/1000 of a second. To relax, the wire must cool again. Rates up to several cycles per second are possible with active cooling.

Flexinol Muscle Wire Specifications

Wire Diameter	50 µm	100 µm	150 µm
Resistance	510 Ω/m	150 Ω/m	50 Ω/m
Contract Force	35 grams	150 grams	330 grams
Typical Current	50 mA	180 mA	400 mA

How much power do Muscle Wires need?

Power varies with wire diameter, length, and surrounding conditions. At room temperature typical currents range from 50 to 400 mA. Power levels can be higher, but once the wire has fully shortened, power should be reduced to prevent overheating.

What are the advantages of Muscle Wires?

Muscle Wires have many advantages over motors or solenoids including small size, light weight, low power, very high strength-to-weight ratio, precise control, AC or DC activation, long life and direct linear action.

These topics and dozens more are covered in detail in our new 96 page book, *Working With Shape Memory Wires*.

Get our new 96 page Book and *moving* Muscle Wire Sample Kit. It includes 20 cm of 50 µm, and 40 cm each of 100 and 150 µm diameter Muscle Wire (1 meter total), crimps and complete instructions – everything you need to *get moving* today!

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CIRCLE 7 ON FREE INFORMATION CARD

comers upgrading from the "no-code" Technician to Tech-Plus and the General Class license is increasing monthly. In response, the National Amateur Radio Association (NARA) has introduced this book, intended to motivate and help beginners to improve their status. The largest chapter in the book is devoted to Samuel Morse and his telegraphic codes. It provides numerous hints for becoming code proficient, including advice on how to avoid the dreaded speed plateau at 8–9 words per minute. The remaining chapters are tied to the nine sub-elements contained in the General Class question pool. The theory behind the questions is discussed in an easy-to-understand style, and is followed in each chapter by the questions found in the sub-element on the test. The correct answers are presented at the end of the book.

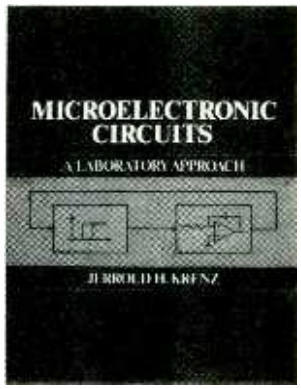
UPGRADE! is priced at $9.95 (plus $2.00 shipping and handling) and is published by The National Amateur Radio Association, P.O. Box 598, Redmond, WA 98073; Tel: 206-869-8052; Fax: 206-861-5780.

CIRCLE 75 ON FREE INFORMATION CARD

MICROELECTRONIC CIRCUITS: A Laboratory Approach

by Jerrold H. Krenz

To help readers achieve an understanding of semiconductor circuits and devices, this book presents a series of experiments that emphasize the close connection between theoretical conclusions and experimental observations. The experiments are grouped into several broad categories. The first section highlights the importance of small-signal models and sophisticated circuits of the type used in integrated music systems, such as operational amplifiers. Part 2 covers the switching characteristics of devices and gates. The third section stresses the limitations associated with the "non-ideal" behavior of an operational-amplifier. The next three sections cover various timing circuits, phase-locked loops, and specialized circuits. Questions are



posed in the concluding section of each experiment to encourage readers to correlate experimental results with theoretical predictions, and design exercises challenge readers to obtain a specific design through an extension of the theoretical and experimental results of previous experiments. The book covers both linear and switching types of devices, with an emphasis on their electrical characteristics. Throughout the book, computer simulations of electronic circuits demonstrate the interrelation of experimental and simulation approaches in "testing" electronic circuits.

Microeelctronic Circuits: A Laboratory Approach costs $29.00 and is published by Prentice Hall, Englewood Cliffs, NJ 07632; Tel: 201-767-5937.

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BOOKS FOR THE MEDIA ARTS 1992

from Focal Press

This 35-page catalog is filled with "how-to" books for professionals and students of broadcasting, audio, and video. The 1992 catalog is the first from Focal Press to also feature videotapes and audio tapes. More than 40 new titles are featured, and the complete selection includes a total of 230 titles. Several new books in related areas such as audio-visual, photography, and cinematography, are included.

Books for the Media Arts 1992 is free upon request from Focal Press, 80 Montvale Avenue, Stoneham, MA 02180; Tel: 1-800-366-2665; Fax: 617-279-4851. ■

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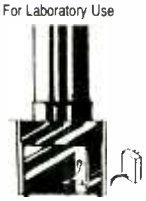

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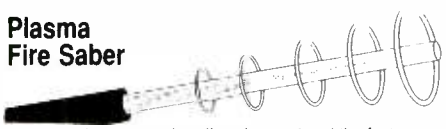

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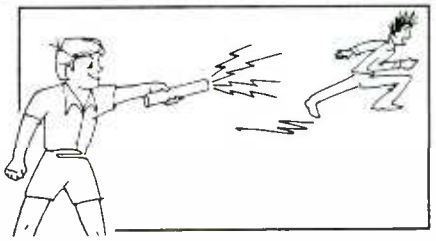

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Build an electrical device that is affective up to 20 feet. May be enclosed for handheld, portable field or laboratory applications.
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Ion Ray Gun

- Projects charged ions that induce shocks in people & objects without any connection! Great science project as well as a **high tech** party prank.

IOG3 Plans ..... $10.00 IOG3K Kit/Plans $69.50

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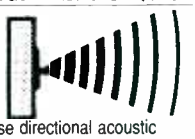

Shirt pocket size electronic device produces time variant complex shock waves of intense directional acoustic energy capable of warding off aggressive animals, etc.
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Highly sensitive stethoscope mike.
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This high tech, all new device is a full range, tune-able FM radio built in to a pair of sunglasses. Great for covert listening of wireless devices and regular entertainment
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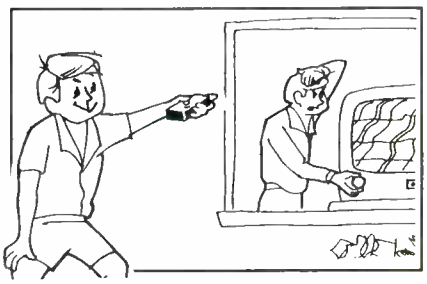

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High brightness red HeNe laser visible for miles. **Produce your own light show!** Projects a beam of red lite clearly visible under most circumstances. Can be used to intimidate by projection of a red dot on target subject. Also may be used to "listen in" utilizing our laser *window bounce* method #LLIS1 below. **Easy to Build Modules Produce A Working Visible Laser**
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SALE! SALE! SALE! SALE!

Low Power 0.5mw HeNe Laser Tube with plans to build a low cost visible red laser system. Great for low budget science fair project! **LATO5 .. $24.50**

Laser Pen - Great for movies, drive-ins, even science projects. **LAPN1 Ready to Use $149.50**

"Laser Bounce" Listener System

allows you to hear sounds from an area via a lite beam reflected from a window or other similar object. System uses our ready-to-use LATR1 Laser Terminator gun site as the transmitter. The receiver section is supplied as an easy-to-build kit, including our cushioned HS10 headsets. **Order # LLIST20 System, includes our LATR1 Ready-to-Use Laser Gun Site, LLR1K Special Receiver Kit, and HS10 Headset, all for only $299.50**

Visible Red Laser Diodes

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Device uses invisible infrared illumination for seeing in total darkness. Excellent for low cost night vision,along with observing lasers and other IR sources. Functional unit, many useful applications
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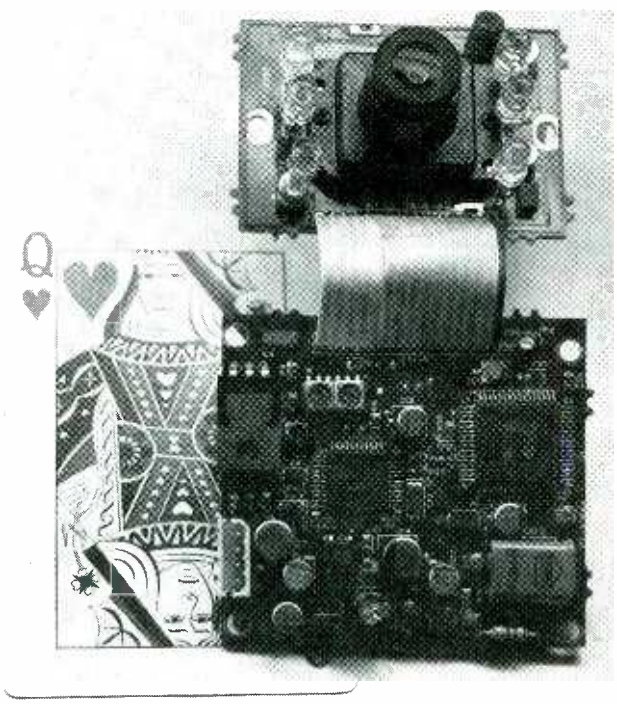
NEW PRODUCTS

Micro Video Camera

Although it weighs only 2.3 ounces and is less than 2-inches square, *Supercircuits' PC-2ex* micro video camera produces 240 lines of resolution and features 80,000-lux light capacity. The device uses a CCD pickup, so it won't burn in or smear when exposed to bright light sources, and VSLI technology, which results in an extremely small package with low power requirements. The PC-2ex's output is standard NTSC video, compatible with television monitors, VCR's, and Supercircuits' Amateur-TV



transmitters for wireless transmission up to two miles from the receiver. Other uses include security and surveillance work, radio-controlled airborne video, robotics, "toy vision," and hobby applications limited only by one's imagination. A wide-angle f2.0 lens is included, along with a modular-connector video/power cable.

The PC-2ex micro video camera costs $196.95 (plus $6.50 shipping and handling). For additional information, contact Supercircuits, 1403 Bayview Drive, Hermosa Beach, CA 90254; Tel: 310-372-9166.

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TWO-CHIP ENGINEERING COPROCESSOR

A two-chip engineering coprocessor from *Intel* improves performance of technical, engineering, and scientific applications on Intel386 DX microprocessor-based machines by as much as 70%. Technical applications use a lot of processing horsepower, and tend to bog down computer performance, wasting time and reducing productivity. The *RapidCAD Engineering CoProcessor* improves performance on technical software applications such as computer-aided design, three-dimensional modeling, rendering, and math/statistical analysis. Floating-point operations and CPU functions are combined to boost the speed of such tasks as three-dimensional rendering. In addition, the coprocessor speeds up the more than 2100 software packages that support Intel Math CoProcessors.

The RapidCAD is made of two chips. The larger of the two, RapidCAD-1, combines the complete functions of the Intel386 DX microprocessor and the Intel387 DX Math Coprocessor in a single device, replacing the system's Intel 386 DX CPU. The smaller chip, RapidCAD-2, drops into the socket that is normally reserved for the math coprocessor. It contains the interface logic needed to manage math exceptions, such as dividing by zero, on PC-compatible systems. Installation by a qualified technician is recommended. The RapidCAD Engineering coprocessor comes with a user's guide, diagnostic and demonstration software, a chip-removal tool, and a storage case for the displaced chips.

The RapidCAD Engineering CoProcessor has a suggested list price of $499. For more information, request information package "BO" from Intel Corporation, 3065 Bowers Avenue, P.O. Box 58065, Santa Clara, CA 95052-8121; Tel: 800-538-3373 ; Fax: 800-525-3019.

CIRCLE 66 ON FREE INFORMATION CARD

IN-LINE WATTMETER

You can measure true power consumed by both AC and DC electronic devices—including operating power consumed by common loads rated for 1300 watts or less, such as lamps, appliances, heaters, small motors, and instruments—with *Extech's In-Line Wattmeter JAC380690*. The instrument even measures DC current components created by rectifiers within the load. A built-in circuit breaker protects the wattmeter from overloads and load faults. Autoranging measuring ranges include watts, true-rms volts, true-rms amps, and power factor, with a basic accuracy of 0.5% +/−1 count. To make measurements, the wattmeter is simply plugged into a wall socket and the device to be measured is plugged into a three-prong socket at the back of the meter. A Hall-effect transducer built into the wattmeter provides for correct power readings regardless of the load-power factor, line voltage noise, or current distortion. The meter has a large, 3½-digit, backlit LCD readout, and is packaged

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Now! Experience the electronics behind the MIDI revolution as you build your own computer-controlled music center

Only NRI's innovative, at-home training in Electronic Music Technology gives you hands-on experience with the equipment that's revolutionizing the music industry—Atari ST Series computer with built-in MIDI ports, Casio HT-3000 synthesizer with advanced MIDI operations, and ingenious MIDI software that links computer keyboard to synthesizer keyboard—all yours to train with and keep!

This year, over $1.5 billion worth of digital electronic music instruments, from keyboards to drum machines, will be sold in the U.S. alone. Enthusiasts everywhere—professional musicians and recording technicians, even people who have never touched a musical instrument before—are discovering the excitement of today's electronic music technology.

At the heart of this excitement is MIDI (Musical Instrument Digital Interface), an innovation that's transformed musical instruments into the ultimate computer peripherals...and opened up a whole new world of opportunity for the person who knows how to use, program, and service this extraordinary new digital equipment.

Now NRI's breakthrough Electronic Music Technology course puts you at the forefront of this booming new technology with exclusive training built around a MIDI-equipped computer, MIDI synthesizer, and MIDI software you keep.

Dynamic new technology opens up new career opportunities

The opportunities are unlimited for the person who's trained to take advantage of today's electronic music phenomenon. Now you can prepare for a high-paying career as a sound engineer, recording engineer, or road technician... even start your own business selling and servicing today's high-tech musical instruments. Or simply unleash your own musical creativity with the breakthrough training and equipment only NRI gives you.

Only NRI gives you hands-on training with today's MIDI technology

The Atari ST Series computer included in your course becomes the heart of your own computer-controlled music center. With its tremendous power, superior graphics capabilities, and built-in MIDI interface, the 16/32-bit Atari ST has almost overnight become the computer of choice for today's most knowledgeable electronic musicians.

Your Casio HT-3000 synthesizer features a five-octave, MIDI-compatible digital keyboard with built-in monitor speakers, advanced tone editing and writing, pattern memory, keyboard split, tone and rhythm banks, chord memory, and dozens more state-of-the-art capabilities.

Plus you get ingeniously designed MIDI software that opens up amazing new creative and technical possibilities... you actually build your own 4-input audio mixer/amplifier...and you test the electronic circuits at the core of today's new equipment with the hand-held digital multimeter also included in your course.

*NRI training **includes** an Atari ST computer, Casio synthesizer, exclusive MIDI software, and much more—all yours to train with and keep! (TV not supplied)*

No previous electronics or music experience necessary

No matter what your background, NRI gives you the skills you need to take advantage of today's opportunities in electronic music technology.

With your experienced NRI instructor always available to help, you master the basics of electronic theory step by step, gaining the full understanding of electronics that's now so essential for technicians and musicians alike.

You move on to analyze sound generation techniques, digital logic, microprocessor fundamentals, and sampling and recording techniques... ultimately getting first-hand experience with today's explosive new technology as you explore MIDI, waveshaping, patching, sequencing, mixing, special effects, and much more.

Plus, even if you've never been involved with music before, NRI gives you enough basic training in music theory and musical notation to appreciate the creative potential and far-reaching applications of today's electronic music equipment.

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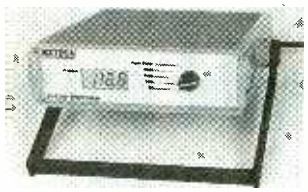

in a durable ABC plastic case with a handle and power cord.

The model JAC380690 120VAC in-line wattmeter has a list price of $799; a 220 VAC version (*model JAC380963*) has a list price of $829. For more information, contact Extech Instruments Corporation, 335 Bear Hill Road, Waltham, MA 02154; Tel: 617-890-7440; Fax: 617-890-7864.

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VIDEO CHARACTER GENERATOR

Home-video makers can add high-quality, professional-style titles to their productions using *Sima's ScreenWriter* video character generator. The device was designed with simplicity in mind. Used with a television and VCR, up to seven title pages can be created and stored in the ScreenWriter's memory. A selected title is automatically superimposed on the chosen scene during tape editing or transfer, with the touch of a button. Four different letter sizes are available, along with special effects including zoom and vertical or horizontal scroll-

ing. A user-friendly QWERTY-style keyboard includes a full set of international characters, and command keys are color-coded. To keep things simple, each line of a title can be set up and then moved around on the screen to achieve the most pleasing arrangement, before the title is inserted. A battery back-up allows titles to be stored in memory for up to one year.

The ScreenWriter video character generator has a suggested retail price of $319.95. For additional information, contact Sima Products Corporation, 8707 North Skokie Boulevard, Skokie, IL 60077; Tel: 708-679-7462; Fax: 312-286-7227.

CIRCLE 68 ON FREE INFORMATION CARD

AC/DC CURRENT TRANSDUCER

When used in conjunction with a digital voltmeter, *Amprobe's model CT 600 AC/DC* current transducer will measure AC and DC current up to 600 amps. The instrument features a coil cord with output banana plugs, a function/range-select switch, a DC-zero adjust knob, and a low-battery indicator. It offers a frequency response of 40–400 Hz

AC, and overload protection to 800 amps AC/DC. A carrying case and a 9-volt battery are included.

The model CT 600 AC/DC has a suggested list price of $89.95. For additional information, contact Amprobe Instrument, 630 Merrick Road, P.O. Box 329, Lynbrook, NY 11563; Tel: 516-593-5600; Fax: 516-593-5682.

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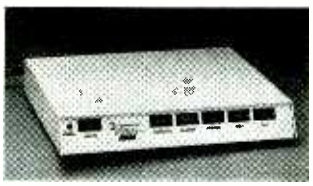
COMPUTER POWER CONTROL CENTER

Intermatic's EG43T Power Control Center combines a surge suppressor and a multi-outlet power-control center in one unit. It offers maximum protection from surges and heavy-duty EMI/RFI noise filtering for a combination of up to six computer items: PC's, printers, disk drives, peripherals, and other accessories. It responds in less than a nanosecond to prevent dangerous voltage surges from damaging the equipment being protected. That protection is provided on all three lines (hot to neutral, hot to ground, and neutral to ground). In addition, the power-control center offers the best UL Standard 1449



clamping level (the voltage point at which the surge protector cuts off the power surge to prevent overvoltage in the line) available—330 volts.

The power control center is encased in a fully shielded steel case. Intended to sit under the monitor, the device is designed to improve the user's angle of sight and reduce glare. Users can turn their equipment on or off via a single master switch located on the front panel. Five front-panel rocker switches correspond to individual plug-in receptacles on the rear panel, while an unswitched receptacle on the rear panel provides uninterrupted power with surge protection. Other features include an indicator light that shows that the unit is operating properly, a 15-amp circuit breaker, and a six-foot power cord.

The EG43T Power Control Center has a suggested retail price of $119.95. For more information, contact Intermatic, Inc., Intermatic Plaza, Spring Grove, IL 60081-9698.

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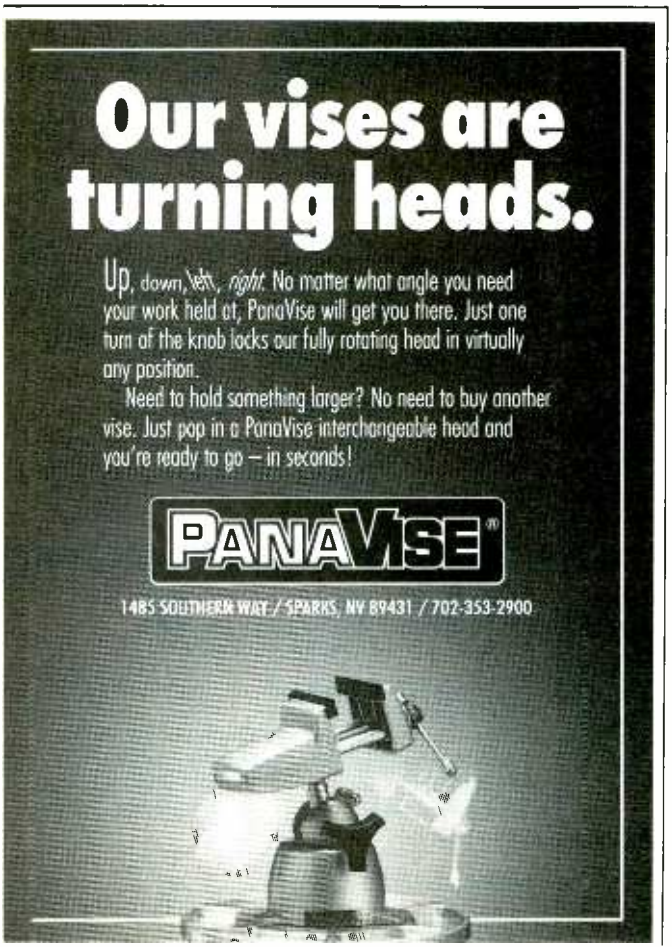
ROTATING MICROGRABBER TEST PROBE

Designed for surface-mounted device (SMD) and high-density



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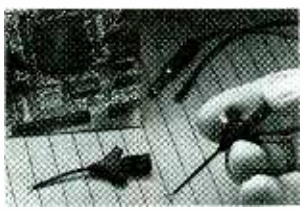
lead testing, *ITT Pomona's Series 5790 Rotating Micrograbber* test probe is also well suited for testing of fine-gauge wires. Spacings as small as 1.2mm (0.05-inch) and wire as fine as 0.1mm (0.004-inch) can be accessed with the Rotating Micrograbber's fine-pointed pincer. The rotating finger grips and body allow the user to grasp the lead firmly. The extended guide tube reaches into extremely tight areas. And, unlike rigid test probes, the flexible



Rotating Micrograbber can be bent and fixed at a 35° angle. The 1.2mm barrel allows for tight stacking of multiple probes, which is particularly helpful for any application that requires multiple, high-density connection testing, and when using logic analyzers or oscilloscope accessories. The probe is rated at 42-volts, 2-amp maximum, and is available in black or red.

The Series 5790 Rotating Micrograbber costs $4.60 in single quantities. For further information, contact ITT Pomona Electronics, 1500 East Ninth Street, P.O. Box 2767, Pomona, CA 91769; Tel: 714-469-2900; Fax: 714-629-3317.

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The Data Precision DP100 costs $595 in single units; quantity discounts are offered. For more information, contact Analogic Corporation, Electronic Products Group, 8 Centennial Drive, Peabody, MA 01960; Tel: 508-977-3000 ext. 3873; Fax: 508-531-1266. ■

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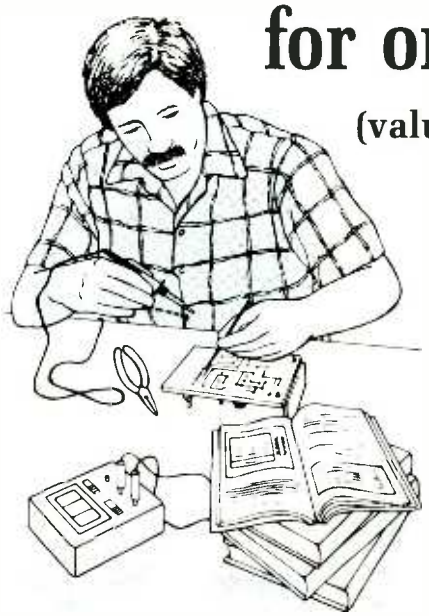

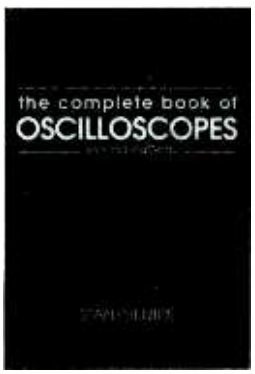

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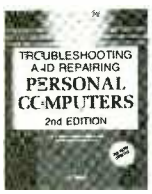

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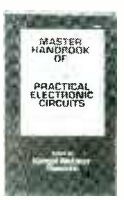

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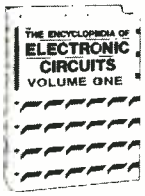

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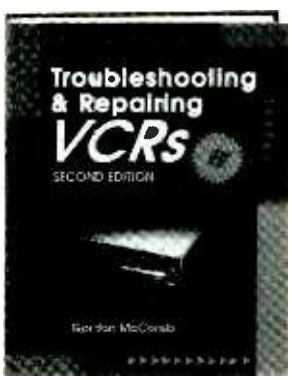

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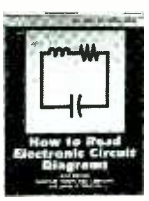

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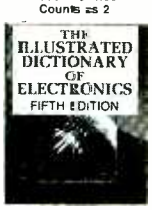

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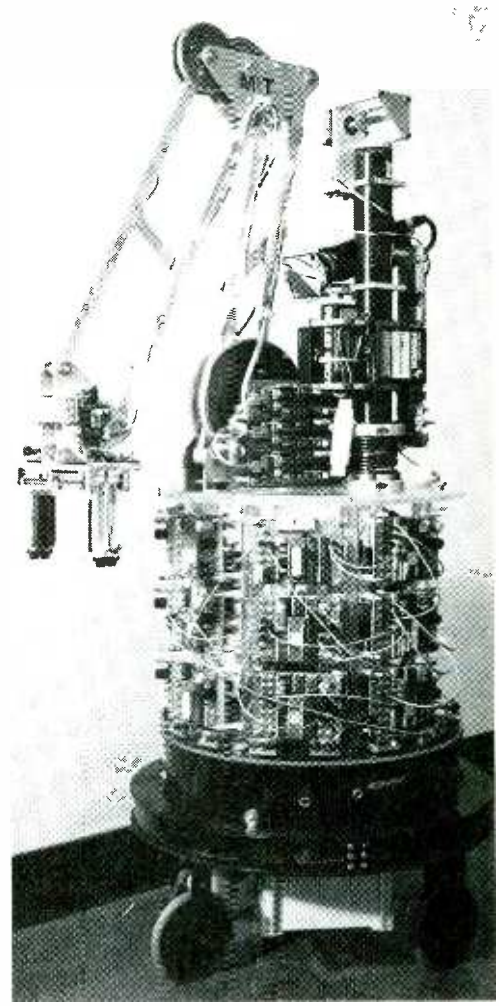
DESIGN your own ROBOT

Learn the fundamentals of brain activity and how to simulate animal behavior by building your own robot.

BY JONATHAN CONNELL

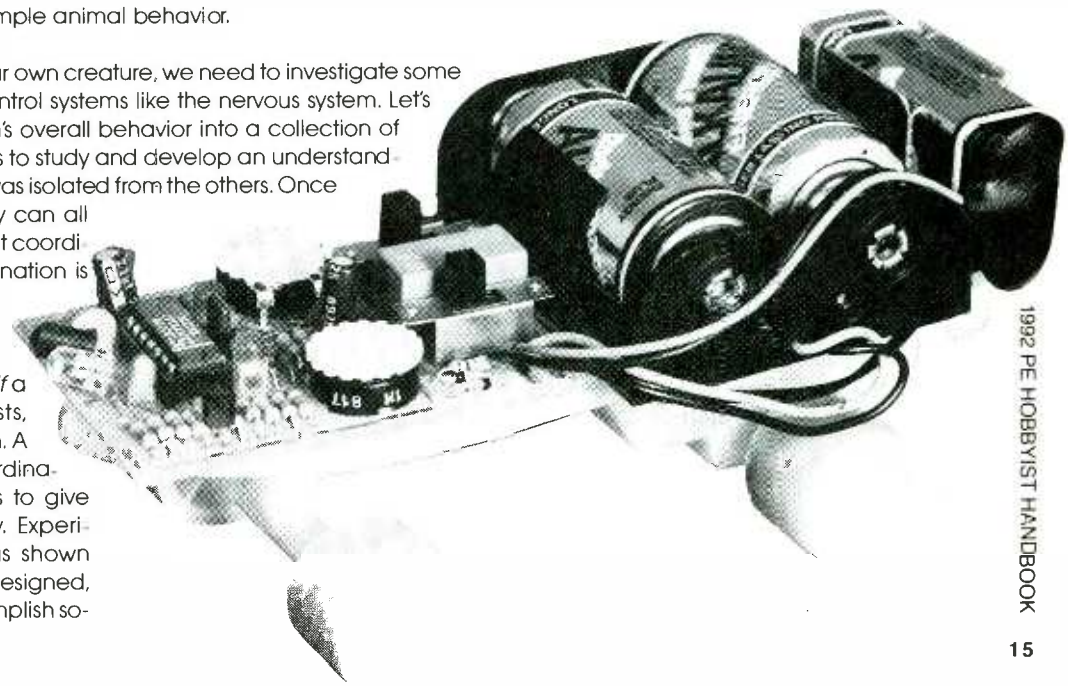


The human brain is very complex. It contains billions of neurons and has trillions of connections between them. Although, many areas have a uniform structure, there are several-hundred architecturally distinct regions. That makes simulating a human brain very difficult.

By contrast, there are many insects and marine animals that have far fewer neurons. Some of them have been studied in detail and scientists have a good idea of how the various components of their brains are connected together. There is also a rich collection of experimental data detailing what sort of behaviors are present in each animal and how various groups of neurons interact to perform the necessary computations. So, at least for now, it's more feasible for us to build robotic models of such simple creatures rather than humans. Also, since man evolved from simpler organisms, the knowledge gained from such an endeavor should ultimately lead us to a better understanding of our own minds.

In this article, we'll investigate the nature and capabilities of elementary, animal-like reflex systems. We'll also show you how to construct an inexpensive mobile robot based on simple animal behavior.

Behavior. Before designing our own creature, we need to investigate some of the principles of natural control systems like the nervous system. Let's start by breaking an organism's overall behavior into a collection of separate reflexes. This allows us to study and develop an understanding of each reflex as though it was isolated from the others. Once each reflex is understood they can all be put together in a model that coordinates their activity. This coordination is necessary to prevent potential conflicts between reflexes.



Each reflex can be modelled as a set of "if-then" rules—*if* a particular circumstance exists, *then* perform a specific action. A simple way to model the coordination of the animal's actions is to give each rule a different priority. Experimental robotics research has shown that such systems, if cleverly designed, are powerful enough to accomplish sophisticated tasks.

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The functioning of a rule-based system is best illustrated by an example. Consider the coastal snail. This creature spends its life at the edge of the ocean, eating algae off rocks. The best place for this kind of snail is in a crack right above the waterline. There it can find a rich concentration of food and the creature is in no danger of being dried out by the sun or gulped-up by a passing bird. Unfortunately, the snails are occasionally swept away by a wave, so to avoid starvation they must have some way of seeking out this optimal region again.

Ethological studies have revealed that the snail has two primitive drives: to climb upward and to avoid light. We will refer to these reflexes as "up" and "dark." However, neither of these instincts completely controls the snails' behavior. In fact, there are some situations in which they play no part. For instance, if there is no difference in light intensity between directions, the dark behavior is quiescent and the snail crawls straight upward. Similarly, when the snail is on a more or less flat surface, the up drive is inactive and the snail's direction of travel is determined solely by the illumination gradient.

Overall, however, dark is the stronger reflex. If a very bright light source is present, the snail will crawl away from it even if this means going downward.

Surprisingly enough, if one turns the snail upside down, instead of avoiding light, it will now head toward bright areas. We can say that this is due to a third reflex, "bright," which provides the animal with an urge to seek out light. Since the bright reflex ends up controlling the motion of the animal, it must override the output of the dark module. Yet this new behavior only becomes active, or "potentiated," when the animal is inverted. When the snail is right-side up, the creature acts out one of the lower level behaviors.

There is one further twist to all this. It has been observed that the light-seeking behavior occurs only underwater. If the animal is in air, it will invariably seek out dark areas, even if it is upside down. We can model this by adding another behavior, called "crack," to the creature's repertoire. When the snail is out of the water, this behavior takes precedent over all the other drives and causes the creature to seek out dark places.

As shown in Fig. 1, we can draw the interaction of the reflexes (or "behavioral modules") as boxes. We can

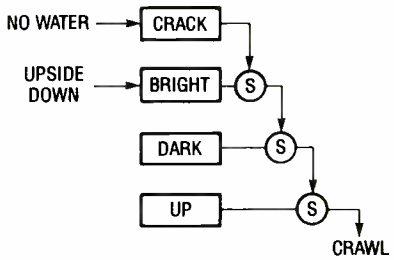

Fig. 1. The overall activity of a sea snail can be broken down into four natural tendencies or behaviors. In some situations, one tendency suppresses another. For example, bright behavior suppreses dark behavior.

indicate the priority of the behavioral modules through the use of circles with an "S" (which stands for suppressor node) in it. In the case of conflicting motion commands, the behavioral module which injects its signal into the side always wins and gets control of the snail's body. The dominant behavior

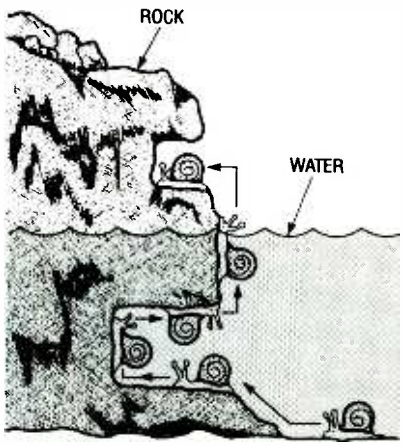

Fig. 2. The priorities placed on a snail's behavior cause it to climb up out of the water, seek a dark crack in the landscape and stay there.

supresses the weaker behavior.

This collection of four behaviors allows the snail to find the best foraging area, even if it has to negotiate major obstacles along the way. Imagine, as shown in Fig. 2, that the snail starts on the ocean floor, a short distance offshore. Since the rocks are slightly darker

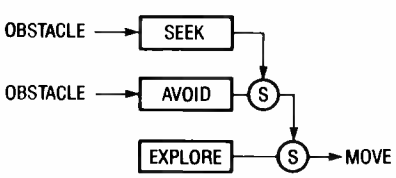

Fig. 3. Our robot will have three basic behaviors that will cause it to explore its world, avoid obstacles, and seek out objects.

than the surrounding sand, it crawls along the bottom towards them. Then, when it reaches an outcropping, it starts climbing the face. However, every time it comes across a notch in the rock, it is drawn inward by the darkness. Upon reaching the end of the crack, the snail starts climbing the rear wall and eventually reaches the ceiling. Here, it becomes inverted and thus moves outward toward light again.

Having successfully overcome this impediment, the snail continues climbing toward the surface. When it reaches the edge of the water, it ascends still further until it comes across another crack. As before, the dark-seeking behavior will take over and directs the snail into any crack encountered. However, since it is now above water, the snail does not head upward or turn around when it reaches the back, but instead stays deep in the crack to search for food.

The Robot's Behavior. Using behavior-based control systems we can now design our own synthetic creatures. The one to be described here is called "*Muramator*," which is Latin for "wall lover." As its name suggests, the robot follows the edges of walls and furniture. To design such a robot, we start by breaking its desired "behavior" down into separate parts.

The most primitive behavior we'll call "explore." This module should constantly urge the robot to go forward. While that causes the robot to move around its environment, it also causes the robot to get stuck easily. To prevent this, we'll add another behavior, "avoid," which overrides the output of the explore circuitry. Avoid's job is to steer the robot away from any obstacles that might be encountered.

With just these two behaviors a robot is capable of wandering around its environment for long periods of time. However, it tends to bounce around like a drunken pool ball. To make the robot more responsive to its world, let's add a third behavior, "seek." This module can search for objects and guide the robot toward them.

A dynamic balance between seek and avoid will keep the robot running roughly parallel to the edges of objects. Like an ancient mariner, the robot will attempt to keep the shoreline of its world in sight at all times.

The whole algorithm (shown in Fig. 3) has been successfully used by several larger robots. Our abstract specifica-

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tions now need to be translated into real rules. To do this we need to know the actual perceptual and motion capabilities of our robot. To keep construction simple, for the body we have chosen a commercially available toy vehicle that is able to stop, go forward, or turn in place toward the left. No other actions are possible.

There are 3 different bodies (all available at Radio Shack) that will work with the Muramator circuit. The preferred body is a wire-controlled skate board. This configuration is called the "Whirligig" or WG model. Another option is to build the robot around a wire-controlled dinosaur (Radio Shack No. 60-2284), referred to as the "Dizzy Lizzy" (or DL) model. The DL model has a more appealing appearance, but the WG model has crisper performance. Still another option is the "Piro-jette" (or PJ) model, which uses a wire-controlled Stealth Fighter (Radio Shack No. 60-2305). However, the wings of that model have a tendency to get stuck on obstacles.

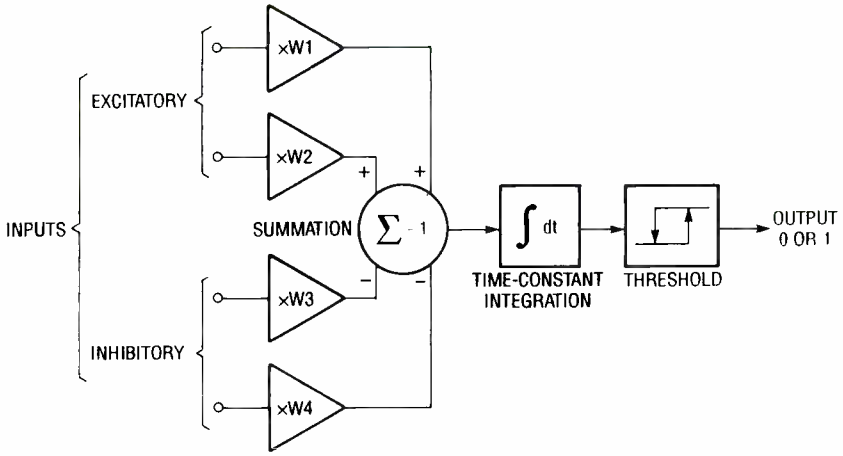

Fig. 4. A neuron receives input from other neurons and ascribes a certain amount of importance (weight) to each. Some weights are negative some positive. It then sums the overall value of the inputs, integrates them, and if the integrated value reaches a certain level the neuron outputs a one.

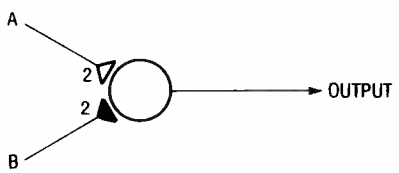

Fig. 5. This symbol of a neuron shows one excitatory input (A), one inhibitory input (B), the synapse (the circle), and the output. Both inputs have a weight of 2 as indicated.

Since the Whirligig is the technically best model, we'll be covering that one here. You can get further information on using the other bodies from the kit supplier mentioned in the Parts List. Unfortunately, your choice of model might be constrained by which toys your local store has in stock, although they may be able to order the model you want. In any event, most Radio Shack stores stock most of the toys during the holiday season.

For sensing, we'll use a single infrared proximity detector. That device works by emitting a beam of light then looking for a bright reflection. The sensor is able to "see" objects in an almond-shaped region about 3-inches wide by 12-inches long.

The implementation of the first behavior, explore, is trivial: we just run the robot's motor. The next behavior, avoid, is also fairly simple. If the obstacle detector senses anything, we run the robot's motor in reverse. This causes the creature to turn away from the stimulus.

However, for this to work, the obstacle sensor must be oriented properly: On one hand, it is important that the robot have some forward vision to avoid ramming into objects directly in its path. However, if the sensor points straight forward, the robot is likely to side-swipe obstacles. Therefore, we compromise and aim the sensor about 30° to the right of the robot's midline. That naturally makes the robot more sensitive to obstacles on the right; a sensible choice since our robot avoids things by turning left.

The last behavior, seek, is more difficult to instill in the robot. Unfortunately, we can't directly determine where the wall is and how to steer the robot toward it. The robot only looks in one direction, and anytime it sees something, it is programmed to turn until the sensor reading disappears. However, if the proximity detector is active a large percentage of the time, we can assume that the robot is still near obstacles. Open spaces, on the other hand, are characterized by the absence of any sensor readings.

That forms the basis for our seeking strategy: When the robot has not seen anything for awhile, it spins around in an attempt to locate the edge of the world again. Notice that if the new seek behavior is omitted, the creature will not turn back toward the wall, but in-

PARTS LIST FOR THE MURAMATOR

SEMICONDUCTORS
U1—LM339 quad comparator integrated circuit
D1—1N4001 rectifying diode (not used in the WG model)
D2–D11—1N914 small-signal diode
Q1, Q2—MPS2907 PNP transistor
Q3—TIL414 IR phototransistor
LED1—SEP8703-1 infrared emitting diode
LED2, LED3—Light-emitting diode

RESISTORS
(All fixed resistors are 5%, ¼-watt units.)
R1–R3—1-megohm
R4—470,000-ohm
R5–R7—220,000-ohm
R8, R9—100,000-ohm
R10–R14—47,000-ohm
R15, R16—10,000-ohm
R17–R20—1000-ohm
R21—330-ohm
R22–R23—1-megohm potentiometer

CAPACITORS
C1—4.7-µF, 35-WVDC, electrolytic
C2—0.1-µF ceramic disc
C3, C4—.01-µF metalized film
C5—470-pF metalized film
C6—22-µF, 35-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS.
K1—12-volt DPDT relay
S1—DPDT subminiature slide switch
S2—SPDT subminiature slide switch
B1—9-volt transistor-radio battery
B2, B3—1.5-volt C-cell battery
Printed-circuit board, wire-controlled skate board (Radio Shack No. 60-2298 or equivalent), 14-pin IC socket, 9-volt battery holder, 9-volt battery clip, 2 C-cell battery holder, wire, solder, etc.

A drilled and etched printed-circuit board with instructions is available for $25 (post paid) from Johuco Ltd., Box 390, Vernon, CT 06066. CT residents must add appropiate sales tax.

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stead it would zoom off into space. Since the robot avoids things by turning left, it has a good chance of finding things if it turns right instead. Yet, because our creature can only turn to the left, we must make a right turn the long way around. Thus, we generate a carefully timed burst of movement to yield approximately 270 degrees of rotation.

However, the creature is basically blind during a programmed turn, and may rotate all the way past the wall when seeking it. To fix this, as soon as the robot senses an object nearby, the seek circuit will be reset (*i.e.*, it will start measuring the amount of time it spends near objects again). That not only causes the robot to stop turning, it also synchronizes the unit so that it correctly measures the time since the last obstacle sighting.

Neurons. We have seen that it is not necessary to give a robot an explicit plan to perform action; instead, general rules suffice. This greatly reduces the complexity of the "nervous system" required. Typically, a set of ordered reflexes is adequate for simple navigation, but what mechanisms make these reflexes possible? In animals the answer is, of course, neurons. So, as a guide to implementing our "creature" electronically, let us see how real neurons work.

Neurons communicate via electrical/chemical impulses. To transmit a signal, one neuron releases a puff of a specific chemical across a gap (called a "synapse") toward the next neuron. The next neuron absorbs the chemical into one of its inputs (which consist of tree-like structures called "dendrites"). This substance briefly opens a number of ion channels in the receiving neuron's cell membrane, and the resulting flow of charge carriers causes it to act like a miniature battery.

The combined charges are funnelled back to the body of the cell (known as the "soma"). If enough dendrites are activated, the neuron gradually becomes more and more electrically charged. When there is enough accumulated potential, the neuron spontaneously generates its own series of impulses which travel down an output fiber (the "axon"). Eventually this signal impinges on the inputs of succeeding neurons and a similar series of events takes place.

A Neuron Model. Our model of a neuron takes into account all of these phenomena. As shown in Fig. 4, there are a number of inputs (like dendrites) that converge on a single "summation" node, which is similar to a neuron's soma. The summation node adds all the inputs and passes them to an integrator. The integrated signal is passed to a threshold unit that evaluates the signal to determine whether any output should be produced.

Our model also incorporates some other salient features of real neurons not yet mentioned. For instance, all the inputs are not treated the same. Each input is amplified by its own gain or "weight factor," which is represented by the amplifier symbols shown. In this way, inputs with a large weight factor will influence the neuron more than inputs with a small weight factor. This reflects the anatomical fact that certain synapses in animals are more transmissive than others.

In addition, we also show inputs with negative weights (the lower two inputs). These correspond to "inhibitory connections" often observed between actual neurons. They can suppress the action of neurons.

Another characteristic of neurons that our model contains can be called "leakage." You can think of a neuron as a tub being filled with water. There are a number of hoses of different sizes feeding into the tub (the excitatory inputs) as well as a number of drain spouts (the inhibitory inputs). After the tub (neuron) has filled up, it fires. However, once "full," the neuron would fire at the slightest input so the tub has built-in leakage to gradually drain the remaining water.

To reproduce this effect, the summation node contains a "−1" term. This is essentially an inhibitory input that is always on. When none of the other inputs are active, the sum is now negative so the integrated excitation always decreases toward zero. However, we never let the value of the integral go negative; we restrict the integrated excitation to be between 0 and 1 at all times. This reflects the fact that we can not fill a tub above its rim or drain it below its bottom.

Interestingly, while real neurons also have limits to the voltages that they can produce, the voltage can drop below the usual "rest voltage." In animals, it is possible, and sometimes computationally useful, to discharge a cell below this neutral level. Such a condition makes it harder for later inputs to trigger the neuron.

The final twist to our neural model is the nature of the threshold circuit. We use a device known as a "Schmitt trigger" instead of a simple comparator. This device has two thresholds, a high one for rising signals and a lower one for falling signals. In our neuron model, the output switches on when the value of the integrated excitation reaches 1. The neuron will continue to output a 1 until the integrated output descends to 0 again.

This is much like the thermostat in a typical house. If you set the temperature to 70°F, the furnace will not turn on until it gets as cold as 68°F or so. Then it will proceed to warm the house until the temperature slightly exceeds 70°F, say up to 72°, before shutting off. Although this feature is not totally accurate from a neurological point of view, it's a convenient feature to have.

Supplementary Reading.

Vehicles, Valentino Braitenburg, MIT Press, 1986.

Minimalist Mobile Robotics, Jonathan Connell, Academic Press, 1990.

Mind Children, Hans Moravec, Harvard University Press, 1988.

The Study of Instinct, N. Tinbergen, Oxford University Press, 1951.

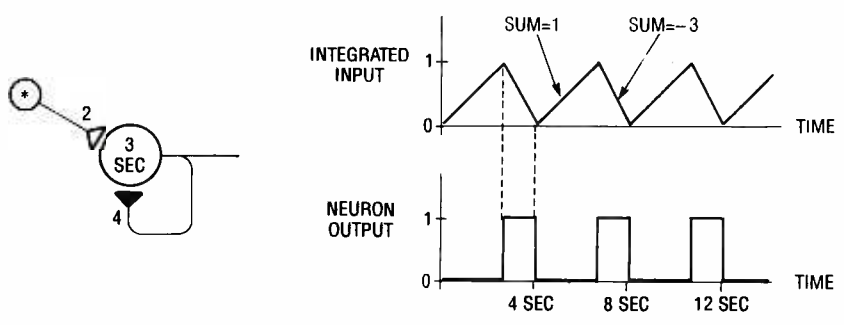

Fig. 6. The simple two-neuron system shown in A, can perform the operation of an oscillator. Its internal integration signal and final output are shown in B.

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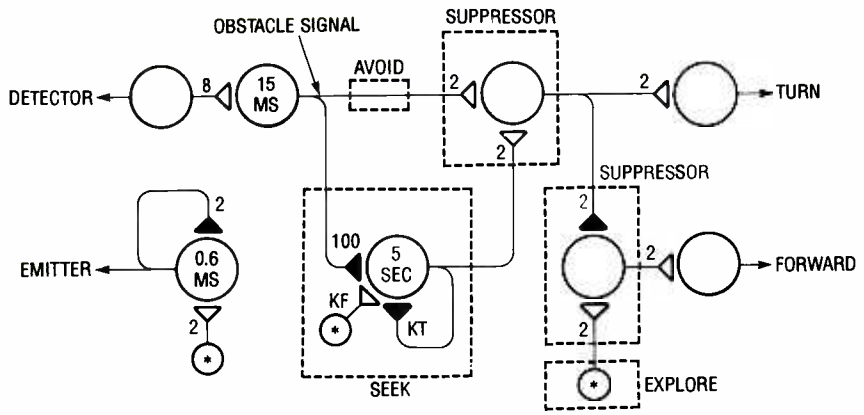

Fig. 7. The robot's 4-behavior activity can be emulated using 11 neurons. Can you find the two oscillators here? (Hint: look for feedback loops).

Neuron Examples. To see how such simulated neurons are used, consider the symbol shown in Fig. 5. Here, we depict the body of the neuron as a circle with an arrow coming out of it to represent the output. Input terminals are shaped like the bell of a trumpet and have their associated weight written next to them. White terminals are excitatory, whereas black ones are inhibitory. Since the structural details do not matter, we show all the inputs impinging directly on the cell body.

This neuron will only generate an output if input A is active and B is not. First, suppose neither A nor B is active. The input sum is:

$$0\times2 - 0\times3 - 1 = -1$$

(the last term comes from the leakage property of the model). This negative result causes the accumulated value inside the neuron (if any) to decay until the output switches to zero. Now suppose A comes on. The new sum is:

$$1\times2 - 0\times2 - 1 = +1$$

If we set the time constant of the neuron to be very short, the output will almost immediately switch to one. Finally, imagine that B comes on as well. The computed sum for this case is:

$$1\times2 - 1\times2 - 1 = -1$$

which forces the neuron to turn off.

A more complicated example is the oscillator shown in Fig. 6A. The central part of this configuration is similar to an AND-NOT gate. Here, the neuron itself supplies the inhibitory input, while another neuron provides excitation. The asterisk inside this auxiliary neuron indicates that it is of a special type that is always on. Assume that the central neuron's internal potential starts off at zero and that its output is off. The initial input sum is:

$$1\times2 - 0\times4 - 1 = +1$$

Thus, the integrated input starts climbing slowly as shown in the upper plot of Fig. 6B. The value written inside the neuron tells how long it takes for the neuron to fully charge with an input sum of 1. As can be seen, it takes 3 seconds for the integrated value to reach one.

Once the integral has reached the prescribed threshold level, the output of the neuron comes on. That is shown in the lower plot of Fig. 6B. However, this changes the overall sum sent to the integrator. It is now:

$$1\times2 - 1\times4 - 1 = -3$$

so the neuron's internal charge starts to decay. Yet, because of our special threshold stage, the neuron's output value remains at one until the integrator output again reaches 0. This happens one second after the output comes on. Once the output turns off, the whole cycle repeats.

As can be seen, the resulting output is a pulse train with a period of 4 seconds. The frequency of a cycle, as well as the width of the on and off portions, can be changed by adjusting the input weights because higher sums (whether positive or negative), alter the output in less time.

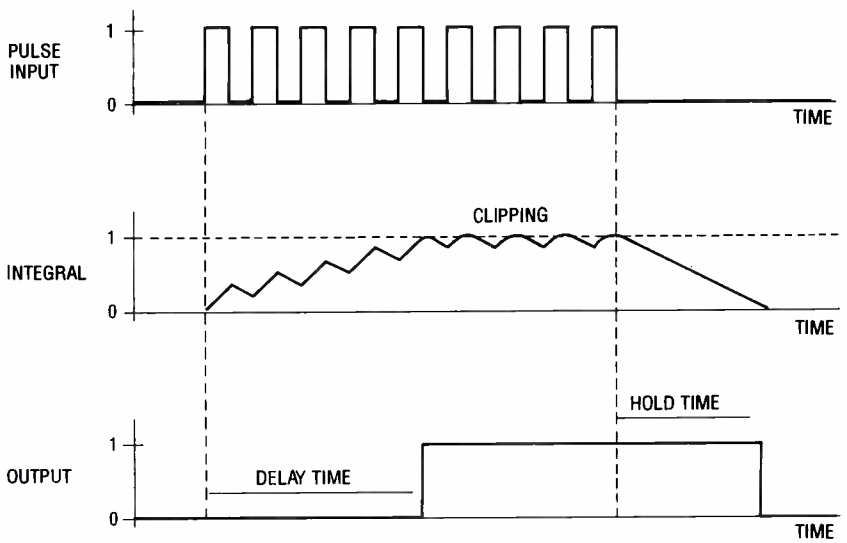

Fig. 8. Each detection of an infrared pulse (the top graph), causes the neuron to charge (middle graph). When the neuron reaches the threshold value, its output goes high and remains high till the neuron completely discharges (as shown by the bottom graph).

The Neural Network. The total collection of behaviors required for Muramator can be emulated by a network of 11 neurons as shown in Fig. 7. For motor control, the robot's brain has one neuron that drives the robot forward and another that causes it to turn. That makes the explore behavior easy to implement: a continuously active neuron provides input to the "forward" neuron. The activity of the avoid behavior is also simple: it just activates the "turn" neuron when the robot "sees" something. That is particularly easy since the appropriate obstacle-detection signal is directly available at the output of the neuron labeled "15 ms" (to be described later).

Notice that neither explore nor avoid is directly connected to the motor neurons. Instead, each sends its command via a single intermediate neuron. When designing large networks it is good practice to insert an "interneuron," such as this, to serve as an interface point where higher level signals can be injected. In this case, avoid indirectly suppresses the default forward drive by inhibiting the interneuron that would carry out the explore behavior. That blocks the forward behavior and allows the more important avoid module to substitute its own instructions. Tech-

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nically, the avoid circuit should really have two interneurons: one to generate the turn command and one to suppress the forward command. This arrangement would let us cascade suppressor nodes so that the most important behavior could suppress all the others with a single connection.

The third behavior, seek, is composed of two additional neurons. Neglecting the weight-100 input, we can see that the remaining structure is identical to the basic oscillator presented earlier. The output of this unit feeds directly into the avoid interneuron and thus causes the robot to turn. There is no interneuron involved in this pathway because there are no higher level behaviors that might need to suppress seek. An important feature of this module is that the weights of both the excitatory and inhibitory connections (KF and KT) of the oscillator can be varied. Adjusting the KT weight makes the output of the oscillator remain high longer and thus causes the robot to turn through a greater angle. Adjusting KF controls the interval between turns and thus determines the distance that the robot travels before spinning around to look for the wall again.

However, the creature is basically blind during one of these programmed turns, and may rotate all the way past the wall when seeking it! This is the reason for the inhibitory connection with a weight of 100. As soon as the robot senses an object nearby, the oscillator is turned off. This not only causes the robot to stop turning, it also synchronizes the unit so that it correctly measures the time since the last obstacle sighting.

The remaining four neurons form the proximity-detection subsystem. The neuron in the lower-left corner of the diagram is directly connected to the infrared emitter and generates the outgoing signal. That neuron functions as a simple oscillator and produces a symmetric square wave. It is necessary to modulate the infrared beam so the detector can differentiate it from ambient infrared sources such as sunlight.

Once the beam bounces off some target, the two neurons in the upper-left corner of the diagram are responsible for processing the returned signal. The first neuron in the chain represents the detector. It is "on" when infrared radiation is detected. Since it receives a series of pulses when the robot is near an object, the output of this neuron resembles the top plot of Fig. 8.

The next neuron smooths out this waveform. When the detector neuron is on, the input to the second neuron is:

$$1 \times 8 - 1 = +7$$

so the internal potential of this neuron increases. Between pulses the input sum is simply -1 and thus the potential slowly decays. The charging of the neuron is shown in the middle plot in Fig. 8. As can be seen, it takes several pulses to charge the neuron up to a high

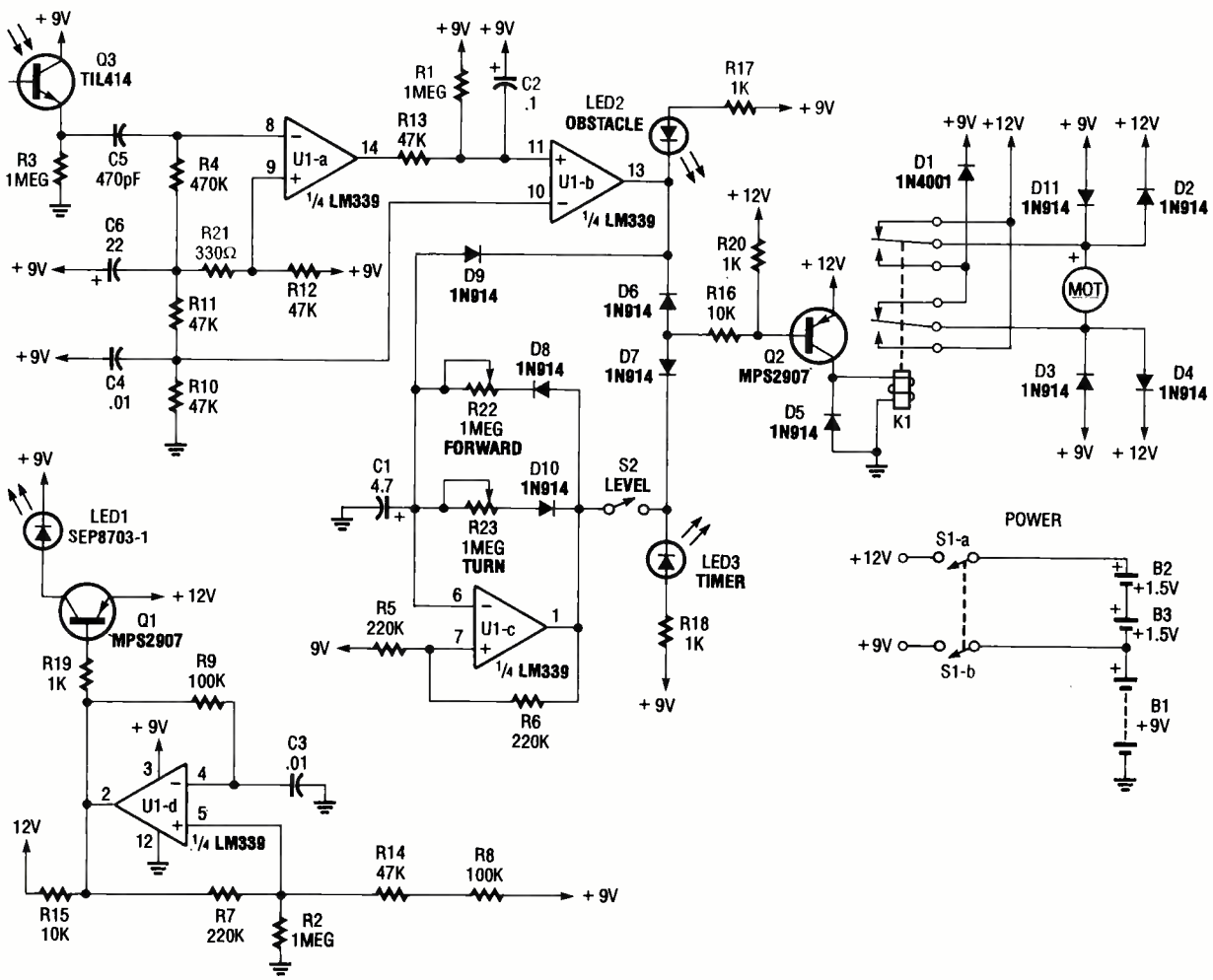

Fig. 9. All eleven of the robot's neurons are emulated by this circuit. Some neurons are based on comparators, while others are implemented with simple diodes.

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enough level to generate an output, which is shown in the bottom plot.

This is useful for rejecting noise pulses. Similarly, the slow decay constant allows the system to "fly-wheel" through signal dropouts: the output of the neuron will remain on for several cycles after the stimulus vanishes. This same phenomenon can also be used to artificially increase the size of the avoidance turns the creature makes.

Circuitry. The final step is to compile all of this into circuitry. The actual schematic for the creature is shown in Fig. 9. In terms of actual circuitry, the 11 neurons in our model are implemented in a number of different ways. Some are modelled with voltage comparators, some with diode logic, and some with electro-mechanical devices. Keep this in mind as we describe the electronics for each of the creature's component behaviors.

Let us start with the explore behavior module. The explore reflex is incorporated directly into the relay circuitry (right side of diagram). Normally the robot's motor is connected so it runs forward. However, whenever the relay is energized by Q2, the voltage applied to the motor is reversed and the creature turns instead. An extra diode, D1, can be inserted to slow the creature down, if necessary. The diodes around the motor (D2–D4, and D11) and across the relay's coil (D5) serve no behavioral function, they just clamp inductive spikes to the power-supply rails.

Thus, the explore neuron, the first suppressor, and the turn and forward neurons are all emulated in this piece of circuitry. The transistor for the relay can be considered the equivalent of the second suppressor node in the neural diagram, and diodes D6 and D7 act as the two excitatory connections to this interneuron.

The circuitry for the LED oscillator (see the lower-left corner of Fig. 9) corresponds directly to the neural model. Here, the feedback from a comparator's output to its positive input provides the "hysteresis" needed by our dual-threshold neural model, while the resistor and capacitor on the negative input form the required integrator. The 10k resistor to +12 volts mimics the action of the necessary always-on neuron. This arrangement generates a squarewave that is amplified by another MPS2907 transistor to drive the IR LED. That unit radiates infrared energy (much like a TV remote control) into the

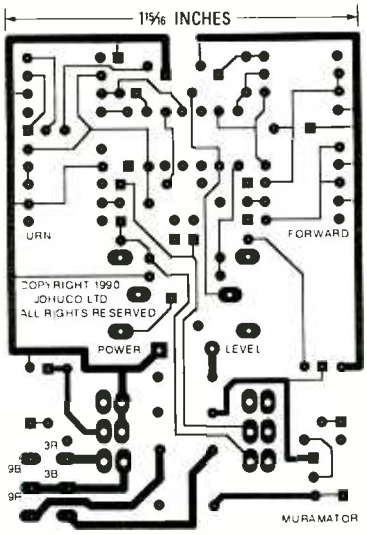

Fig. 10. This foil pattern is for the component side of the Muramator circuit board. The labels for the potentiometers and switches will help you use those controls.

environment, which then bounces off nearby objects.

The next behavior, avoid, switches the relay on using the signal from the infrared proximity detector. The circuitry for the detector is shown in the upper-left side of the diagram. The reflected IR signal biases a TIL414 phototransistor, which applies a small voltage across a 1-megohm resistor, R3. That signal is AC-coupled via a 470-pF capacitor into a simple threshold-detector formed by one section of the LM339 quad comparator. This is the "detector" neuron from the neural-network diagram. The capacitors on the voltage divider con-

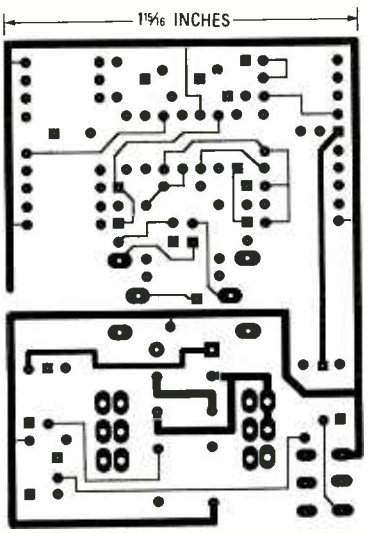

Fig. 11. This foil pattern for the solder side of the robot must be properly registered with the component-side pattern. Remember to connect all vias when the board is finished.

nected to the positive input of the comparator help stabilize the reference voltage against transients caused by switching the IR LED on and off, and operating the motor.

An inverted version of the obstacle-detection signal then enters a low-pass filter formed by R13 and C2. Since the LM339 has open-collector outputs, the decay rate of the voltage across C2 is governed solely by R1. It takes several pulses to discharge C2 sufficiently enough to generate an output. This is useful for rejecting noise pulses. As you'll see, the slow decay constant allows the obstacle-detection signal to remain on for a period of time after the stimulus vanishes. By substituting a larger value for C2, you can increase the size of the avoidance turns the "creature" makes.

The RC-filtered voltage enters U1-b, which also acts as a simple comparator. The threshold level for this unit is obtained from the same voltage divider used for the first stage. This comparator combined with the previously described low-pass filter corresponds to the second detection neuron. The total result of all this processing is a clean digital signal indicating when an obstacle is present. It is connected to a red LED that indicates when the robot is "seeing" something.

The last of the creature's behaviors, seek, is built from an oscillator similar to the one used to generate the IR beam. The oscillator has an active-low output: when pin 1 of U1-c is at zero volts, the robot should turn. Note that the oscillator's output is connected back to the integrating capacitor (C1) through two diodes. These diodes steer current through the potentiometers so that the top potentiometer controls the capacitor's charging time and the lower potentiometer controls the discharge rate.

Notice also that in the seek circuitry there is a diode (D9) descending from the obstacle-detection indicator, LED2. Since D9 has negligible resistance, it can "instantly" discharge capacitor C2 when the creature detects an obstacle. This connection models the weight-100 input in our neural design and is used to properly synchronize the oscillator as mentioned earlier.

The design also must have an arbiter that can combine the commands from each of the basic behaviors. To this end, both the seek oscillator and the avoid circuitry are connected to the relay's driver transistor through diodes D6 and D7. This arrangement is used to model

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the top "suppressor" neuron back in Fig. 7, as we mentioned earlier. Because both the obstacle detector and central oscillator have active-low outputs, these diodes form a logical OR gate. If the creature either sees something (LED2 turns on) or the turn timer kicks in (LED3 turns on), the relay will be activated and the creature will turn in place. The switch labelled "level" was installed to selectively disable the seek oscillator. That lets you investigate how the creature acts without this behavior. Of course the robot won't do anything at all unless its built, so let's get to that now.

Circuit Construction. Because of the complexity of the wiring, it is recommended that you use a printed-circuit board to wire the components together. For those of you that wish to make your own boards, the foil pattern for the component side of the board is shown in Fig. 10, and the foil-pattern for the other side is shown in Fig. 11. Since the board is double-sided, if you chose to make your own, you must solder tiny pieces of bus wire into the via holes and solder component leads to the pads on both sides of the board where applicable. Keep that in mind when soldering all components.

If you do not want to etch the circuit yourself, a drilled and etched plated-through printed-circuit board with instructions is available from the kit supplier mentioned in the Parts List.

With the board all ready to go, start by installing the 14-pin DIP socket at the location for U1 as shown in the parts-placement diagram of Fig. 12. Be sure to mount it and all the other components on the top side of the board (the side with the writing on it). Note that one end of the socket has a small notch. It should go toward the square pad on the printed-circuit board. Now flip the board over and solder its pins to the pads.

Now, guided by the parts-placement diagram, install the fixed resistors. Take each of the trimmer potentiometers and flatten the crinkles in its leads (if any) by squeezing the lead with needle-nose pliers. Now bend the two side leads of each potentiometer sharply downward away from the plastic adjustment dial. Next, gently bend the center lead of the potentiometer in the same direction. The bend should be made about halfway out from the body. Insert the potentiometers in the positions shown and solder them from

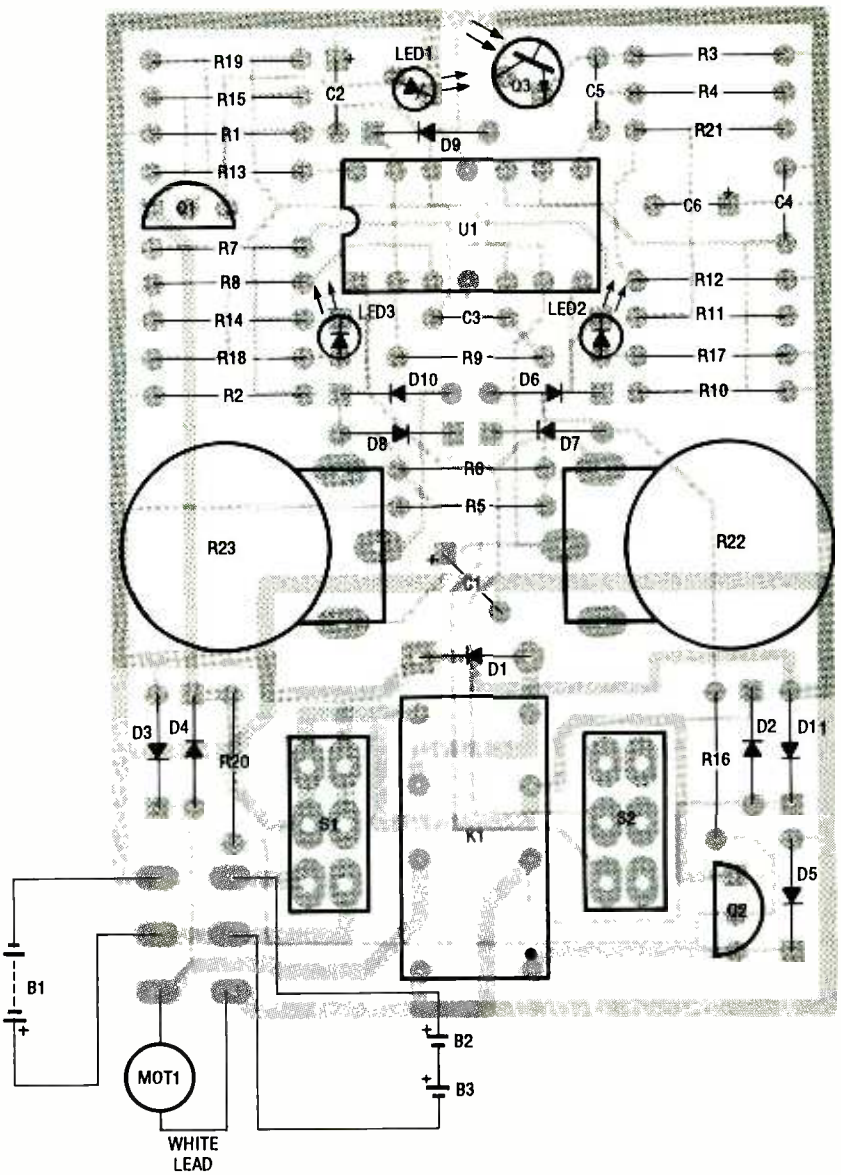

Fig. 12. Stuffing the board should be easy with this parts-placement diagram. Note that the pads for LED1 and Q3 are tilted at 30°.

the top of the board. Then turn the board over and apply more solder from the back side to completely fill the holes.

Next install, solder, and trim the ten 1N914 diodes and D1 in the places shown. Of course it is important to orient the diodes as illustrated.

The 0.01-μF and 470-pF capacitors can be installed with any orientation. However, C1, C2, and C6 are polarized so be sure to insert the positive lead of each capacitor into the square pad for the component. Once all the capacitors are installed, bend, solder, and trim their leads.

The orientation of the transistors is important. Insert them positioned as shown in the parts-placement diagram. Sometimes the transistors come in a metal case rather than plastic. For this type, insert the device so that the lead closest to the tab on the case goes into the square pad.

Next install and solder the DPDT relay. The two plain LED's go near the corners of the 14-pin socket and should be installed next with the proper orientation.

Now, install the switches on the top side of the board. Do not push them completely down to the board, instead leave a tiny air gap under each switch to prevent the case from shorting out any of the copper traces nearby.

Cut a ⅜-inch by ¾-inch wide piece of black electrical tape and wrap it around the body of the TIL414 phototransistor. It should be used to cover

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only the sides of the component leaving the rounded end exposed. Install and bend the leads of the IR devices so that the body of each one lies along the surface of the board. Note that the orientation of the holes will place them at a 30° angle with the centerline of the board.

Next insert the LM339 integrated circuit into the socket with pin 1 oriented near the square solder pad used for the socket.

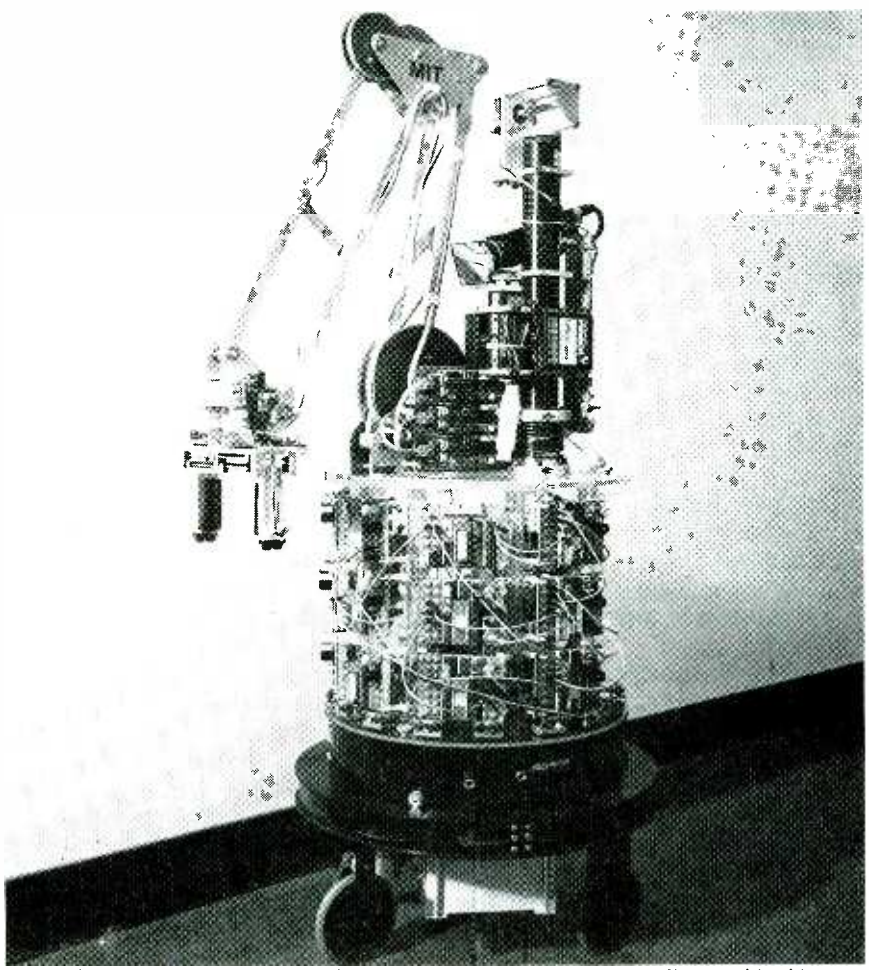
Take a 9-volt battery snap-on connector and cut its wires down to 4 inches. Strip and tin the ends and solder the wires into the lower-left corner of the board. The red wire should go into the hole marked "9R" and the black wire should go in the hole marked "9B."

If the C-cell holder you get has no leads of its own, you will have to add them. You can use a 3-inch section of the toy's wire-control cable for that. Strip and tin both ends of the two wires you use and attach them to the terminals on the holder.

If your battery holder has leads, then trim them to 3 inches, and strip and tin the ends. Whether initially present or not, attach the lead from the positive terminal to the pad marked "3R," and connect the negative lead to the pad labelled "3B."

Checking the Circuit Board. Now that all the components have been installed, double check to ensure that everything is in the right place and oriented in the correct direction. Look for the dark bands on the diodes, the flattened rims of the LED's, the markings on the capacitors, the notched end of the chip, and the flat sides of the transistors.

Now turn the board over and check all the solder joints. Except for 2 holes in the lower-left corner of the board, all holes should have something soldered into them. Check to make sure that all the leads are securely soldered in place. Also make sure you have used enough solder on each joint—you should not be able to see the edge of the hole underneath.



This robot was designed and built by the author using the principles discussed in this article. Named Herbert and seen on PBS's "Discover" program, its function is to collect empty beverage cans.

Also check the bottom of the board for solder bridges. There is only one place on the board where adjacent pads should be connected: beneath two terminals of the power switch. If any other two pins have a blob of solder between them, remove it by heating the bridge then tapping the board against the table. If you find any other suspicious-looking connections, heat them up to see if they are actually mistakes.

Electrical Tests. Now it is time to test the basic operation of the board so install the batteries. Start with the power switch down (away from the potentiometers), and the level switch up. In a dark room, you should see a dim orange glow inside the IR emitter. If you don't, check the orientation of the IR LED and the transistor at the top of the board.

Now put your hand in front of the IR components. The obstacle LED should come on and go off again when you move your hand away. If it doesn't, check to be sure the LM339 is inserted properly and that C2 is connected with the correct polarity. If the LED lights at the wrong time, check its orientation. You should also hear the relay click every time the LED changes state. If not, check the orientation of Q2 and D5; those are located in the lower-right corner of the board.

Next, adjust both potentiometers so that they are in the middle of their ranges (arrows point toward the left and right edges of the board) and then move the Level switch down. The timer LED should now blink periodically and the relay should click. If the light doesn't blink, check that the LM339 chip is inserted properly. If there are no clicks, check the orientation of the diodes near the center of the board. Next, test whether rotating the turn potentiometer adjusts how long the light stays on. Also test to find out whether adjusting the forward knob controls how long it is between blinks. If these controls seem reversed, check the orientation of the timer LED.

Finally, test the synchronization. When the timer LED is on, move your hand into the detector's field of view. The timer indicator should immediately go out and stay off until you move your hand away and the obstacle indication disappears. If not, check the orientation of the diodes near the center of the board and look for possible cracks in them.

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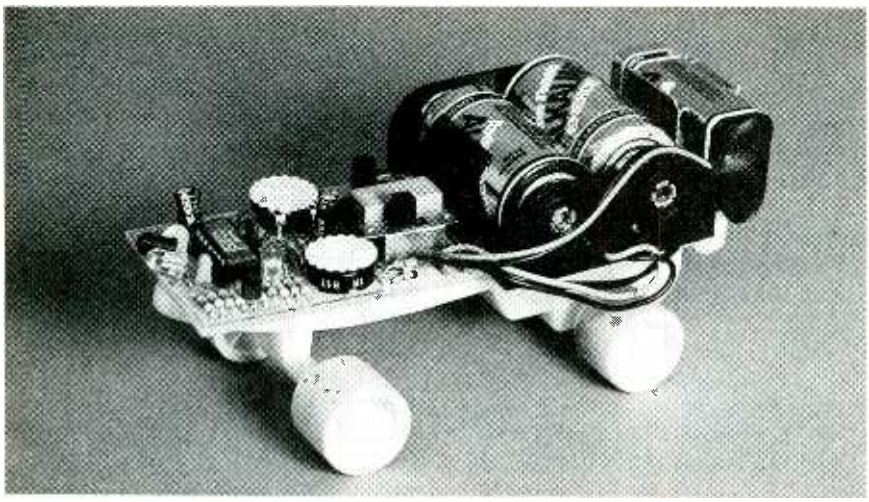

Meet Muramator, the simple 11 neuron robot described in the article. The version shown here is built on the Radio Shack Skateboard chassis.

Final Assembly and Calibration. The circuitry as well as the appropriate batteries now need to be mounted on the robot's body. Start by removing the human figure from the top of the skateboard. It is held on by two screws through its feet. To get to the screws, turn the vehicle over then remove the 3 screws that hold the rear wheel assembly onto the board. After removing the figure, reassemble the vehicle being careful to keep the white plastic gears firmly seated in their slots.

Next cut the wire-control cable at about 6-inches from where it exits the back of the board. Strip and tin the ends and solder them into the circuit board. The one with the white streak should go to the hole near the center of the board while the other wire should go to the hole in the corner. Now use double-sided foam tape to mount the U-shaped metal battery clip to the rear of the board.

Affix the C-cell holder to the skateboard directly in front of the 9V battery clip using double-sided foam tape. As the last step, use an elastic band to secure the circuit board to the vehicle. The rubberband is only a temporary restraint; once you are sure that everything works properly, you can use a piece of double-sided foam tape instead.

Once the electronics are mounted on the robot, it is necessary to calibrate the "creature." Carefully align the two IR components so that they point exactly parallel to each other and about 30° off the centerline of the robot body. Then turn the robot on and place it on the floor. Check to see that the robot runs forward when it is in an open space. If the obstacle-detection indicator is always on when you put the robot on the floor, tilt the IR components slightly upwards until the light goes off. Next, hold the robot and move it to within 8-inches of an obstacle. Verify that the obstacle LED lights up and that the robot's motor runs in reverse.

Experiments. If you now let the "beast" loose. It should try to avoid things in its path. Muramator works best on wood or smooth tiled floors—it has a hard time plowing through carpeting. If the "creature" seems to lurch a lot or has trouble turning, shift the batteries around to change its balance.

You might try designing an experimental obstacle course for the vehicle to see what it can and cannot do. For instance, with the seek switch off if the robot encounters an obstacle that juts out, such as a convex corner, it will swerve away from it, but never come back toward it. That happens because the robot has no memory of which direction it was travelling so it cannot get back on track. You might also want to try changing the direction of the IR components, or purposely mis-align them, to see how these parameters alter the creature's behavior.

Switch in the second layer of control by sliding the Level switch on. Start with both potentiometers midway through their ranges. If you keep Muramator in a large open area, the timer LED should flash at regular intervals. When this light is on, the robot should perform some sort of spin. Once the circuitry appears to be working properly, adjust the Forward potentiometer until the robot goes about 8 inches between turns. Then adjust the Turn potentiometer so that the robot makes about ¾ of a revolution (270°) every time it turns. Muramator will now not only avoid objects, but turn around if it hasn't seen anything in a while. Together, these reflexes cause it to follow along walls and to circle any post-like object it sees.

Changing the values of the two potentiometers can produce noticeably different results. Note that if the turn timer is set for too long an interval, the robot will only regain the wall after a number of turns. If the obstacle had been a post rather than a corner, the robot might not have found it again at all. On the other hand, consider the scenario in which the travel distance is set too long; the robot may wander way off into the middle of the room when it encounters a corner. The first travel leg after an avoid turn is often longer than the succeeding ones. Thus, even though the robot heads back in the right direction, it will be too far away to see the wall again. Yet this can be a useful feature in a world with more than one robot because corners then become a natural meeting place for the "creatures."

Another interesting test involves two identical vehicles. If you set the travel distances very short with the turn angle at 180°, and send the two robots head-to-head, they will veer off from each other and then turn around for another pass. Robot jousting! It helps if you cover both opponents with commercially available Scotchlite retro-reflective tape. This increases the sighting distance for other robots to about 18 inches. To achieve the maximum range, make sure each robot's infrared beam is pointing level with respect to the floor. This is just one example of how robots can interact with each other. With a larger number of individuals, there maybe other interesting possibilities as well.

We have now progressed from a vague concept to an actual working robot. This transformation was made by applying the methodology of breaking an activity into component behaviors. We codified these behaviors as simple situation-action rules and finally cast the rules into circuitry based on a simple neural model. These same steps can be applied to other creatures with other behaviors. You might try designing some yourself, at least on paper. Incrementally extending this line of research to larger, more complex creatures is a promising path for developing a deeper understanding of how the human mind itself works. ■

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Build a LAVA LAMP

Watching the hypnotic motion of a Lava Lamp is fun, but did you ever wonder how one works? Here's the answer, and a guide that shows you how you can build one yourself.

BY RALPH HUBSCHER

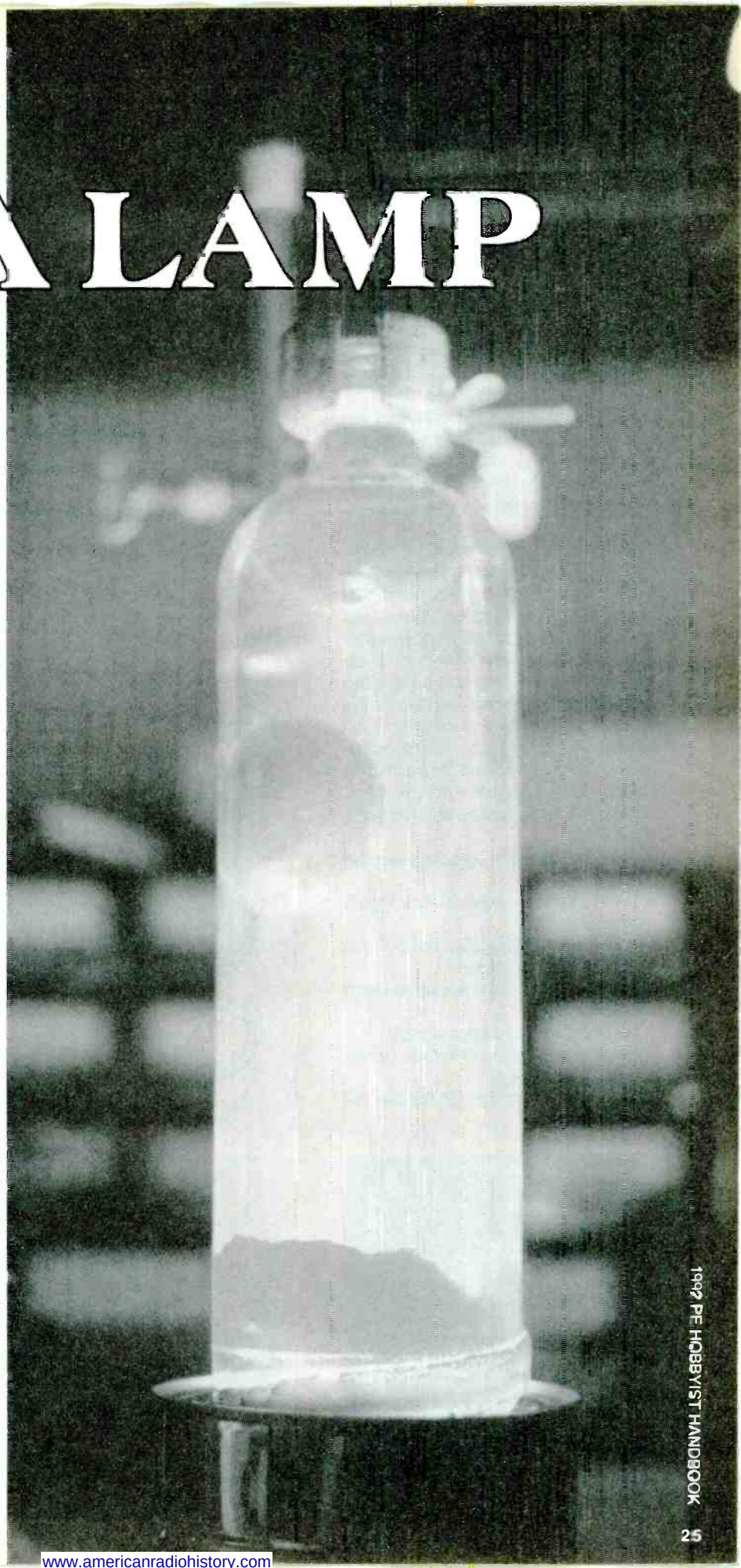
While hiking in the mountains this past summer, I stopped at a small restaurant for a spot of refreshment. I wound up with more, however; I left with an idea.

The owner had a unique decorating scheme, but what caught my attention were the decorative, table-lamp like devices that occupied each table in the establishment. They consisted of a cylinder-shaped bottle with a very short neck. In it, one red liquid moved leisurely up and down in a second, colorless liquid. The bottle was mounted on a stand and illuminated, and a decorative roof-like cap hid the bottle cap.

The red liquid bulged, formed bubbles and balls which rose very slowly and changed shape. Near the surface they sometimes coalesced with other balls, but always sank, only to go through the routine again. It was quite a spectacle and, like watching fish in an aquarium, you could look for hours.

Of course, the lamps were versions of the "Lava Lamp" that was so popular in the late 1960's and early 1970's. But as that psychedelic age faded, so did the lamp's popularity. Eventually, they were consigned to the farthest corners of closets or dark recesses of musty curio shops.

While Lava Lamps have made a bit of a comeback of late, why buy something when building one presents more of a challenge, and a lot more fun? I



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decided that I'd try to figure out how they were made and build my own.

What's Inside a Lava Lamp? Examining the lamp, a few facts became clear. Obviously two immiscible fluids had been poured together, one of them dyed for contrast, and heat was applied at the bottom to make the bottom liquid warm up and expand. When expanded, that liquid's specific gravity is lower, and therefore it tends to move upward to where it is cooler. Once the liquid reaches the top of the container, it cools off, becomes heavier again, and starts sinking towards the bottom and the source of heat. The source of heat is the light bulb that illuminates the vessel containing the two fluids.

The first thing that must be determined is the nature of the liquids. I started out assuming the transparent fluid was water. The second fluid looked like SAE 50 motor oil, but oils float on water while this liquid sank, so it had to be something else. I remembered reading about some imported devices of this type and that they contained poisonous and dangerous chlorinated hydrocarbons. I looked through the Handbook of Chemistry to get alternate ideas, and made a list of requirements.

Assuming fluid 1 is water, the second fluid should:

- be insoluble in water, so the liquids remain separate
- be heavier than water, but not too heavy, in order to just sink
- not be emulsifiable in water so that it separates rapidly
- be non-flammable (for safety)
- be compatible with water (some substances will react)
- be stable in air (an air bubble remains on top)

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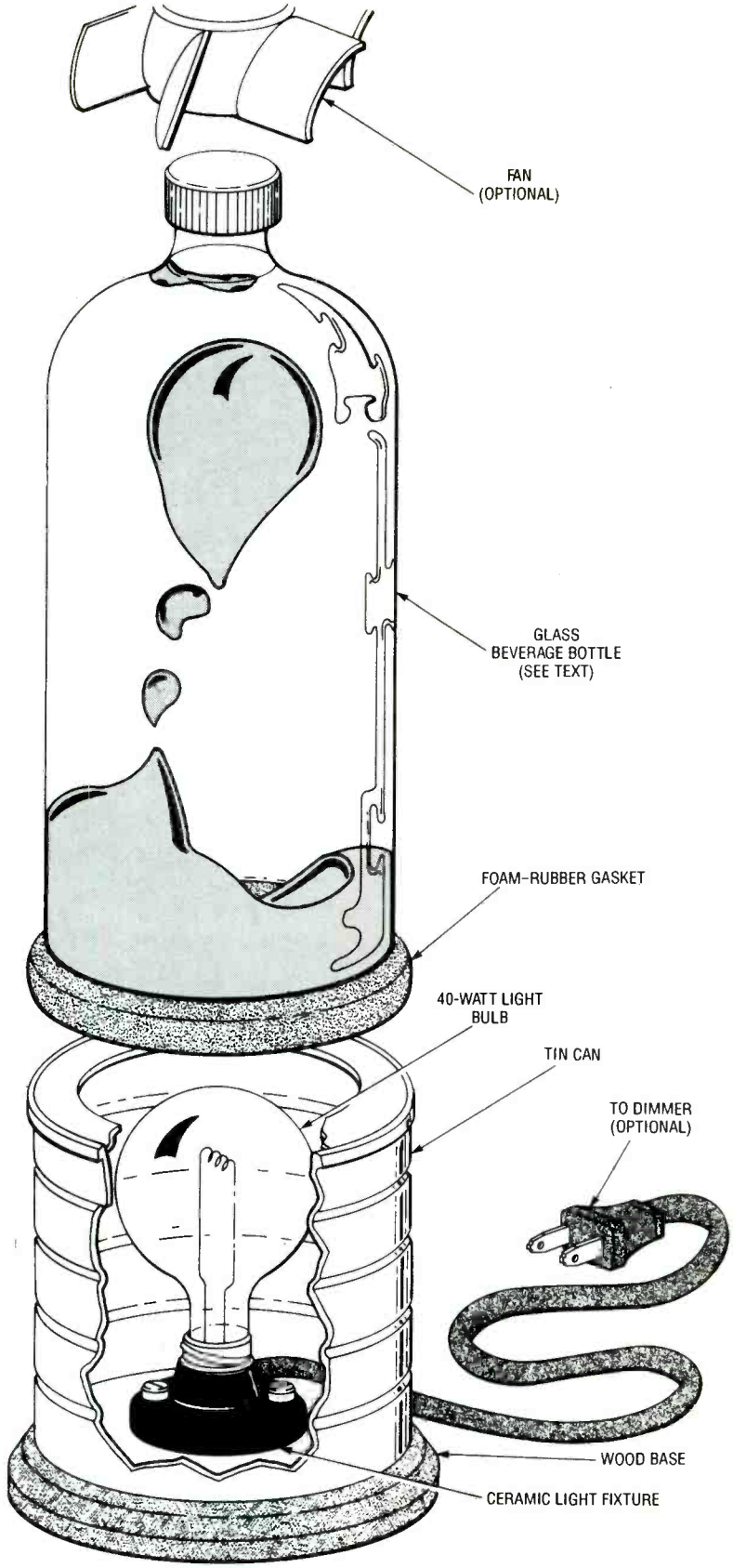

Fig. 1. Here are the major components of the Lava Lamp. Heat from the light bulb warms the benzyl alcohol in the glass container, causing bubbles to rise to the top, where they cool and eventually drift downward again.

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- not be very poisonous (in case of breakage)
- not be chlorinated (in case of breakage)
- have a high boiling point (in case of breakage)
- be somewhat viscous so as to form "oily" bubbles
- be reasonably priced
- have a greater coefficient of expansion than water

That list of requirements is quite demanding. In fact, as any chemists out there will quickly realize, it eliminates about 999 out of 1000 possible compounds. After a thorough search, I came up with four chemicals which might be worth a try, but none of them were without a question mark. The list can be found in Table 1.

MATERIALS LIST FOR THE LAVA LAMP

Benzyl alcohol
Water
Table salt
Glass beverage bottle, 10-inches or taller
Tin can, pint-size or larger
Plywood (see text)
Foam rubber, ¼-inch (approximate) thickness
Ceramic light fixture
Light bulb, 40 watts
Rubber grommet, AC plug with line cord, small fan (optional, see text), light dimmer (optional, see text), hardware, etc.

PARTS LIST FOR THE LIGHT DIMMER

TR1—ECG 5603, NTE 5603, 2N6071, or equivalent Triac
D1—ECG 6408, NTE 6408, or equivalent Diac
R1—3000-ohm, ¼-watt, 5% resistor
R2—500,000-ohm potentiometer
C1—0.1-μF, ceramic-disc capacitor
SO1—AC socket
PL1—AC plug with line cord
F1—5-amp fuse
S1—SPST switch
Wire, solder, hardware, etc.

Looking that list over, I decided to try benzyl alcohol. That substance, as well as the rest of the chemicals mentioned in this article, can be obtained through just about any reasonably stocked chemical supply house (check your local telephone book). Although benzyl alcohol is a little more soluble in water than the rest of the chemicals that are listed in Table 1, it seemed to work well so I stayed with it.

TABLE 1—CHEMICAL CHARACTERISTICS

Chemical	Specific Gravity	Boiling Point (°C)	Solubility in Water
Benzyl alcohol	1.043	204.7	slightly soluble
Cinnamyl alcohol	1.04	257.5	slightly soluble
Diethyl phthalate	1.121	298	insoluble
Ethyl salicylate	1.13	233	insoluble

TABLE 2—SALT CONCENTRATIONS

% Salt	Specific Gravity
1	1.0053
2	1.0125
4	1.0268
5	1.0341
6	1.0413

Before we proceed, some words of caution are in order: **While benzyl alcohol is a relatively harmless chemical, all chemicals are poisonous to one degree or another—you can kill yourself with salt. Of course, you must not drink it and skin contact should be avoided, if possible. Further, if benzyl alcohol should get into your eyes, wash it out with plenty of water while you hold your eye open using both hands, and then call a physician immediately! Finally, breathing benzyl alcohol should be avoided, (although it has such a high boiling point that hardly any of it evaporates).** By the way, the oxidation products of benzyl alcohol—beuzaldehyde and beuzoic acid—are used as food additives, specifically as artificial almond flavoring and as a preservative, respectively.

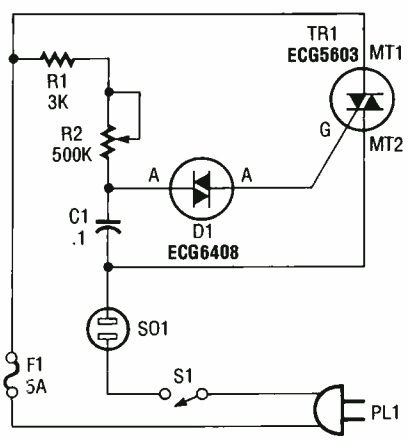

Fig. 2. Using a light dimmer is one way to control the amount of heat applied to the Lava Lamp. Nearly any dimmer circuit, including the one shown here, can be used.

A suitable red oil-soluble dye was found quickly. An old red felt pen was cut up (without spillage) and the dye-containing felt strip in it was placed in a jar with some benzyl alcohol. The dye was an excellent choice. It was stable in air and light, and insoluble in water—just perfect.

The red-dyed benzyl alcohol was then poured into a heat-resistant beaker, water was added, and the blend was heated on a hot plate. Nothing happened! Apparently, the specific gravities of the two liquids were too far apart and the liquids simply stayed where they were originally. I decided to try adding sodium chloride (table salt) to the water to increase its specific gravity. Table salt's affect on the specific gravity of water is shown in Table 2.

My initial tests showed that 5% and 6% salt concentrations were too high—the benzyl alcohol just floats to the top when heated and stays there. But a 4.8% salt solution worked fine. To get that concentration, I dissolved 48 grams of salt and filled up a container to 1 liter.

I now had all the components for my Lava Lamp. Benzyl alcohol (specific gravity 1.043 g/cm^3) settles on the bottom of the vessel filled with a 4.8% salt-water (brine) solution (specific gravity approximately 1.032g/cm^3). When the vessel is heated, the benzyl alcohol expands enough to become lighter than the brine and red bubbles rise to the top. There, the bubbles cool off, become heavier than the brine again, and sink. The cycle then repeats.

Construction Details. The first step is to find a suitable vessel. Use a glass beverage bottle shaped roughly as

(Continued on page 109)

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Explore the ins and outs of speaker crossovers and learn how to custom design your own speakers.

How to Design Your

I know a young man who had inherited some speakers from his girlfriend and decided that they would make a great addition to his car's stereo system. Shoving all the empty Coke cans aside, he squeezed the boxes into his back seat (which they filled). Naturally any speaker *that* big must be able to handle lots of power, so he didn't hesitate to connect the leads to his 200-watt power booster. Almost immediately after cranking the volume up until no lyrics were distinguishable, a "pop" occurred. It was barely audible over the music, but after that the speakers didn't sound so good.

He opened up one of the speaker cabinets and exclaimed "Hey, what's this fuzzy stuff all over the inside of my speaker cabinet, and why doesn't the little speaker work?" Well, the fuzzy stuff was the remains of a crossover capacitor whose voltage rating had been seriously exceeded. By exploding, it had in fact nobly saved the tweeters. Whether they were worth saving is another question.

The capacitor was used as a simple "crossover network" (commonly called just a crossover.) In this article we'll explore why crossovers are used and how you can design one of your own to suit your specific needs. Hopefully by the end, you'll be able to avoid the catastrophe my young friend experienced.

Why Use Crossovers? It was discovered very early that a wide range of frequencies can be reproduced more effectively if that range is split up among several different speakers, each optimized for its particular portion of the range. The first generation of speakers taking advantage of the concept contained a woofer for low frequencies and a tweeter for highs. Next, a midrange driver was added. That driver was sometimes called a squawker, because of its sound quality if used alone. For some reason, the name didn't appeal to Madison Avenue. Since the introduction of the third speaker, four- and five-way systems have been introduced, though, as Paul Klipsch pointed out, "with no resulting additions to the nomenclature."

What these systems really needed was a crossover network. The job of a "crossover" is to split the electrical energy among the various speakers. A woofer is fed through a low-pass filter that, as you might guess, passes low frequencies and rejects highs. The tweeter is fed through a high-pass filter that rejects low frequencies. If one or more midrange speakers are used, they are fed through band-pass filters that pass only a certain band of frequencies, rejecting higher and lower ones. Usually, a band-pass filter is just a high-pass filter followed by a low-pass filter, so there are really only two types of circuits that we need examine.

There are three reasons why a crossover is needed: The first is simple efficiency—why waste high-frequency power by applying it to a speaker that can't reproduce highs?

The second, and more important reason, is to protect the midrange and tweeter from damage. Since our ears are more sensitive to high frequencies than to lows, low-frequency sounds (and signals) must be endowed with more energy to be heard. The extra power given to the lows can be easily handled by a woofer, since it has a characteristicly high mass, but it could damage smaller midrange and tweeter drivers.

The final reason is to improve the frequency response as much as possible. Many drivers have very irregular response, sometimes with large peaks in response outside their desired frequency range. For example, many woofers have large peaks at around 1500 to 3000 Hz. A crossover can ensure that energy above, say, 1200 Hz will be delivered to a midrange or tweeter, but not to the woofer.

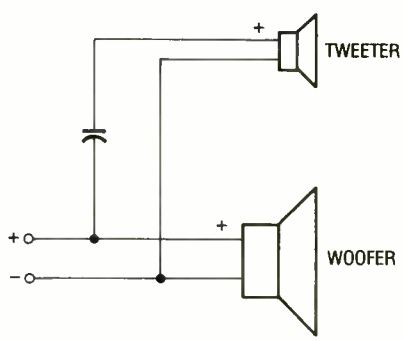

Fig. 1. A simple capacitive crossover can protect a tweeter from damage.

The Simplest Crossover. A crossover usually consists of very simple circuitry. The simplest crossover network uses no low-pass filter at all, and only a capacitor for the high-pass filter. Such a network is shown in Fig. 1. My friend's freebie speakers were of this kind. A capacitor's reactance is inversely proportional to frequency, according to the formula:

$$X_C = \frac{1}{2\pi fC}$$

where f is the frequency and C is the capacitance in farads. Since reactance limits the alternating current, and capacitors have a high reactance at low frequencies, the capacitor does not allow much low-frequency current to flow to the tweeter. The so-called "crossover frequency" is the frequency at which the capacitive reactance equals the tweeter's impedance. Thus we can find the needed capacitor value by substituting the tweeter impedance Z_T into the previous equation and solving for C as follows:

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Own Speakers

$$C = \frac{1}{2\pi f Z_T}$$

You can use this equation to find the size capacitor you need, or you can use the graph shown in Fig. 2.

There is a "gotcha", though, even in this simple design, and we may as well deal with it now. Speaker impedance is not constant with frequency. Therefore, your "8-ohm" speaker may have an impedance of 10 or 12 ohms or more at the crossover frequency. Thus you must determine the speaker's impedance at that frequency.

Fortunately, there's an easy way to measure the speaker's impedance. All you need is a signal generator, a voltmeter, and an ammeter. If you don't have an ammeter you can use a 1k resistor and a voltmeter instead.

The test setup with the ammeter is shown in Fig. 3A. After wiring up the circuit, you adjust the audio generator to produce the desired crossover frequency, and read the voltage and current from the meters. The impedance will be the voltage divided by the current.

The setup without the ammeter is shown in Fig. 3B. You adjust the audio generator as before and read the voltages as shown. To determine the impedance divide the value of the voltage across the speaker (V_s) by the resistor voltage (V_r) and multiply by 1000.

We are not quite through yet: When you go looking for capacitors at your local electronic emporium, you'll find that you need to know more than just the value. There's a voltage rating to be reckoned with, too. The rating you choose will determine the maximum power that your system can handle. The voltage can be calculated by using:

$$V = \sqrt{2PZ}$$

where P is the maximum power your amplifier can produce, and Z is the highest speaker impedance into which the amplifier can produce full power (usually 8 ohms for home stereos and 4 ohms for car units). Alternatively, you can read the voltage from Fig. 4. I always buy at least 100-WVDC capacitors, allowing a theoretical maximum of a 600-watt amplifier. That provides a comfortable safety margin.

Another choice you'll have is the type of capacitor. The cheapest way to go is to use a non-polar electrolytic. Standard electrolytics, including Tantalums, require a DC polarizing voltage, but a non-polar electrolytic has two standard units inside, connected "back-to-back" (*i.e.* the two positive leads connected together).

Many smaller stores have only polarized units, especially in values above about 2 μF, but you can make a non-polar capacitor by wiring two polarized capacitors back to back as mentioned. Each capacitor must have twice the capacitance that you want the non-polar unit to have.

While electrolytic capacitors can be used in crossovers, they do have a tendency to soak up some of the speaker's power at high frequencies, so that you don't get maximum performance from the tweeter. The technical name for that fault is "dielectric absorption."

Polyester film capacitors, or better yet, polypropylene film units, have almost no dielectric hysteresis loss in the audio range. The difference between electrolytics and film capacitors is audible, unless you've sacrificed your hearing to too much loud stuff.

They are available in values up to about 12 μF, and they can be wired in parallel to obtain larger values. (Capacitor values add when capacitors are wired parallel to one another.) In fact, if the values you need are over 6 μF, it's often cheaper to buy smaller capacitors and parallel them than to buy a single large unit.

Adding a Low-Pass Filter. If you choose to add a low-pass filter for the woofer, it can be just a simple coil (or inductor). A coil's reactance is proportional to the frequency it handles:

$$X_L = 2\pi f L$$

where L is the inductance in henrys. Putting a coil in series with the woofer causes the woofer to get progressively less power as the frequency is increased. The correct coil inductance can be found by using:

$$L = \frac{Z_W}{2\pi f}$$

where Z_W is the woofer impedance at the crossover frequency. Alternatively, you can use the chart in Fig. 5. The circuit with the coil added is shown in Fig. 6.

Coils can be bought at many electronics stores and from mail-order houses. Again, you have some choices

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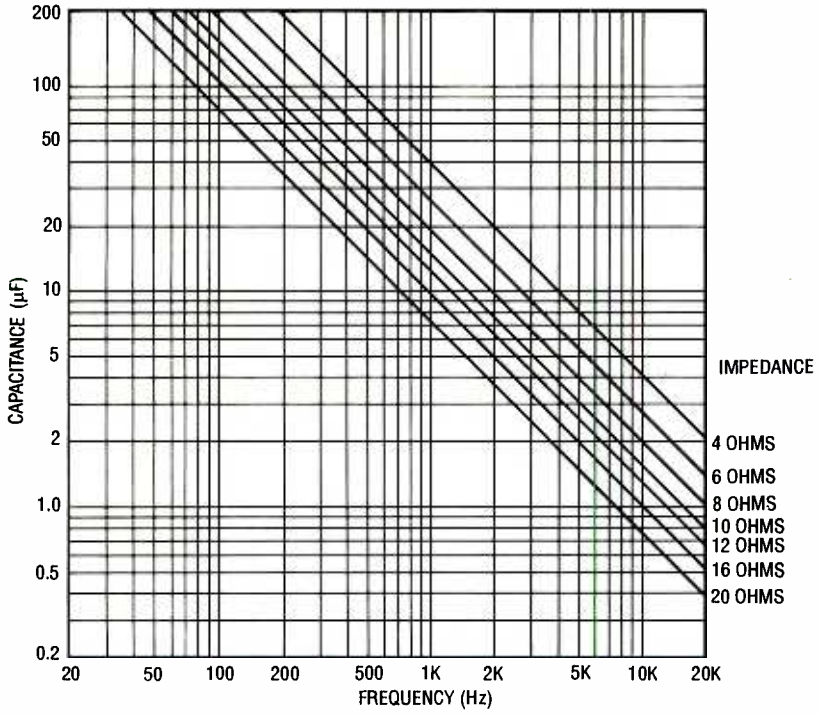

Fig. 2. Select capacitor values for two-way speaker systems from this easy-to-use graph.

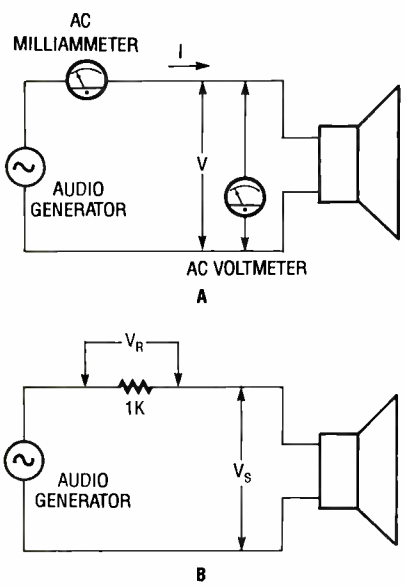

Fig. 3. Measuring speaker impedance is easy. You only need a signal generator, a voltmeter, and an ammeter (A). If you don't have an ammeter, you can use a resistor and voltmeter instead (B).

to make, the first of which is whether you want to use an iron- or air-core coil. Iron-core coils are commonly available because it takes fewer turns of wire to make them. Unfortunately, the magnetic characteristics of iron are not very linear, so those coils introduce some distortion. However, in a well-designed iron-core coil the distortion will usually be under 1% or so, as long as you do not exceed the rated power. However, at excessive power levels, an iron-core coil will make your system sound really raunchy.

Your other choice is to use an air-core coil. They do not introduce distortion, but unless large enough wire is used to wind them, they can degrade your system's damping factor. (For a discussion of damping factor, check out a copy of Howard Tremaine's *Audio Cyclopedia*, published by Howard W. Sams, from your local library.) Figure 7 indicates the minimum wire gauge that is suitable for coils of various inductances, assuming a nominal 8-ohm speaker. For a 4-ohm speaker, use coils wound with wire three sizes larger. The graph is based on a coil resistance that is not over 5% of the speaker's DC resistance (*e.g.* 0.3 ohm for an 8-ohm speaker with a 6-ohm DC resistance).

Unlike the capacitor (unless you're *really* adventurous), a coil is a component that you can make from scratch. Being able to "roll your own" is only an advantage if you can't find the value you need; it may not be a good way to save money. You see, copper "magnet wire" for winding coils costs roughly one-fifth as much when bought in 50-lb bails as it does when bought a pound at a time. So a coil maker can sell you a prewound, tested coil at a healthy profit while still charging you no more than you would have to pay for the wire alone, unless you have a friend who's into motor rewinding. (Those are the guys who buy most of the 50-lb bails.) How to wind crossover coils is a subject for another article, though.

The frequency response of a simple coil-and-capacitor crossover network is shown in Fig. 8. Notice that at frequencies a little beyond the crossover frequency, the response falls off at a rate of 6-dB-per-octave (an octave is a dou-

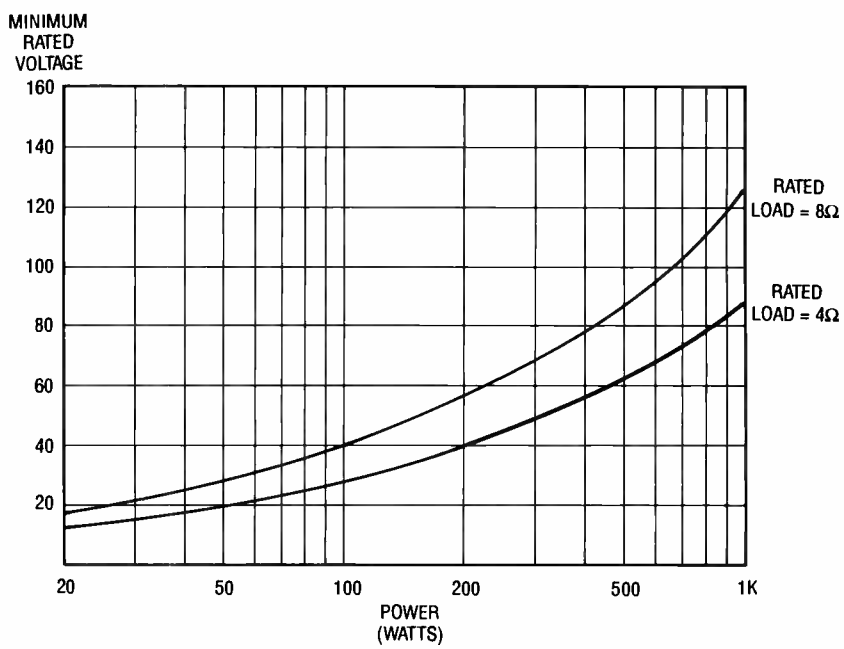

Fig. 4. You can determine the capacitor voltage rating if you know your amplifier's maximum output power by using this graph.

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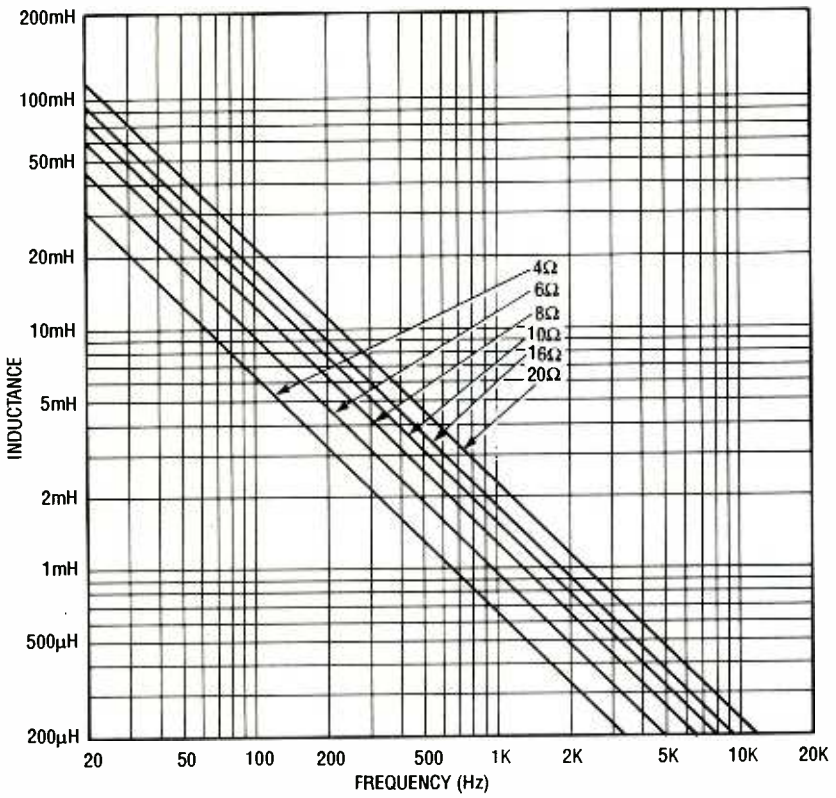

Fig. 5. Inductors can be selected from this graph if you know the frequency and load requirements of your speaker system.

bling or halving of frequency). That is characteristic of "first-order filters," which are filters that have only one reactive device (whether it's a coil or capacitor). Since the woofer's low-pass filter has only the coil, and the tweeter's high-pass filter has only the capacitor, each is a first-order filter, and this is a first-order network.

Adding a Midrange. We could add a midrange speaker to our system, using another coil and capacitor as shown in Fig. 9. The additional components form a band-pass filter. The values of the components can be determined from:

$$C1 = \frac{1}{2\sqrt{2}\pi f_H Z_T}$$

$$C2 = \frac{f_H - f_L}{\pi Z_{ML} f^2_M}$$

$$L1 = \frac{Z_{MH}}{4\pi(f_H - f_L)}$$

$$L2 = \frac{\sqrt{2}Z_W}{2\pi f_L}$$

where the various impedances are indicated by a subscript: W for woofer, T for tweeter, and M for midrange, and L and H denote the values at the low and high crossover-frequencies, respectively. (For example, two impedances are needed for the midrange driver: Z_{ML} at the low crossover frequency, and Z_{MH} at the high frequency.) The frequency f_M is the "geometrical center frequency" of the midrange section, and it is given by $f_M = \sqrt{f_H f_L}$. A peculiar feature of many 3-way crossovers is that they boost the midrange about 2 dB above the woofer and tweeter. That is no real problem, but it does mean that the midrange should be made about 2 dB less sensitive than the other two speakers (more on that later).

A Two-way, Second-Order Crossover. Figure 10A shows a 2-way second-order crossover network and Fig. 10B contains its response curves. Notice that at frequencies a little distance from the crossover frequency, each of its curves falls off at a rate of 12 dB per octave. The first-order filter's response is also shown (dashed lines) for comparison.

You might be wondering why you would want to use a second-order filter, since it requires twice as many components. There are two possible reasons: In high-power systems, the woofers can often stand 200 watts or more. Tweeters, however, can only handle a small fraction of that power. Thus it becomes very important to cut off the high-energy low frequencies as sharply as possible.

For example, let's say a first-order system is built with a crossover frequency of 1000 Hz, and a 100-watt, 500-Hz sine-wave is fed into the system. The tweeter will have to handle about 50 watts. With a second-order crossover, the tweeter would only have to handle about 25 watts.

The second reason for using a higher-order crossover is that whenever two speakers are reproducing the same frequency at roughly the same levels,

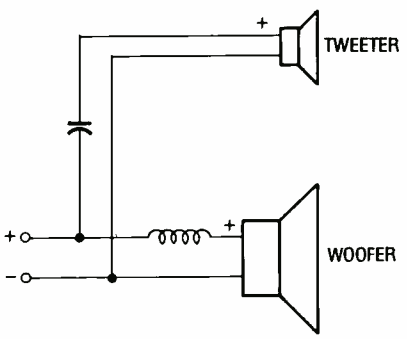

Fig. 6. This is a simple two-way first-order crossover. It prevents the woofer from receiving a significant amount of high-frequency energy.

there will be interference between them, reinforcing some frequencies and cancelling others. By using a higher-order crossover, you can reduce the range of frequencies in which such overlap is possible. To choose the values for a 2-way second-order crossover, use these equations:

$$C1 = \frac{1}{4\pi Z_T f_H}$$

$$C2 = \frac{1}{4\pi Z_W f_L}$$

$$L1 = \frac{Z_T}{\pi f_H}$$

$$L2 = \frac{Z_W}{\pi f_L}$$

Notice that the tweeter in Fig. 10A is connected with opposite polarity than the one in Fig 6. This is necessary because of the phase shift introduced by the second-order network. In order for the woofer and tweeter to pump air in phase at the crossover frequency (where they're both working), they have

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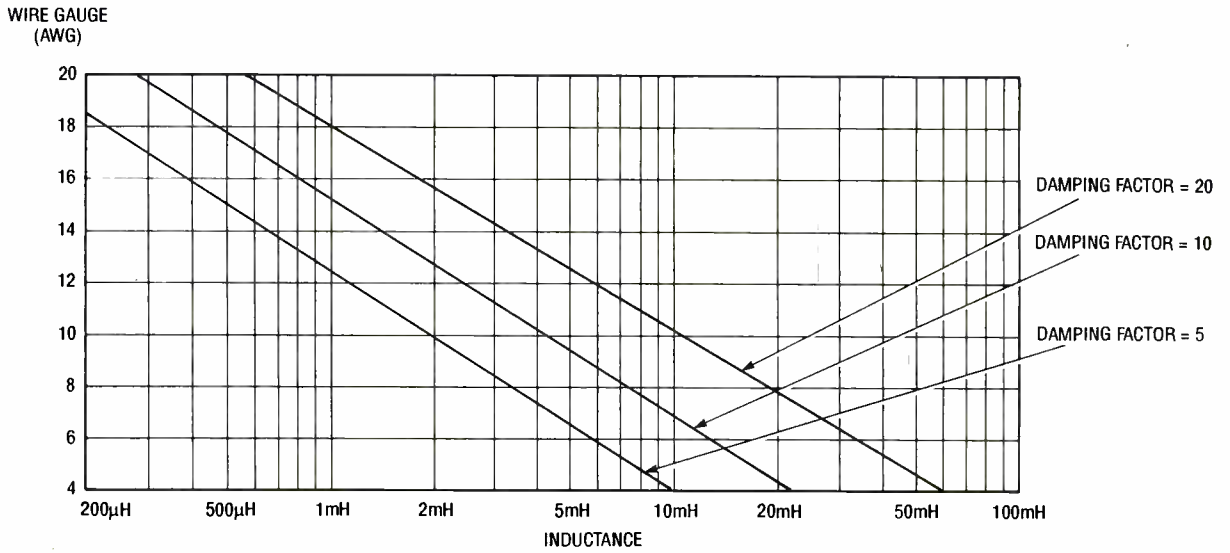

Fig. 7. The wire size of an inductor is important. It restricts the dampening capability of the drivers.

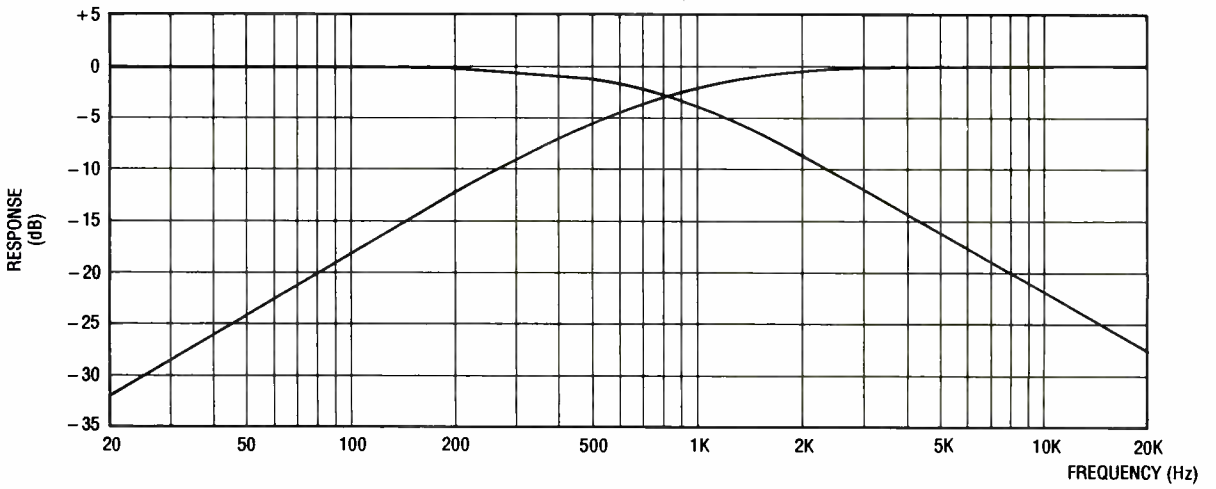

Fig. 8. This is the typical response of a first-order two-way crossover network. Note the shape decline in response beyond the crossover frequency.

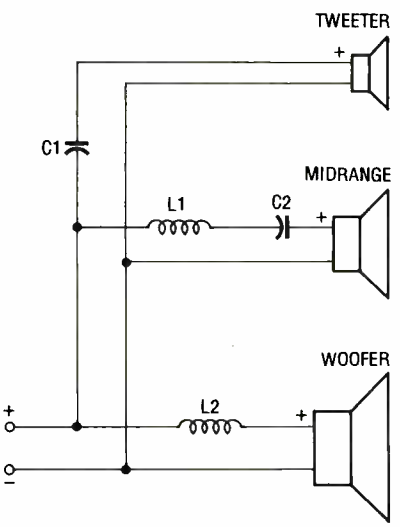

Fig. 9. This three-way first-order crossover can greatly enhance the sound quality of a speaker system.

to be connected as shown. Otherwise, their outputs will cancel and produce a response dip at the crossover point.

A Three-Way, Second-Order Crossover. Figure 11 shows a 3-way second-order crossover network. Note the tweeter is wired with the same polarity as the woofer, but now the midrange is reversed. Calculate the parts value as follows:

$$C1 = \frac{1}{4\pi Z_T f_H}$$

$$C2 = \frac{f_H - f_L}{2\sqrt{2}\pi Z_{ML} f^2_M}$$

$$C3 = \frac{1}{2\sqrt{2}\pi Z_{MH}(f_H - f_L)}$$

$$C4 = \frac{1}{4\pi Z_W f_L}$$

$$L1 = \frac{Z_T}{\pi f_H}$$

$$L2 = \frac{Z_{MH}}{\sqrt{2}\pi(f_H - f_L)}$$

$$L3 = \frac{Z_{ML}(f_H - f_L)}{\sqrt{2}\pi f^2_M}$$

$$L4 = \frac{Z_W}{\pi f_L}$$

A Practical example. As an example, let's see what components we would need to make a typical speaker system. We'll use a 12-inch woofer and a horn tweeter with stated impedances

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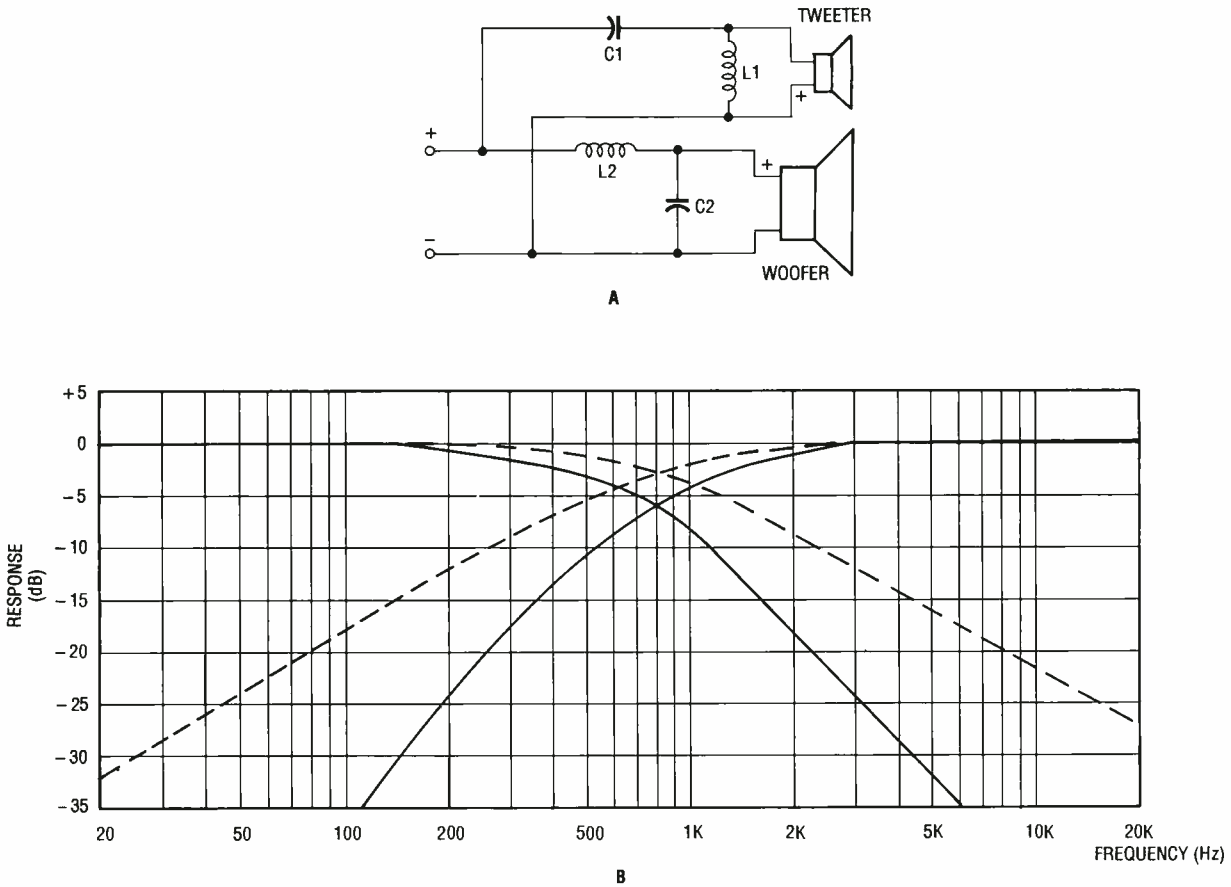

Fig. 10. A two-way second-order network is a more frequency-selective circuit (A). As you can see the response declines at 12 dB per octave (B).

of 8 ohms. We'll choose a 2-kHz crossover frequency. Measuring the actual speaker impedances, we find that Z_W is 20 ohms and the Z_T is 9 ohms at 2 kHz. If we only use a simple capacitor crossover, the capacitor's value would be:

$$C = \frac{1}{2\pi f Z_T} = \frac{1}{2 \times \pi \times 2000\text{Hz} \times 9\Omega} = 8.8\mu\text{F}$$

Moving on to a two-way first-order crossover will require adding a coil whose inductance is:

$$L = \frac{Z_W}{2\pi f} = \frac{20\Omega}{2 \times \pi \times 2000\text{Hz}} = 1.6\text{mH}$$

If we decide to improve performance and increase tweeter protection by using a second-order network, we'll cut the capacitor value in half and double the inductor value. Thus we will need two 4.4-μF capacitors and two 3.2-mH coils.

Perhaps, after looking more closely at the response curves for our woofer and tweeter, we decide that our system could be improved if we used a midrange speaker also. We decide on crossover frequencies of 500 and 4,000 Hz. Measuring impedances, let's say we find that the woofer presents 18 ohms at 500 Hz, the midrange has 8.9 ohms at 500 Hz and 12.6 ohms at 4,000 Hz, and the tweeter has a load of 9.8 ohms at 4,000 Hz. Plugging those numbers into the equations for a second-order, three-way network, we find:

$$f_M = \sqrt{4000\text{Hz} \times 500\text{Hz}} = 1414\text{Hz}$$

$$C1 = \frac{1}{4\pi Z_T f_H} = \frac{1}{4 \times \pi \times 9.8\Omega \times 4{,}000\text{Hz}} = 2\mu\text{F}$$

$$C2 = \frac{f_H - f_L}{2\sqrt{2} \times \pi Z_{ML} f^2_M} = \frac{4000\text{Hz} - 500\text{Hz}}{2\sqrt{2}\pi \times 8.9\Omega \times (1414\text{Hz})^2} = 22.1\mu\text{F}$$

$$C3 = \frac{1}{2\sqrt{2}\pi Z_{MH} f_H - f_L} = \frac{1}{2\sqrt{2} \times \pi \times 12.6\Omega \times (4{,}000\text{Hz} - 500\text{Hz})} = 2.6\mu\text{F}$$

$$C4 = \frac{1}{4\pi Z_w f_L} = \frac{1}{4 \times \pi \times 18\Omega \times 500\text{Hz}} = 8.9\mu\text{F}$$

$$L1 = \frac{Z_T}{\pi f_H} = \frac{9.8\Omega}{\pi \times 4{,}000\text{Hz}} = 0.78\text{mH}$$

$$L2 = \frac{Z_{MH}}{\sqrt{2}\pi(f_H - f_L)} = \frac{12.6\Omega}{\sqrt{2} \times \pi \times (4000\text{Hz} - 500\text{Hz})} = 0.81\text{mH}$$

$$L3 = \frac{Z_{ML}(f_H - f_L)}{\sqrt{2}\pi f^2_M} = \frac{12.6\Omega \times (4000\text{Hz} - 500\text{Hz})}{\sqrt{2} \times \pi \times (1414\text{Hz})^2} = 5\text{mH}$$

$$L4 = \frac{Z_W}{\pi f_L} = \frac{18\Omega}{\pi \times 500\text{Hz}} = 11.4\text{mH}$$

Many years ago, I built a three-way speaker system using prime-quality

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components and well-designed, well-built crossovers and cabinets. The system sounded harsh at the top end, however. Measurements using sine-wave signals did not reveal the problem. After quite a lot of head-scratching, I determined that the problem was tweeter resonance. I was crossing from the midrange into the tweeter at 2500 Hz using a second-order crossover. The tweeter's resonant frequency was 1600 Hz. What was actually happening was that the tweeter was receiving enough energy at 1600 Hz to make the voice coil move far beyond its linear range. As a result, the tweeter was producing a lot of distortion whenever the music had frequencies around 1600 Hz. Figure 12 shows a notch-filter circuit that can be added to the crossover across the tweeter to block energy at the tweeter's resonant frequency. The design equations are:

$$C_N = \frac{1}{2\pi R_E Q_{es} f_s}$$

$$L_N = \frac{Q_{es} R_E}{f_s}$$

$$R_N = R_E + \frac{Q_{es} R_E}{Q_{ms}}$$

where R_E is the speaker's DC resistance, Q_{es} and Q_{ms} are the electrical and mechanical Q's of the speaker, and f_5 is the speaker's resonant frequency.

Those characteristics should be available from the speaker's manufacturer, but you can measure measure R_E, using a digital multimeter, for yourself. You can also find f_s by using the test setup shown back in Fig. 3. Adjust the signal generator's frequency for the lowest current (voltmeter-ammeter method) or the highest voltage across the resistor (resistance-voltmeter method). "Guess" values of Q_{es} and Q_{ms} would be about 1.2 and 0.7, respectively, for typical dome tweeters. Fortunately, guessing wrong on the Q's will not seriously affect the circuit's operation.

The notch-filter circuit can also be used with the midrange driver, but it is seldom needed there unless a dome-type midrange is used. Cone and horn midrange units usually have very well-damped resonances that don't cause problems.

If a second-order network is better than a first-order one, wouldn't a third (or fourth or fifth) be better still? Perhaps marginally so, but each time you add an inductor in series with a speaker, you add some resistance and reduce the damping factor, so there's a point of diminishing returns. Many designers believe that if you need more than a second-order crossover, you should use an active circuit; once again, active crossovers are a subject for another time.

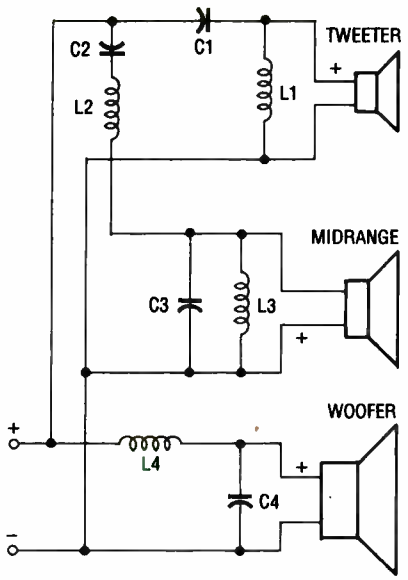

Fig. 11. A three-way second-order crossover has a pretty impressive name but it's pretty easy to build. Note the reversed midrange polarity.

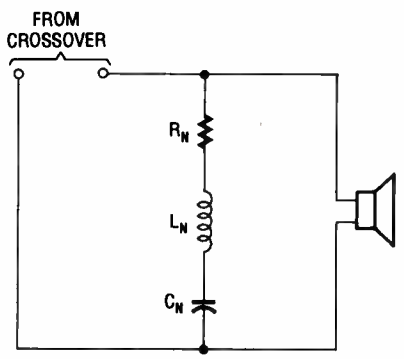

Fig. 12. A notch filter like this one can be used to stop annoying resonance.

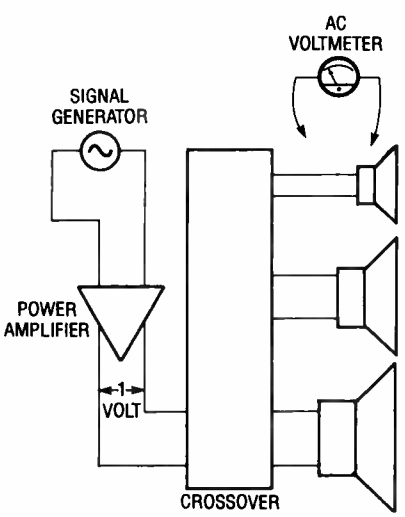

Fig. 13. This crossover test setup is easy to arrange and use. Be sure your power amplifier is supplying no more than one volt before connecting the crossover.

Selecting Drivers. We've left one of the most important concerns for last: how do you choose a woofer, midrange, and tweeter that will sound good together? First, you make sure that the three have overlapping responses. Preferably, you will have published response curves at your disposal that you can use to verify this, but at least you can check the stated response specifications. Then you can place the crossover frequencies in the middle of the overlaps. (It should go without saying that you don't want speakers with published response curves that have serious humps or dips in the middle.)

Second, the woofer and tweeter should have the same sensitivity ratings (given in dB at 1 watt from a distance of 1 meter). As mentioned earlier, the midrange should be 2 dB less sensitive than the woofer and tweeter, because three-way crossover networks actually have a 2-dB gain in their midrange section.

Finally, all three speakers should be rated for at least the minimum power you plan on using. Midrange and high-frequency speakers often have two power ratings: an actual power rating and a "system" power rating. As an example, a tweeter rated for use in a 100-watt system may have an actual power rating of about 6 watts, provided that a second-order crossover of 300 Hz or higher is used.

Building and Testing. When you build a crossover network, mount the components on a plywood board that can be screwed to the inside of the speaker cabinet, preferably with some sponge weatherstrip underneath the board to suppress rattles. You can mount the components using hot-melt glue or silicone "bathtub caulk." Always mount adjacent coils at right angles to each other to prevent magnetic interaction.

Once you have built the crossover network, it pays to make a few measurements before you hook up the stereo for a sound check. Figure 13 shows a test setup that you can use to make the

(Continued on page 104)

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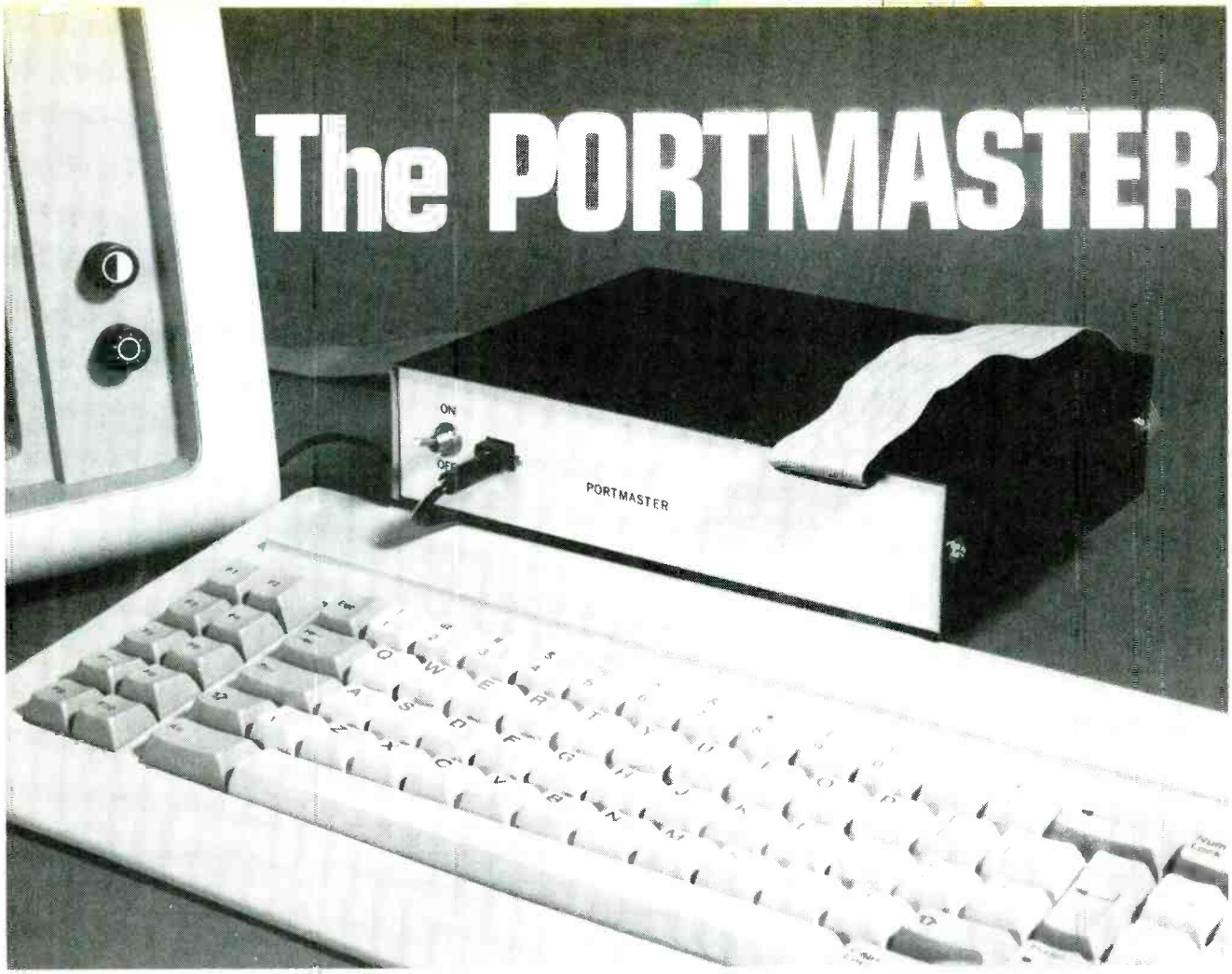

The PORTMASTER Home-Automation System

If you're a computer owner who'd like to connect your machine to the real world, but are afraid it would be expensive or difficult, then this is the project for you: A down and dirty interface that can be expanded to control up to 240 devices!

BY JOHN YACONO AND MARC SPIWAK

It doesn't take a genius to realize that computers are quickly changing our lives. They help us perform calculations that balance our checkbooks, they keep both our business and personal lives in order, and even help us reach out and grab data from remote locations (not that we don't have enough to sort through already).

With all that computers already do, it probably comes as no surprise that they can also manage the relatively simple tasks of life, like turning on the coffee pot in the morning and waking you up with gentle music. A question that you may have is "How do I get *my* computer to do that sort of stuff?" Simple; just build the *Portmaster*.

The Portmaster is a very simple device that provides an active low at one of its outputs based on data it receives from any IBM-compatible parallel-printer port sporting a DB-25 connector. The simplest version of the Portmaster possible (containing only three chips including a voltage regulator!) can operate 16 devices. In its most potent form, it is capable of handling 240 external AC and/or DC devices!

Along with more everyday uses, the stripped-down, 16-output version is excellent for pulsed operation of robot arms with up to 8 degrees of freedom. (For those of you not into robotics, a human arm—sans fingers—has only four degrees of freedom.) Common robot arms made for hobbyists have only four degrees of freedom. That means you can operate two of them with the Portmaster (the possible uses for such an arrangement we'll leave to your imagination).

We'll show you how to connect the Portmaster to household devices, too. By using the program we provide and a toggle circuit, you can operate any electrical device, AC or DC, either remotely or on a time schedule. The program provided contains some example inputs that operate a toaster, air conditioner, stereo system, table lamp, outdoor-lighting system, and sets a burglar-alarm system for day and night operation. All that, and we still use only seven of the prototype's 32 outputs! Now, let's get to the nuts and bolts of the circuit.

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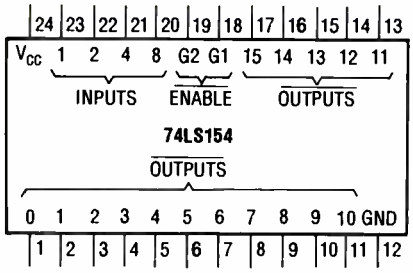

Fig. 1. Here's the 74LS154 demultiplexer's pinout diagram. They decode the output from the computer.

4-to-16 Converter Chips. The design of the Portmaster revolves around chips called 4-to-16 converters—also known as demultiplexers. When a converter receives a 4-bit number (called a "nibble," as opposed to the common 8-bit "byte"), it sets one of its sixteen outputs low based on the nibble's value.

The demultiplexers we used (see Fig. 1) are 74LS154 types. The four inputs (which accept the nibble in parallel fashion) are pins 20–23. Pin 23 accepts the least-significant bit (with a decimal value of 1), and pin 20 receives the most-significant bit (decimal value 8). The outputs (assigned values 0–15) are, in numerical order, pins 1–11 and 13–17. Two enable pins (numbers 18 and 19) will allow the chip to respond to input only when they are both low.

Let's assume that both the enable pins of an IC are low, which enables the chip. When binary 0000 (decimal value 0) is received by the device, output 0 (*i.e.* pin 1) goes low. If binary 0001 (decimal value 1) is received by the chip, output 1 (*i.e.* pin 2) goes low, etc. To summarize, the value of the nibble selects (addresses) the output that should go low. If an output is not selected, it floats high. If a chip is not enabled, all its pins are high.

PARTS LIST FOR THE PORT MASTER

U1—LM7805 5-volt, 1-amp voltage regulator, integrated circuit
U2–U4—74LS154 4-to-16 line demultiplexer, integrated circuit
C1–C4—0.01 μF, Mylar
PL1—Male DB-25 connector
J1—Coaxial DC-power jack
S1—SPST on/off switch
Perfboard materials, four 16-contact terminal strips (or other suitable output jacks), 25-pin ribbon cable, three 24-pin wire-wrap sockets, 6-volt DC wall adapter, cabinet, perforated construction board, hardware, wire, solder, etc.

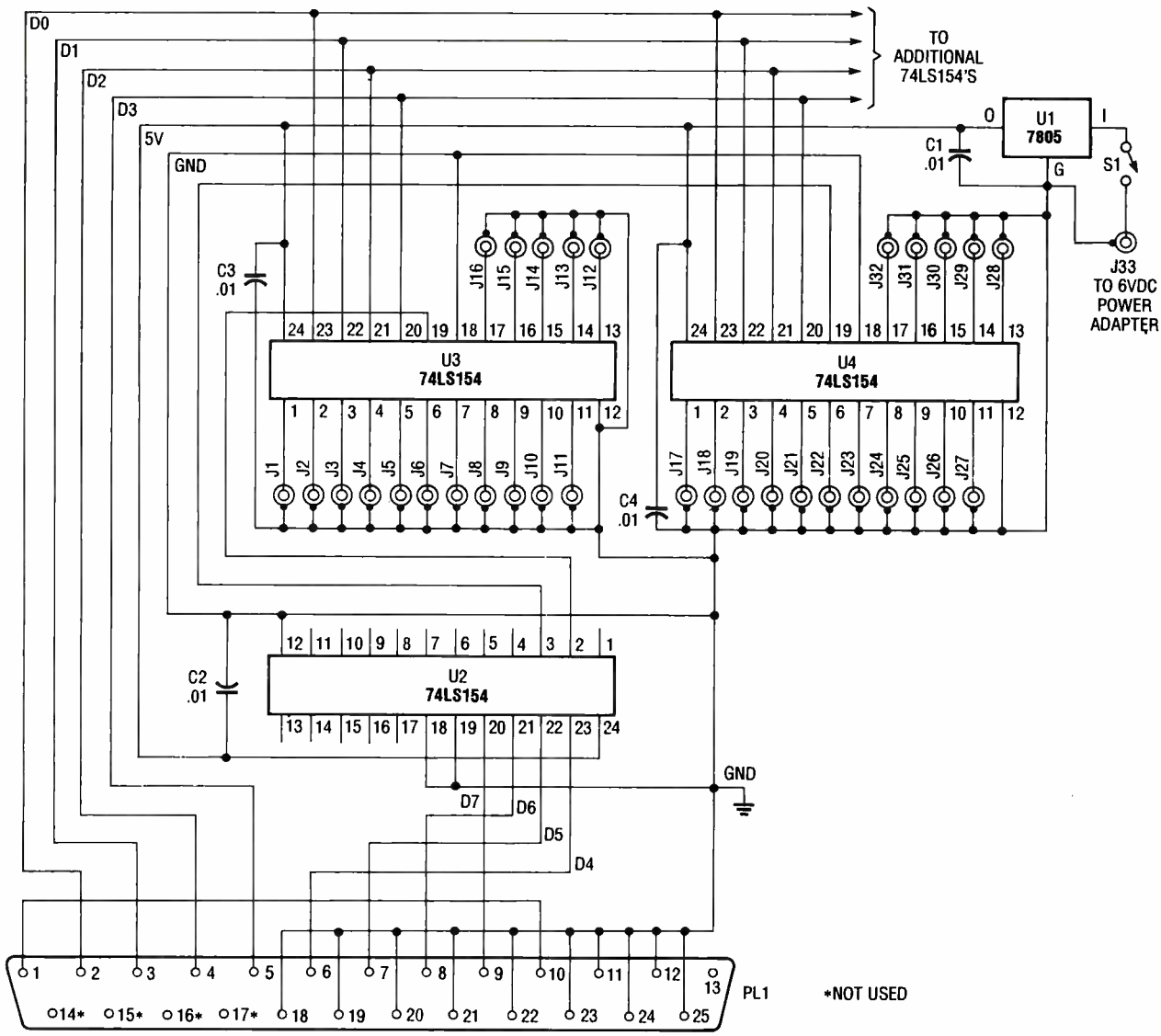

Fig. 2. This is the schematic diagram of the Portmaster. Despite its versatility, it doesn't take many parts at all to build the circuit.

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Handling 8-Bits with 4-Bit IC's. So how do chips that handle 4 bits deal with the 8 bits from a computer? To help answer that question, take a look at Fig. 2. The data bits, D0–D7, come from the computer via pins 2–9 on a DB-25 connector, PL1. When they arrive at the Portmaster, they are separated into two groups: a low nibble (D0–D3) and a high nibble (D4–D7).

The low nibble is sent along a bus to a series of demultiplexers (we show two, U3 and U4). The number of demultiplexers you use along the bus depends on how many outputs you want. If you want sixteen outputs, one chip will do; If you want thirty-two outputs, two chips are needed. Each chip you add provides another 16 outputs.

If all the chips receive the same nibble, why won't they all operate in unison? To answer that question, take a look at the enable pins (pins 18 and 19) of both U3 and U4. Pin 18 of both chips is tied low, but their pin 19's are controlled by outputs of U2, another demultiplexer. That IC is controlled by the high nibble from the computer. So the high nibble is used to enable only one of the chips on the bus at a time via U2. Thus, only one output can be activated at a time; the chip is chosen by the high nibble (through U2) and the particular output is selected by the low nibble on the bus.

Notice that output "0" (pin 1) of U2 is not used. It is avoided for a few reasons: When a computer's parallel-port is idling (no data is being sent), it usually keeps the bits of the high nibble low. That would put a low on U2's "0" output, enabling any chip connected to it. Parallel ports usually keep a couple of lines in the low nibble active when they idle. With a chip enabled and data in the low nibble, an output will be enabled every time the port idles.

Another reason involves the way DOS and some programs handle parallel-printer output. When DOS, and programs that depend on DOS, send characters to the port, DOS keeps track of how many characters have been sent. If too many have been sent since the last carriage-return/linefeed command, then DOS automatically generates one. It does that by sending ASCII characters number 13 (carriage-return) and number 10 (linefeed) out the port. That would activate outputs "13" and "10" of any chip enabled by output "0" of U2. So, unless you know what you're doing, don't use pin 1 of U2. Besides, even without using that pin, you can control 240 devices!

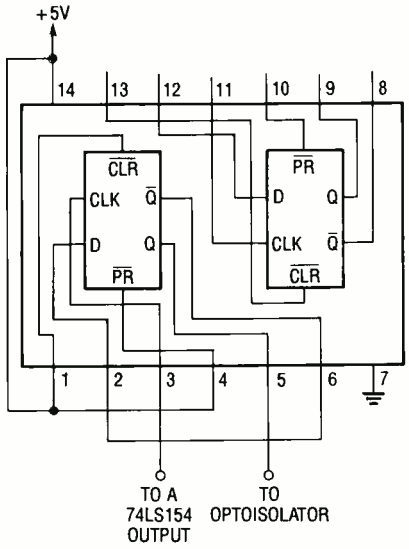

Fig. 3. You can configure any of the outputs for toggled operation by adding a D-type flip-flop as shown. (Note only one flip-flop in the package is wired ready for use.)

Momentary and Toggled Outputs. The outputs of the 74LS154's are active low. That, as we've mentioned, means they go low when selected, and float (they are "inactively" high) when not selected or when their chip is not enabled. So an output is only low (active) as long as the character that selects it is coming from the port. When there is another character at the port, or no character, that output floats.

Thus, the outputs are momentary, which is perfectly okay for some applications. For example, it's alright for the outputs to be only momentary if you wish to pulse several outputs one after another in a multiplexed fashion, such as in a robot-arm controller or a fancy light display. Or, if you only wish to activate one device at a time (in an exclusive fashion), you can transmit the appropriate character to the Portmaster over and over again. That leaves the output continuously low until your computer stops transmitting the character. Then you can activate another device.

You can configure any of the outputs for toggled operation as well. That will permit you to latch the outputs high or low and operate multiple devices at once. All you need do is add a D-type flip-flop configured for toggled operation as shown in Fig. 3. That IC contains two flip-flops and can be used to convert two outputs to toggled operation. To use the second flip-flop in the IC, connect its "D" and $\overline{Q}$ terminals together and tie its CLEAR, and PRESET pins high.

Connecting It to the "World." The Portmaster outputs, with or without flip-flops, are TTL compatible, so its outputs can be directly connected to any TTL device without the need for interface circuitry. If you want to control a CMOS-compatible or some other low-current DC load (*i.e.* a robot-arm motor for example), then connect the circuit shown in Fig. 4A between the appropriate output and the device it will control.

To control an AC device, again with or without flip-flop assistance, use the circuit in Fig. 4B as an interface between the Portmaster and the AC load. If the AC device is a household device, you'll probably want to connect a bypass switch across TR1. That will allow you to operate the device without computer intervention.

Parallel-Interface Handshaking. Computers transmit more than just character data through their parallel ports; they also send control signals. The computer also expects to receive signals generated by the printer. Let's examine how the Portmaster deals with those signals.

Figure 5 shows the four important signal types and their relationship in time. At the top of the diagram are the eight data lines lumped together as a single band. Don't let that confuse you though; the value of the bits is not important. What is important is the time at which data is present at the output port.

The data that is being output on lines D0–D7 starts to change at time t1, and it's available for use by time t2. At t2, the computer sends a momentary low-going pulse, called the strobe signal, through pin 1 to the printer to indicate that the data is ready and waiting on the data lines. After t2, the printer can either output a busy signal (through pin 11), which keeps the computer from sending more data to the port, or it can wait until it's ready before sending an acknowledge signal (through pin 10), which will also keep the computer from proceeding. There are some printers that halt the computer in both ways, even though that's a little redundant.

How does the Portmaster do any handshaking without any pulse-generating components? Simple—the device lets the computer "shake" its own "hand." The busy line is tied low, because the computer doesn't care whether or not the busy line goes through any transitions. As long as it's never high, it will just wait for the acknowledge signal. The *level* of the busy

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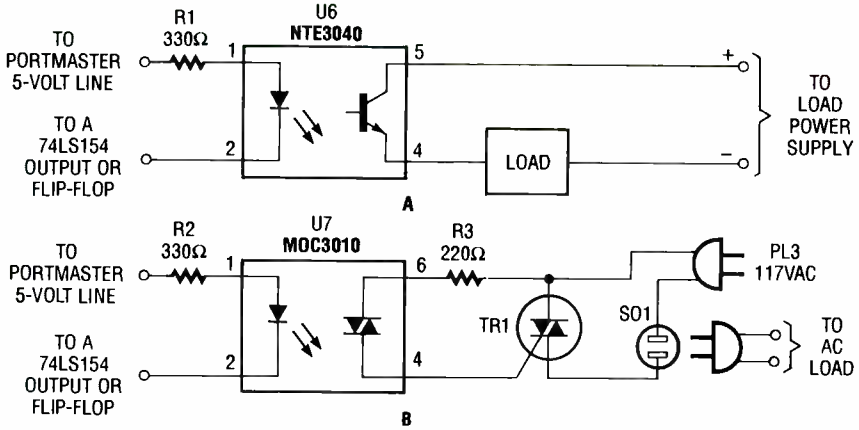

Fig. 4. To control a CMOS-compatible DC load, connect the circuit shown in A. To control an AC device, with or without flip-flop assistance, use the circuit in B.

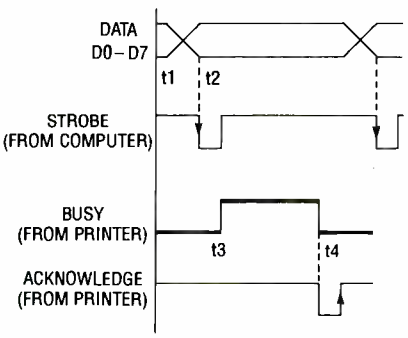

Fig. 5. Here are the four important computer signals and their relationship in time. Don't feel unsettled about not knowing the actual bits given at the top, they're not important.

line is what's important, not its *transitions*. That's why the busy-line levels are drawn in bold in the illustration.

The computer must therefore rely on the acknowledge line to detect the device's readiness. When the computer sends the strobe pulse, it considers the falling edge to be the start of transmission (indicated by the arrow on that edge). By the time the strobe line is low, the computer has already begun waiting for the acknowledge pulse. Interestingly enough, the computer only concerns itself with the rising edge of the acknowledge pulse; it pays no attention to the pulse's logic level or its falling edge.

Since the computer starts waiting for the rising edge of the acknowledge pulse right after the falling edge of the strobe pulse, we can use the rising edge of the strobe pulse in place of the rising edge of the acknowledge pulse. To accomplish that, the Portmaster has an internal connection between pins 1 and 10 and the computer sends itself what it thinks is the rising edge of the acknowledge pulse.

Pulsing an Output. Turning on a given output is as easy as addressing that output. The lowest address is address 16 and it activates output 1. So to activate output 1, all you have to do is send ASCII value 16—*i.e.*, CHR$(16) in BASIC—to the printer port. Accordingly, to activate output 2, send ASCII character 17, etc. To summarize:

ASCII value = 15 + output number

See the Table 1 for a list of pertinent characters, their ASCII value, and the ports they control.

You can control the Portmaster using DOS, a batch file, a program written in any language, or any other piece of software that lets you send characters to the parallel-printer port.

Note: If the data-output duration of your computer port is too brief to activate the devices you use, simply output the required character more than once at a time.

We have included a program written in BASIC that gives you the ability to remotely control any devices connected to the Portmaster in both an interactive and timed way.

The Program. Listing 1 is a program you can use to control any device you have in your house. The program was written under the assumption that you would use D-type flip-flops configured to toggle as inputs to the controlling optoisolators.

The first two lines initialize the variables and set up a two-dimensional array called "TOGGLE." TOGGLE is a 32-by-3 array (remember arrays in basic start with element "0") with the indexes used as follows:

TOGGLE(*device-output number – 1, device data*)

The device data stored for each device output consists of two "toggle times" (stored in elements "0" and "1"), and the device name (stored in element "2"). A toggle time, simply enough, is a string representing the time (given in 24-hr. format) that you want a device output to be toggled. The device-name string is used by the program to tell you which device has been toggled when toggling occurs.

Lines 30–340 initialize the values of the toggle array. There is some sample data provided for outputs 1, 2, 3, 4, 5, 7, and 8. If you analyze the data you will notice that we skipped device 6 (which is element 5). Skipping devices just leaves them unused and will cause no harm. Also note that a device's first toggle time can be earlier or later than its second toggle time; as you will see, the order doesn't matter. We took the liberty of putting colons in the blank toggle times just to keep ourselves from having to enter them later.

Line 350 just initializes a string used for

TABLE1—IBM CHARACTERS

Character	ASCII Value	Output	Character	ASCII Value	Output
▶	16	1	(Space)	32	17
◀	17	2	!	33	18
↕	18	3	"	34	19
‼	19	4	#	35	20
¶	20	5	$	36	21
§	21	6	%	37	22
▬	22	7	&	38	23
↨	23	8	'	39	24
↑	24	9	(	40	25
↓	25	10	)	41	26
→	26	11	*	42	27
←	27	12	+	43	28
L	28	13	,	44	29
↔	29	14	–	45	30
▲	30	15	.	46	31
▼	31	16	/	47	32

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LISTING 1—
PORTMASTER HOME-CONTROL PROGRAM

```
10 CLEAR
20 DIM TOGGLE$(31,2)
30 TOGGLE$(0,0)="18:00":TOGGLE$(0,1)="08:00":TOGGLE$(0,2)="air
   conditioner"
40 TOGGLE$(1,0)="11:00":TOGGLE$(1,1)="06:00":TOGGLE$(1,2)="outdoor
   lights"
50 TOGGLE$(2,0)="13:00":TOGGLE$(2,1)="06:15":TOGGLE$(2,2)="night-time
   burglar alarm"
60 TOGGLE$(3,0)="08:00":TOGGLE$(3,1)="18:00":TOGGLE$(3,2)="daytime
   burglar alarm"
70 TOGGLE$(4,0)="07:15":TOGGLE$(4,1)="07:20":TOGGLE$(4,2)="toaster"
80 TOGGLE$(5,0)=":":TOGGLE$(5,1)=":":TOGGLE$(5,2)=""
90 TOGGLE$(6,0)="06:15":TOGGLE$(6,1)="6:45":TOGGLE$(6,2)="stereo"
100 TOGGLE$(7,0)="06:30":TOGGLE$(7,1)="06:45":TOGGLE$(7,2)="table
    lamp"
110 TOGGLE$(8,0)=":":TOGGLE$(8,1)=":":TOGGLE$(8,2)=""
120 TOGGLE$(9,0)=":":TOGGLE$(9,1)=":":TOGGLE$(9,2)=""
130 TOGGLE$(10,0)=":":TOGGLE$(10,1)=":":TOGGLE$(10,2)=""
140 TOGGLE$(11,0)=":":TOGGLE$(11,1)=":":TOGGLE$(11,2)=""
150 TOGGLE$(12,0)=":":TOGGLE$(12,1)=":":TOGGLE$(12,2)=""
160 TOGGLE$(13,0)=":":TOGGLE$(13,1)=":":TOGGLE$(13,2)=""
170 TOGGLE$(14,0)=":":TOGGLE$(14,1)=":":TOGGLE$(14,2)=""
180 TOGGLE$(15,0)=":":TOGGLE$(15,1)=":":TOGGLE$(15,2)=""
190 TOGGLE$(16,0)=":":TOGGLE$(16,1)=":":TOGGLE$(16,2)=""
200 TOGGLE$(17,0)=":":TOGGLE$(17,1)=":":TOGGLE$(17,2)=""
210 TOGGLE$(18,0)=":":TOGGLE$(18,1)=":":TOGGLE$(18,2)=""
220 TOGGLE$(19,0)=":":TOGGLE$(19,1)=":":TOGGLE$(19,2)=""
230 TOGGLE$(20,0)=":":TOGGLE$(20,1)=":":TOGGLE$(20,2)=""
240 TOGGLE$(21,0)=":":TOGGLE$(21,1)=":":TOGGLE$(21,2)=""
250 TOGGLE$(22,0)=":":TOGGLE$(22,1)=":":TOGGLE$(22,2)=""
260 TOGGLE$(23,0)=":":TOGGLE$(23,1)=":":TOGGLE$(23,2)=""
270 TOGGLE$(24,0)=":":TOGGLE$(24,1)=":":TOGGLE$(24,2)=""
280 TOGGLE$(25,0)=":":TOGGLE$(25,1)=":":TOGGLE$(25,2)=""
290 TOGGLE$(26,0)=":":TOGGLE$(26,1)=":":TOGGLE$(26,2)=""
300 TOGGLE$(27,0)=":":TOGGLE$(27,1)=":":TOGGLE$(27,2)=""
310 TOGGLE$(28,0)=":":TOGGLE$(28,1)=":":TOGGLE$(28,2)=""
320 TOGGLE$(29,0)=":":TOGGLE$(29,1)=":":TOGGLE$(29,2)=""
330 TOGGLE$(30,0)=":":TOGGLE$(30,1)=":":TOGGLE$(30,2)=""
340 TOGGLE$(31,0)=":":TOGGLE$(31,1)=":":TOGGLE$(31,2)=""
350 S$=""
360 PRINT "Do you want to toggle a";S$;:INPUT " device [Y/<CR>]";A$
370 IF A$<>"Y" AND A$<>"y" GOTO 430
380 INPUT "Number of device";I
390 LPRINT CHR$(I+15)
400 PRINT "Device number ";I;" (";TOGGLE$(I-1,2);") toggled."
410 S$="nother"
420 GOTO 360
430 T$=LEFT$(TIME$,5)
440 IF T$=OLDT$ GOTO 430
450 PRINT T$
460 FOR I=0 TO 31
470 FOR J=0 TO 1
480 IF TOGGLE$(I,J)=T$ THEN LPRINT CHR$(I+16);:PRINT "Toggling device
    # ";I+1;"(";TOGGLE$(I,2);")"
490 NEXT J
500 NEXT I
510 OLDT$=T$
520 GOTO 430
530 END
```

the following line. Lines 360–420 form a loop that puts you in a "remote-operation" mode. As long as you stay inside that loop (by responding to the question in line 360 with a "Y") you can toggle any device on or off from your computer. Just type in the device number when prompted by line 380. (Note that the S$ string is redefined in line 410 to simply provide the program with good grammar for the prompt in line 360.)

The remote-operation mode also allows you to turn devices on and off to set their initial state before entering the "timed-operation" mode. If you don't answer the question in line 360 with a "Y," you end up at line 430, the beginning of the timed-operation loop.

At line 430, the time is placed in string T$ with the seconds trimmed off by the LEFT$ function. Ignoring line 440 for a moment, the current time is printed on the monitor (by line 450) and the computer enters two FOR/NEXT loops where the current time is compared to all the toggle times. If any toggle times match the current time (see line 480), then the appropriate character is sent to the Portmaster and a message appears on the monitor to give you the device number and name.

When the FOR/NEXT loops are completed, the time string is transferred to the OLDT$ string and the program jumps back to line 430. There it gets an updated time and, if the time hasn't changed since the last time the program requested it, line 430 forces the program to keep requesting the time until it does. That keeps the program from printing the same time over and over again from line 450, and it also keeps it from entering the FOR/NEXT loops until there's a need to.

Construction. The Portmaster was assembled on a piece of perfboard and installed inside a metal project cabinet; both items are available at Radio Shack. The connections between components were made with wire-wrap wire and an inexpensive hand tool. We chose to go with a much larger case and PC board than necessary for three reasons: it's easy to work that way, there's plenty of room on the board for expansion, and 32 outputs take up a lot of room on the outside of the cabinet. We also chose metal for its shielding properties, but you can probably get away with a plastic case.

On the front of the cabinet we installed the DC power jack and on/off switch. The ribbon cable also exits from the front. Four terminal strips, with sixteen contacts each, are mounted on the back of the unit. They provide the Portmaster's thirty two outputs, with a ground connection for each one.

The first step in building the unit is to cut off a strip of the perfboard as wide as the cabinet's height. That was used to mount the four terminal strips on. Four holes were drilled in the corners of what was left of the perfboard, with matching holes drilled in the bottom of the cabinet. Later on, those holes will be used for mounting the board in the case. The next step is to test-position the components on the board, keeping in mind future expansion. During the construction, it's a good idea to leave the IC's out of the wire-wrap sockets.

The ribbon cable was attached to the board using individual wire-wrap pins soldered to the ends of the wires. The pins are arranged on the board in the pattern that you would see them on the DB-25 connector that's crimped on the free end of the cable; that makes wiring the board a little easier. You can see from Fig. 2, that pins 14–17 are not used, so they are simply cut off the cable after entering the cabinet. You'll

(Continued on page 103)

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Shoot the Classic Milk Drop

Build a time-delay, flash-trigger circuit that lets you capture shots that would be next to impossible otherwise.

BY JAMES R. BAILEY

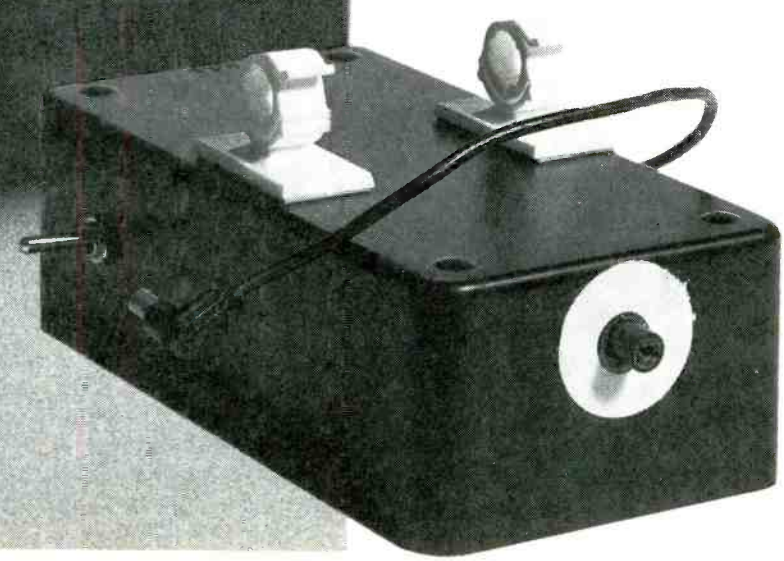
If you are like me, you have been amazed at the simple, yet classic beauty of the familiar "milk drop" photos. They are among the thousands of well-known images created by famed inventor and educator, Dr. Harold Edgerton. Now, you can shoot your own "classic" using your own camera and flash, coupled with this easy-to-make time delay flash trigger.

How It Works. The schematic diagram for the time delay circuit is shown in Fig. 1. The circuit is built around a single 4093 quad 2-input NAND Schmitt trigger. Two gates from that quad package (U1-a and U1-b) are configured as a set-reset flip-flop, which is triggered by a phototransistor (Q1). As long as Q1 is illuminated by a beam of light, one input of U1-a is held high. When the beam is interrupted, say by a falling milk drop, the input to U1-a is pulled low via resistor R1.

That causes U1-a's output to go high, thereby forcing U1-b's output low. At that point, C2 (which, in conjunction with R2 and R3, determines the length of the time delay) begins to discharge through R2 and R3. The actual delay time in seconds is given by:

$$t_d = C \times (R2 + R3)$$

When C2 has discharged sufficiently, U1-c's output goes high, triggering SCR1 and firing your flash. Now C1 begins to charge through R4, which takes about a half second. When that time has elapsed, U1-d's output goes low, reset-



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ting U1-a and U1-b to their initial state. Capacitor C2 then quickly recharges through D1, so that it's ready for the next shot. The half-second delay produced by C1 prevents double exposing your shots.

Construction. The author's prototype of the trigger-delay circuit was built on a printed-circuit board (see Fig. 2) measuring 1½ by 2½ inches. After etching your circuit board, install the components using Fig. 3 as a guide. Be careful when handling U1. It's a CMOS device and can be damaged by static discharges. Also, when installing C1 and C2, be sure to observe the proper polarity.

Mount the phototransistor, Q1, near one end of the circuit board. The lead nearest to the flattened edge of the phototransistor is the collector, and should be connected to the +9-volt bus (as shown). Before installing Q1 bend the ends of its leads to form a 90° angle to line up with a hole that will be drilled in one end of the circuit's enclosure (more on that in a moment). Just about any phototransistor will work for Q1. Both infrared and visible light types are acceptable.

You'll need a short length of black plastic tubing to fit over Q1 to help keep it lined up with the hole. The author used a section cut from an old disposable ballpoint-pen housing. A hole about 1/16 inch was drilled in the sealed upper end of the pen housing to allow light to get to Q1. Be careful not to make the hole too large; if you do, a drop of milk may be too small to block all the light.

GE C106D SCR's come both with and without heat-sink tabs. For this project the tab is unnecessary, so you can cut it off if desired to prevent shorting. You can also use Teccor T106D's. Do not substitute any other SCR for SCR1; either version of the 106D is inexpensive and have been used successfully on many flash and control projects.

Next prepare the enclosure that will house the time-delay circuit by drilling holes for S1, R2, Q1, and the flash cord. The author's circuit was housed in an enclosure measuring about 5 1/16 by 2 5/8 by 1 5/8 inches. The author drilled a hole in one end of the enclosure for Q1. That hole should be small enough to fit Q1's plastic tubing snugly. Cement the tubing in place.

Drill a hole in the side of the enclosure for the flash sync cord. For the sync cord, cut the male end off of a photographic extension cord. Use the female end and the wire for this project.

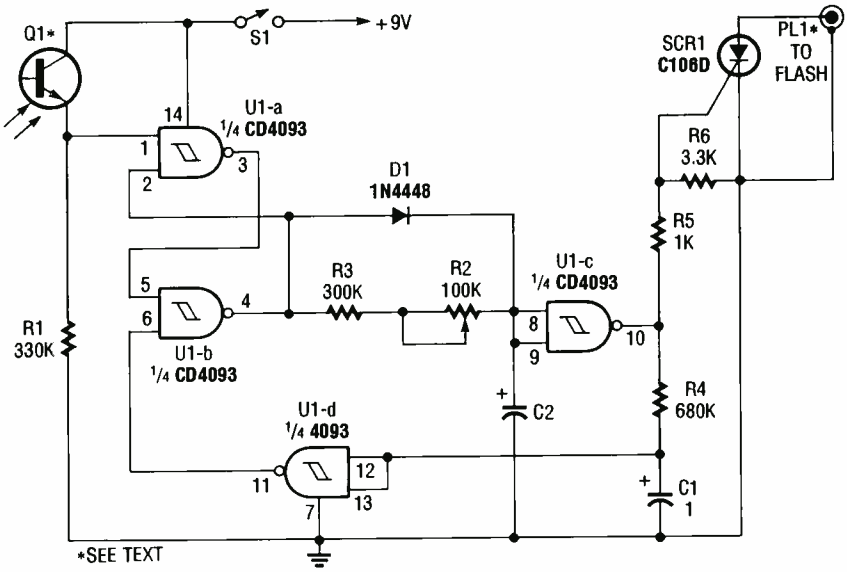


Fig. 1. The time-delay trigger circuit is built around a single 4093 quad 2-input NAND Schmitt trigger. Two gates from that quad package (U1-a and U1-b) are configured as a set-reset flip-flop.

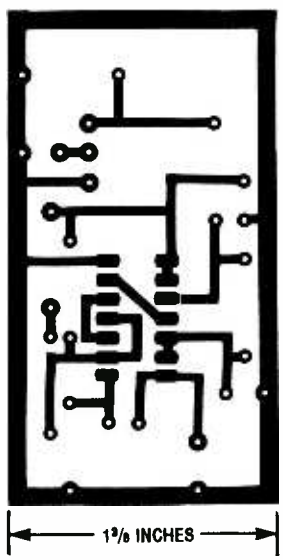
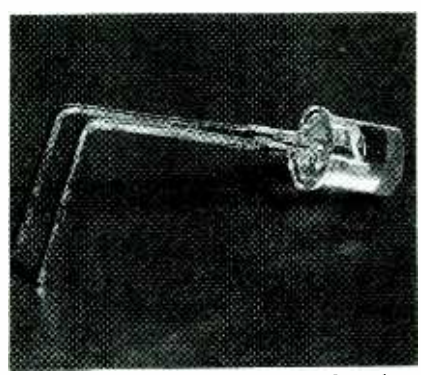


Fig. 2. The author's prototype unit was built on a printed-circuit board measuring 1⅜ by 2½ inches.

Attach two adhesive-backed plastic cable clamps to the bottom of the case along the centerline. They are used to attach the delay unit to the ringstand. Cut a disc about 5/8-inch in diameter from a white, self-adhesive label. Make a hole in the center to fit around the photocell opening in the case. Mount the disc around the hole. The disc will serve as a target for lining up to take your splash photos.

Testing. Before mounting the circuit board in the enclosure, attach the battery and make sure that the circuit is functioning correctly. Temporarily solder the sync cord to the appropriate points on the circuit board. The white or center lead goes to the anode of SCR1. The black lead or outer conductor goes to ground. A few flashes have negative-polarity sync circuits; if that is the case with your unit, it will be necessary to reverse those connections.

To determine if the sync cord is properly connected for your flash unit, plug the sync cord into your flash unit. If your flash unit has a variable-power "manual" setting, set it to minimum power for the quickest recycle time. Turn the flash unit on, but leave the delay turned off for the moment. Connect a voltmeter across the anode and cathode of SCR1. The anode should be positive and the cathode negative. The voltage is unimportant and is likely to be any-



Just about any phototransistor (infrared or visible light type) is fine for Q1. Before installing Q1, bend the ends of its leads to form a 90° angle (as shown here) so that it lines up with the hole in the end of the enclosure.

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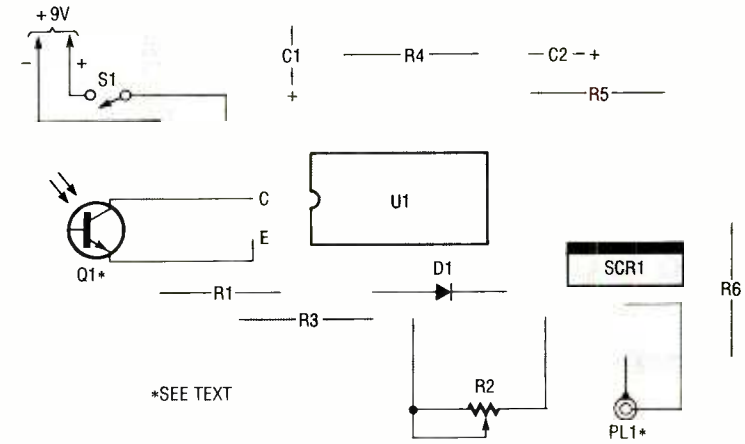
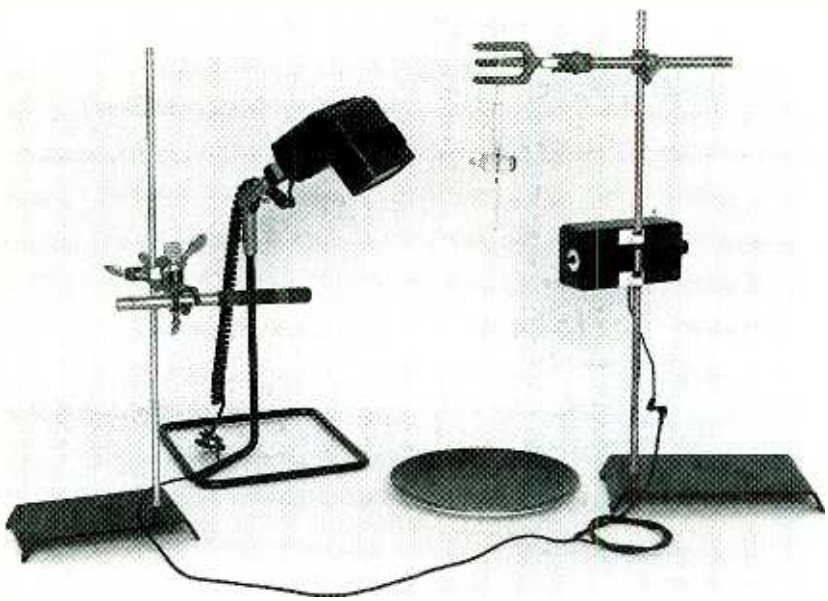


Fig. 3. Install the components using this figure as a guide. Be careful when handling U1. It's a CMOS device and can be damaged by static discharges. Also, when installing C1 and C2, be sure to observe the proper polarity.



Here is the author's set up. Two adhesive-backed plastic cable clamps were used to attach the time delay trigger circuit to the ringstand.

PARTS LIST FOR THE TIME DELAY FLASH TRIGGER

SEMICONDUCTORS

U1—CD4093 quad 2-input, NAND Schmitt-trigger, integrated circuit
Q1—NPN phototransistor, see text
SCR1—C106D or T106D silicon-controlled rectifier
D1—1N4448 or similar fast-recovery silicon diode

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1—330,000-ohm
R2—100,000-ohm potentiometer
R3—300,000-ohm
R4—680,000-ohm
R5—1000-ohm
R6—3300-ohm

ADDITIONAL PARTS AND MATERIALS

C1, C2—1-μF, 35-WVDC, Tantalum capacitor
S1—SPST toggle switch
Perfboard materials, 5 1/16- × 2 5/8- × 1 5/8-inch plastic enclosure, cable clamps, 9-volt transistor-radio battery and connector, sync cord, knob, wire, solder, hardware, etc.

where from 2 to 250 volts—depending on the design of the flash. If the anode is negative with respect to the cathode, unsolder the sync cord leads from the board and reverse the connection.

Attach a 9-volt battery to the battery connector and turn on the power switch. Make sure no direct light is shining on Q1. The flash should fire every second or so. Rotating R2 should change the time interval between flashes. If the flash does not fire, check the battery to make sure it's fresh. Shine a bright pen light on Q1 and the flashing should stop. Briefly interrupt the beam with a pencil or other object and the flash should fire a moment later.

If a fresh battery fails to make the flash fire, momentarily place a short across the sync cord to see if the flash is working. It should fire each time you short out the sync cord. Assuming the flash is working, check the following voltages: with Q1 lit, pin 1 should be at 8.5 volts and 0 volts when dark; pin 3 should be at 0 volts with Q1 lit; pin 4 at 8.5 volts with Q1 lit; pin 10 at 0 volts with Q1 lit; pin 11 at 8.5 volts with Q1 lit. With the exception of pin 1 of U1, the voltages should alternate between the high and low readings with Q1 dark.

If the voltages do not check out, then SCR1 is probably defective, otherwise suspect U1 or that a capacitor is installed backwards.

Once you have everything working, temporarily disconnect the sync cord from the printed-circuit board, feed it through the hole in the enclosure, and reconnect it to the circuit board at the point indicated in Fig. 3. Insert Q1 into its tubing and secure the circuit board to the bottom of the enclosure with double-sided foam adhesive tape. Mount S1 and R2 to the enclosure.

Add a piece of insulating cardboard or foam over the circuit board to isolate it from the battery, which will lay above it in the case. Close up the enclosure, and install a knob on the shaft of R2.

Taking the Photo. The ideal source for falling milk drops is a glass laboratory burette. Mount it on a ring stand with its tip about eleven inches above the table. Place a dark or brightly colored dinner plate below the burette. Clip the delay box onto the ring stand (see photos). Position the photocell so that it is about ½ inch below the tip of the burette. Fill the burette with either milk or half milk/half water.

Support a pen light about a foot away from the delay box and aim it at the photocell. Tape a black paper hood around the pen light to confine the beam. It should light the ring around the photocell. Connect your flash to the delay and set it for minimum

(Continued on page 106)

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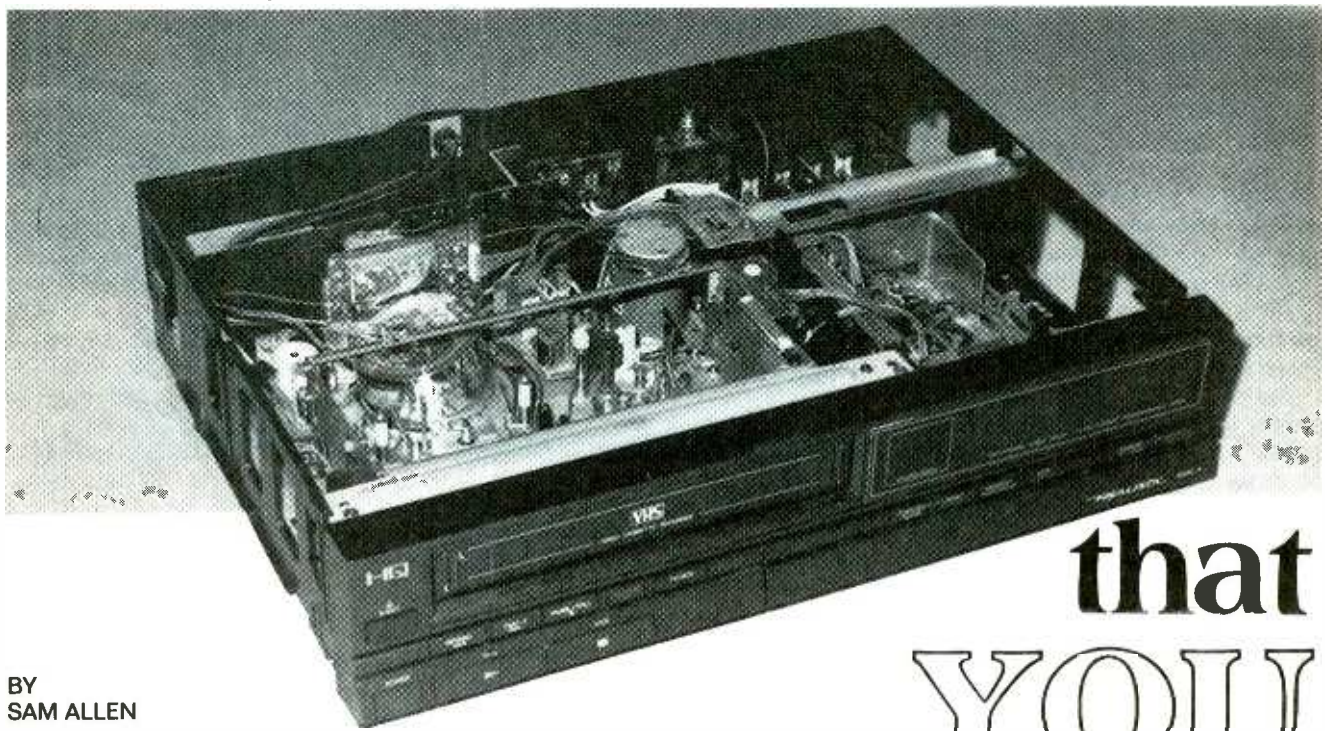
Simple VCR Repairs that YOU Can Do!



BY
SAM ALLEN

Depending on the malfunction, you might be able to fix your own VCR and avoid an expensive repair bill, or even having to buy a new one.

As soon as someone finds out that you are interested in electronics, they will usually ask you to fix something. For instance, they might want you to repair a malfunctioning VCR. If you are just getting started in electronics, you probably feel that VCR repair is way over your head. While you might be right to some extent, you'd be surprised how many VCR's are totally disabled by minor problems that even a beginner could fix. Surprisingly, a VCR that just won't work at all is usually easier to repair than one that just has poor picture quality.

In this article, I will present the repair techniques you'll need to know to cure some of the most common VCR problems. As you'll come across them more often, the solutions I'll provide are for front-loading VHS units. However, some of the problems I'll discuss are common to all types of machines, so the generalities of the techniques described may be useful for repairing different machines.

Sizing-Up the Job. Before you commit to work on a unit, there are a few things you should find out: First, make sure the machine is out of warranty, since you will void the warranty if you open the case. This is very important when repairing a friend's machine; sometimes people forget they have a warranty, so make sure it has expired.

Another thing to consider when working on someone else's VCR is the owner's attitude. If they are wary and think you may cause more damage to the machine, don't work on it or you are likely to lose a friend if the unit turns out to be unfixable. If their attitude is, "Oh well, it's no good now; you can't hurt it," then go ahead. I like to work on stuff that has already been into a commercial shop for an estimate. If the owner decided that the cost of repair is too high to make it worthwhile, then they won't get upset if I can't fix it, but they are pleasantly surprised if I can.

Finally, get a good idea of what the problem is; think about (or ask) how the problem began. That can give you a clue as to what to look for. For example, if the problem began after the VCR was dropped, then you can suspect a broken circuit board. That is a problem that you should be able to find and fix without too much trouble with some tips I'll provide later.

If a VCR won't load after the kids were using it, it may have a foreign object jamming the mechanism; another problem you can fix. I worked on one VCR that wouldn't rewind after someone had kicked the button with his foot. Knowing this, I could center my attention on the button itself and the problem was easy to find and repair. On the other hand, a problem that appears out of the blue with no apparent cause may be harder to troubleshoot. Make your decision accordingly.

Some Basics. Before getting into repair procedures, I want to give you a few ground rules. The first tip may seem obvious, but before you disassemble a

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unit, check all of the controls to see that they are set properly. I have had several people give me VCR's to repair that only needed to be set up properly. For example, if the unit won't record off the air, the problem may be that the tuning controls aren't set to a station or a switch may be in the "aux" position instead of the "tuner" position. Some models may be completely inoperative if a switch is set to the timer position. There are lots of other possibilities, and the more complex the controls, the more likely that one of the controls has been overlooked; so be sure to check out the control settings thoroughly.

The next rule on the list: be sure the power cord is not plugged in before working on a VCR. When you do need to make a powered-up test with the cover off, be sure to observe every safety precaution. I assume you have some electronics background, so you should know better than to touch any connections in the primary circuit during such phases of repair.

There are some rules that apply specifically to VCR repair. For example, when part of a mechanism seems to be jammed, the first impulse is to spray some lubricant on it—don't do it to a VCR. Spray lubricants cause more harm than good. More problems are due to slipping than the need for lubrication.

Also, while you are working inside a VCR, keep your fingers away from the head(s), rollers, and guides in the tape transport. Oil from your hands will damage the head and cause slipping in the tape transport system.

Last, don't randomly adjust things inside the VCR to try and correct a problem; you will usually end up creating further problems.

Foreign Objects in the Mechanism. In a house with small children, the most common VCR malfunction is a unit that won't load. That problem is usually due to a toy or other object that has been pushed into the tape door. I have found crayons, pennies, toy cars, buttons, and candy inside VCR's.

To eliminate the problem, remove the case and look for the foreign objects inside the VCR. Usually all you need to do is remove the objects and the VCR will function.

In the case of candy, crayons or the like, you may need to do some clean up. For candy, you need a water-based solvent; window cleaner works well. Alcohol works for crayons.

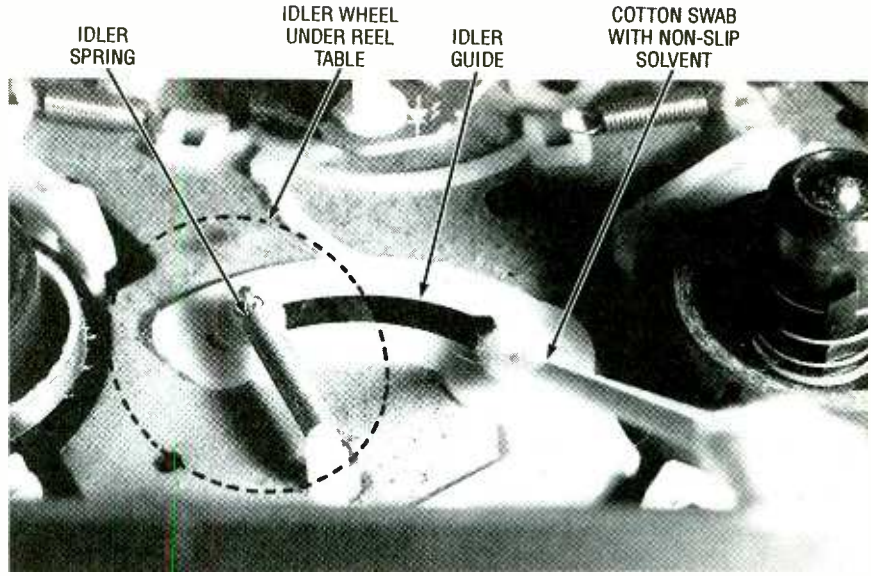

Fig. 1. A lot of problems can be traced to slipping idler wheels. If your VCR has a guide like the one shown here between the reel hubs, it uses an idler wheel. The idler wheel (indicated by the dashed outline) is below the reel table. To avoid a lot of disassembly, apply non-slip solvent to the rubber part of the idler by inserting a cotton swab through the hole in the guide.

Use a cotton swab moistened with the cleaner. Don't drip the cleaner onto circuit boards or motors. Wipe all surfaces dry with another swab. After the clean up, you should relubricate the gears with teflon grease (Radio Shack cat. #64-2326, for example). Don't use a lot; just swab on a very thin film. After the mechanism is working, insert a head-cleaning cassette and follow the cassette manufacturer's directions for cleaning the head. It provides insurance in case any foreign substance (cleaning fluid, finger oil, etc.) has gotten on the head or tape-transport components.

Slipping Transport Components. Oftentimes the source of trouble is in the tape-transport mechanism. Suspect such trouble if the VCR loads a tape, begins to play it, and then shuts down; a VCR has sensors and a system-control circuit that will turn off the power if the reels aren't moving. If the system control circuit didn't shut down the VCR when a drive component was slipping, the tape would go slack and get wrapped around the head, causing major damage.

If you suspect a slipping belt or idler, remove the case, then insert a tape and start the machine. Watch the tape movement. If one of the reels doesn't move or is slow and jerky, you need to look for a slipping or broken belt or "idler wheel."

A broken belt is usually easy to spot once you have the machine opened up, but a slipping belt is hard to detect. If none of the belts are broken try cleaning them with a non-slip solvent (for example, Radio Shack #44-1013), then test the reel operation again. Incidentally, don't overlook the belt that drives the counter; many machines use the counter as a sensor in the system-control circuit to verify reel movement.

An idler wheel (see Fig. 1) transmits mechanical power by friction. A rubber "tire" around the edge of the wheel rubs against the motor shaft and another driven part. If the rubber becomes hard, glazed, or slippery, then there won't be enough friction for the idler to grip the other parts and turn them.

Quite a few VCR's use an idler wheel to drive the tape reels. You can tell if your machine uses one by looking between the "drive hubs" used to turn the tape reels. If there is a plastic guide that looks like the one shown in Fig. 1, then your machine uses an idler wheel.

To fix the problem, swab the rubber on the wheel with non-slip solvent. Wipe it dry, swab it again, then wipe it dry. If your VCR is the type shown in Fig. 1, you can avoid a major disassembly by applying the non-slip solvent to the idler by pushing a cotton swab moistened with solvent through the guide slot. Turn the tape-drive hub by hand as you press the swab against the rubber on the idler wheel.

Sometimes the spring that pulls on

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the idler has lost some tension. Remove the spring and cut off a few turns, then make a new loop on the end with needle-nose pliers. Re-attach the spring and try out the machine.

Physical Damage. A VCR that has been dropped or abused may have a broken circuit board, broken controls, or bent metal parts. The display/control board directly behind the front panel is the most vulnerable. Remove the front panel and examine the board, particularly at the corners. If it is broken, you can sometimes salvage it by soldering jumper wires across all of the broken traces and replacing any broken components.

If one or more of the front-panel controls won't work but their functions can be performed via the remote, then the problems may simply be a damaged front-panel control. The pushbuttons on the front are mechanically linked to the actual switches mounted on the control/display circuit boards. Remove the front panel and try operating the VCR by pressing the switch located on the circuit board. If it operates normally, look at the rear of the front panel to find out what's wrong. Usually a plastic rod that connects the pushbutton to the circuit-board mounted switch has been broken or misalligned. You can usually get it working by bending it back into alignment or gluing the parts back together. If a part is missing, you can make a replacement from a scrap of plastic. It doesn't have to be too elegant as long as it will depress the switch.

Sometimes the pushbuttons and the front panel are molded as a single unit. Small strips of plastic act as hinges and springs. If these strips break, then the button may slip out of alignment or simply fall out. You can use silicone glue (such as Radio Shack #64-2306) to re-attach the button. The silicone remains rubbery after it sets, so it will allow enough movement in the button to activate the switch on the circuit board.

Loading Problems. Front-loading VCR's use motor-driven cassette baskets to load cassettes onto their reel table (see Fig. 2). An inoperative cassette basket will completely disable a VCR. One common problem is that a cassette gets jammed in the basket. If the cassette can't be ejected, the system-control circuit will shut down the VCR.

There are several causes for jamming. Sometimes the cassette case is warped or damaged in a way that jams it in the basket. If the cassette has been inserted upside down or backwards it will jam. Even inserting the cassette at a slight angle can cause it to jam. The solution to any of these problems is to open the VCR case and examine the stuck cassette. Try to wiggle it around and find the place where it is binding. Find the small motor that runs the loading mechanism. Gently turn the gear on the motor by hand to try to back out the cassette. If the problem is the cassette itself, then once you get it out, the VCR should function normally.

Sometimes there is a problem with the cassette basket that will cause a tape to jam. For example, inside the basket there are some springy metal fingers that grip the cassette; if they have lost tension, the cassette can slip backwards as the basket moves. That can cause the rear of the cassette to get wedged in the loading slot as the basket moves down. The solution is to gently bend the fingers to increase the tension. Too much tension on the fingers or some other cause of friction between the cassette and the basket can lead to the same problem, so be careful when making the adjustment.

Some VCR's have a switch that senses forward movement of the basket as a signal to start the loading motor. There are a variety of types, but most are leaf switches mounted on the cassette basket. The contacts are supposed to close when a tape is fully inserted. If that switch is activated before the cassette is all the way in, the tape will get wedged in the slot, so check that switch if the problem persists.

Also, check the loading switch if you can slide a cassette into the slot, but the motor that pulls the tape in won't turn on. Some have a small plastic finger attached to the end that presses against the cassette. That finger is prone to break off. Manually close the switch. If the loading mechanism starts, then you probably just need to glue a small piece of plastic onto the end or reposition the switch so it is activated by the cassette.

If manually closing the contacts won't activate the motor, try bypassing the switch with a jumper. If that activates the motor, then the switch contacts are dirty. Clean the switch with contact cleaner. Don't spray directly on the switch because over-spray will get on other components and could cause damage; instead spray a little cleaner on a piece of paper, then rub the paper between the contacts of the switch.

If the switch seems to be okay, then

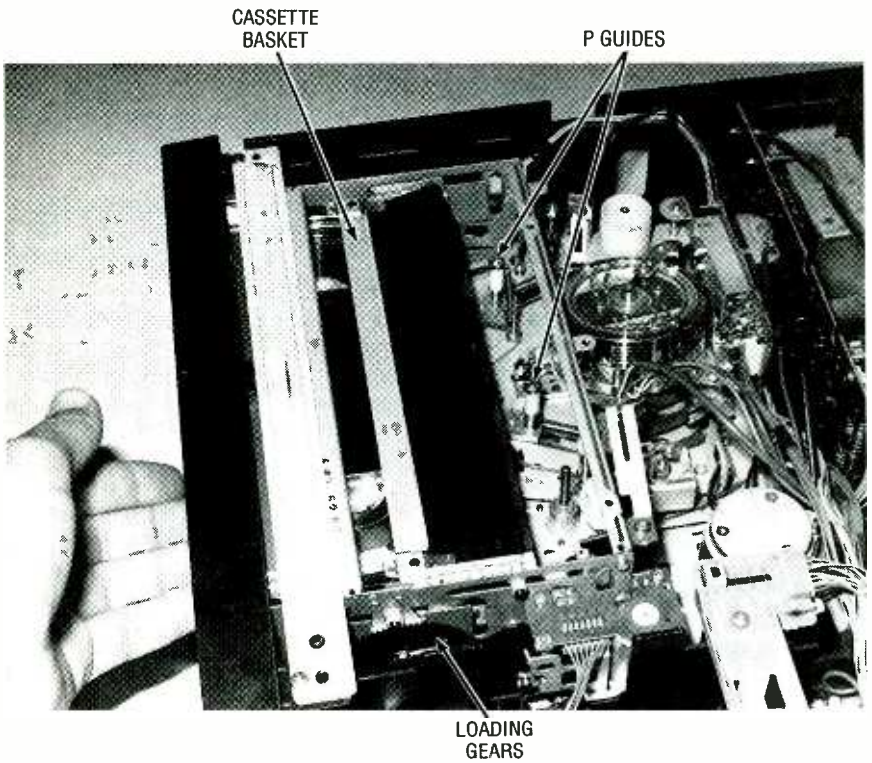

Fig. 2. When you insert a cassette, a switch activates a motor that drives the cassette basket. The basket pulls the cassette in and then lowers it onto the reel table. If the loading gears become out of time (slip a tooth), then the mechanism will jam as it lowers the basket.

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check out the motor. Some of these motors will run on 9 volts, so (with the power cord unplugged) attach clip leads between the motor terminals and a 9-volt battery. You may need to reverse the polarity to get the motor to run. If it won't run with the battery, try a 12-volt supply. If it still won't run, you need to replace the motor. Sometimes you can get the motor working by spraying contact cleaner into the area of the brushes and manually rotating the shaft.

If the motor starts to turn then stalls, there is probably something jamming the loading mechanism. Look for a foreign object, a loose screw, or a bent part.

The motor drives a large gear that is connected by a shaft to a similar gear on the other side of the basket. If one of the gears slips a tooth, one side of the basket will jam as the basket changes from inward to downward motion.

The procedure for correcting this problem is called "timing the cassette basket." First mark the present location of the gears by making a dot with a felt tip pen on the two gears at the point where they mesh. Next remove the clip that attaches the gear to the shaft on the side opposite the motor. Remove the gear and reinstall it offset one tooth from the original position. Try loading a cassette and see what happens; if the problem is worse you've moved the gear the wrong way, so try again by moving the gear in the other direction. If the problem is better but still binds, move the gear another tooth in the same direction.

Power-Supply Problems. Most of the circuit boards in a VCR are too complex to troubleshoot unless you have a lot of experience, but the power-supply board is fairly easy for anyone with some basic electronics knowledge. When the VCR is totally dead, the power supply is an obvious starting point. The power supply can also be responsible for a number of other problems. If the supply isn't delivering the correct voltages to all of its outputs, some systems may not function correctly while others function normally; so if there is a mysterious problem that you can't explain, check each output of the power supply.

With a dead supply, I like to start by using an ohmmeter to check for continuity from one blade on the power plug to the other. If you have continuity, then the primary circuit is probably fine

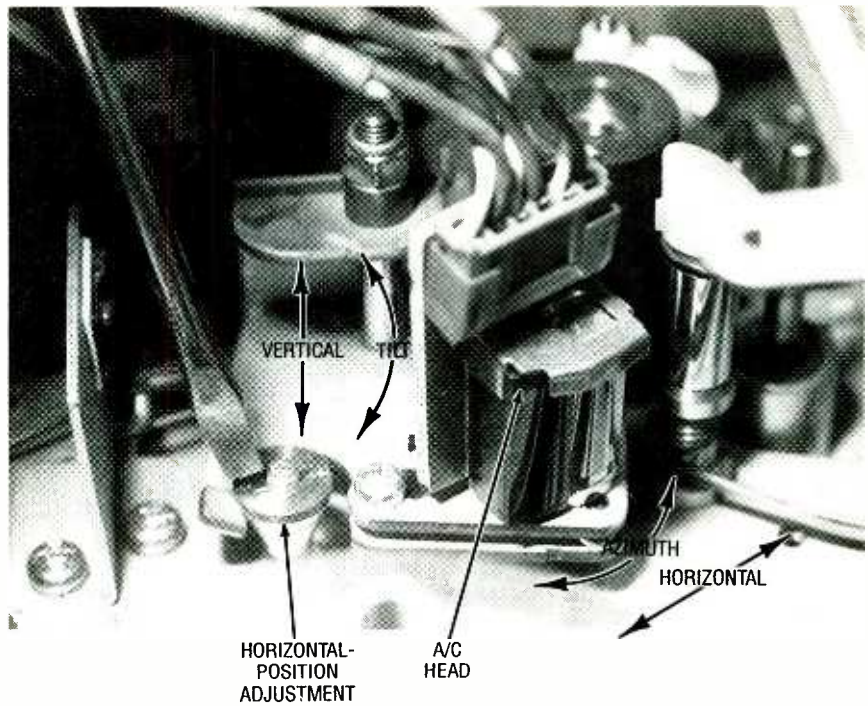

Fig. 3. This is the A/C (audio/control) head. There are four adjustments: horizontal position, vertical position, tilt, and azimuth. The adjustments affect sound quality and sync. They also have an effect on picture tracking.

and you can move on to check the secondary circuits. If you get an open-circuit reading, make another check with the probes on the terminals where the cord attaches to the board. If you get continuity here, then the cord or plug is bad.

If you still get an open circuit reading, look for a blown fuse. There are usually several fuses at different locations on the board. Check them with the ohmmeter since you can't always tell by looking. If the fuses are blown, replace them and try out the VCR. If they blow again, then there is a short or a component is drawing too much current; find the problem before you try any more fuses. If the unit functions normally, it's safe to assume that some transient blew the fuse and the VCR will be all right now.

If the fuses are intact, check for continuity through the primary transformer winding. If the primary checks out all right, then power up the VCR and use a voltmeter to measure the various outputs. Some boards will be marked with voltages. If there are no voltage markings on the board, you need a schematic to do a complete job; but as a basic test you can check each output and assume it is okay if you get a reading above 5 volts. If one of the outputs is dead, look for burned resistors or other components in the circuit. A good way to locate a bad component is to start at the transformer end of the circuit and take a voltage reading. If there is no voltage at this point, then the problem is probably in the transformer. If there is voltage present, then follow the circuit and take voltage readings at each component. When you lose the voltage, you have found the defective component or a possible short.

Bad Sound or Slight Tracking Problems. VCR sound is recorded with a separate audio recording head similar to the recording head in a cassette recorder. That head also records a control pulse on the tape that is used to keep the video head tracking correctly. Because of its dual purpose, the head is called the audio/control head or A/C head. If it becomes misaligned, it can cause distorted sound or sound that is out of sync with the lip movements on the screen. Because the A/C head also controls the picture tracking, adjusting it can be tricky. There are usually several adjustment screws for horizontal position, tilt, azimuth, and vertical position (see Fig. 3).

If the sound is in sync but it's muffled or distorted, try adjusting the tilt and azimuth. Note the original position and count each half turn as you make the adjustments. Try the tilt first. Adjust about one and a half turns one way; if there is

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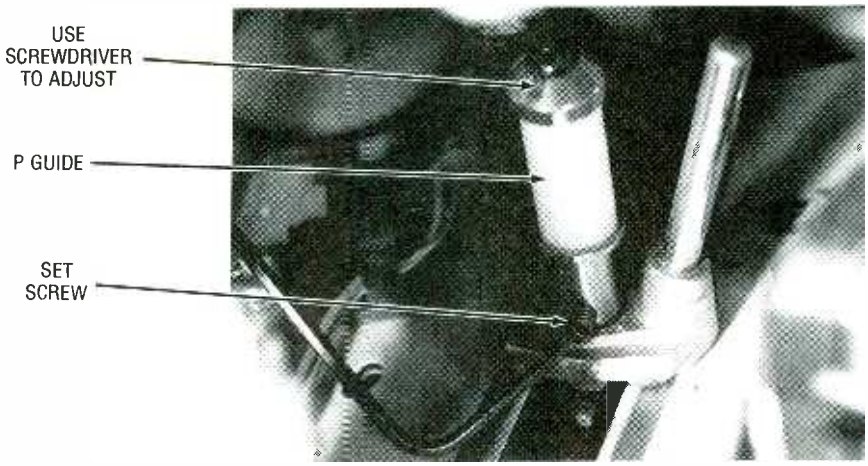

Fig. 4. The P guide adjustment affects picture tracking. Loosen the set screw with an Allen wrench before making the adjustment with a screwdriver.

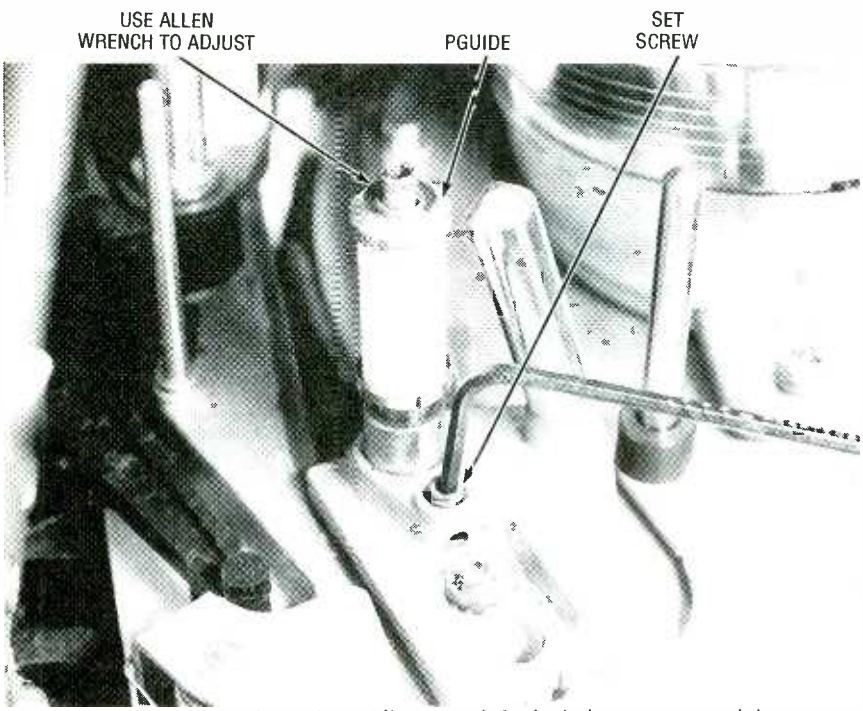

Fig. 5. This type of P guide needs an Allen wrench for both the set screw and the adjustment. Be sure to lock the adjustment with the set screw when you are done.

no improvement, adjust it back to the original position then one and a half turns the other way. If there is still no improvement, return to the original setting and try adjusting the azimuth using the same procedure. Watch the picture as you make the adjustments. If white lines begin to appear on the screen, adjust the head until the lines disappear making sure that the sound is still okay.

When the sound is out of sync with the lip movements on the screen, the horizontal position of the A/C head needs adjusting. First study a tape as it plays to analyze the exact nature of the problem—do the words begin before the person opens his mouth? Or does he open his mouth before the sound starts? If the sound comes first, then the head needs to move in the same direction as tape travel. If the sound occurs late, you must move the head in the opposing direction.

The horizontal position is adjusted by turning the large adjusting nut shown in Fig. 3 (the screwdriver is pointing to the horizontal adjustment nut). On some models, you may need to loosen the mounting screws and move the head slightly. Observe the picture as you move the head; tracking lines will appear and disappear. Position the head so that the sound is in sync and there are no tracking lines in the picture.

Tracking problems that can't be fixed using the tracking control on the front panel can usually be eliminated by adjusting the A/C head. Set the front-panel tracking control to the center position, and adjust the vertical and then the horizontal position of the head as you would for audio problems.

Severe Tracking Problems. If there are scratchy white lines in the picture that you can't clear up with the tracking control, and adjusting the A/C head doesn't help, then the problem may be with the P guides. The P guides are motor-driven pins that pull the tape out of the cassette and wrap it around the head (look back at Fig. 2 to help locate them). They control the position of the tape on the head. If they are out of alignment, tracking lines will appear.

There are two P guides; the one closest to the supply reel is called the entrance P guide and the one closest to the take-up reel is called the exit P guide. If the tracking lines are in the lower portion of the picture, then the exit P guide needs adjusting; if they are in the upper portion, the entrance P guide needs adjustment.

There are two types of P guides: one that can be adjusted with a screw driver (see Fig. 4) and one that requires an allen-head wrench (shown in Fig. 5). Before adjusting either type, you must first loosen an allen-head set screw. Note the position of the guide you want to adjust, loosen its set screw, then insert a tape and play it. Turn the adjustment on the top of the P guide a little and watch for an improvement in the picture.

After you have adjusted the P guides, remove the tape and unplug the machine, then lock the adjustment with the set screw. If you weren't able to correct the problem by adjusting a P guide, reset it to its original position.

A VCR that Damages Tapes. Tape follows a complicated path inside the VCR. When you press play or record, the two P guides pull the tape out of the cassette and wrap it around the video head. The tape is held in position by other guides and pulled across the heads at a uniform speed by a capstan and pinch roller. Problems anywhere along the tape path can lead to tape damage.

The most obvious symptom of prob-

(Continued on page 114)

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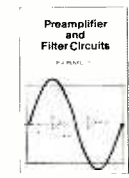

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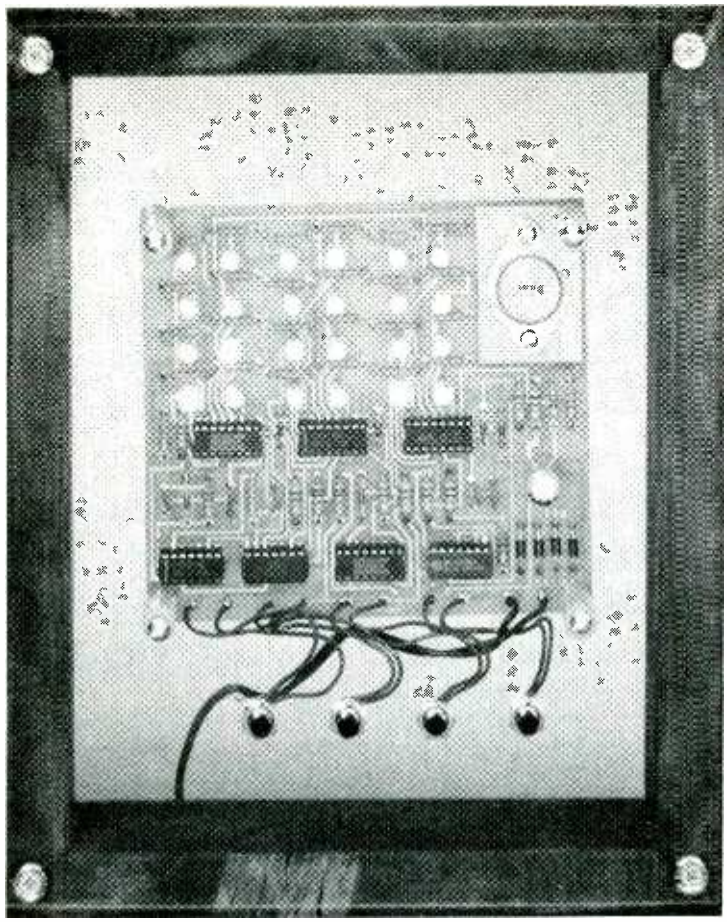

Build a BINARY CLOCK

BY FRED BLECHMAN

Here is an unusual timepiece that is sure to receive lots of attention. Aside from its conversational value, it can also acquaint you with the binary numbering system—the language of computers.

The trouble with most digital clocks is that they are a bit boring. Oh, they look all right and keep accurate time, but what the world needs is the convenience and accuracy of electronic time keeping along with a little excitement and intrigue. The *Binary Clock* presented in this article, which you can build from scratch or from a kit, is the answer. It looks great, keeps good time, but not everyone can read it; you have to know something about the binary numbering system to figure out what time it is—making it an effective conversation piece.

One or more of a field of 24 lights changes from green to red, or red to green, each second, making the display both eye-catching and mysterious. You can sit back, watch your clock, and know what time it is while everyone else is in a quandary.

A Little Background. About 15 years ago a special BCD clock chip was available, and Electronic Kits International (EKI) offered a BCD clock in kit form. Designed by David McDonald, EKI's circuit *guru*, it had only red lights, and not much circuitry. Since then, the special chip has become unavailable, so the clock has been completely redesigned by David to use discrete integrated circuits and a special two-color display. It's much better looking than the original, easier to read, and you can learn a lot about digital counting and gates by following the "theory of operation" of David's ingenious little circuit.

Since the clock "counts" from the 60-Hz (cycles per second) AC line, the Binary Clock will remain as accurate as the atomic clock standard used by the power company, unless the power is interrupted. Also, because the Binary Clock has both RESET and HOLD (stop) buttons, it can be used as a one-second timer or stopwatch.

Description. The Binary Clock display consists of 24 bi-color light emitting diodes (LED's) in six vertical columns and four horizontal rows. The two left columns represent 1–12 hours, the two middle columns represent 0–59 minutes, and the two right columns represent 0–59 seconds. (More information on how to read the binary clock display will be given later in this article.)

Two power supply voltages are generated from an AC wall-plug transformer. An unregulated voltage (about 14-volts DC) powers seven integrated circuits—counters, AND gates, NAND gates, and flip-flops. A voltage regulator provides 7-volts DC, and is a source or sink for the bi-polar LED's. When current flows in one direction through this special type of LED, it lights green. When the current is reversed, it lights red.

The integrated circuits count incoming pulses from the AC power line, and control LED current flow, sequentially advancing in binary-coded-decimal format to display seconds, minutes, and hours to the closest second. Four switches are used for reset, fast set, slow set, and hold.

The strong of heart can build this clock from scratch, although there is a considerable amount of circuitry involved. An available double-sided printed circuit board simplifies construction to about three hours. A complete kit, less enclosure, is also available, saving you the time and cost of finding all the parts—especially the

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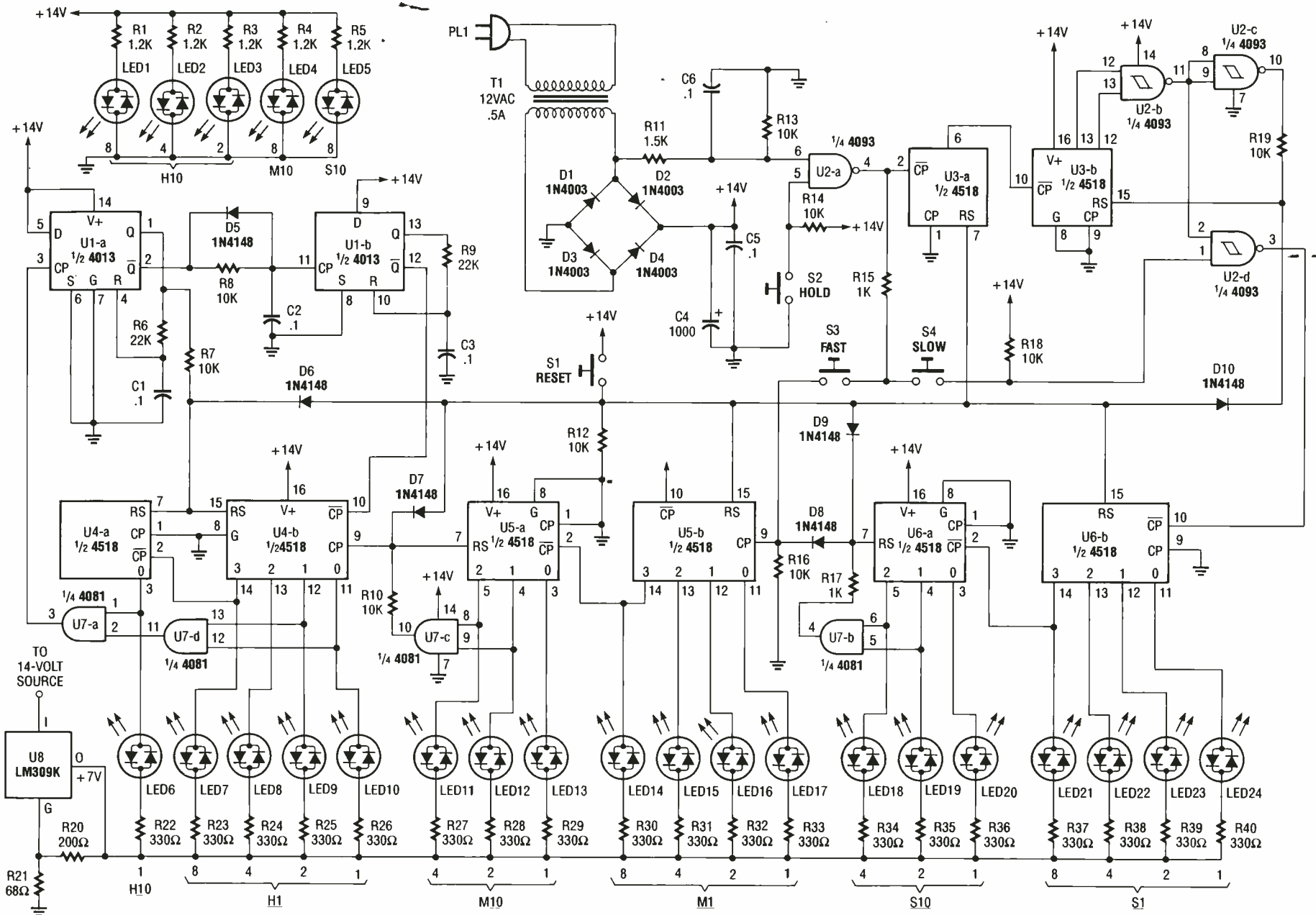

Fig. 1. The Binary Clock is an unusual timepiece, in that, in order to read the time displayed by the LED's, you must understand the binary numbering system, which has only two digits: 1 and 0.

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bi-polar LED's. A classy enclosure is also offered.

Theory of Operation. The schematic diagram of the Binary Clock is shown in Fig. 1. Power for the circuit is derived from a 117-volt, AC wall-plug transformer (T1) that provides 12 volts AC at the secondary winding. That voltage is applied to a full-wave bridge rectifier (consisting of D1–D4), and filtered by capacitors C4 and C5, to provide an unregulated 14-volt DC source. The unregulated 14-volt output of the rectifier is used to power the integrated circuits, U1–U7.

That unregulated source is also fed to the input of U8, an LM309K 5-volt, voltage regulator whose output voltage is boosted via resistors R20 and R21 to about 7 volts DC. The two voltages—14 and 7 volts—are used to control the direction of current flow through the LED's. LED6–LED24 are connected between the + 7-volt output of U8 and the output pins of U4, U5, and U6. Each of those outputs is normally at or near ground potential. That produces a current flow from the + 7-volt bus through the LED to ground, and the LED turns green. In this case, the + 7-volt bus is the source.

However, when an integrated-circuit output pin connected to an LED is active (high), it is essentially at + 14 volts, and current flows through the LED in the opposite direction, toward the lower + 7-volt bus, and the LED turns red. In this case, the + 7-volt bus is the sink. Simply put, when an output is low, the associated LED is green; when the output is high, the LED turns red. Incidentally, since the LED's are bi-polar, if you connect them opposite to the direction shown, they'll light in the opposite condition. Red will be the default, and green will be the active high mode. Throughout the remaining discussion, however, we will assume green is default and red is active.

The trick now is to get the IC outputs to clock in such a way that they can be used to count seconds, minutes, and hours in binary-coded decimal, changing the proper LED's from green to red (or back to green) at the proper time. That means we need one-second clock pulses. The clock pulses are derived from the intersection of D1 and D2. Sixty positive half-wave cycles are produced every second through the transformer from the 60-Hz AC power line.

Resistors R11 and R13 comprise a voltage divider to drop the voltage, which is filtered by C6 and applied to pin 6 of a NAND Schmitt trigger, U2-a. Pin 5 is held high through R14. Whenever a positive pulse is detected at pin 6, pin 4 of U2-a goes low. That negative-going pulse is applied to pin 2 of U3-a, a divide-by-10 counter configured for negative-edge triggering.

At each incoming clock pulse on pin 2, the outputs of U3-a (pins 3, 4, 5, and 6) count upward in BCD (binary-coded decimal—1, 2, 4, 8, referred to as bits 0, 1, 2, 3 in the schematic diagram) until U3-a internally resets on the tenth count. That drops the output on pin 6 low, providing a negative-edge clock pulse to the input of U3-b, another decade counter. In other words, U3-b receives a clock pulse for every 10 power-supply pulses or every sixth of a second.

Now we need to divide by six, so that we have an output of one-pulse-per-second. That is accomplished by U2-b, another NAND Schmitt trigger, which monitors the output of U3-b at pins 12 and 13. Because those two outputs represent numerical values of 2 and 4, when both are active, the count is 6 (2 + 4 = 6). Since it took 10 input pulses for each count of U3-b, 6 counts of U3-b is actually 60 pulses, or one second. Putting it another way, U3-b pins 12 and 13 both become high exactly once each second, on the sixth count.

That instantly causes pin 11 of U2-b to go low, pulling pins 8 and 9 of U2-c low, which, in turn, forces pin 10 high. That places a high on reset pin 15 of U3-b, through R19, instantly causing pins 12 and 13 of U3-b to drop low. Notice that the reset pulse is isolated from the other integrated circuit reset pins by D10.

Now look back at U2-b. Since pins 12 and 13 have just been reset low, pin 11 goes high, bringing pins 8 and 9 of U2-c high. That makes pin 2 of U2-d, another NAND Schmitt trigger, high. Since the other input to U2-d at pin 1 is held high by positive voltage through R18, pin 3 of U2-d goes low. That negative edge provides a clock pulse to the seconds counter, U6-b, at pin 10. At that point, everything repeats, creating a clock pulse every second to U6-b.

Now that the clocking is established, how about the counting by the LED's? When the clock is first plugged in, all the LED's should turn on green, but random circuit power-up may cause one or more of the LED's to turn on red. Pressing switch S1 feeds a high voltage to the reset pins of U4, U5, and U6, forcing all their outputs low, causing LED6–LED24 to turn green.

PARTS LIST FOR THE BINARY CLOCK

SEMICONDUCTORS

U1—4013B, CMOS dual D flip-flop, integrated circuit
U2—4093B, CMOS quad 2-input NAND Schmitt-trigger, integrated circuit
U3, U4, U5, U6—4518B, CMOS dual synchronous divide-by-10 counter, integrated circuit
U7—4081B, CMOS quad 2-input AND gate, integrated circuit
U8—LM309K, voltage regulator, integrated circuit
D1–D4—1N4003, 1-amp, 200-PIV, general-purpose rectifier diode
D5–D10—1N4148, general-purpose small-signal diode
LED1 to LED24—bi-color light-emitting diode, red/green

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1–R5—1200-ohm
R6, R9—22,000-ohm
R7, R8, R10, R12–R14, R16, R18, R19—10,000-ohm
R11—1500-ohm
R15, R17—1000-ohm
R20—200-ohm
R21—68-ohm
R22–R40—330-ohm

ADDITIONAL PARTS AND MATERIALS

C1–C3, C5, C6—0.1-µF, ceramic-disc capacitor
C4—1000-µF, 16-WVDC, radial-lead, electrolytic capacitor
S1–S4—SPST normally open pushbutton switch
T1—12-volt AC, 500-mA wall-plug transformer
Printed-circuit or perfboard materials, sockets, enclosure, hook-up wire, solder, hardware, etc.

Note: The following items are available from Electronic Kits International, Inc., 16631 Noyes Avenue, Irvine, CA 92714, Tel. 800-453-1708 and 714-833-8711: A complete kit with all parts and case, $59.90 (order B01098); all parts except case, $47 (order B00898); etched and drilled double-sided circuit board, $10.50 (order B00798); set of all eight integrated circuits U1–U8, $20 (order B00098); set of 24 dual-color LED1–LED24, $20 (order B06007); formed Plexiglas case with hardware (see text), $14.90 (order B24003). Add $5.00 total per order for shipping and handling, California residents please add local sales tax.

Fed directly from the 14-volt line to ground through 1.2k resistors, LED1–LED5 are always green. They are

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only put into the display for cosmetic purposes, to visually fill in the 6 × 4 display matrix, and they never change states.

When the first clock pulse enters U6-b, pin 11 goes high. Because that places that pin at a higher voltage (around 14 volts) compared to the other side of the LED, which is tied to the +7-volt bus, the current reverses and the LED turns red, indicating a count of one second. When the next one-second clock pulse enters U6-b, pin 11 goes low and pin 12 goes high. That causes LED24 to turn green, and LED23 to turn red.

Following the binary-coded decimal output of U6-b, during the third second both LED23 and LED24 will be red. In the fourth second, LED22 will be red, and LED23 and LED24 will be green, and so on.

Finally, at the tenth count, when U6-b resets internally, pin 14 drops low, providing a negative-edge clock pulse to pin 2 of U6-a. Every tenth second, another pulse causes U6-a to count upwards, indicating tens of seconds. But we know that there are only sixty seconds in a minute, so how does the clock stop counting at 60 and advance to show minutes?

Look at pins 5 and 6 of U7-b. They are monitoring the signal level on pins 4 and 5 of U6-a. At the 40th second, pin 5 goes high and stays high as the clock counts up toward 60. At the 60th count, however, pin 1 goes high for the first time together with pin 5. With both pins 4 and 5 of U6-a high, pins 5 and 6 of U7-b are now also high, making pin 4 of U7-b high. That provides a reset pulse to pin 7 of U6-a through R17, and also sends a positive-edge clock pulse through diode D8 to pin 9 of U5-b. LED17 turns red to indicate the one minute count.

The minute LED's light red in BCD sequence, until both LED14 and LED17 are red at nine minutes. At the tenth minute, U5-b internally resets, so pin 14 of U5-b drops low, clocking pin 2 of U5-a. As the tens-of-minutes are counting upward, once again the sixtieth minute count is monitored, this time by U7-c, in a similar manner to that of U7-b monitoring sixty seconds.

Hours counting is the same for the units column, since it counts from 1 to 9. However, the tens-of-hours column has to stop at 12 hours and reset not to 0, but 1! That takes some fancy electronic footwork, which is performed by U1-a, U1-b, U7-a, and U7-d.

When LED6 and LED9 are both red,

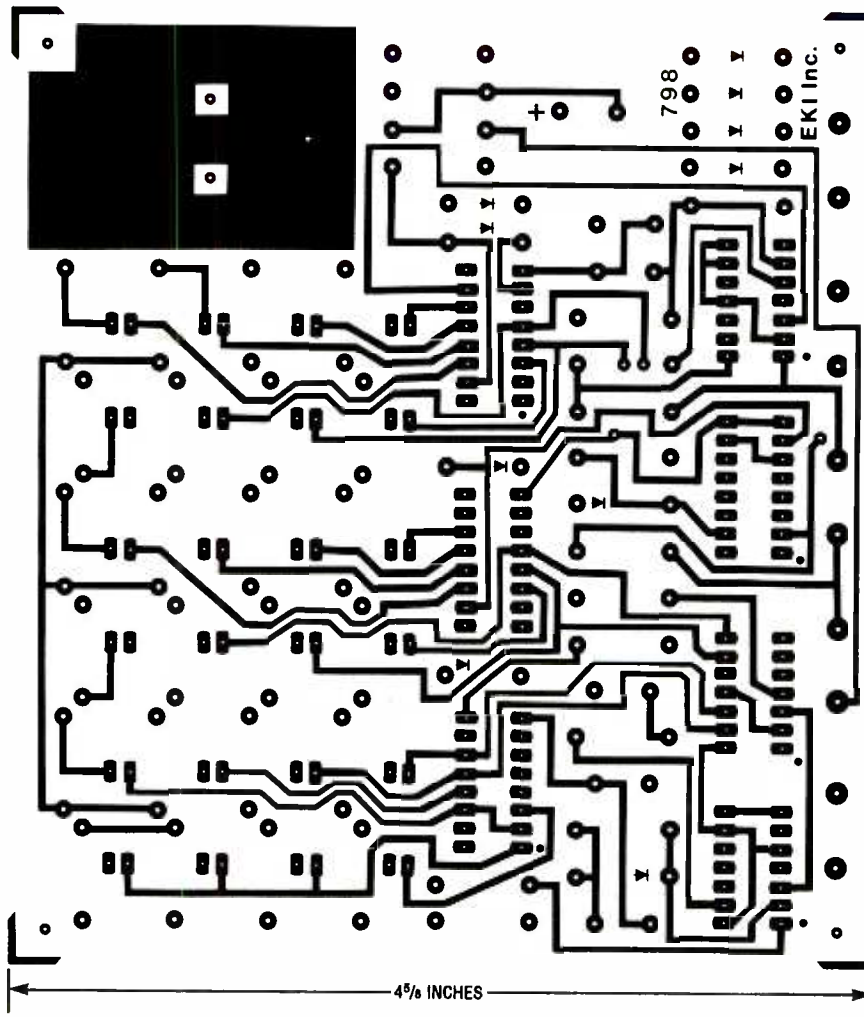

Fig. 2. The Binary Clock was built on a double-sided printed-circuit board; the component side is shown here.

signifying 12AM or 12PM, the next hour would try to count to 13. That, of course, is not allowed with a 12-hour clock. At the 13-hour count, pin 11 of U4-b goes high. Since pin 12 is already high, this means both input pins 12 and 13 of AND gate U7-d are high, making its pin-11 output high. That forces pin 2 of U7-a high. Since the other input, pin 1, is already high, the output of U7-a at pin 3 goes high.

Two things now have to happen. All the hour LED's must be reset to green (the others already are green, indicating zero seconds and minutes), and the one-hour LED, LED10, must be made red. Flip-flops U1-a and U1-b are wired so that the D pins are high. That forces their $\overline{Q}$ outputs to reset to high, and the Q outputs low. The positive-edge pulse from the output of U7-a is applied to the clock input of U1-a at pin 3. That, in turn, causes U1-a pins 1 and 2 to change states; pin 1 goes high and pin 2 goes low. The positive pulse from pin 1 travels through R7 to reset U4-a and U4-b, causing LED6, LED9, and LED10 turn green. That pulse also goes through a time delay created by RC circuit R6 and C1, to pin 4, which resets U1-a, causing pin 2 to go high and pin 1 to go low.

At that point, the positive-going pulse from pin 2 of U1-a goes through a short RC delay circuit, consisting of R8 and C2, to trigger the clock input (pin 11) of U1-b. That instantly makes the $\overline{Q}$ output of U1-b at pin 12 to go low, and pin 13 go high. The output at pin 12 clocks pin 10 of U4-b, thus turning LED10 red, indicating 1 AM or 1 PM. Flip-flop U1-b is then reset when the pin 13 pulses after a short delay created by R9 and C3, which is feed to the reset input of U1-b at pin 10. Flip-flop U1 is now set for its next action 12 hours later.

Clock time setting is accomplished via switches S1–S4. The RESET switch, S1, applies a positive voltage, directly or through diodes, to reset all the LED's to green and the count to zero. The HOLD

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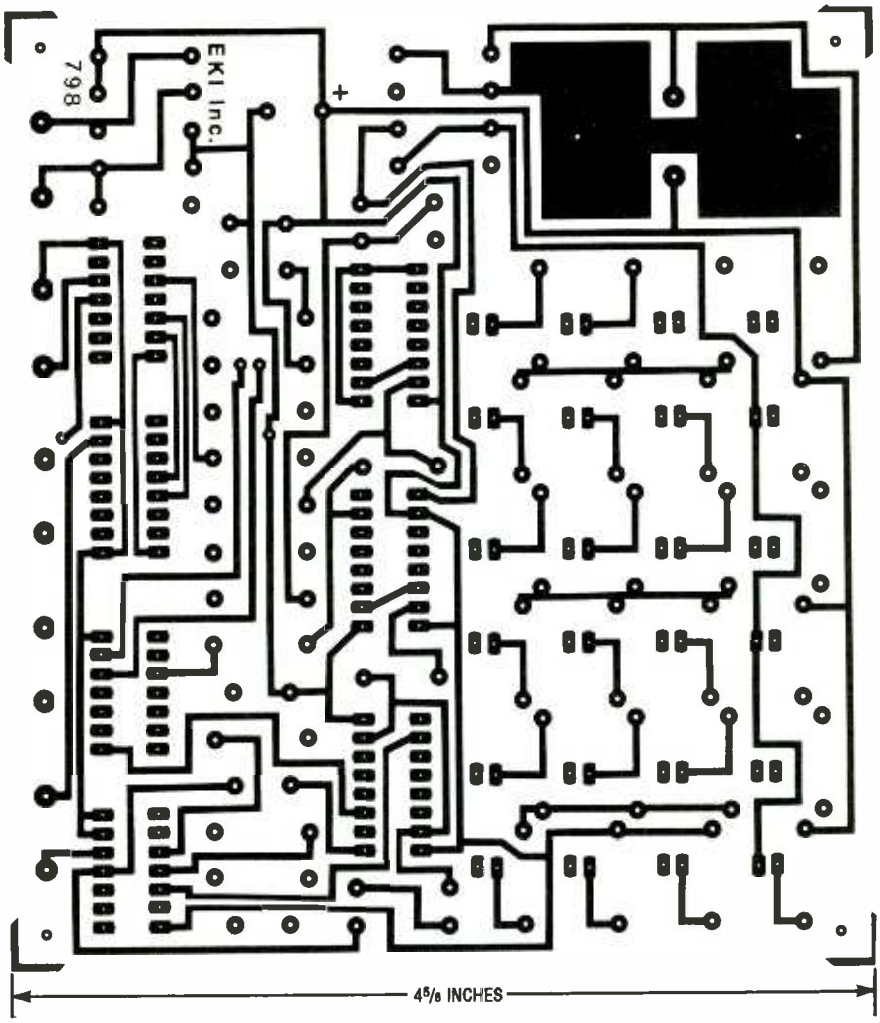

Fig. 3. Here's the foil side of the Binary Clock's double-sided printed-circuit board.

switch, S2, stops all counting by grounding one input to U2-a. The FAST switch, S3, applies positive clock pulses to U5-b sixty times per second, thus advancing the display sixty minutes—one hour—each second. Similarly, the SLOW switch, S4, causes U6-b to count at sixty times the normal speed, advancing the display one minute for each second of real time.

Construction. There is really nothing critical in the wiring of the Binary Clock. You can build it on a perfboard, using wire-wrap to complete the electrical connections, but there will be a lot of wires! Certainly, a printed-circuit board is a better approach.

However, the printed-circuit layouts shown in Figs. 2 and 3 represent a two-sided board with "plated-through" holes. If you are not equipped to produce that kind of board, I'd certainly recommend that you purchase the printed-circuit board offered in the Parts List. It is a very clean design, with no jumpers (except the plated-thru holes.)

Figure 4 shows the parts-placement diagram for the double-sided, printed-circuit board. (Only the component-side of the board is shown in that layout.)

Most of the parts are readily available, but the bi-polar LED's are, by their nature, fairly expensive. The wall-plug transformer, T1, does not have to be a 12-volt AC unit; you can operate the Binary Clock, with less brightness, using a 9-volt AC unit—just make sure that it can supply at least 250 mA.

If you assemble the Binary Clock from the kit offered in the Parts List, it should take only about 2½ to 3 hours to complete. There are only a few precautions. Make sure all your 278 solder joints are good, with no bridges between pins on the IC sockets. Polarity is critical on the LED's, or they will light green when they should be red, and red when they should be green. The LED's (with the board oriented as shown) should be mounted with the flat side down for a background of green, with red doing the counting.

The six small-signal diodes (D6–D10), the four power diodes (D1–D4), and the large filter capacitor (C4) all must be installed with the proper polarity as shown in the parts-placement diagram. After all the soldering is done, insert the integrated circuits so that they are all oriented in the same direction, with pin 1 on the left, as shown in the parts-placement diagram.

Integrated circuits U1–U7 are CMOS devices and as such are static sensitive. Extreme care should be exercised when removing them from their anti-static pad since only a small static discharge can permanently damage them.

Checkout. When you plug the transformer into 117-volts AC, all 24 LED's of the display should turn on green, but a few may turn on red. Press the RESET switch, S1. If all the LED's don't turn green, you have a problem. If none of the LED's light, make sure you have power. Check both the 14-volt and 7-volt buses for the proper voltages.

If individual LED's don't light, they may be defective, badly soldered, or the integrated circuit driving that unit might be defective, improperly oriented, or improperly seated in its socket. If an LED turns red on reset, it might be installed with reversed polarity. Once you have all the LED's properly lighted, check the counting sequence; if everything is working correctly, it should start with the LED in the lower right corner turning red on the first second.

The count should proceed in binary fashion up the last, rightmost, column (seconds), then to the tens of seconds column, and so forth. Press switch S2 to stop the count. Switch S2 is used to synchronize the display to real time, to the second. Press switch S4 and the two right-most columns should blink furiously as the minutes column counts once per second. Press switch S3 and the minutes columns goes wild as the hours columns advance once per second.

When everything is working, use S3 to set hours and minutes less than real time, S4 to advance minutes and seconds slightly ahead of real time, and then press S2 to hold count until real time catches up with clock time. If you go too far, you will need to count ahead another twelve hours, stopping just ahead of real time.

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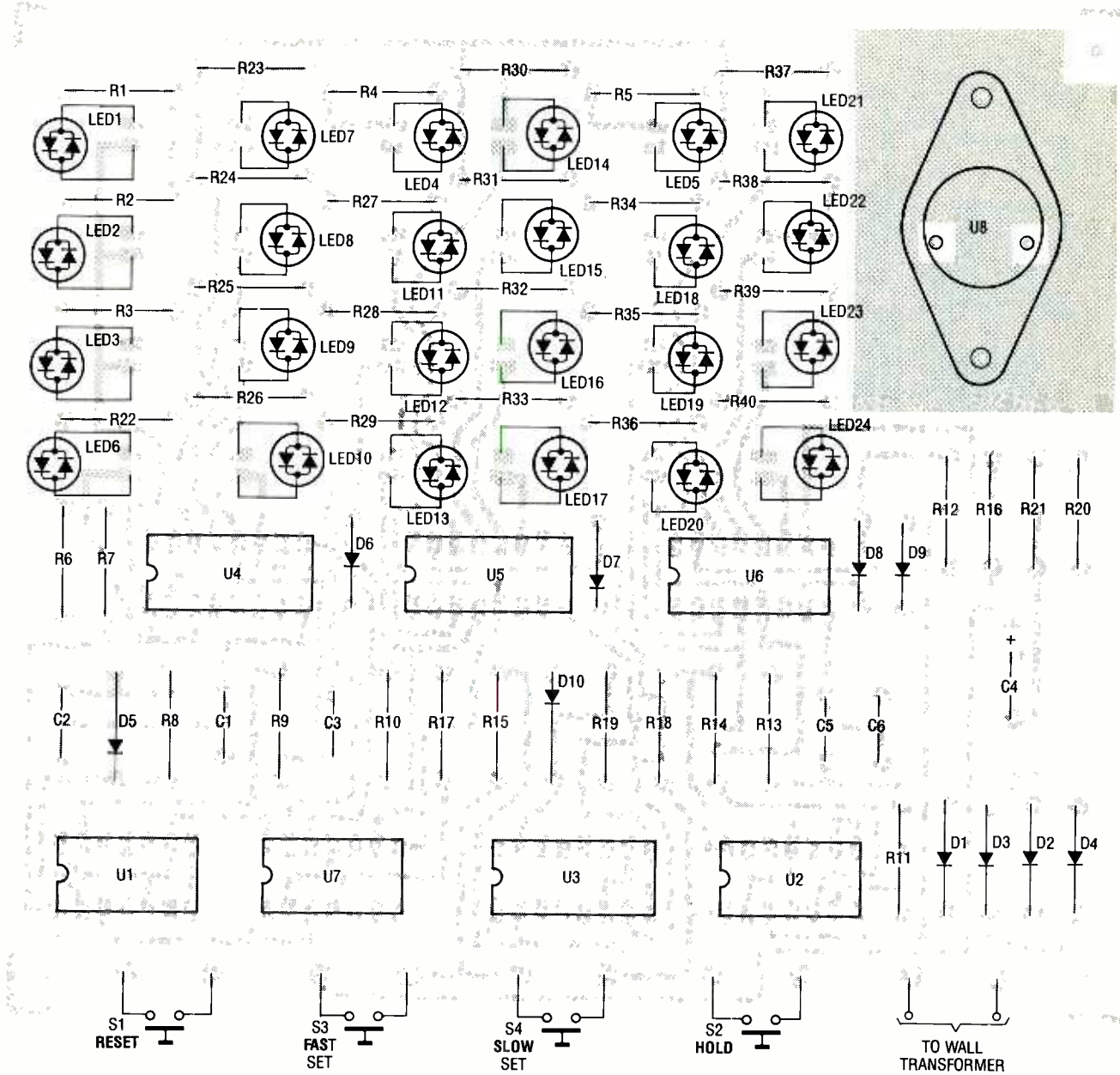

Fig. 4. Here is the parts-placement diagram for the Binary Clock's printed-circuit board. It is recommended that the all DIP IC's be socketed.

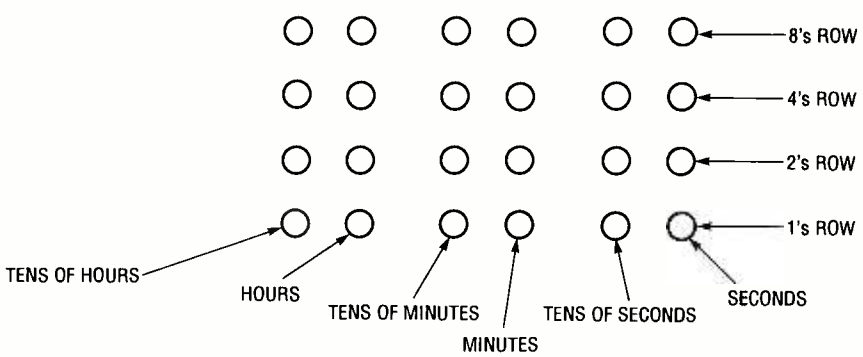

Fig. 5. The Binary Clock uses vertical columns of LED's that display the time in binary-coded decimal (BCD) form. Each LED in the columns represents a specific numerical value that are added together to determine seconds, tens of seconds, minutes, tens of minutes, hours, and tens of hours.

Preparing the Enclosure. You can "package" the Binary Clock any way you please. The photos show a wooden frame with Plexiglas plates front and back. The clock is mounted on spacers to "float" between the Plexiglas plates, making for a very striking display. The wooden frame and undrilled Plexiglas plates, with screws, nut, and spacers, are offered by the supplier in the Parts List.

The front panel is prepared for mounting by drilling four small holes for the mounting screws, four holes to mount the switches, and four holes in the corners to mount the Plexiglas to the

(Continued on page 109)

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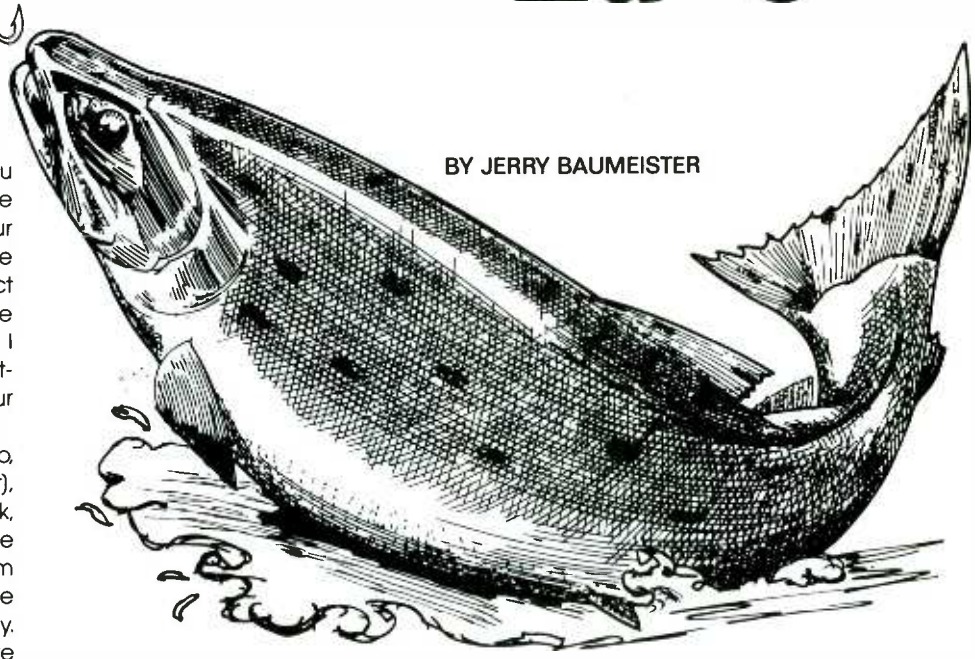
Build an Electronic Fishing Lure

Does your present lure fail to attract the fish to your line? If so, perhaps an illuminated lure will change your luck, and enable you to catch the big one that always seems to get away.

BY JERRY BAUMEISTER



It rained all weekend again. I had planned to go fishing but it just wasn't in the cards. So, I thought I would tinker around with my electronic stuff and wait for the rain to stop. Obviously, my heart wasn't in it, because what grew out of that weekend was a strange, but effective, fishing lure. Perhaps, it is stretching the definition of "electronics" to call it an electronic device, but it does use electricity and in some mysterious way it communicates with fish.

The lure is the essence of simplicity (see Fig. 1). Using a paper clip, a calculator battery, and a light-emitting diode (LED) or micro lamp, you can make an effective multi-purpose fish-catching device and amaze your friends at the same time. If you're like me, your friends have come to expect strange ideas from you and this device will certainly strengthen that image. I think it may even be legal, but you better check the local laws governing your favorite fishing hole to be sure.

The lure consists of a large paper clip, a flat, wafer-type battery (1.5 or 3 volt), an LED or micro lamp, a treble hook, and a pair of needle-nose pliers. The author's version uses a 3.0-volt lithium battery (CR-2430), but the lure can be modified to use any size wafer battery. There is one problem though; if you are going to use an LED as the light source, you'll need to use a 3-volt battery. It takes 1.6 volts of junction potential to "light" an LED and the 1.5 volt batteries just don't have enough voltage.

How it Works. The circuit behind the fish lure (see Fig. 2) is so simple—a battery, resistor, and a lamp—that it is almost not worth showing. A resistor can be added (as shown) to limit current through the light-producing element and to regulate the brightness of the light, but it is not usually needed because the internal resistance of the battery will keep the current at about 33 mA.

The prototype unit used a 1.5-volt lamp powered from a 3-volt battery. That's a bit over the lamp's designed voltage, and tends to shorten both battery and lamp life a bit. However, the extra brightness is attractive to the fish and since catching fish is what this is all about, operating the lamp a little "hotter" than the lamp designers had intended seems a worthwhile tradeoff.

You can use either an LED or micro lamp. You can even use one of those flashing LED's, but make sure it can operate from a 2.5-volt source. I have found that in the waters around my home, diffused yellow LED's work best for black bass. (I don't know why. I guess it's just part of the mystery that makes fishing so interesting.)

Water proofing was not necessary for the ponds where I fish. The resistance of local pond water around here is about 10,000 ohms per cm. Since the resistance through the lamp circuit is about 11 ohms, most of the current flows through the lamp circuit and not the water (current follows through the path of least resistance). The resistance of the circuit using an LED instead of a micro lamp is a bit higher, but it is still low

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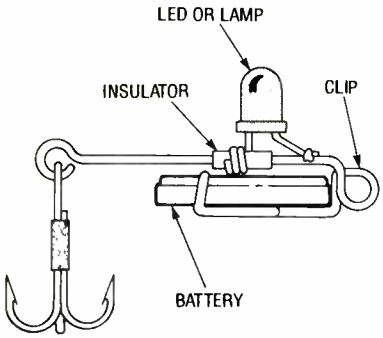


Fig. 1. The Electronic Fish Lure was created from an ordinary paper clip twisted so as to hold the leads of an LED in contact with both poles of a battery.

PARTS LIST FOR THE ELECTRONIC LURE

LED1—Light-emitting diode or micro lamp
R1—Optional, see text
B1—1.5–3-volt, flat wafer-type, calculator battery, see text
Paper clip, cellophane tape, thin-plastic or film insulating material (see text), treble hook, fingernail polish (see text), etc.

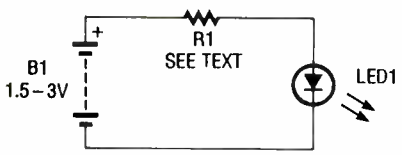


Fig. 2. Here is the simple circuit that comprises the electrical portion of the Electronic Fish Lure. Note: The resistor (R1) may or may not be needed; that will have to be determined by experimentation.

enough to feed the lion's share of the current through the lamp.

In chlorinated water, water that has a high ionic concentration, or in salt water, water proofing is necessary. A little fingernail polish works just fine. Just paint the entire lure, battery and all. You can even use different colors to jazz it up a little. I favor yellow lures with red dots, but use whatever color scheme or pattern that works for you.

The lure can be turned on and off by removing the battery or by sliding a small piece of plastic or film between the battery and the point where it touches the lamp lead. Push the film in to turn the lamp off, remove it to turn the lamp on.

Construction. The wire clip is everything. Take your time and get it right. Start, as shown in Fig. 3, by straightening a large paper clip. Figure 3A shows the

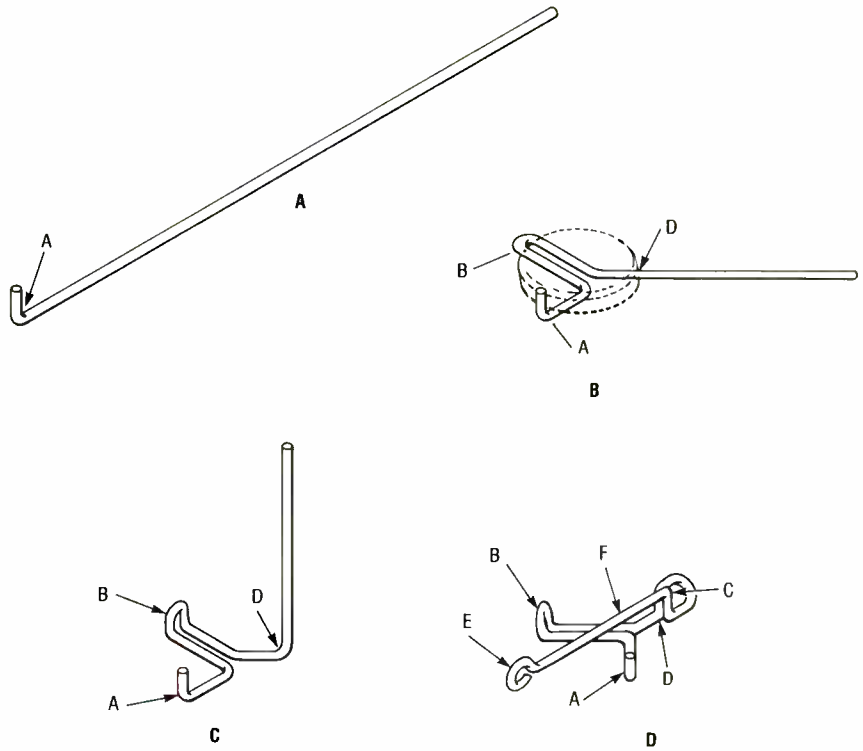
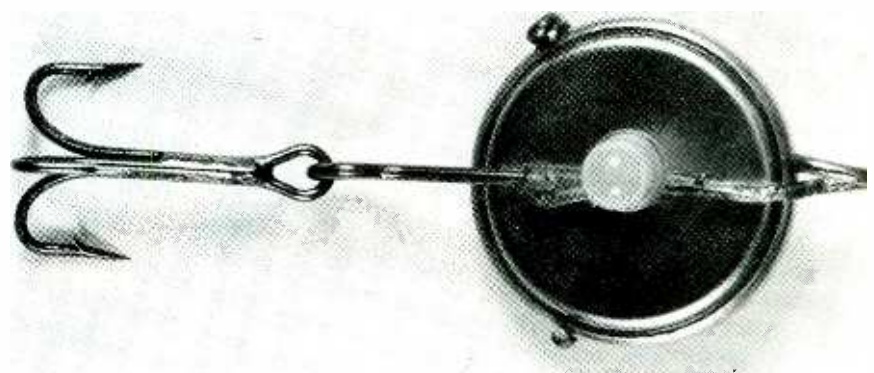


Fig. 3. Follow this clip-bending diagram to form the battery holder for the Electronic Fish Lure. Starting with a straightened large paper clip, make a bend at point A (A), follow by the bend at point B (B), and then the bend at point D (C). Then form a loop at point C and another at point E (D).



Here is the finished lure. Under some circumstances, depending on the conductivity of the waters you fish, it may be necessary to insulate the electrical portion of the unit. Should insulating be necessary, a coat or two of fingernail polish works well.

first bend, a 0.2-inch, 90-degree bend. With the bend pointing toward the ceiling, bend the wire to conform to the diagram in Fig. 3B. Next bend the last 0.2-inch of the double wire at point B in the same direction as point A (toward the ceiling).

Lay a battery, with cellophane tape covering the negative side, on the wire form. The cellophane tape is to keep the battery from shorting during construction. You will need to remove the tape before using the battery in the finished lure. The positive (+) side of the battery should be resting on the wire and firmly against the bends at points A and B.

Next bend the wire at point D toward the ceiling forming a 90-degree bend tight against the battery (as shown in Fig. 3C). Bend the wire at point C and form a loop as shown in Fig. 3D. At the point where the loop reaches point D, bend the wire 90 degrees to the vertical and then again 90 degrees at a point 0.2-inch away to extend over the negative side of the battery. Finally, bend a loop in the wire at point E as shown.

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200,000-Volt Van de Graaff Generator

The first known electrical generator was built in 1660 by the German experimenter, Otto von Guericke (also known to historians as the inventor of the air pump). Though Guericke's generator consisted of little more than a revolving ball of sulfur, that frictional device was capable of developing a very strong charge of static electricity.

The generator's ball was made by pouring molten sulfur into a spherical glass container "about the size of a child's head." When the sulfur cooled, the glass was broken open, and the globe removed and equipped with an iron axle. The assembly was then mounted on a wooden frame that allowed the ball to spin freely. When a dry hand was applied to the rotating sulfur sphere, the ball would become electrified, attract small objects, make a crackling sound, and glow faintly in the dark.

Van de Graaff's Generator. Otto von Guericke's machine quickly became obsolete, but the *triboelectric* principles that allowed that generator to operate did not. It is an elementary physical fact that extremely high voltages can be generated by the repeated contact and separation of dissimilar substances, a process that is otherwise known as friction.

In 1927, New Zealand physicist Ernest Rutherford voiced the need for "a copious supply of atoms and electrons ... transcending in energy the alpha and beta particles from radioactive substances." He was talking about an accelerator. Rutherford's wish inspired a young American scholar by the name of Robert J. Van de Graaff.

Van de Graaff knew that charged particles could be moved to high speeds by high voltages. He also knew that conventional methods of electrical transformation might not provide the necessary energy. But the electrostatic characteristics of the atomic nucleus gave him an idea. Van de Graaff decided to find some way of generating high electrostatic voltages in order to, as he phrased it, "meet the atom on its own terms."

Have hours of high-voltage fun when you experiment with this working high-voltage generator.

BY STANLEY A. CZARNIK

The first Van de Graaff generator was built at Princeton University in the fall of 1929. Van de Graaff built the machine from scrap: a silk ribbon, a small motor, and a tin can. The silk had to be pure; there is a story about how Van de Graaff would visit local fabric shops and set fire to silk samples to see if the cloth was tainted. Van de Graaff's primitive static device developed about 80,000 volts. The high-voltage output was restricted by corona discharge from the edges of the can.

The public became aware of Van de Graaff's new technology in 1931. That's when he demonstrated the creation of over 1,000,000 volts between the spherical terminals of two belt-driven generators. Following that, general interest in these magnificent machines grew very quickly.

Giant Generators. The early success of Van de Graaff's creations was encouraging. Immediately, researchers began making plans for a much, much bigger generator. The size of the machine was to be limited only by the size of the building found to keep it in. A suitable structure was located on the estate of Colonel E.H. Green at South Dartsmouth, Massachusetts. It was the biggest enclosure anyone could find. It was a hangar built originally to house a dirigible, or blimp.

Engineers built two separate machines: one for the positive charge, and one for the negative. The spherical terminals, about 15 feet in diameter, were made of welded aluminum and mounted on two large tubular insulators, each 24 feet high and 6 feet across. The generators were carried on railway track. That allowed technicians to vary the distance between the electrodes. The giant Van de Graaff system was capable of generating nearly ten-million volts.

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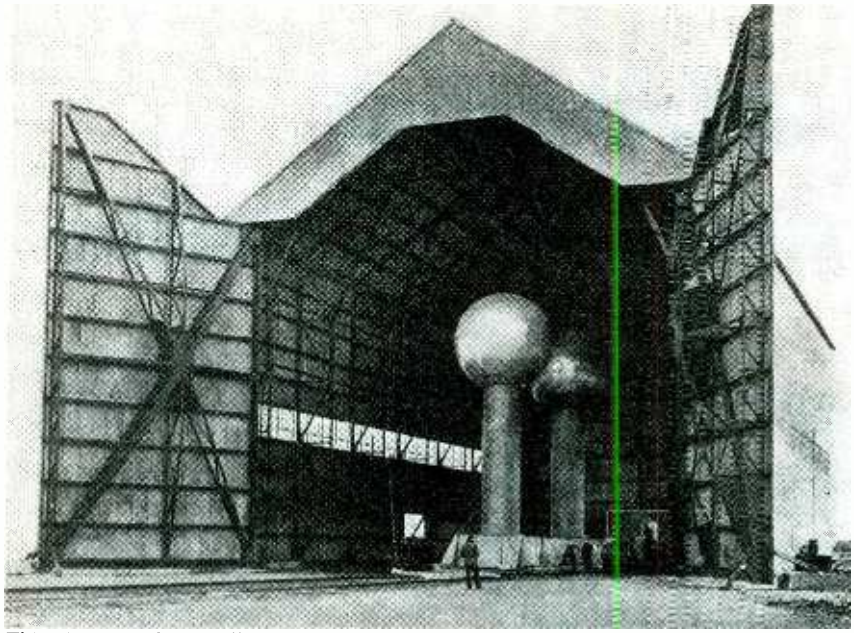


This giant Van de Graaff generator system was built in Dartsmouth, Massachusetts in the early 1930's. The machine was capable of developing nearly ten million volts. The very large structure in the background was, originally, a hangar built for a blimp.

A Working Model. With a kit of parts from Analytical Scientific, a laboratory supply company in Texas, you can build your own 200,000-volt Van de Graaff static generator in about one hour. (See the Parts List for ordering information.)

The fully assembled machine is about 18 inches high. The spherical aluminum terminal, mounted on top of a heavy plastic tube (PVC pipe), is about 7 inches in diameter. The generator runs on 117 VAC and comes complete with a small electric motor and all the necessary hardware; there's even a spare rubber belt. It's a classic design and an excellent addition to any home-experimenter's workshop.

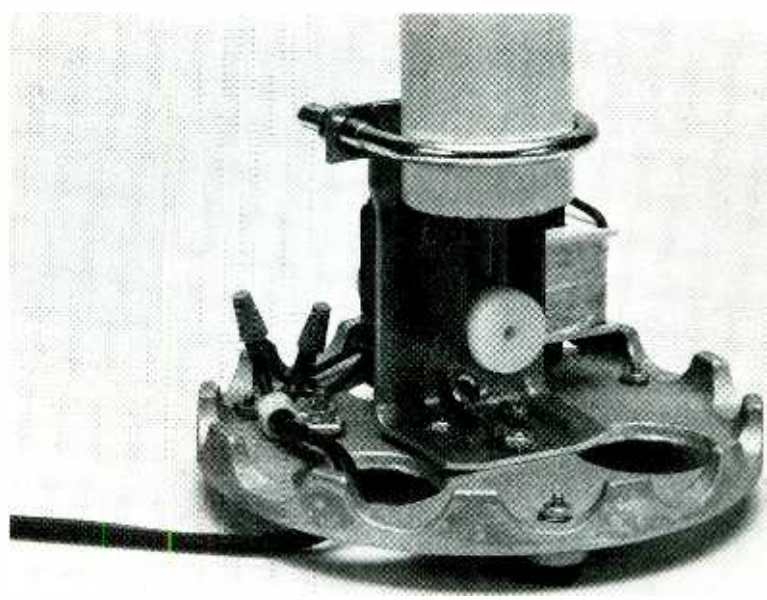
Building your Model. Once you've obtained the kit, begin by attaching the three rubber feet to the round metal base. Now locate the L-shaped motor bracket and the lower brush, which is the short length of stranded wire that's connected to a soldering lug. Push three small screws (8-32 × ½-inch) up through the bottom of the base and the motor bracket. Place lock washers on the screws and secure the assembly with three 8-32 hex nuts. The lower brush goes on the screw furthest away from the 90-degree bend in the motor bracket. The brush should point towards the vertical section of the bracket. Handle the brush carefully as it is delicate.

The next step is to find the electric motor and mount it by passing the two threaded studs plus the armature shaft through the three remaining holes in the motor bracket. Place lock washers on the threaded studs and secure the motor with a couple of hex nuts.

Now look for the white plastic pulley. Push the pulley over the armature shaft. If you have trouble, tap the end of the pulley very gently with a small hammer or the handle of a screwdriver. The pulley should not come into contact with the motor bracket.

The plastic pipe is held against the upper portion of the motor bracket with a large U-bolt, a metal strip, and two large hex nuts. One end of the pipe has a couple of semi-circular notches cut into it. That end of the pipe should be up; the plain end should be down. The lower end of the pipe should extend about ⅝ inch below the U-bolt. The notches on top should line up with the pulley at the bottom. To check the alignment, simply look straight down through the center of the pipe.

Next, locate the rubber belt and slip it over the metal pulley. Place the pulley into the two notches on top of the insulator and allow the belt to fall through the tube. Pull the lower end of the belt down and place it over the lower pulley. Try to avoid handling the belt too



This is how the inside of your Van de Graaff generator will look just before the lower aluminum shell is placed over the round metal base. Note the arrangement of the stranded wire brush, the rubber belt, and the pulley assembly.

WARNING!! This article deals with and involves subject matter and the use of materials and substances that may be hazardous to health and life. Do not attempt to implement or use the information contained herein unless you are experienced and skilled with respect to such subject matter, materials, and substances. Neither the publisher nor the author make any representations as to the accuracy of the informaton contained herein and disclaim any liability for damages or injuries, whether caused by inaccuracies of the information, misinterpretations of the directions, misapplication of the information, or otherwise.

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much as skin oils can reduce its effectiveness.

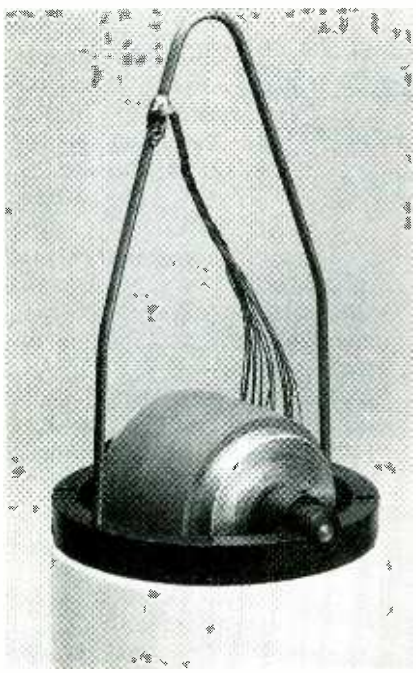
Now, very carefully, adjust the lower brush so that it just barely touches the rubber belt. Spread the strands of wire gently so that as many of them as possible are touching the rubber.

Find the collector support and upper-brush assembly. That's the short length of stranded wire soldered to a V-shaped piece of stiff wire. Push the V-shaped wire into the two small holes at the upper end of the insulator (PVC pipe). And here again, adjust the stranded wire brush so that it just barely touches the rubber belt.

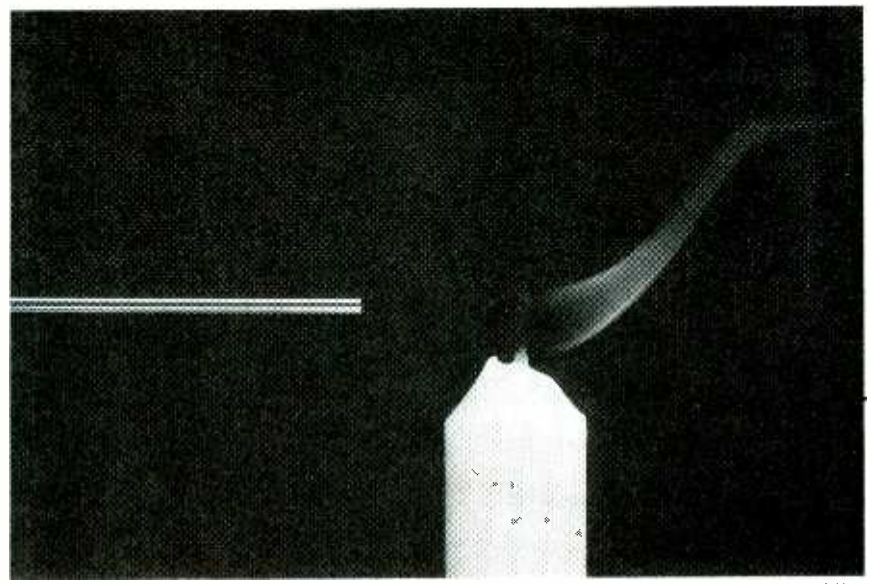
Return to the bottom of the generator and hook up the 117-VAC line cord. Use the wire nuts provided with the kit. The line cord is held in place with a plastic strain relief. Don't forget to connect the little green ground wire. Both the strain relief and the ground wire are attached to the base of the generator with a small screw and a hex nut.

Finally, lower the cylindrical aluminum shell over the plastic tube and push it down over the base. Then place the spherical terminal over the collector support. It should balance perfectly. Now stand back and admire your new Van de Graaff generator. It's a work of electromechanical art!

Testing. Plug your generator in and the motor should turn. If it doesn't, remove the upper spherical terminal and give the pulley a little spin in the right direction. That should start the generator. Replace the aluminum sphere immediately.



The upper brush and upper terminal support fit into the upper end of the tubular insulator. Note how the wire brush is positioned to make contact with the rubber drive belt.



This photograph illustrates the creation of what is sometimes called an "electric wind." Tape one end of a narrow metal rod to the top of your Van de Graaff generator. Turn on the machine and light an ordinary household candle. Now bring the candle close to the free end of the rod. As molecules of ionized air rush from the metal tip, the flame is blown to one side.

Wait a few moments for a charge to build up on the terminal. Now approach the sphere with a large fluorescent tube. When the tube is three or four inches away from the sphere, the machine will discharge, and the tube will flash. If that doesn't happen, or if the flash isn't very bright, your generator is not working properly.

Unplug the unit and remove the upper terminal and the lower shell. (Please be careful. A small static charge may be waiting for you when you touch the aluminum sphere.) Check the belt and the pulleys for dirt and moisture. They should be clean and dry. Then check the brushes. If the wire strands are too far away from the belt, the generator will operate very poorly, or not at all.

Finally, check both the upper terminal and lower shell for dust and lint. They, too, must be very clean. I was able to improve the performance of my own Van de Graaff generator by cleaning both the shell and the terminal with a bit of good quality metal polish and a soft cloth. That seemed to make a big difference in the machine's operation. In fact, it might be a good idea to polish the aluminum sections before putting the machine together.

MATERIALS LIST FOR THE VAN DE GRAAFF GENERATOR EXPERIMENT

Van de Graaff generator kit
Aluminum-foil strips, very thin
Candle
Fluorescent tube
Foam plastic packing material
Metal polish
Metal rod, 8 to 10 inches long
Tape

The Van de Graaff generator kit is available from Analytical Scientific, Post Box 198, Helotes, TX 78023, Tel. 512-684-7373. The catalog number is MLE-10-065 and the price is $137.75. Include $4.00 for shipping and handling within the continental U.S. The Analytical catalog is $3.00, which is refundable with first order. TX orders must include appropriate sales tax.

Theory of Operation. Here's how your Van de Graaff generator works: The electric charge originates with the friction of the rubber belt moving over the lower plastic pulley. The plastic pulley acquires a negative charge that appears on the outside of the belt while a positive charge appears on the inside. The negative charge is picked up by the ionized air around the lower brush. The positive charge is carried to the upper brush by the belt where it is transferred to the aluminum sphere.

(Continued on page 105)

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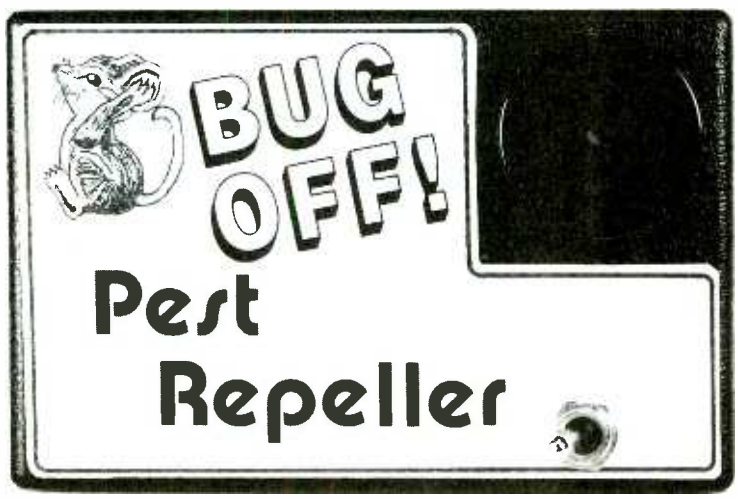
BUG-OFF: The Popular Electronics® Pest Repeller



Build a project to protect you from pests while hiking, or lounging 'round the pool, and learn something new about the 555 timer in the bargain!

BY JOHN YACONO

Ahhh, the great outdoors! It's so nice to get out in the fresh air and enjoy nature. Unfortunately, sometimes nature can turn a pleasant picnic into a please-the-ants picnic. Every camping trip I've been on has turned into a swat fest as night fell. As for me, I've never been too fond of rubbing malodorous ointments on myself and spraying ozone-eating aerosols in Mother Nature's face. Not being one to give up my enjoyment of the outdoors or my principles, I set to work to build a portable electronic pest repeller, affectionately called *Bug-Off*.

If you haven't heard of one before, or don't know what makes them tick, such pest repellers send out ultrasonic pressure waves (at 22–65 kHz) that are an annoyance to insects and certain small animals. Note that the version shown here is only powerful enough to affect insects, although it is an easy matter to amplify the output using a low-power, wide-band op-amp. For those interested in this, several suitable circuits were shown in "Using Wide-band Op-Amps" in the January, 1990 issue of **Popular Electronics**.

The basic Bug-Off unit is a very interesting little circuit. In it, a 556 dual-timer chip is suited-up with a few common components that turn it into a sweep-frequency oscillator. In the course of this article, I'll supply you with both construction and design details so that you can grant a 555 a 50% duty cycle and even use one as a voltage-controlled oscillator (something mentioned in text books, but never really covered).

Nuts, Bolts, and Paperwork. I have a commercially built, AC-powered pest repeller at home that works pretty well, so I decided to look inside of it before designing anything. To my surprise I found a lone 555 with support components that caused it to operate as a VCO (voltage-controlled oscillator). I had always known that was possible, but oddly enough I didn't remember ever seeing any design equations for VCO operation.

After checking two manufacturer's data books, and two 555-timer cookbooks, I realized my memory was not faulty (not this time anyway). Undaunted, I went on to figure out the equations for voltage-controlled operation for myself. Before giving you the results of my labor, a brief summary of 555-timer operation is a very good idea.

A 555 wired for astable operation is shown in Fig. 1. Let's ignore the control terminal for now, and just assume it's not connected. If you apply power to the circuit, capacitor C starts to charge through R_A and R_B, and the output is high. The FET in the 555 can initially be ignored as it is off. The rate of charge is thus determined by R_A, R_B, C, and V_{CC}.

The resistor network composed of R_{i1}–R_{i3} (all equal to 5 kilohms) divides the supply voltage (V_{CC}) into $\frac{1}{3}V_{CC}$ and $\frac{2}{3}V_{CC}$ (called the "trigger" and "threshold" voltages, respectively). Note that both comparators (C1 and C2) monitor the voltage stored in the capacitor; Comparator C1 compares the capacitor voltage to the threshold voltage and C2 compares it to the trigger voltage.

When the capacitor charges up to the threshold voltage, C1 goes momentarily high, toggling the flip-flop. That causes the internal FET to start draining the charge off the capacitor via R_B (without any of the discharge current flowing through R_A), and the output terminal goes low. The rate of discharge is thus determined by R_B, C, and V_{CC} (but not R_A). Once the capacitor voltage drops to the trigger voltage, C2 is triggered and toggles the flip-flop. The FET then turns off, the output goes high, and the capacitor begins to charge again.

There are a few interesting facts about the process. First, the timing is independent of the power-supply voltage (V_{CC}). That's because even though you may increase the charge rate by increasing the supply voltage, the threshold voltage is also increased, so it takes longer for the capacitor to reach that voltage (neat, huh?). The capacitor dissipates that higher voltage slower, but the trigger voltage is also higher, so the capacitor doesn't have to go as low. The time it takes for the capacitor to

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charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$, which is the time the output remains high, is given by:

$$t_h = 0.693(R_A + R_B)C$$

The time it takes for the capacitor to discharge from $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$, which is also the length of time the output is low, is given by:

$$t_l = 0.693(R_B)C$$

Note the absence of R_A in the last equation. That's because only R_B is in the discharge path. Note also that that prevents us from attaining a 50% duty cycle (t_h can't equal t_l). Some may propose doing away with R_A, but that would short the power supply through the discharge pin at the beginning of the discharge cycle. However, there is another method for obtaining a 50% duty cycle, as you'll see.

Special Operation. A 50% duty cycle can be easily obtained by putting a diode pointing down (cathode toward the capacitor) in parallel with R_B, and setting R_A equal to R_B. That way R_B is bypassed during charging, but it is still in the discharge path.

Now let's upset the scheme a different way by applying a voltage (V_{CON}) to the control terminal (but without using the diode trick for now). Doing so doesn't change the characteristics of the basic charging circuit (composed of R_A, R_B, and C), but it does change the values of the threshold and trigger voltages. However, that does not affect the discharge time (t_l) of the capacitor for the same reason a different supply voltage doesn't affect it (go back to the previous section if you forgot why). It does change the charging time (t_h), which can be computed with the following formula:

$$t_h = (R_A + R_B)C(-0.693 + \ln[1 + 1/(1 - V_{CON}/V_{CC})])$$

There are a few implications to all this: The first is that by changing the control voltage you can perform pulse-width modulation. You can also modulate the frequency and simultaneously modulate the duty cycle. In fact, using this technique, you can't change one without changing the other. By swinging the control voltage up and down, you can sweep a range of frequencies. That's exactly what the Bug-Off circuit does to ensure maximum effectiveness—it sweeps a range of frequencies to disturb the widest possible variety of species.

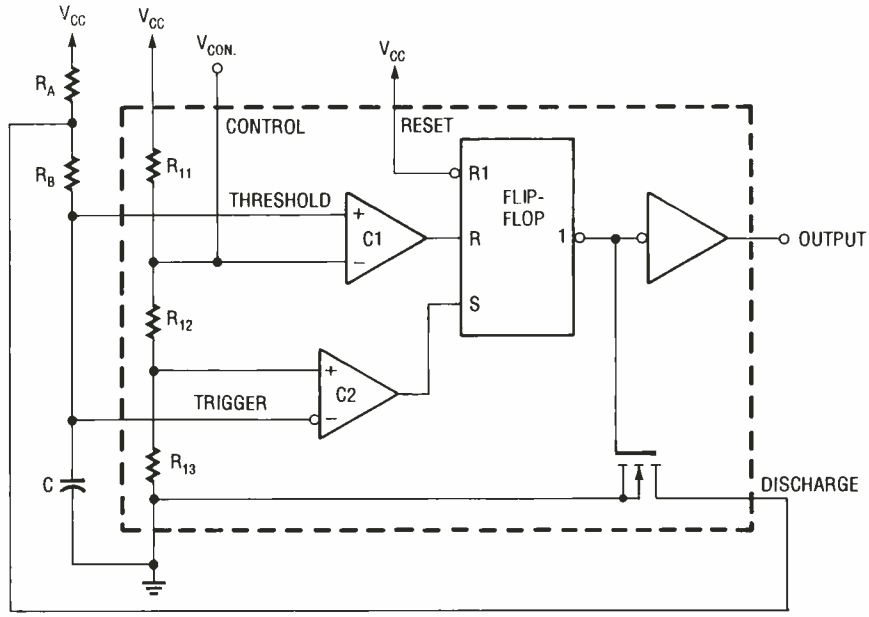


Fig. 1. This is a 555 timer IC (depicted in block-diagram form) connected to some support components to form a basic astable multivibrator.

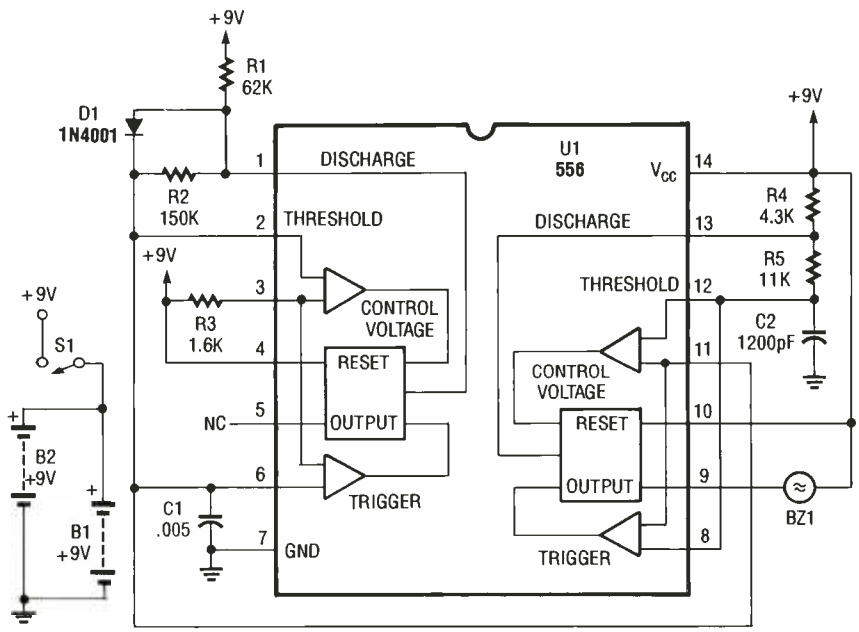
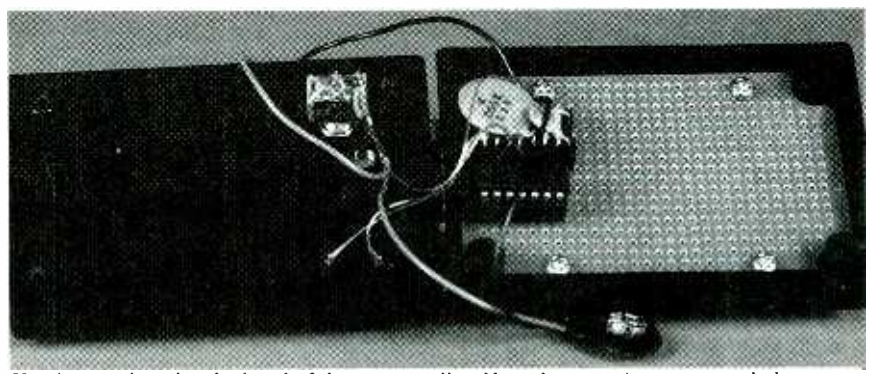


Fig. 2. The two timers in the full-blown project have some interesting characteristics. Both of them have their thresholds externally set, the oscillator on the left has a 50% duty cycle, and the oscillator on the right acts as a VCO.



Here's a peek under the hood of the pest repeller. Note the capacitors are neatly bent to permit the cover to be put on.

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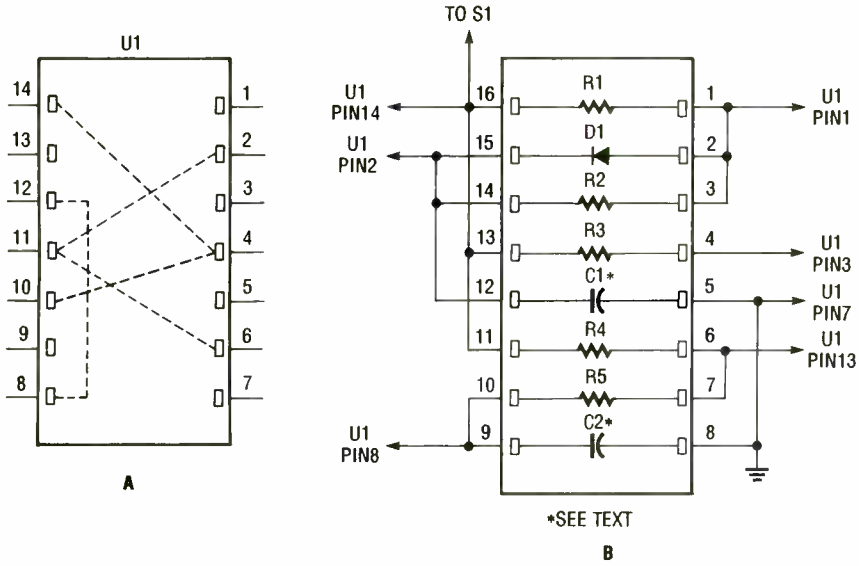


Fig. 3. If you wire the socket for U1 as shown in A, and the component socket as shown in B and interconnect them, you'll only have to connect the buzzer, battery, and switch to get your project up and running.

rather than the output from pin 3. That's because a timers output simply swings between V_{CC} and ground, but the charging capacitor gradually moves between the trigger and the threshold voltages. The capacitor will thus cause the VCO to sweep a range of frequencies rather than jump between two of them.

The oscillator on the left has two interesting characteristics: a 50% duty cycle, and modified threshold and trigger voltage levels. The voltage levels are modified by R3 to cause C1 to charge from 4 to 8 volts. The reason that is done is to allow the VCO to have a wide voltage sweep (thus, a wide frequency range), without causing it to have a ridiculously high or low duty cycle.

The oscillator on the left is configured for a 50% duty cycle because of the exponential charging curve of the capacitor. When the capacitor (C1) starts to charge, its voltage changes rapidly, causing the VCO to rush through the frequencies generated during the beginning of the charging cycle. During discharge the opposite happens—the frequencies generated with the control pin near its maximum are rushed through. So over one complete charge/discharge cycle, the frequencies are given fairly equal treatment as long as the charge and discharge times are the same (*i.e.*, the duty cycle is 50%).

Note that R1 and R2 are not equal, though we mentioned they should be for a 50% duty cycle. That's because the use of R3 alters the duty cycle so that the values of R1 and R2 have to be adjusted to re-establish the 50% duty cycle.

The oscillator runs at a frequency of 980 Hz, sweeping the VCO twice (once up, once down) each cycle. That means a creature will be zapped at least around 1960 times a second

(Continued on page 102)

PARTS LIST FOR THE BUG-OFF ELECTRONIC PEST REPELLER

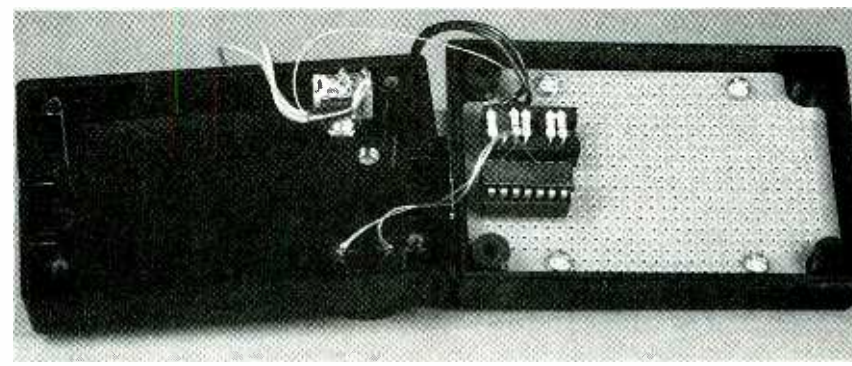
RESISTORS

(All resistors are ¼-watt, 5% units)
R1—62,000-ohm
R2—150,000-ohm
R3—1600-ohm
R4—4300-ohm
R5—11,000-ohm

ADDITIONAL PARTS AND MATERIALS

BZ1—Piezo buzzer element
D1—1N4001 1-amp, 50-PIV, rectifier diode
U1—556 dual oscillator/timer, integrated circuit (Exar, Radio Shack 276-1728)
C1—0.005-µF, ceramic-disc capacitor
C2—1200-pF, ceramic-disc capacitor
S1—SPST on/off toggle switch
B1, B2—9-volt transistor radio battery

Battery clips, perfboard, project case, 14-pin and 16-pin wire-wrap sockets, wire-wrap wire, solder, etc.



As you can see, using an IC socket keeps the project neat and small.

The Circuit. The Bug-Off circuit is shown in Fig. 2. The internal resistors are not shown for the sake of clarity. Note that it actually makes use of two 555 timers (both packaged in one 556 case). One timer circuit is shown on the left of the IC package, and the other is on the right. They are both set up as oscillators with some special features. **Note:** If possible, use the IC specified in the Parts List. Due to slight internal differences, IC's from other manufacturers may not work properly.

The oscillator on the right is a VCO and is used to sweep frequencies between 25.8 and 65.2 kHz. Its duty cycle varies from 40 to 76%. Keeping the duty cycle as close to 50% as possible is a good idea because it ensures that piezo element BZ1, which is the output transducer, will fully charge and discharge, and generate harmonics that are close to fundamental. Such piezo elements are great at creating pressure waves, and are sometimes used as sound generators in water, which requires high-pressure transducers in order to operate over long distances.

One more thing should be mentioned concerning the transducer: get a high-efficiency type that operates with the highest resonant frequency possible. However, don't worry that the resonant frequency is not near the ultrasonic range. The voltage swing applied to the crystal forces it to electrostric (contraction due to an applied voltage) without the need for resonance; We are really concerned with generating noise in the form of pressure waves, not pure tones.

The VCO receives its control voltage from the oscillator on the left. Note that the voltage on capacitor C1 is used

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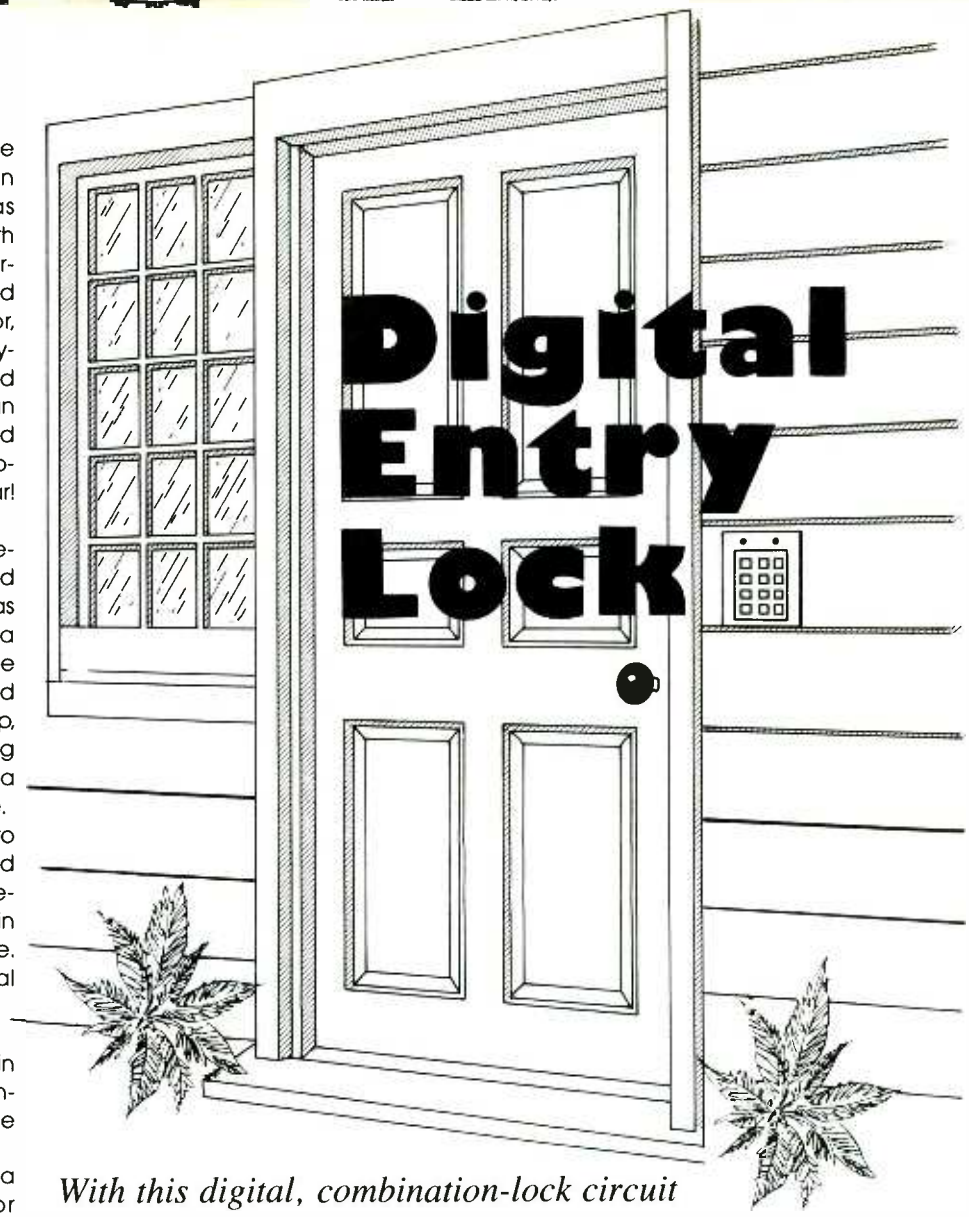
Digital Entry Lock



With this digital, combination-lock circuit you may not be able to throw away your keys, but at least they won't have to be your constant companions

BY FRED BLECHMAN

What started out as a simple keyless switch to operate an electric garage door has ended up as a *Digital Entry Switch* with various uses. By entering a preset four-digit code, it can be used to open and close your automatic garage door, driveway gate, or any other electrically-operated device. In addition, if used with an external latching circuit, it can be configured to prevent unauthorized use of electrical or electronic equipment—including your computer or car!

Background. I needed my remote-controlled garage door to be opened by a delivery service when no one was home. The normal operation was with a remote-control transmitter, or an inside pushbutton switch. Obviously, I could have added a key switch to the setup, but that would have meant carrying around another key, and furnishing a duplicate key to the delivery service.

In addition, it was often necessary to enter the garage from outside, and short of lugging around the remote-control unit, there was no way to gain access to the garage from the outside. Then it dawned on me that a digital switch might be the answer to my dilemma. With a digital switch, I could enter the garage by punching in the appropriate code, and I could inform the bonded delivery service of the entry code.

The original solution was to buy a ready-made digital garage-door opener. The commercial unit worked fine, until a passing thunderstorm zapped it. When an identical replacement suffered the same fate a few weeks later, I abandoned that device.

I found a circuit that would do the same job, but by the time I added a keypad and relay, my homebrew digital switch became a real Rube Goldberg. It worked, but became more and more unreliable with time—partly because my door mechanism was getting old and sluggish. So I replaced the door mechanism with a universal garage-door keyless entry system, which came complete with a membrane keyboard and a flat ribbon cable that plugs into a connector on the controller's circuit board. The installation was simple: You merely screw the keypad on the outside of the garage and feed the cable to the control circuit inside.

Once installed, I thought to myself, this is really a first-class product. But the darn thing didn't work! My automatic garage-door opener was "tired." It required that the remote or manual switch be held down for about one second to assure operation, and the universal garage-door keyless entry system only provided about a half-second closure of its internal relay. The door would start to move, but never completed its mission.

After a lot of head-scratching and experimenting, I made several phone calls to the manufacturer. I was told that the system was not intended for old, beat-up garage doors like mine, and the half-second closure works perfectly with any normally-operating garage door.

Not long afterward, I stumbled on a special-purpose IC, the LS7220 keyless-lock IC, that, with just a little effort on my part, could be made to handle the task quite well. A block pinout diagram of the LS7220 keyless-lock IC is shown in Fig. 1. Normally that unit is used to accept a four-digit code to enable and lock an output "on."

However, the specification sheet showed a very simple circuit for a time-adjustable momentary output—just what I wanted! All that was needed with the LS7220 was a keyboard, a capacitor, and a relay (with a few support components). I thought to myself, how simple can you get? I put together a sample circuit and it worked like a charm, even with my old and sluggish door opener!

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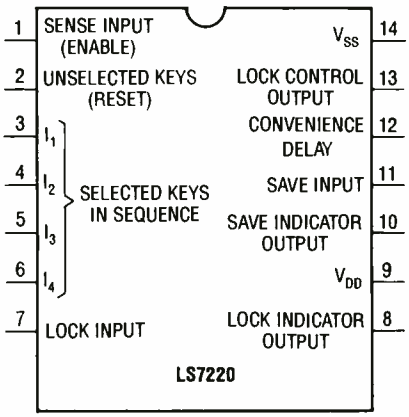

Fig. 1. The LS7220 keyless lock (a pinout of which is shown here) is a special-purpose IC designed to accept a four-digit code.

Circuit Description. Figure 2 shows a schematic diagram of the *Digital Entry Lock*. The circuit can be powered from a 6- to 12-volt DC, wall-plug transformer or you can design your own power-supply circuit. Standby current is very small (about 15 microamperes), and operating current is about 40 milliamperes (depending on the operating voltage). Capacitor C1 assures minimum ripple from the DC supply.

The keypad must be one that provides each key with a contact to a common connection. In this case, the common connection goes to the positive supply rail, so that when a key is pressed, a positive voltage is passed through to the wire associated with that key. Each of the twelve keys are brought out to separate wires, and each wire is connected to a different pin of a 24-pin socket (SO1).

To activate (unlock) the circuit, a pre-programmed four-digit access code must be entered in the proper sequence. The four-digit access code is programmed into the circuit by connecting jumpers between terminals of a 24-pin plug-in header. (More on that later.)

When the correct access code is entered (in the proper sequence), positive voltages appear at pins 3, 4, 5, and 6 of U1. That causes U1 to output a positive voltage at pin 13, which is fed through resistor R2 to the base of Q1, causing it to conduct. With Q1 conducting, its collector is pulled to ground potential, energizing relay K1. The normally-open relay contacts close, switching on any external device.

Capacitor C2 controls the total time that the output of U1 at pin 13 is positive after the release of the first key. With a

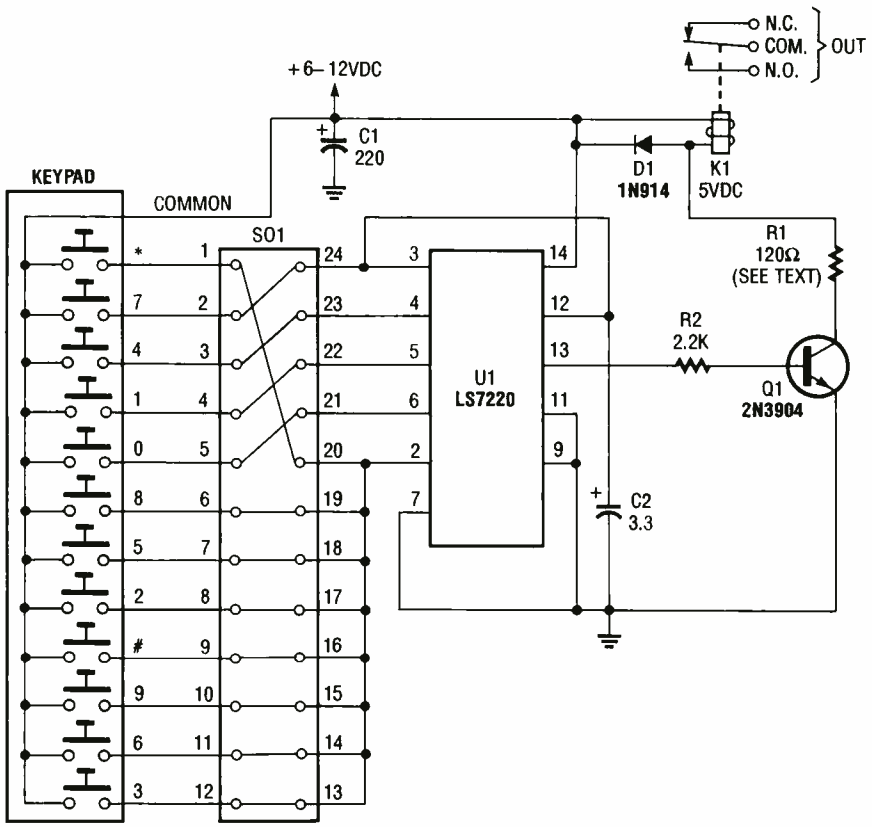

Fig. 2. The operation of the Digital Entry Lock is simple; when a four-digit access code is entered (in the proper sequence), the device connected to K1's normally-open contacts is activated. Any incorrectly entered (including the right digits in the wrong sequence) digit immediately resets the lock.

value of 3.3 µF for C2, active time after release of the first key is about two seconds, assuming a 6-volt supply or four seconds with a 12-volt supply. Therefore, if you push the subsequent keys too slowly, the relay may not close at all! To increase the time allotted for code entry, you will have to increase the capacitance value of C2.

Incidently, resistor R1, which is in series with the relay coil, is not required if you are using a power supply of less than about 9 volts. The resistor must be used for higher voltages; it is intended to provide a voltage drop, so you don't burn out the relay coil.

Construction. There's nothing critical about building the Digital Entry Lock. A pre-drilled printed-circuit board is available from the supplier listed in the Parts List. But for those who prefer to

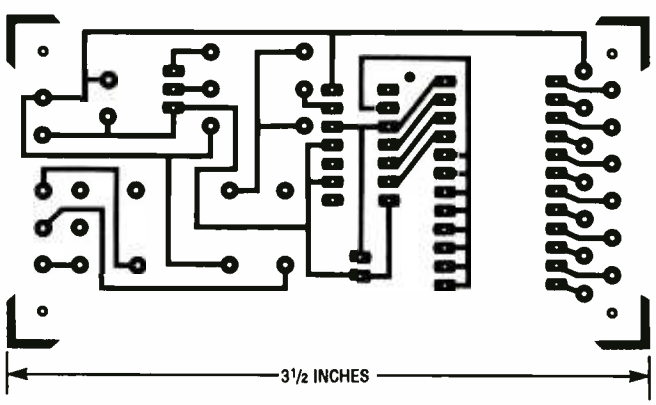

Fig. 3. There's nothing critical about building the Digital Entry Lock. Shown here is the simple foil pattern used to etch the author's printed-circuit board. For those not wishing to roll their own, the board (as well as a complete kit of parts, and selected individual components) can be ordered from the supplier listed in the Parts List.

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PARTS LIST FOR THE DIGITAL ENTRY LOCK

SEMICONDUCTORS

U1—LS7220 keyless lock, integrated circuit (see supplier below)
Q1—2N3904 general-purpose NPN silicon transistor
D1—1N914 or equivalent small-signal silicon diode

ADDITIONAL PARTS AND MATERIALS

R1—120-ohm, ¼-watt, 5% resistor (see text)
R2—2200-ohm, ¼-watt, 5% resistor
C1—220-µF, 16-WVDC, electrolytic capacitor
C2—3.3-µF, 16-WVDC, electrolytic capacitor
K1—5-volt DC SPDT relay (Arrow NF 2E-5V or equivalent)
SO1—24-pin DIP socket
Printed-circuit board materials, 12-key keypad, 24-pin header, enclosure, 6–12-volt power source, wire, solder, hardware, etc.

Note: The following items are available from EKI, Inc., 16631 Noyes Ave., Irvine, CA 92714; Tel. 714-833-8711. A complete kit of parts for the Digital Entry Lock (#2-1051), including all parts and a circuit board for $22.95; A partial kit (#2-2851), containing the electronic components only for $19.95; the printed-circuit board only (#2-2751) for $3.95; Arrow NF 2E-5V relay only (#4-1010) for $3.95; Keypad only with special connector board (#4-1011) for $7.95; LS7220 (EKI-7220) digital lock IC only (#4-1012) IC $6.95. Please add $3.50 per order for shipping and handling. California residents please add local sales tax.

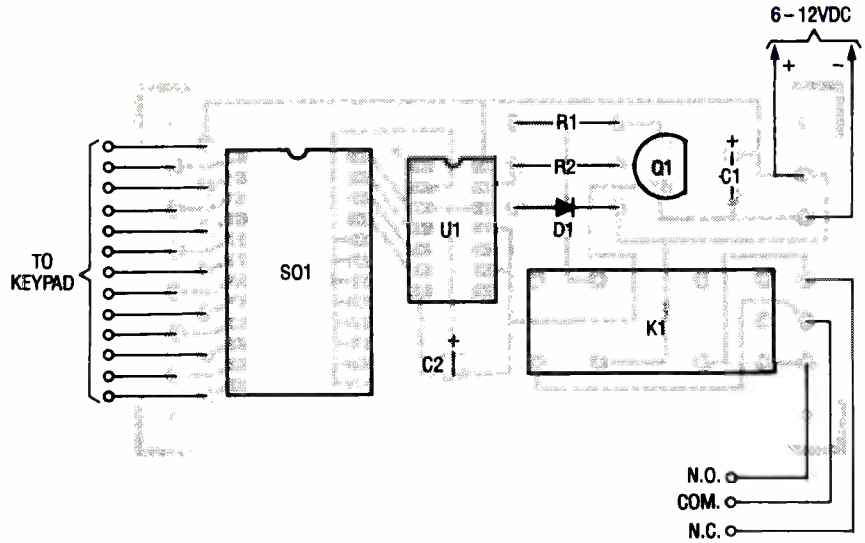

Fig. 4. Assemble the Digital Entry Lock's printed-circuit board guided by this parts-placement diagram. Once assembled, check your work for the usual construction defects—cold solder joints, solder bridges, misplaced and misoriented components, etc.

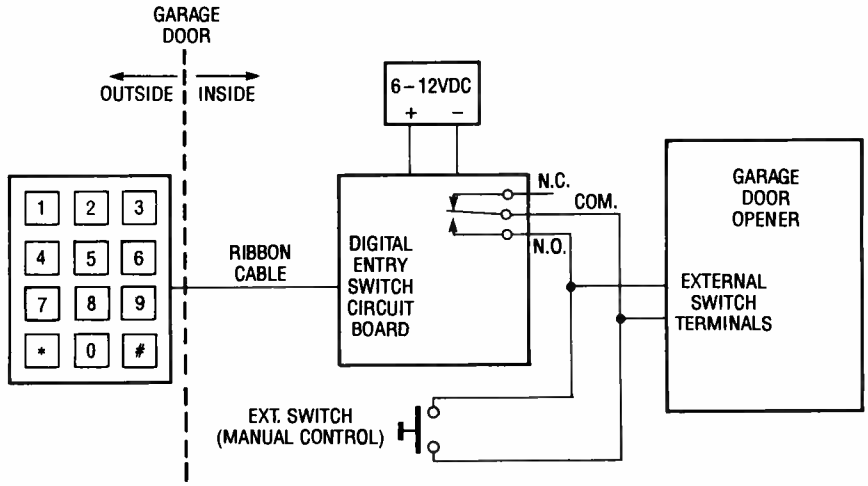

Fig. 5. In the author's application, the Digital Entry Lock was connected in parallel with the existing manual control switch for an automatic garage-door opener. That installation allowed the garage door to be opened by entering a four-digit access code, while leaving manual control of the garage door intact.

"roll" their own, a foil pattern for the printed-circuit board is shown in Fig. 3. You could even use point-to-point wiring on a perforated board, but that would mean risking all sorts of construction errors that tend to creep into electronics construction projects—so that's not recommended.

If you opt to go the printed-circuit route (using the pattern in Fig. 3), Fig. 4 shows the location and orientation of all the board-mounted and off-board parts. Once the printed-circuit board has been assembled and your work checked for the usual construction defects—cold solder joints, solder bridges, misplaced and misoriented components—it's time to consider the enclosure that will house your creation.

The circuit board could be mounted in a small case outfitted with a jack for a plug-in power supply and binding posts for the relay contacts. The interconnections between the keypad and the printed-circuit board are best handled through a length of flat ribbon cable. The ribbon cable will have to be cut to a length suitable for your installation. The keyboard, of course, is mounted near the entry point.

Programming the Lock. In order to activate the output of this switch, a positive voltage must be applied to pins 3, 4, 5, and 6 of U1 in that order. Any other sequence will not open the lock. Also, putting a positive voltage on pin 2 of U1 resets it to look for the first digit of the code.

The circuit can be programmed to respond to almost any four-digit access code desired—repeated digits are not allowed; for example, 1020, 9668, 7647, etc., are not allowed. When programming the circuit for a specific access code, the first digit of the code must be jumpered to pin 3 of U1, the second to pin 4, the third to pin 5, and the fourth digit to pin 6 via a 24-pin header.

Now place jumpers on the 24-pin header so that the first key wire on the left side of the jumper goes to pin 24 of the header, the second key wire to pin

(Continued on page 108)

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Dress up your favorite electronic project by designing and building a customized plastic enclosure that will fit it like a glove

BY WALTER W. SCHOPP

Build Your Own Custom Cases

So you've just finished that special project and you are proud of the way it works, but it has an odd size printed-circuit board and now you need an enclosure in which to house it. Since you've spent a lot of time designing and building the project, you want an enclosure that will dress up its appearance. Leafing through parts catalogs you turn up a variety of enclosures—some that are either too long, some too wide, others too tall, or too expensive.

Under most circumstance, you usually have to settle for a larger enclosure that fits your project like a marble fits in a shoe box—oh well, at least its within your budget. But have you ever thought about producing your own custom-fitted project enclosure? Such an enclosure can add a lot of eye appeal to your project.

What's Needed. Making your own plastic enclosures can be just as enjoyable as building the project itself, and doing so is easier than you may think. The three ingredients that go into producing your own enclosure are the materials (plastic-sheet stock), the tools (basically, a few wood working tools), and the "know how" (which we'll supply). The plastic-sheet stock needed to produce small enclosures is fairly inexpensive and easy to find. Checking the yellow pages of the phone book will turn up retail plastic-supply stores that will even cut your pieces to size. Many stores will even make your enclosure for you, for an additional charge.

The plastic-sheet stock comes in all thicknesses and colors. It also comes in rods, square bars, and tubing of all sizes. Acrylic cement and applicators, special drills, and just about anything else you'll need to work with plastics are usually available at the plastic-supply house, and many of them even provide a catalog of stocked items.

Few tools are needed for working with plastics and you may even have them already. A small table saw with the correct blade is a basic tool needed for cutting plastic sheet stock. In order to cut plastic smooth enough for joining, a special blade is required. An 8- or 8½-inch carbide, fine-tooth blade with a minimum of 60-teeth per inch is needed. The blade should have all the teeth evenly spaced with little or no set. Such blades are often used for cutting aluminum or copper and can be found in most hardware or tool-supply stores.

The rest of the tools needed are minimal; small coarse and fine flat files and some medium-grade sand paper.

What Size Enclosure? The most rudimentary element of enclosure fabrication is knowing what size enclosure is required. It may seem silly to make such a point, but a great deal of plastic can be turned into scrap by ignoring that simple principle. A basic enclosure consists of six parts: the top and bottom, and two sides and two ends. The sides and ends (as shown in Fig. 1) are glued to the bottom, and the top is removable.

A simple but effective way to determine the length and width of the enclosure is to take the size of your printed-circuit board, add to that the thickness of the two sides and end pieces plus the clearance needed for the additional plastic parts used for attaching the lid to the enclosure (more on that later). That gives you the overall size of the top and bottom pieces. The side and end pieces are cut to the height, as determined by the parts to be housed, needed for your project. Be sure to allow ample space for any off-

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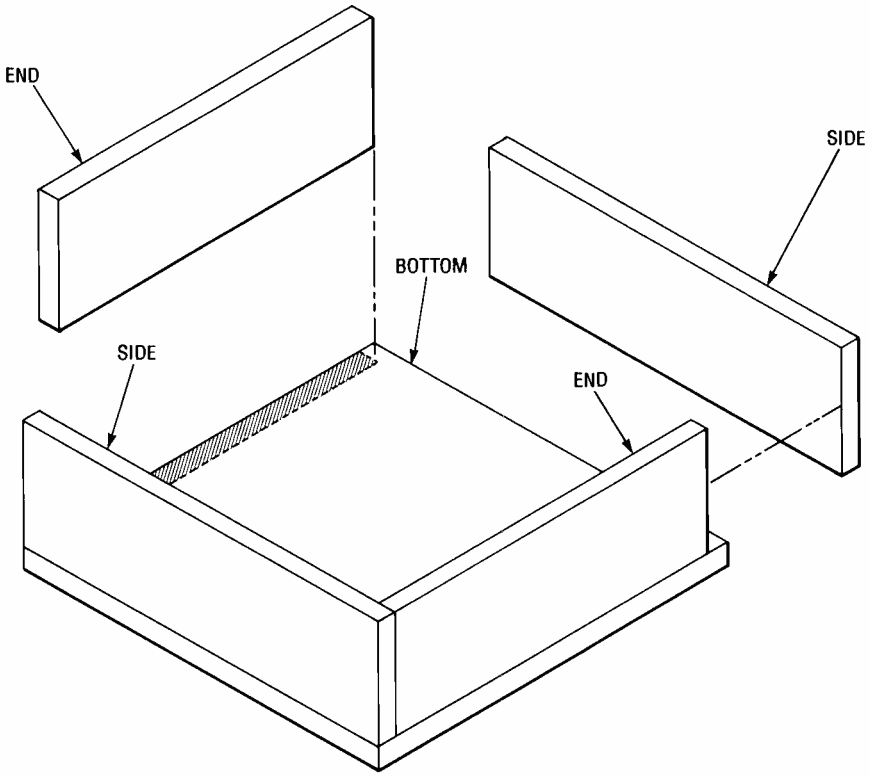

Fig. 1. A simple enclosure consists of six parts: a removable top and a stationary bottom, two sides, and two ends.

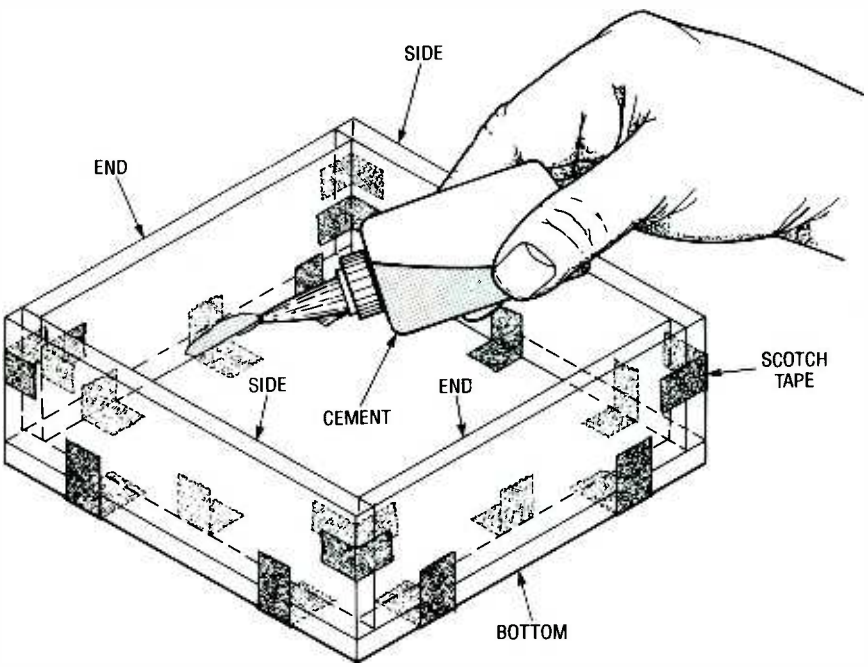

Fig. 2. Once you have all the parts cut, tape the sides, ends, and the bottom together, making sure that all the joints are tight and square. Then use liquid-acrylic cement to make the joints permanent.

board components, including a battery holder if used.

Building The Enclosure. Once you have all the parts cut, tape the sides, ends, and the bottom together with Scotch tape, making sure that all the joints are tight and square. Use the tape wherever it is needed to make a good, tight joint. When the enclosure is taped correctly, it will be surprisingly sturdy (see Fig. 2). Acrylic cement, in liquid or paste form, is available from plastic-supply stores.

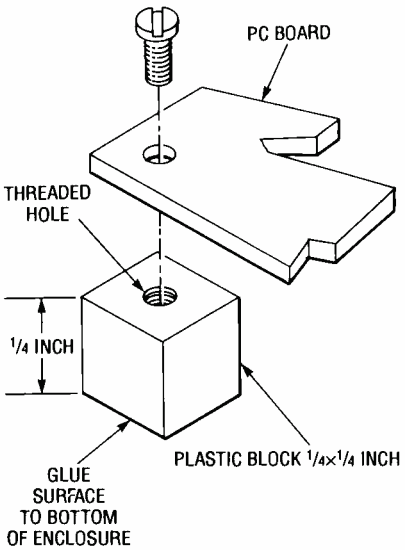

Fig. 3. Printed-circuit mounts can be added to the enclosure by first screwing ¼-inch square scraps of acrylic to the board, applying a little acrylic cement to the bottom surfaces of the acrylic squares, and placing the assembly in the desired location within the enclosure.

Because paste-type cement must be applied to the edges and narrow surfaces of parts before they are joined, it is not suitable for this application. The liquid form is easily applied with an applicator bottle that has a long metal capillary tip that can reach into corners. A plastic, disposable hypodermic needle makes a wonderful cement dispenser.

The liquid cement has the consistency of water, so when the cement is ap-

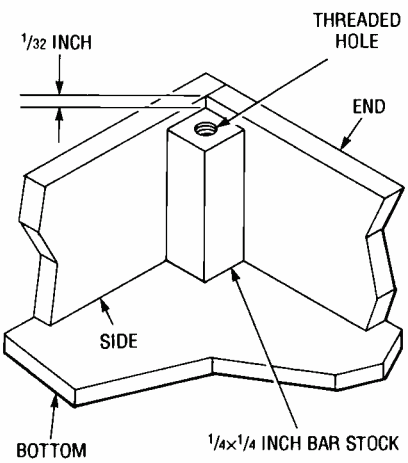

Fig. 4. One way to handle lid mounting is to cut ¼-inch square bars of acrylic to about 1/32-inch shorter than the height of the sides. Cement the four pieces into the four corners of the enclosure. Once dry, place the lid on the enclosure and drill screw holes through the lid and into the lid mounts.

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plied to the joints, capillary action will take the cement between the joint. Do the bottom joints first and allow about 30 minutes or so before handling. After sufficiently dry, place the enclosure on its side, do the lower two corners, and allow to set. Once the side joints are dry, flip the enclosure to the other side and complete the other two corners.

Use the cement sparingly, with just enough liquid to go into the joint without running over the flat surfaces or running out the back side of the joint. Liquid cement will etch the surface of the plastic if left to dry; any cement that is outside of the actual joint should be wiped off quickly. A little practice will make you very proficient at applying just the right amount.

Once you have the basic enclosure and the separate lid, the next thing that is needed is a way of mounting the printed-circuit board to the bottom of the enclosure and a way of attaching the lid to the enclosure itself. Making small pads on which to secure the board to the enclosure is one method for mounting the board. Cut four small squares of ¼-inch thick scrap acrylic to about ¼-inch square, see Fig. 3.

Use a #43 drill bit to make a hole in the center of each piece and tap the hole for a 4-40 thread. Mount the pads to the bottom of your circuit board with

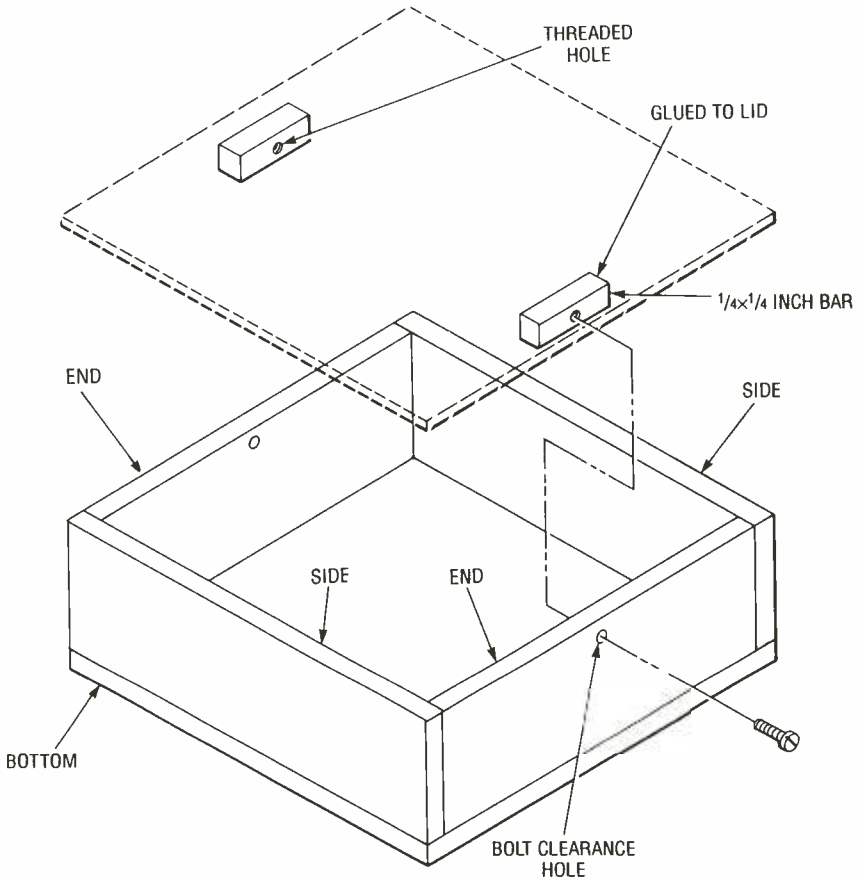
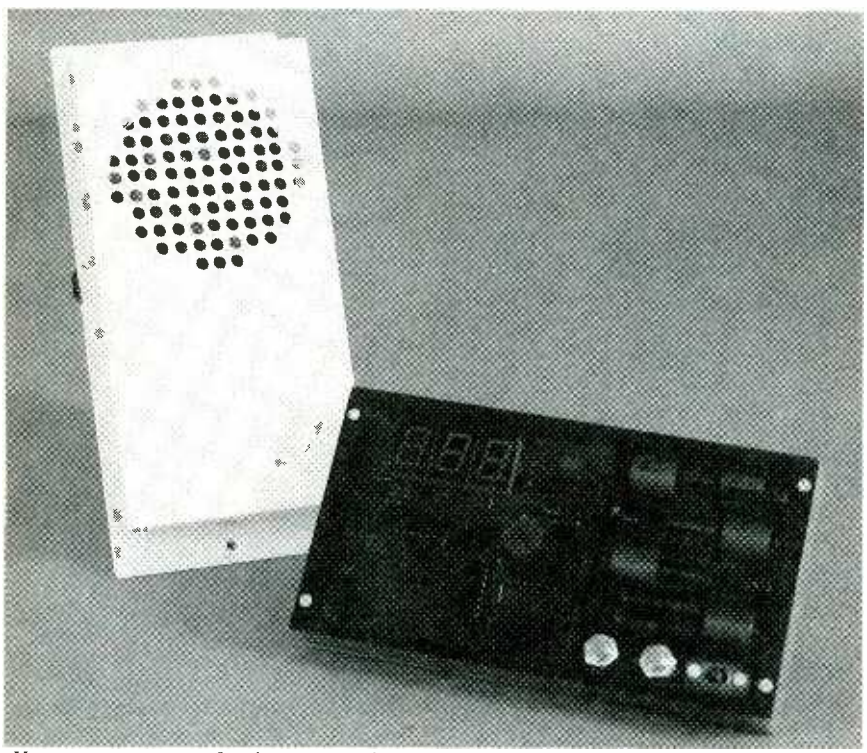


Fig. 5. Another way to handle lid mounting is to cement lengths of an acrylic bar to the lid on both ends, and drill screw holes through the side or end panels of the enclosure and the acrylic bar.



Here are two custom fitted project enclosures. The one to the left has a perforated speaker area near the top; the other has its front panel made of tinted translucent acrylic eliminating the need of a cutout area for the display.

4-40 × ¼ inch screws making sure the screws do not extend below the bottom surface of the pads. With all four pads mounted to the board, wet the pads with cement and set the board into your enclosure where you want it. To ensure a tight bond, place a little weight at the center of the board while the cement dries. After 30 minutes, the screws and PC board can be removed and the pads will be permanently bonded in the desired location.

Mounting the lid is easy, however, since plastic parts needed to mount the lid are located inside the enclosure. You'll need to decide on your mounting scheme before you layout and cut the enclosure parts. One way to handle lid mounting is to cement four lengths of a ¼-inch square bar, cut to about 1/32-inch shorter than the height of the sides, into the four corners of the enclosure (see Fig. 4). Then just put the lid in place and drill a pilot hole using a #43 drill through the lid into the center of the corner pieces. Tap the four holes in the corner pieces for 4-40 screws and enlarge the holes in the lid to accept the screw.

(Continued on page 105)

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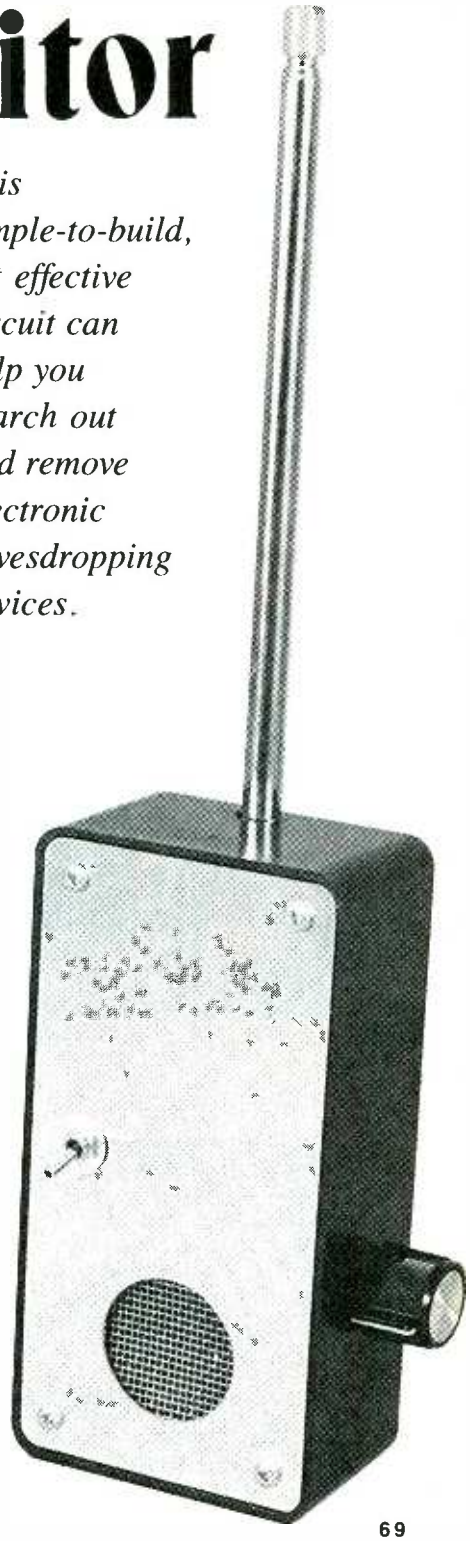
The Countersurveillance Monitor

BY VINCENT VOLLONO

This simple-to-build, yet effective circuit can help you search out and remove electronic eavesdropping devices.



Many valuable ideas and information are lost from businesses and homes through electronic eavesdropping. In the business world, industrial espionage is due for the most part to the fact that whosoever gets their product to the market first is likely to reap huge profits as the others try to catch up. On the domestic side, with so many people now self employed and conducting business from a home office, the entrepreneur can become easy prey to those seeking to profit from the work of others.

You think domestic espionage is an unprofitable venture?... Think again! Consider that many of the video games and applications programs that you run on your home computer are written by hobbyists and hackers, and not by some computer scientist working for a large corporation that has vast sums of money to spend on security. And how many corporate mergers have been openly discussed in the informal surroundings of some CEO's home? But what is the small businessman or private individual to do when commercially available countersurveillance devices can run into the hundreds and even thousands of dollars?

That's where the *Countersurveillance Monitor* described in this article comes in. The Countersurveillance Monitor is a simple circuit that allows you to sweep for (detect) electronic eavesdropping devices (more commonly called bugs). The circuit contains no exotic parts and many of the components are so common that they may be found in your parts bin.

A Little Background. Electronic bugs are very small—perhaps as small as a postage stamp—radio-frequency (RF) transmitters, that are secretly placed in a room that is to be monitored. Such transmitters emit an RF signal that can be picked up from distances of 1 mile away or more, depending upon the sensitivity of the receiver. The receiver is, of course, used to tune in the RF signals, thereby allowing the snooper to monitor any conversation taking place within the covered room.

Because most bugs are RF sources, almost any wideband receiver can be used as a bug detector. Our bug detector is essentially a highly sensitive, wideband receiver. When it detects an RF signal ranging from 1 to 2000 MHz it generates an audio output. The frequency of the audio output goes from a low growl for a weak signal to a high pitched squeal as the signal strength increases. In other words, the closer you get, the higher the pitch of the audio output. That allows you to sweep an area with the Monitor to determine the location of the transmitting device.

An important feature of the bug detector is its RF-gain stage; it is centered around a high-gain microwave transistor, which greatly improves sensitivity. By increasing the antenna length and setting the sensitivity control to its maximum level, extremely weak signals can easily be located. On the other hand, by reducing the length of the antenna and lowering the sensitivity setting, strong signals can be tracked down. Powered from a 9-volt transistor-radio battery, the circuit draws very little current, making for long battery life.

Circuit Description. Figure 1 shows a schematic diagram of the Countersurveillance Monitor. The circuit, built around a single integrated circuit (U1, an MC3403P quad op-amp), three transistors (Q1–Q3), and a few support components, receives its input from the

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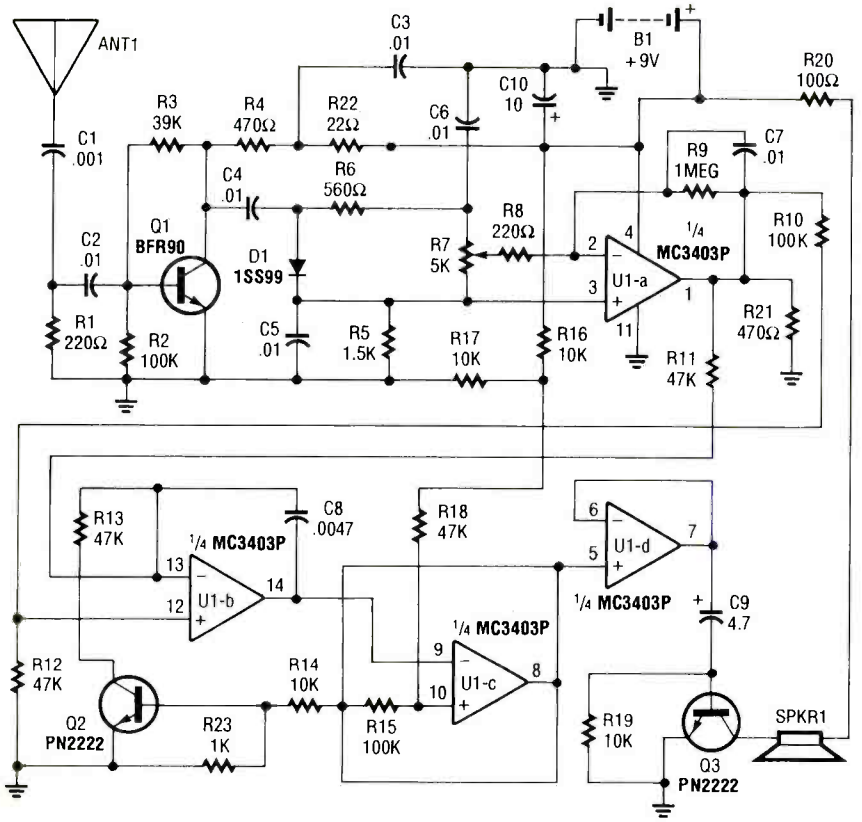

Fig. 1. The Countersurveillance Monitor is built around U1 (an MC3403P quad op-amp), three transistors (Q1–Q3), and a few support components.

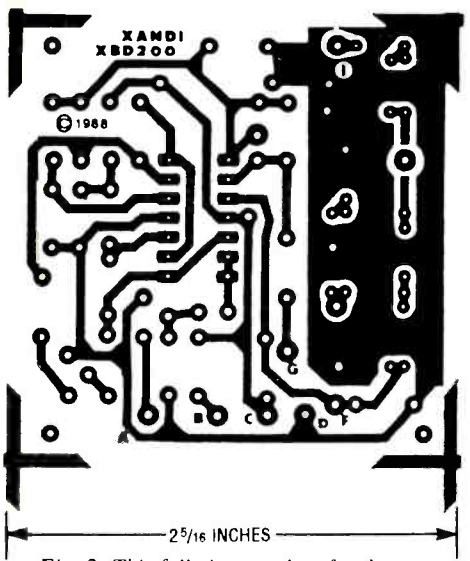

Fig. 2. This full-size template for the Countersurveillance Monitor's printed-circuit artwork is provided for those who wish to etch their own boards. For those not so inclined, a pre-etched and pre-drilled board, as well as the parts that mount on or connect to it, can be purchased from the supplier listed in the Parts List.

antenna (ANT1). That signal is fed through a high-pass filter, formed by C1, C2, and R1, which eliminates bothersome 60-Hz pickup from any nearby power lines or line cords located in and around buildings and homes.

From the high-pass filter, the signal is applied to transistor Q1 (which provides a 10-dB gain for frequencies in the 1- to 2000-MHz range) for amplification. Resistors R2, R3, and R4 form the biasing network for Q1. The amplified signal is then AC coupled, via capacitor C4 and resistor R7's (the sensitivity control) wiper, to the inverting input (pin 2) of U1-a. Op-amp U1-a is configured as a very high gain amplifier. With no signal input from ANT1, the output of U1-a at pin 1 is near ground potential.

When a signal from the antenna is applied to the base of Q1, it turns on, producing a negative-going voltage at the cathode of D1. That voltage is applied to pin 2 of U1-a, which amplifies and inverts the signal, producing a positive-going output at pin 1. Op-amps U1-b and U1-c along with C8, R10–R18, and Q2 are arranged to form a voltage-controlled oscillator (VCO) that operates over the audio-frequency range. As the output of U1-a increases, the frequency of the VCO increases. The VCO output, at pin 8 of U1-c, is fed to the input of U1-d, which is configured as a non-inverting, unity-gain (buffer) amplifier. The output of U1-d is used to drive Q3, which, in turn, drives the output speaker.

PARTS LIST FOR THE COUNTERSURVEILLANCE MONITOR

SEMICONDUCTORS

U1—MC3403P quad op-amp, integrated circuit
Q1—BFR90 or MFR901 NPN microwave transistor
Q2, Q3—PN2222 general-purpose NPN silicon transistor
D1—1SS99,ECG-112, or equivalent silicon diode

RESISTORS

(All fixed resistors are ¼-watt, 5% units.)
R1, R8—220-ohm
R2, R10, R15—100,000-ohm
R3—39,000-ohm
R4, R21—470-ohm
R5—1500-ohm
R6—560-ohm
R7—5000-ohm potentiometer
R9—1-megohm
R11–R13, R18—47,000-ohm
R14, R16, R17, R19—10,000-ohm
R20—100-ohm
R22—22-ohm
R23—1000-ohm

CAPACITORS

C1—.001-µF, ceramic-disc
C2–C7—.01-µF, ceramic-disc
C8—.0047-µF, ceramic-disc
C9—4.7-µF, 16-WVDC, radial-lead electrolytic
C10—10-µF, 16-WVDC, axial-lead electrolytic

ADDITIONAL PARTS AND MATERIALS

S1—SPST toggle switch
B1—9-volt transistor-radio battery
ANT1—Telescoping antenna
SPKR1—8-ohm, 0.2-watt, 2¼-inch, speaker
Perfboard materials, enclosure, battery connector, battery holder (optional), IC socket (optional), wire, solder, hardware, etc.

Note: The following items are available from Xandi Electronics (P.O. Box 25647, Tempe, AZ 85285-5647; Tel. 1-602-829-8152 for general information or catalog requests, 1-800-336-7389 for orders only): A complete kit of parts (XBD200KB), which contains an etched and drilled PC-board and all resistors, capacitors, semiconductors, and the potentiometer (enclosure not included) for $35.90 plus $4.00 for shipping and handling. COD orders add $6.00. AZ residents must add 6.7% sales tax.

Construction. The Countersurveillance Monitor was assembled on a

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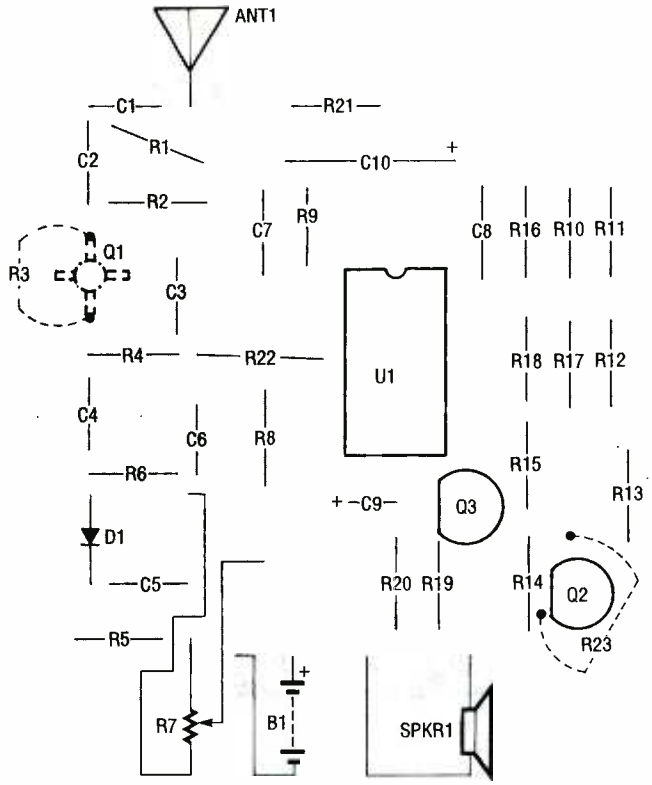


Fig. 3. Assemble the circuit's printed-circuit board using this parts-placement diagram as a guide. Note that transistor Q1, resistors R3 and R24 (all of which are shown as dashed lines) must be installed on the copper side of the board.

pre-etched, pre-drilled printed-circuit board that is available from the kit supplier listed in the Parts List. But, for those of you who'd prefer to etch your own board, a full-size template of the printed-circuit artwork is shown in Fig. 2. The circuit was designed to be housed in any plastic enclosure that's large enough to hold the circuit board, its 9-volt battery power source, a small speaker, potentiometer R7, and of course, switch S1.

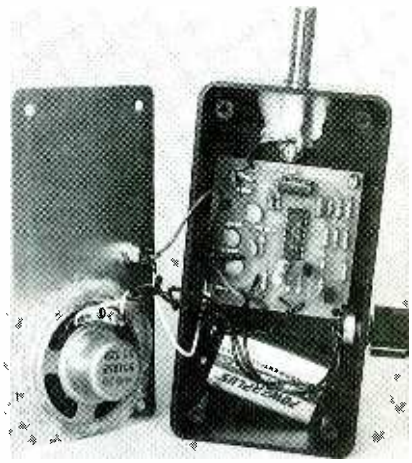
Once you've etched or obtained the board and all the parts listed in the Parts List, construction can begin. Start by installing the passive components on the board, guided by Fig. 3. Once the passive components have been installed and checked for placement and orientation, install the semiconductors. The use of an IC socket for U1 is optional; however, if you decide not to use an IC socket for U1, be careful not to overheat the IC's terminals.

Note that transistor Q1 as well as resistors R3 and R23 (which are shown as dashed lines in Fig. 3) must be installed on the copper side of the board. Since Q1 is a microwave transistor, special care must be taken when installing it and its leads should be kept as short as possible. After that, attach a 9-volt battery connector and the off-board components to the board.

Circuit Checkout. Double-check your work for the common construction errors—misoriented components, solder bridges, misplaced components, etc.—particularly where the transistors and diode are concerned. Make sure that you have installed the resistors in the proper locations. When you are satisfied that all is well, connect a 9-volt battery and turn on the power. You should be able to adjust R7 to cause the speaker to make a siren-like sound. By rotating R7 counterclockwise, you should be able to make the pitch go higher or lower, turning it fully counterclockwise should stop the sound.

When using the unit to detect a bug, set the sensitivity low enough to avoid signals from nearby radio and TV stations. It may take some experimenting at first, but it should quickly become quite easy. When you get within a foot or two of an actual bug, there is no mistaking it for another signal—the audio pitch will be driven to its highest frequency. If you have problems with radio and TV signals, try adjusting the antenna to a shorter length and then setting the sensitivity control for greater sensitivity to compensate for the reduction in antenna length. The Countersurveillance Monitor will also pick up other RF sources: microwave ovens, computers, etc., but those should cause you little concern. What you are looking for is that potted plant or lamp that has suddenly become an RF emitter.

Troubleshooting. In case of trouble, the first thing to do is make sure that the battery is connected properly and is in good working condition. If the power source and its connections are okay, you can check the circuit using an RF source—such as a cordless telephone, a signal generator, or a wireless FM microphone. Before you place the RF source near the antenna input of the Countersurveillance Monitor, connect a DC voltmeter from the cathode of diode D1 to ground. As you move the RF source closer to the antenna, the meter should read an increasingly more positive voltage.



The antenna and speaker for the Countersurveillance Monitor are held in place with silicone cement.

Also make sure that the antenna's connecting cable is not shorted to ground (it is rather close to the circuit's ground plane). Also make sure that none of the component leads are left long; long leads can also cause grounding problems.

Once you get the Countersurveillance Monitor working, you can rest reasonably assured that the homefront is free of eavesdropping devices. And whenever there is a suspicion that perhaps someone is invading your privacy, you'll be ready to tackle your hunt-and-destroy mission! ■

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Build a project that lets you send pictures on the telephone line, record them on audio cassette, and more.

Build Your Own PICTURE PHONE

As a kid (and sometimes now as an "older kid") I read the Dick Tracy comic strip. What appealed to me most about the comic was the vast array of hi-tech gadgets Tracy and the police force had at their disposal. The one that first leaps into my mind (and probably yours too) was his wrist-watch picture phone. Would you be surprised to hear that not only has the day of personal video communication arrived, but you could build a video phone yourself? Further still, with one of the new LCD TV's, a portable phone, a video camera, and the device described in this article, you can come close to making Tracy's little gadget a reality.

The *Phonvu Camera Phone*, as the project is called, takes a digital "snapshot" of the video signal sent to one of its inputs. If you like how the snapshot looks on your video monitor, you can command the Camera Phone to transform the picture into a series of audio signals. The signal can either be recorded on an ordinary *cassette* tape (not a video tape) for video playback later, or sent across the phone lines to another Camera-Phone unit, which transforms the signal back into a picture.

The unit has automatic modes of operation, as well. Using these modes you can have the unit capture and transmit images all on its own so you don't even have to be present!

BY FRANK PERELMAN AND JOHN YACONO

1992 PE HOBBYIST HANDBOOK

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Some Possible Uses. Sending images over the phone is, of course, the most obvious application for the Camera Phone. In comparison to a FAX, the Camera Phone provides higher resolution, can be sent more quickly, doesn't require a halftone mode for photos, can transmit pictures of real objects—not just pieces of paper, and you can view a picture before it is transmitted to get it right the first time. Unlike some inexpensive or older FAX's, the unit automatically takes the phone off hook when transmitting or receiving data. That allows you to intersperse conversation and image transmissions without having to put the phone down.

Its automatic capabilities allow you to monitor a remote location from wherever you are. Say you've got a Camera-Phone unit connected to a video camera and the phone line at the place you wish to monitor. When set to automatically capture and "send" pictures, the unit captures an image, takes the phone off hook (without dialing), and attempts to transmit its data. When it's through with its attempt, it hangs up and tries again a few seconds later with a new captured image. Of course, having the unit pick up the phone costs nothing because it doesn't dial any number.

To view the remote location, you dial the phone number of that location. If the remote Camera-Phone has taken the phone off-hook in an attempt to transmit an image, you'll get a busy signal. The Camera phone will soon hang up the phone so it can capture the next picture, so keep dialing until you get a ring signal. If you then hang on, the remote Camera-Phone unit will take the phone off hook (effectively answering your call) and transmit an image to the Camera Phone at your location.

As I mentioned, the audio signals need not be transmitted by phone to be useful. By recording the audio-encoded video signals on one channel of a stereo cassette, and a regular audio soundtrack on the other, you could make an audio/visual "slide show." All you would need to playback the presentation is one Camera-Phone unit with the special audio option (we'll discuss that later), an ordinary stereo-cassette player, and a monitor.

It can perform other useful functions as well: For example, you could use it to add digital freeze-frame operation to your VCR or TV. When used to freeze VCR pictures, it will eliminate the annoying noise bars that many non-digital VCR's generate in their freeze mode. Using it with a TV is a great way to freeze addresses and phone numbers of mail-order companies without the need to fire up the VCR or waste videotape. Sports enthusiasts will enjoy the ability to freeze the bone-crunching action of most contact sports.

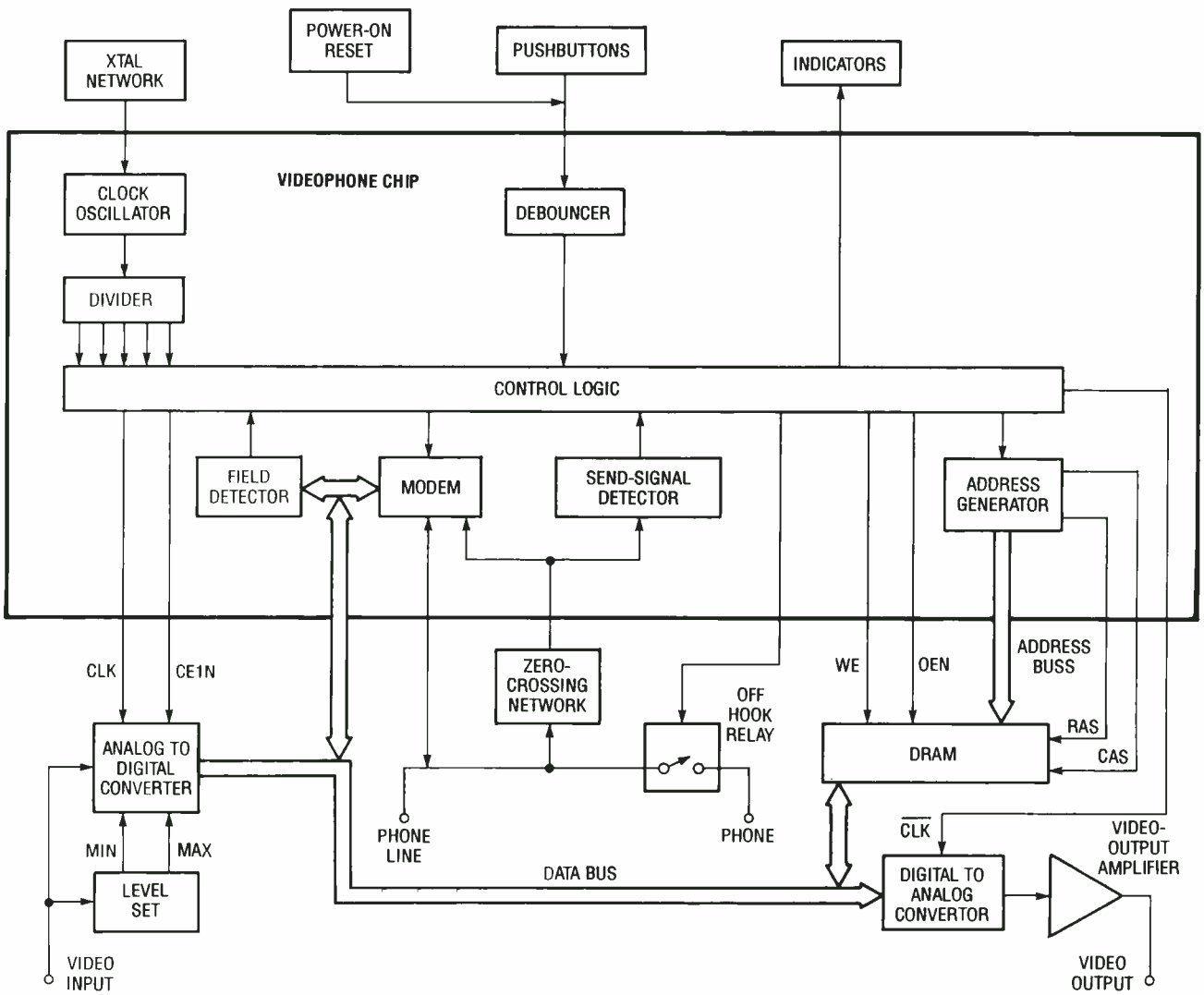

Fig. 1. The internal sections of the chip and the circuitry for the entire Phonvu unit are shown here. The interaction is pretty simple with the control logic running the show.

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There are a variety of options available to expand the usefulness of the Camera Phone. For example, although the basic unit handles black and white images (even though you can feed it color signals) an adapter can be used to allow it to transmit and receive color images. Other options allow you to print received pictures, send them to your computer, modulate audio to come out of your TV speaker, remotely control the unit via a Touch-Tone phone, and more. (A more complete list of options is provided in the Parts List.)

You might be wondering what has made all this possible at a hobbyist price; Well there hasn't been an overwhelming breakthrough in technology, but there is a new IC on the market that drastically reduces the parts count needed for freeze-frame video communication. Aptly enough its name is "Phonvu" (also known as part number PMC-VIDRAM-027). As you'll see, the chip performs many tasks all by itself, so you'll only need one such IC and some commonly available support components to build a Camera-Phone unit. Keep in mind that you'll need two units for two-way communication, but only one for recording images on a cassette or for simple freeze-frame applications.

The Chip. As mentioned, the Videophone chip wears "many hats." The best way to explain what its many internal sections do is to describe how it functions in the Phonvu circuit. The diagram in Fig. 1 shows the blocks that make up the Phonvu circuit as well as a breakdown of the internal sections of the Videophone chip. Refer to that figure as we explain how the chip operates.

For the sake of discussion, we'll make no distinction between the blocks inside the Videophone chip and the blocks that make up the external circuit. For that reason it might appear that you'll need a lot of support circuitry, but that isn't really true.

Also, we'll describe how the circuit works when connected to a telephone, but keep in mind that you can alter the unit to accommodate your application. For example, you can leave off certain functional blocks (*i.e.*, the phone jacks, the zero-crossing network, and the off-hook relay) for simple freeze-frame operation. Or you could add the audio-option circuit (available as a kit from the chip supplier) to record on regular cassette tape.

On a final note, to give you a better feeling for each of the steps Phonvu must take when transmitting a picture, we'll avoid discussing the unit's automatic modes of operation until a bit later. Now let's take a qualitative look at how Phonvu works before getting down to the nitty-gritty.

Initialization. When you first turn on the Phonvu circuit, the Videophone chip needs to know which of its various operating modes it should be in. The operating modes are really beyond the scope of this article. Suffice it to say there are many of them and most are not applicable to building a Camera Phone.

During the first few moments of operation, the chip's control-logic section monitors the pushbuttons—labeled "Picture Adjust," "Send," "Capture," and "Auto"—and a special "Speed" pin to find out the desired operating mode. It checks to see if the pushbuttons or the speed pin are held low, held high, or pulsed, and sets the operating mode accordingly. (We'll explain the function of each pushbutton a little later on.)

The proper initializing signals are produced by a "power-on reset circuit" (look back at Fig. 1) that sets the mode of the Videophone chip by simulating pushbutton and speed pin activity. The POR, as we'll call that block, holds the capture and the speed pins on the chip high, and pulses the auto line. Then it sends a train of pulses to the speed pin to complete the initialization procedure.

That activity tells the chip a few things about the circuit it's in and how it must behave. For one, it indicates that a pushbutton will be used as the picture-adjust control instead of a potentiometer (which you needn't concern yourself with). Also, it sets the amount of memory and addressing scheme that will be used for each picture. Changing those parameters is only important for computer interfacing, so you needn't worry about the particulars. Pulsing the speed pin on the chip ensures that it will work in its "high-speed mode" as opposed to low-speed mode (which again, you need not bother with.) With the chip well informed, it waits patiently for your first command.

Idling. After initialization, the chip's control-logic section continues to monitor the pushbuttons, indicates the current operating mode via LED's that form the indicator section, and activates the various other blocks accordingly. (Note that the Videophone chip contains its own internal debouncing circuit to reduce the parts count of the Phonvu.) To summarize, the primary function of the control logic is to process a request made through the pushbutton circuit, and show the action it takes through the indicators. As you'll see, to do its job, it monitors and orchestrates the action of the other functional blocks.

However, much like a band leader, it requires timing. The timing is provided by an on-board clock oscillator that requires the support of an external crystal and resistor that form the crystal-network section. The clock signal is divided by various amounts and the resulting pulses will be used by the control logic as control signals (*i.e.* CLK, CE1N, WE, and OEN). Through the use of the control signals the control logic will act as a traffic cop for the flow of data, and set both the pace and mode of the whole Phonvu circuit.

Once turned on and initialized, the control logic initiates the "idle mode." That means that any composite-video signal entering through the video-input jack (from a VCR, video camera, or closed-circuit TV camera) will flow through some sections of the Phonvu circuit, and go through some digital maneuvers, only to reappear at the video-output jack.

More precisely, the composite-video signal is sent to an analog-to-digital converter (or ADC) that transforms it into a stream of parallel binary data. However, to do that properly, the ADC needs to know the maximum and minimum level of the video signal. That information is provided by the level-set block. In the idle mode, the control logic sends an output-enable signal and a stream of clock pulses to the ADC (at the CE1N and CLK terminals, respectively) permitting it to put the digitized picture data on the data bus.

The control logic also sends negative clock pulses to a digital-to-analog converter (DAC) section. With each pulse, the DAC picks data up off the bus and converts it back into a video signal. The video signal is provided with enough current to drive it into 75-ohm cable by a video-output buffer. From there it exits the unit through a video-output jack.

By connecting a monitor to the video output, you can view the image traveling on the data bus anytime. In the idle mode, the ADC places a real-time (continuously updated) image on the bus so the monitor would almost ap-

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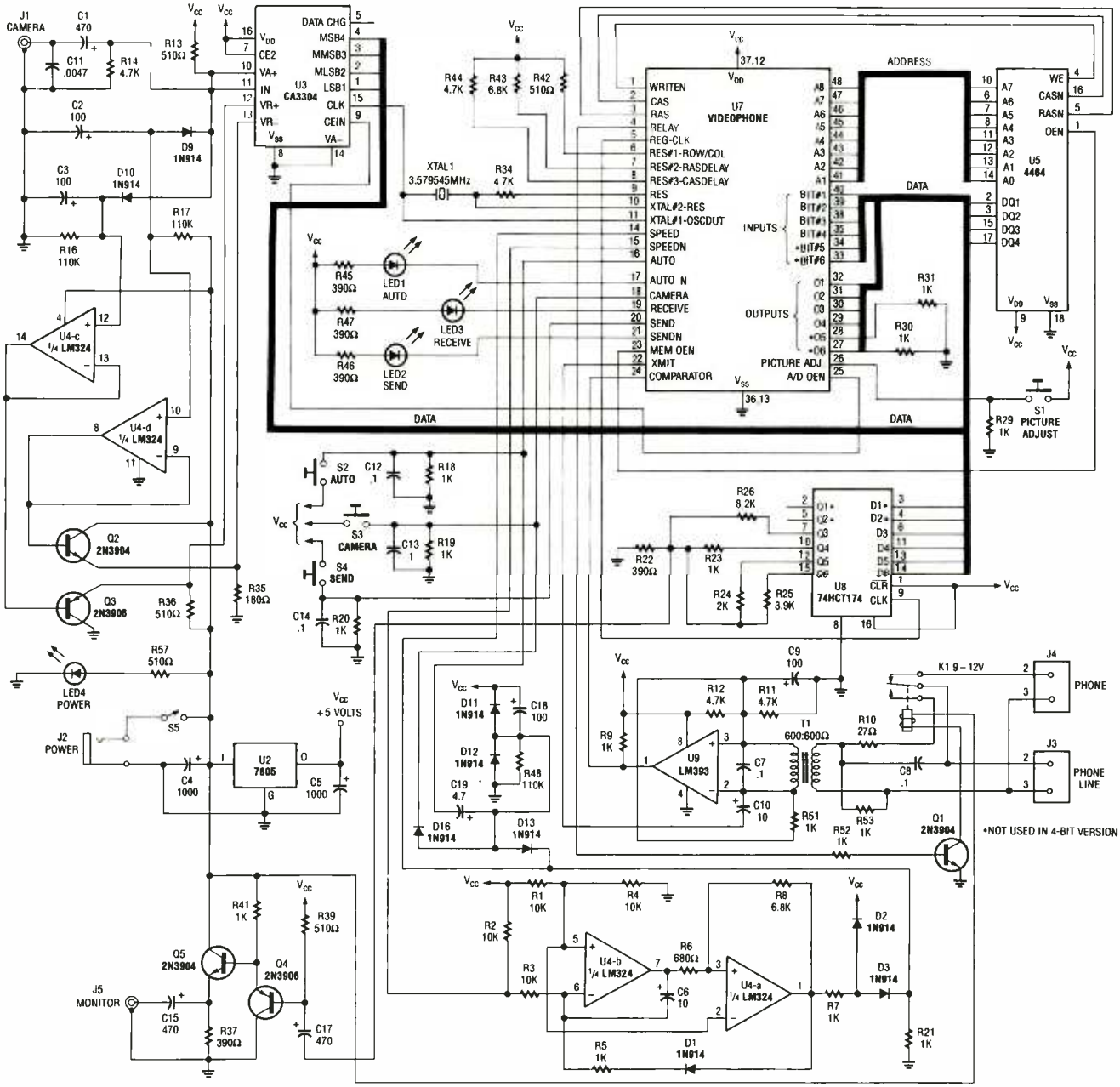

Fig. 2. These are the real "guts" of the 4-bit Phonvu. There are only five basic types of signals handled by the circuit.

pear to be connected to the video-input jack.

Capturing an Image. By pressing the capture pushbutton on Phonvu, the unit enters into the capture mode. In this mode the data from the ADC is recorded in the dynamic RAM (DRAM), but before the control logic can take any action to record an image, it needs to know when the beginning of the picture (the top-most portion) is being digitized. The field-detector section of the Videophone chip determines just that. It observes the incoming digitized video to find the data corresponding to the very top of the screen image. If it senses that data, it signals the control logic. If for some reason (such as poor video-signal quality) the top of the picture cannot be determined, the detector looks for "vertical-sync pulses." Those pulses are used by video equipment to synchronize many internal operations and to indicate that the top of the screen will be sent shortly. If it cannot find them either, then it signals the control logic anyway. If any misalignment occurs (*i.e.*, if the top of the picture appears in the middle) it can be adjusted using the picture-adjust button, as we'll explain later.

Upon receiving the go-ahead from the field detector, the control logic sends write signals to the DRAM. The pulses are synchronized with the ADC operation in such a way that the DRAM picks the picture data up off the bus and stores it in the memory locations dictated by the address generator.

Once the DRAM contains enough data for one picture (one field of video), the ADC is shut off and the DRAM is asked to write the picture data back onto the bus, again under the guid-

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ance of the address generator. The address generator causes the picture data to be written to the bus like an endless-loop tape (*i.e.*, the same picture is sent to the bus over and over again). The now-active DAC transforms the data back into a video signal. The result is a frozen picture on the monitor that shows what was captured in the DRAM.

If for some reason the picture is misaligned or starts in the middle, you can cause the image to shift to the left one pixel at a time by pressing the picture-adjust button. If you want to move a little faster than that, you can press and hold the button down—that simulates the action of pressing the button over and over. If you want to move to the right, release the button for one second and press it again. Each time the button is left idle for more than a second the direction of the shift will change. What the picture-adjust button does is tell the control logic to change the starting address used by the address generator. Once the address generator is adjusted, you should be able to capture picture after picture without further adjustment. The only exceptions to that rule would be using more than one video source (camera, VCR, etc.) or a video source whose timing circuits drifted a lot.

If the picture is properly aligned, but still not quite what you want, another press of the camera button puts you back in the idle mode. That allows fresh real-time video data to travel freely from the ADC to the DAC and tells the DRAM to be quiet. You can now try capturing the picture again.

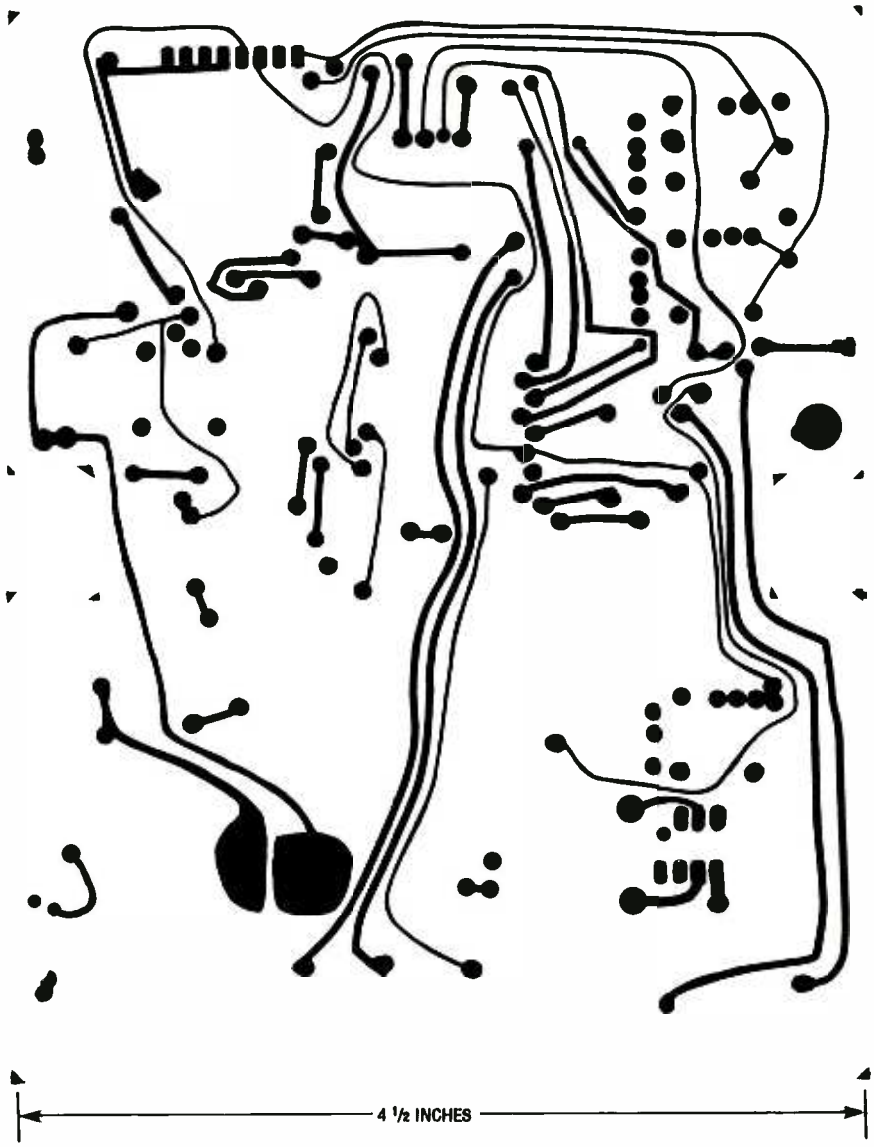

Fig. 3. This is one foil pattern for the main circuit board. Most of the components will be mounted on this side.

Transmitting and Receiving Picture Data. Once you get exactly the picture you want to send, you should call the Phonvu that's to receive the image. (Actually, the destination phone could've been contacted at any time before this.) You can hold a normal conversation with anyone at the other end at this point if you need to tell them to set up the receiving Phonvu.

Assuming the destination Phonvu is connected and turned on, and the phone link is established, you're ready to send the picture you've captured. That is accomplished, quite naturally, by pressing the send button. The control logic responds by lighting an LED indicator and then activates a relay that disconnects your phone from the phone line. It then tells the modem to transmit a special "send" signal. That signal prepares the receiving Phonvu as you'll see a little later. At the transmitting end, the control block then tells the modem to start picking the data (coming from the DRAM) off the bus, modulate it, and transmit the modulated data via the phone line. The data is pulse-modulated using a proprietary technique that is currently up for a patent, so we can't go into too much detail about the modem. When a "screen's worth" of data is sent (about 12 to 16 seconds), the LED shuts off, the modem is deactivated, and the phone is once again connected to the phone line. You can now converse with the receiving end to find out how things went.

The send signal informs the receiving Phonvu that picture data is to follow. Once the send signal is received, the receiving Phonvu activates its relay, effectively stealing the phone line and connecting it to a zero-crossing network, and disables the ADC. As picture data is received, it passes through the zero-crossing network, which detects each transition in the received audio signal and sends the transitions to the modem. The modem converts the audio transitions back into binary and places the data on the bus. Concurrently, the control logic forces the DRAM to read and store the data off the bus. The DAC and output buffer then transform and send the picture to the monitor. When the transmission is complete, the control logic in the receiver releases the phone line and turns the modem off. The DRAM places the received binary data onto the bus over and over again for the DAC to output, just as it would in capture mode.

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The 6-Bit Option. Before we start discussing the Phonvu circuit, you should be aware that it can be built for 4- or 6-bit operation. The 4-bit version costs a little less than the 6-bit version, but has a limited gray scale (*i.e.*, it displays less variations in brightness). The 4-bit gray scale can reproduce 15 different levels of gray, spanning from black to white, while the 6-bit gray scale can discriminate between 50 levels of gray.

The expanded gray scale gives the video image enhanced clarity and sharpness. It also gives the appearance of higher resolution, although resolution has not actually been improved. That is due to the fact it can distinguish the difference in brilliance between adjacent pixels better.

If you're computer oriented, you might wonder why the 4-bit and 6-bit units aren't capable of generating 16- and 64-level grey scales, respectively, which are their theoretical limits. That is because video-sync signals have to be encoded along with the brightness information in this system. Those signals have a greater amplitude than the brightness information so they incur some overhead, which reduces the grey scale a little.

As far as parts are concerned, the two versions are almost identical. The 6-bit version requires a 6-bit ADC instead of a 4-bit ADC, and requires an extra DRAM chip to hold the two additional bits. Beyond that, you'd only need to alter a resistor value and add two more resistors elsewhere. That's not much to do for over 3 times the picture quality.

Both versions operate in an identical manner. So, for the sake of simplicity, we'll discuss the circuitry for the 4-bit version, but provide you with enough information to build the 6-bit version if you wish.

From Video to Data and Back. The 4-bit Phonvu circuit is shown in Fig. 2. The signals that flow through its circuitry can be divided up into five categories: data, data addresses, video, audio (or modulated video), and control/support. We have already discussed most of the control signals used by the circuit, so let's examine the other categories.

How the circuit processes a signal depends on the signal's use and the task the Phonvu unit is performing. For example, during idle mode the incoming analog-video signal needs to be converted to digital so that it can be placed on the data bus. The conversion is performed by U3, an integrated 4-bit ADC, which acts as the ADC block. (Note that chip should be replaced by a CA3306 6-bit ADC for 6-bit operation.) Resistors R13 and R14 adjust the video-signal voltage to a desirable level for the ADC (although R13 should be 4.7k for the 6-bit version).

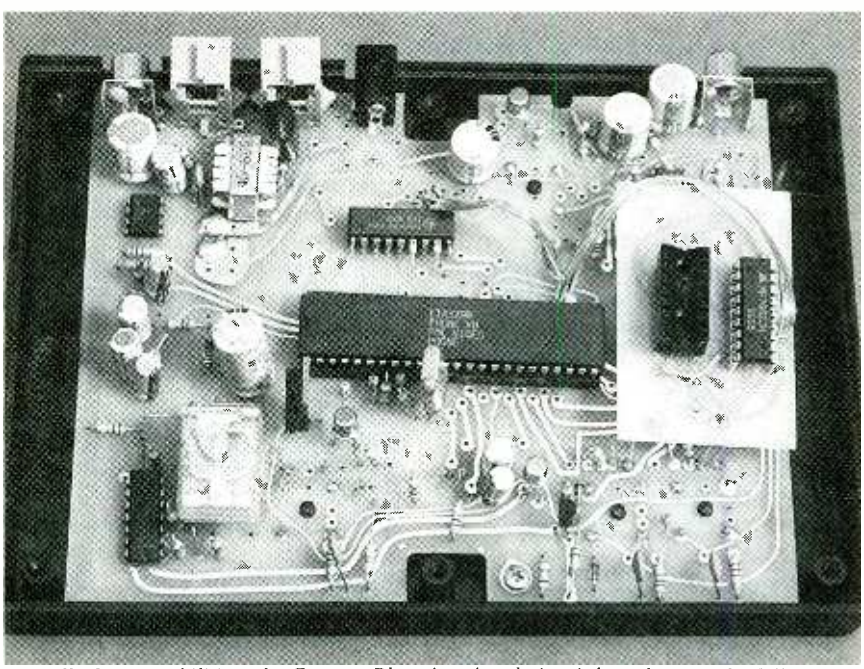
However, the ADC needs to know the minimum and maximum signal levels to encode the data properly. Those voltage levels are stored on C2 and C3, respectively. The voltages are buffered by two op-amps in U4 and passed to the ADC via Q2 and Q3. The transistors are biased to overcome the voltage drop across D9 and D10. The circuitry just described forms the level-set block. The binary data generated in that fashion is placed on the data bus for use by the other functional blocks.

Regardless of its source (the DRAM or the ADC), if data being placed on the bus needs to be converted into a video signal (such as for the idle mode, the capture mode, or when an image has been received from the phone line), it is sent through U8, a hex D-type flip-flop configured as a data buffer. It passes the data bits onto a network of resistors composed of R22–R26. The resistors' values are chosen so that the network reproduces the original video signal from the binary data (see *The Digital Electronics Course* **Popular Electronics**, February 1990 for more information on that topic). The resistor network and the hex flip-flop form the DAC block. For 6-bit operation you will also need to connect a 15k-ohm resistor and a 27k-ohm resistor to the Q1 and Q2 outputs, respectively. The free ends of those resistors should be tied together and connected to the junction formed by R22 and the four other resistors (R23–R26).

The analog signal generated by the resistor network is AC coupled to Q4 via C17. Transistors Q4 and Q5 along with some bias resistors (R37, R39, and R41)—which together form the video-output amplifier—boost the current and send it to the video-output jack through C15.

Data to Audio and Back. When data on the bus needs to be transformed into audio signals (for example, when transmitting an image over the phone), the process is handled exclusively by the modem in the Videophone chip (refer to Fig. 2). It picks the data up off the bus through the pins labeled Bit 1–Bit 6 (the pins for bits 5 and 6 are not needed for the 4-bit version). The audio signals that the modem generates are placed on the phone line via audio transformer T1.

When data is coming in from the phone line, it is AC coupled to Phonvu through T1. The signal is then sent to a comparator composed of an LM393 (U9), which changes state with each transition of the incoming audio signal. The comparator and its support components form the zero-crossing network. The pulses that it generates are



For all of its capabilities, the Camera Phone's printed-circuit board—even the full-blown 6-bit version (pictured here)—is rather small and sparsely populated.

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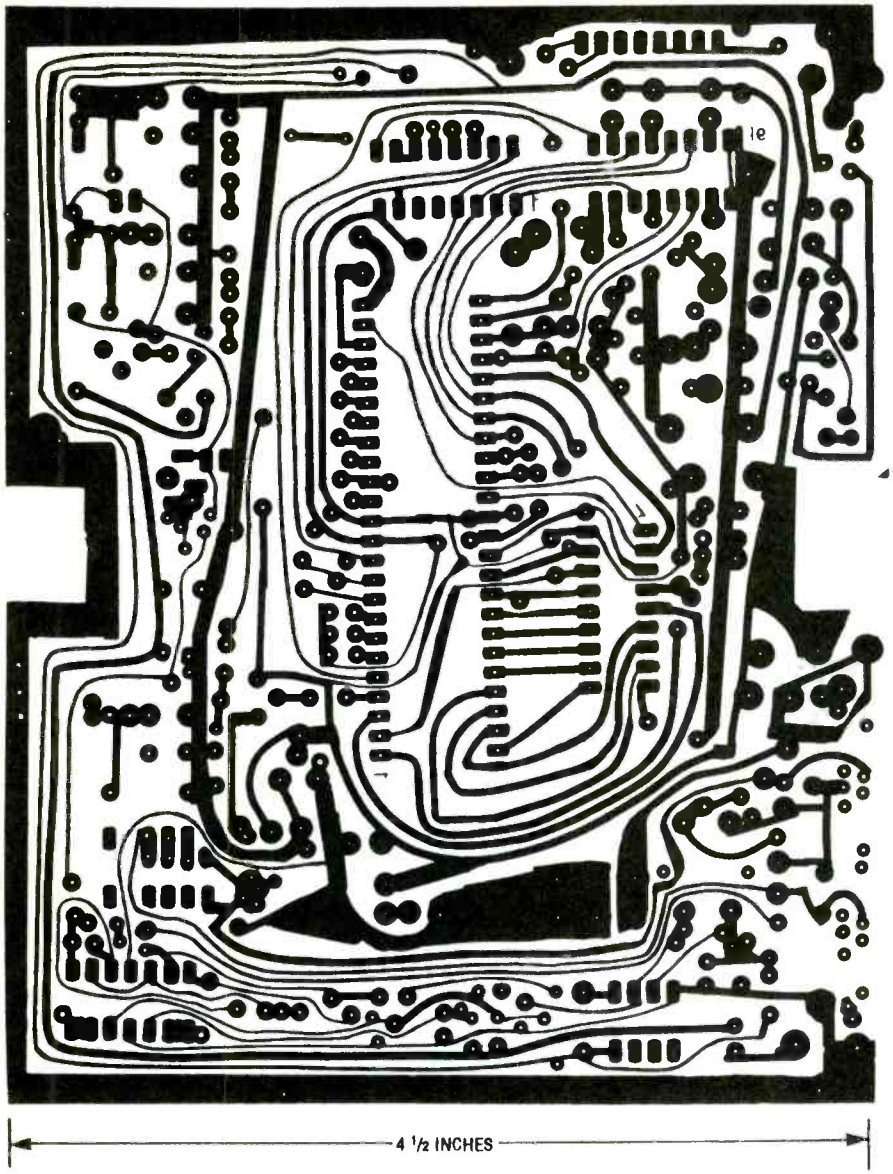

Fig. 4. This is the foil pattern for one side of the main board. It is called the "foil" side because only the LED's and switches are mounted on this side.

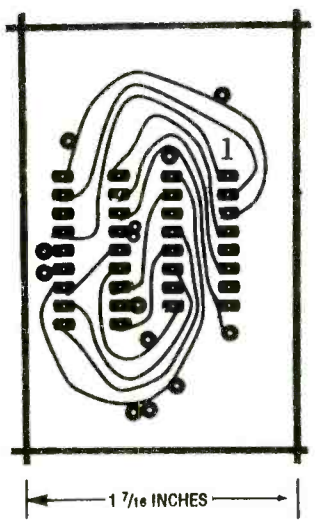

Fig. 5. The adapter board is very simple. It is single-sided, and this is the foil trace.

sent directly to the Videophone chip for processing. The chip places the demodulated digital information onto the data bus via outputs O1–O6.

Whether transmitting or receiving, the off-hook relay (K1) disconnects the phone and replaces it with R10, which acts as a dummy DC load. Resistor R10 tricks the phone-company equipment into thinking that the phone is still present, preventing it from hanging up on the Phonvu unit. Note that the relay is grounded through Q1, which is operated by the Videophone chip itself.

DRAM Operation and Connection. You may have noticed that the Videophone chip's binary inputs and outputs are tied to the same bus (refer again to Fig 2). That's because the DRAM specified for the Phonvu circuit uses one set of pins for both input and output. That greatly reduces the number of circuit traces needed to move the data around. However, since the Videophone chip has separate input and output pins, it can accommodate the more cumbersome memory chips that have dedicated input and output pins, should the need arise.

Since the DRAM uses the same pins for input and output, it needs to know whether to write data already on the bus into memory, or to output data from the memory. Those functions are triggered by signals presented to the WE (*W*rite *E*nable) and OEN (*O*utput *EN*able) pins, respectively.

The memory locations in the DRAM are arranged in "row-and-column order." What that means is that the memory locations are laid out like a table—into rows and columns. To point to a particular memory location (whether for input or output), you need to specify its row and then its column. In effect, that means you need to specify two addresses: a row address and a column address. They are both sent to the same pins on the DRAM one at a time. That means the circuit must tell the DRAM whether it is currently sending a row or a column address. It does so by raising the RAS or CAS pins, respectively. The address generator inside the Videophone IC takes care of the rest.

Control and Miscellaneous Signals. There are just a few more bits and pieces of circuitry that bear explanation. For example, R42–R44 form a special timing network required by some internal circuitry of the chip. Those resistors could not be incorporated into the Videophone chip at the time of manufacture because their values could only be properly determined afterward.

Speaking of timing, the crystal-network block is composed of R34 and XTAL1. Note that the crystal is a commonly found TV-color-burst crystal. However, it is only used for timing purposes; the Phonvu shown here is a black-and-white unit. Color operation requires the color option (see the Parts List).

The indicator block is composed of LED1–LED3 and their current-limiting resistors R45–R47. Light-emitting diode LED1 indicates the automatic-mode the unit is in (if any). Light-emitting diodes LED2 and LED3 indicate whether the circuit is sending or receiving data, respectively.

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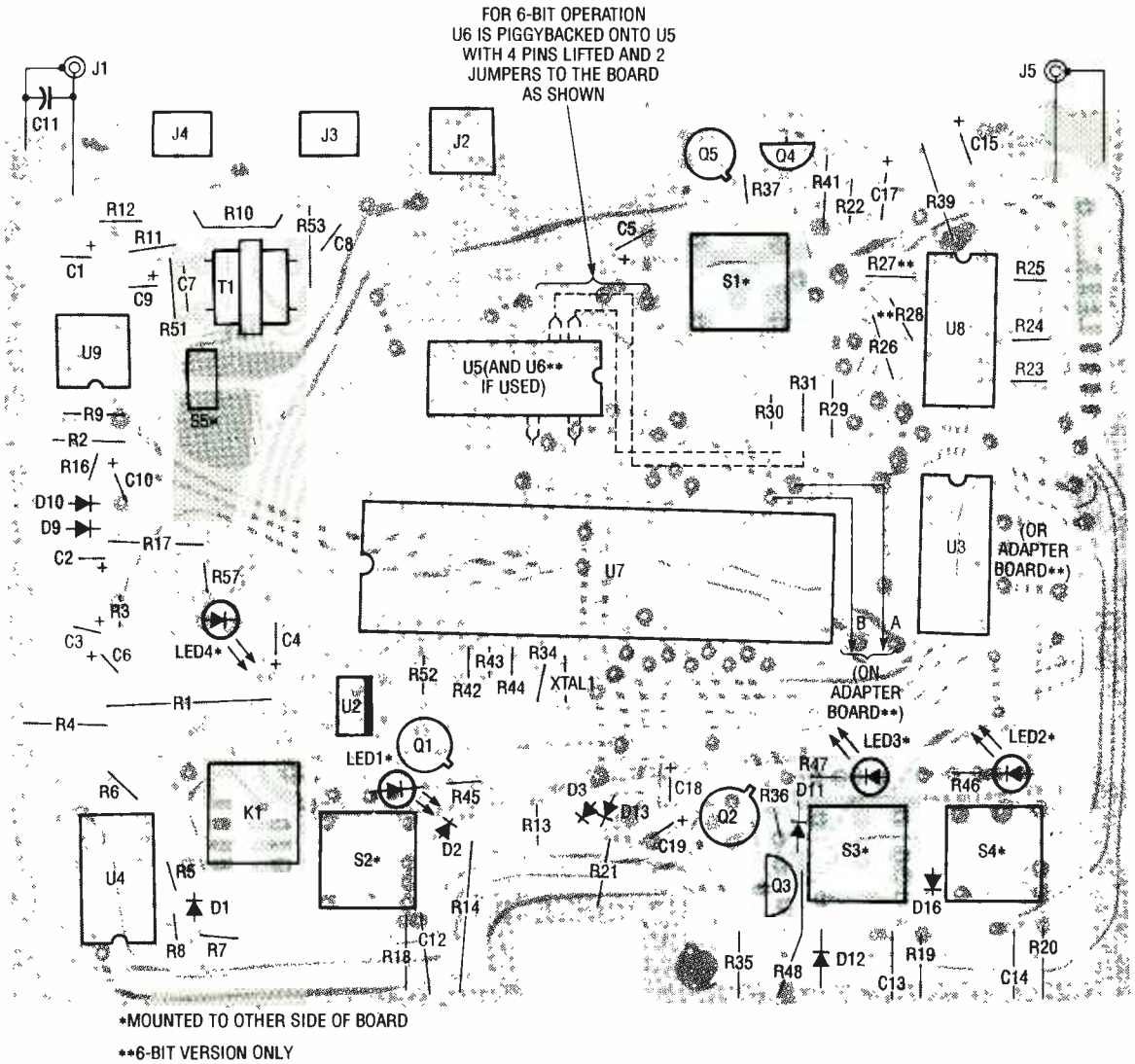

Fig. 6. This parts-placement diagram should help you stuff the main board. Note: the lifted pins on U6 (6-bit version only) and their associated connections are shown with dashed lines.

The four pushbuttons (S1–S4), bring their associated signal lines high when depressed. Resistors R18–R20, and R29, hold those lines normally low, except during initialization, and C12–C14 act as noise decouplers.

As we mentioned before there is a power-on-reset circuit that imitates the action of those switches when power is first applied. There is a special portion of the power-on-reset circuit that performs two jobs: it must first hold the speed pin high, and then send a series of pulses to that pin. That circuit is composed of two op-amps in U4, resistors R1–R8, diodes D1–D3, and capacitor C6. While the circuit holds the speed pin high, the camera pin goes high because of current through D16 via C18. Capacitor C19 charges and discharges, pulling the auto pin high and then low while the camera and speed pins remain high. Then the op-amps work together to send a series of pulses to the speed input. They stop producing pulses when the "speed" pin of the Videophone chip goes high. The chip sends that pin high when the high-speed mode is set.

Last and certainly not least is the power supply composed of a 12-volt DC power adapter (the wall-mount kind), which is not shown on the schematic diagram; C4; U2; and C5. Switch S5 is the on/off switch, and J2 is the jack for the 12-volt adapter. Light-emitting diode LED4 indicates that the power is on.

Automatic and Other Modes of Operation. From the discussion thus far, you already know how the camera, send, and picture-adjust buttons work. But we've saved the most interesting one—Auto—for last. If you press the auto button once, the unit will pick up the phone and transmit a new picture every 38.5 seconds. The unit indicates the automatic mode of operation by lighting the Auto LED (LED1). That mode is useful for hands-free operation so you can pose the object to be pictured. It is also useful for remote surveillance as we mentioned earlier.

Pressing the Auto button again puts the unit into semi-automatic mode and the Auto LED flashes. What that means is that the unit will automatically transmit a picture 4 seconds after one is captured. If you don't like the picture that you've captured, just press the capture button before the 4 seconds have elapsed to put you in the idle mode so you can try again. However, you'll still be in semi-automatic mode, so the unit will transmit a new picture 4 seconds after it is captured unless you interrupt the process again.

You can also get the unit to perform a

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PARTS LIST FOR THE PHONVU CAMERA PHONE

SEMICONDUCTORS

U1—MP7682 or CA3306 6-bit analog-to-digital converter integrated circuit (6-bit version only)
U2—7805 5-volt regulator, integrated circuit
U3—CA3304 4-bit analog-to-digital converter, integrated circuit (4-bit version only)
U4—LM324 quad op-amp, integrated circuit
U5—4464, 64KB dynamic-RAM, integrated circuit
U6—4464, 64KB dynamic-RAM, integrated circuit (6-bit version only)
U7—PMC-VIDRAM-027 videophone, integrated circuit
U8—74HCT174 hex D-type flip-flop, integrated circuit
U9—LM339 comparator, integrated circuit
Q1, Q2, Q5—2N3904, or 2N2222 NPN bipolar transistor
Q3, Q4—2N3906 PNP bipolar transistor
D1–D3, D9–D13, D16—1N4148 or 1N914, small-signal, silicon diode
D4–D8, D14, D15—Not used
LED1–LED4—Red light-emitting diode

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1–R4—10,000-ohm
R5, R7, R9, R18–R21, R23, R29–R31, R41, R51–R53—1000-ohm
R6—680-ohm
R8, R43—6800-ohm
R10—27-ohm
R11, R12, R14, R34, R44—4700-ohm
R13—510-ohm for 4-bit version, 4700-ohm for 6-bit version
R15—Not used
R16, R17, R48—110,000-ohm
R22, R37, R45–R47—390-ohm
R24—2000-ohm
R25—3900-ohm
R26—8200-ohm
R27—15,000-ohm for 6-bit version only
R28—27,000-ohm for 6-bit version only
R32, R33—Not used
R35—180-ohm
R36, R39, R42, R57—510-ohm
R38, R40, R49, R50, R54–R56—Not used

CAPACITORS

C1, C15, C17—470-µF, 6.3-WVDC, electrolytic
C2, C3, C9, C18—100-µF, 10-WVDC, electrolytic
C4—1000-µF, 16-WVDC, electrolytic
C5—1000-µF, 6.3-WVDC, electrolytic
C6, C10—10-µF, 16-WVDC, electrolytic
C7, C12–C14—0.1-µF, ceramic disc
C8—0.1-µF, 100-WVDC, polyester
C11—0.0047-µF, ceramic disc
C16—Not used
C19—4.7-µF, 50-WVDC electrolytic

ADDITIONAL PARTS AND MATERIALS

K1—9–12-volt SPDT relay
J1, J5—RCA jack
J2—Coaxial power jack
J3, J4—Modular phone jack
S1–S4—SPST momentary-contact switch
S5—SPST slide switch
T1—600:600-ohm audio transformer
XTAL1—3.579545-MHz color-burst crystal
Printed-circuit board materials, adapter board (6-bit version only), 12-volt DC power supply, jumper wire, 16-pin wirewrap socket (6-bit version only), IC sockets, case, solder, etc.

Note: The following parts are available from PMC Electronics, PO Box 11148, Marina Del Rey, CA 90292; Tel. 213-827-1852: the Videophone chip and 4/6-bit circuit schematic ($59.95); 6-bit ADC, DRAM, and hex flip-flop chip set ($35); 4-bit ADC, DRAM, and hex flip-flop chip set ($21); 4-bit to 6-bit upgrade kit ($22.95); PC board ($18.95); resistors, capacitors, and diodes ($28.75); pre-cut cabinet ($12.75); 12-volt DC supply ($8.75); total kit of parts (components, cabinet, PC board, 12-volt supply etc.) for 4-bit unit ($150.15); total kit of parts for 6-bit unit ($164.15); completely assembled 6-bit unit ($235); completely assembled 4-bit unit ($210); cassette-recorder interface kit ($14.95); assembled cassette-recorder interface ($29.95); voice-mail adapter kit (reduces speed for voice-mail compatibility) ($23.80); assembled computer/voice mail interface, connector cable, software, and special 6-bit Phonvu unit ($549); video speakerphone TV-audio modulator ($79.95); assembled color-Phonvu unit ($299.95); remote-observation unit ($454.00); a variety of monitors and video cameras are also available (contact PMC for pricing). PMC offers priority-mail delivery at $2.90 for one kit and $3.95 for two kits (contact them directly to arrange for COD, UPS, regular mail, or other deliveries). Include $4 for shipping and handling and California residents add 8.25% sales tax. Credit cards, COD, checks, and money orders are accepted (all orders must be payable in U.S. funds).

few extra functions by pressing combinations of buttons. For example, you can interrupt the send or receive mode by simultaneously depressing the Auto and Send buttons. If you depress and hold down the Capture button, then depress and hold the Send button, and press and release the Auto button, the unit will go into receive mode. It will then display any image that might be coming in on the phone line.

Construction. For a 4-bit unit, you'll only need a main circuit board. The main circuit board is double sided with plated-through holes. As it is very difficult to make such boards, it is recommended that you purchase the main board from the supplier mentioned in the Parts List. Nonetheless, we've provided the foil patterns for the component and "foil" sides of the main board in Figs. 3 and 4, respectively. If using a homemade board, you will have to overcome the problems caused by the lack of plated-through holes. To do that, you will have to solder all components on both sides of the board; you will also need to install feedthroughs (a small piece of wire, such as as a clipped component lead, that is soldered on both sides of the board) at all unused holes. Doing that completes the electrical connections between the two sides of the board.

In a 6-bit unit you'll need an additional adapter board. It is not double sided, but it is also available from the kit supplier. We provide the foil pattern in Fig. 5 for the more ambitious.

Once you've got the boards that you need, you can begin the assembly procedure. Use Fig. 6 as a guide to stuffing the main board. Start by placing the resistors on the board. Keeping in mind that R27 and R28 are only needed for a 6-bit unit, and that there are no resistors labeled R15, R32, R33, R38, R40, R49, R50, R54, R55, or R56 and no diodes D4–D8, D14, or D15 in either unit. Note that if you're building a 4-bit unit, the value of R13 is 510 ohms, but in a 6-bit Phonvu it should be 4.7k.

Next install the capacitors, making sure the polarity of the electrolytics is correct before soldering them in place. Solder C11 onto J1, which will be installed later. Note that there is no capacitor labeled C16.

Now you should install the electronic

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hardware (the jacks, the switches, and the relay). Soldering those components usually requires a little extra heat, so installing them before the semiconductors is prudent. Be sure that you install the switches on the "foil" side of the board. If you're building your units from the kit, be sure to position the switches correctly as it's possible to install them rotated by 90°. You can also install the transformer now.

If you plan to use IC sockets (which is recommended for at least the Videophone chip) install them at this time. If you're building a 6-bit unit, you must install an IC socket in the place marked for U3. That socket will be used to hold the adapter board.

Install the diodes and transistors, making sure that you install the LED's (LED1–LED4) on the same side of the board as the switches. Keep the leads of the LED's long so that you'll be able to position them to mate with the front-panel holes. Install the crystal now, but use a minimum of heat.

You can at last install the integrated circuits, but a few words are in order: First, there is no U6 in the 4-bit unit, but in a 6-bit unit U5 and U6 are piggy-backed (*i.e.*, U6 rests on top of U5). However, no matter what unit you build, install U5 in the board as you would any other IC and solder all its pins. We'll discuss the placement of U6 a little later. Second, there is no U3 in the 6-bit version; the adapter board takes its place—we'll discuss that a little later, too. On a final note, it's a good idea to install the Videophone chip last to avoid damaging it with heat.

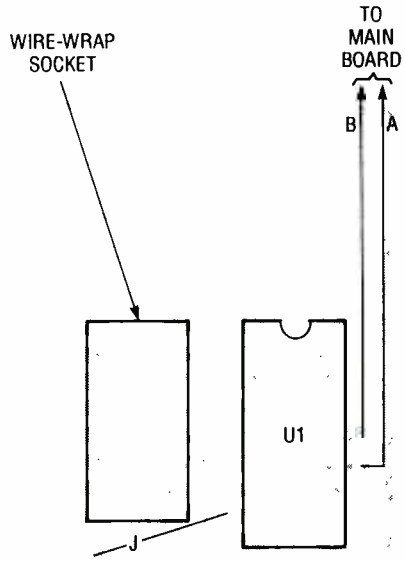

Fig. 7. The adapter board contains only two parts: an IC socket and a 6-bit ADC. Don't forget to add the jumper wire though.

If you're building a 4-bit unit, the circuitry is now complete.

Final 6-Bit Touches. A couple of extra assembly steps are required to complete a 6-bit unit. Pick up U6 (the additional DRAM) and bend pins 2, 3, 15, and 17 so that they're parallel with the body of the IC. Now place it on top of U5 so that the unmodified pins align and solder them to the pins of U5. When performing that operation, be extremely careful not to use too much heat. Excessive heat will damage the IC's. Solder jumper wires between pins 2 and 3 on U6 and the PC board as shown in Fig. 6.

Assembling the adapter board is easy. Start by installing a 16-pin wire-wrap IC socket onto the board as shown in Fig. 7. Solder it in place, but do not trim its leads. Solder the jumper wire as shown and install U1. Use the long leads of the wire-wrap socket to plug the adapter board into the socket that would have been used for U3 in the 4-bit version. Run wires between points A and B on the adapter board to the pads indicated in Fig. 6. The 6-bit unit now complete.

Setting-Up a Phonvu. Plug the 12-VDC supply into the unit via J2 and then into a wall outlet. Plug your video source (a video camera, VCR, closed-circuit TV camera, etc.) into the unit through J1. Plug the phone line into J3, and the phone into J4. Last, connect a monitor to J5. If you don't have a monitor, you can use a modulator to convert the video signals from J5 into TV signals and watch the video on channel 3 or 4 of a connected TV set.

Now you're all set to capture, receive, and send pictures via phone. You should try out all the operating modes we've mentioned to make sure everything is working properly. There is nothing to align or adjust so the unit should work right away. If a captured or received picture is a little misaligned, you should use the picture-adjust button as outlined earlier. The first picture you receive over the phone may tear and/or gyrate because sync signals have not been recorded in memory. The cure is simple enough, just capture a local image when you turn the unit on. The local image will provide sync signals that will remain in memory until the unit is turned off.

With the many optional features available through the kit supplier, you should have no trouble finding at least one good use for Phonvu. Whether you're installing a hi-tech surveillance system, enhancing a communications network, video interfacing with your computer, or just playing Dick Tracy with a friend, the Phonvu Camera Phone should prove to be one of the more rewarding projects you could build. ■

If you purchase the kit (or pre-assembled unit) from the supplier listed in the Parts List, this is what your finished unit will look like.

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TUNE IN THE ZODIAC RADIO

Read about the counter-culture heroes of our age and tune-in to their clandestine broadcasts.

BY ANDREW YODER

RADIO PIRATES

The shortwave radio crackles, "Broadcasting from one mile north of nowhere, this is the Voice of the Voyager." The program continues; a few rock songs are interspersed with low-key banter and frequent laughter from announcers R.F. Wavelength and A.F. Gain. Attracted to the station's curious format, a listener pages through several shortwave guides in an effort to identify the station, but finds nothing. Technically, the "Voice of the Voyager" does not exist.

Many shortwave listeners first encountered pirate radio around 1978 in scenarios like this one. The Voice of the Voyager has since disappeared, but the pirate-radio scene is still growing despite many set-backs. New listeners these days are discovering underground broadcasting from the likes of RNI, Radio Clandestine, WJDI, and Hope Radio.

Stations have changed over the years, and the hobby has become more complicated, yet it's really still the "same game." When the Voyager first took to the air on Christmas Day 1977, the station shared piracy status with only one other station—an AM pirate from New York City. Presently, at least 20 stations operate semi-regularly. Programming ranges from Neo-nazi commentaries to discussions on building antennas. This strongly contrasted with the standard music/talk formats that dominated the scene in the 1970's.

The Media Hype. Pirate-radio stations attract interest because of their ingenuity, program content, and "underdog" status. Radio Newyork International (RNI) prospered with a combination of these elements. Approximately 20 veterans of pirate stations from the New York City area compiled their resources, bought a ship and began broadcasting from international waters off the coast of Long Island. After only a few days, the station was closed down by FCC officials. Still, RNI generated enough media attention to be named the "best station of 1987" by *Rolling Stone* magazine.

RNI's "marketable piracy" greatly influenced others in the pop-culture mass media. At least two highly-rated pop/rock legal stations from Los Angeles and Philadelphia are presently using "pirate radio" as a format. Both pretend they are actually unlicensed, alluding to offshore or mobile transmitters and throwing the "pirate radio" slogan around as though it were a license to be fashionable. The "hipper than thou" executives at MTV have even brought pirates to television—first, by featuring the RNI crew as video jockeys for an afternoon, then by creating the "Pirate Television" program. All the media attention, which seems to have spurred sudden public acceptance of airwave rule-breaking, may promote more hobby pirates in the 1990's.

The Why's and How's. The pleasure of operating a personal radio broadcast and receiving fan mail from across the country brings many pirates into the hobby. As the media exploits the scene, operators suddenly become heroes instead of common criminals. With such "advantages," one might wonder why everyone from "Jimmy, the kid next door" to "Bob, the corner-grocery owner" doesn't start up a free-radio station.

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The truth is it's not that simple. Unlicensed radio broadcasting is illegal, and the Federal Communications Commission (FCC) enforces the rules and regulations. Under such regulations, "if convicted of operating an unlicensed radio station, the operator faces a maximum penalty of one year imprisonment, a fine of up to $10,000 and a possible forfeiture of their radio equipment to the U.S. Government." Even though offenders have never been punished to the legal maximum (most are fined $750 to $2,000), many pirates take every precaution.

"I pirated because I love all aspects of radio," says the Radio Animal, former owner/operator of WKND. "WKND operated as an outlet for so-called 'underground' programs, because we believe we had a right to use the airwaves, to experiment with radio technology, and because it was great to hear from listeners."

FCC agents closed WKND (Weekend Radio) in Pittsburgh, PA in February 1990. It was the end of one of the most professional, highest-quality pirate stations. Commencing on Halloween 1988, the pirate featured a slick, but curious product with music ranging from disco and rap, to punk and heavy metal.

Technically, WKND was a brilliant example of junk-box ingenuity. The "homebrew" 1620-kHz transmitter, built from surplus and junk parts, was modified with separate equalizers for each radio-frequency range. The 6240-kHz shortwave transmitter was simply an ancient Heath CW rig that was modified for AM transmission with a variety of surplus and "cannibalized" parts. The rig was purchased for only $10. On its first broadcast, WKND used an antenna built from 290 feet of aluminum magnet wire (from a television degaussing coil), suspended in the air by 15 helium balloons! The station was heard as far away as Wisconsin with only 25 watts on 1620 kHz. The shortwave transmitter was heard across the country. "Pirates have to be more scrappy and determined, and I suppose that's what makes free radio the special thing that it is," says Radio Animal.

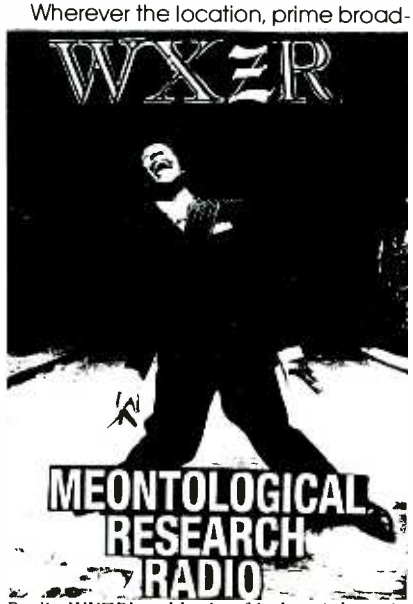
When the FCC agents finally caught up with WKND, Radio Animal allowed them into the basement of his home and gave a full tour of the studio. After the tour, the three sat down and discussed the programming and history of WKND. Then Radio Animal even issued the agents station-verification (QSL) cards! Although he would have been fined about $1,000, he was requested to pay only $500 due to his cooperation. The 1620- and 6240-kHz transmitters were taken by the agents to cover the other $500.

Radio USA has been widely heard since 1983 with a strange assortment of punk music, skits, and commentaries.

Tuning In. Although unlicensed broadcasting is illegal, listening to and reporting pirates is entirely within the law. For those living in the East or Midwest, logging an occasional pirate is simple. Only a decent general-coverage shortwave receiver and some patience is required. Western listeners may have more difficulty, since Zodiac Radio is presently the only station regularly active in that region.

Wherever the location, prime broadcasting times for pirates are weekends and holidays throughout the afternoon and evening hours. Typically, pirates operate in specific frequency bands, especially 7405–7425 kHz (see Table 1).

(Continued on page 112)



Radio WXZR's odd mix of industrial music and skits has been heard across much of North America.

TABLE 1—COMMON PIRATE FREQUENCY RANGES

1610-1630 kHz
6200-6325 kHz
6800-7000 kHz
7355-7530 kHz
15010-15100 kHz

TABLE 2—ACTIVE STATIONS AND THEIR ADDRESSES

Address	Station
C	East-Coast Pirate Radio
B	Hope Radio
A	KNBS
B	RFM
A	Radio Garbanzo
B	Radio Mexico
A	Radio USA
B	Samurai Radio
A	Secret Mountain Laboratory
C	Secret Society Radio
A	Voice of Laryngitis
B	Voice of Monotony
B	Voice of Stench
	WBRI
	WENJ
	WHBH
D	WJDI
A	WLAR
B	WXZR
A	Zodiac Radio

(A) P.O. Box 452, Wellsville, NY 14895
(B) P.O. Box 628, Slanesville, WV 25444
(C) P.O. Box 6527, Baltimore, MD 21219
(D) P.O. Box 142, Cottekill, NY 12419

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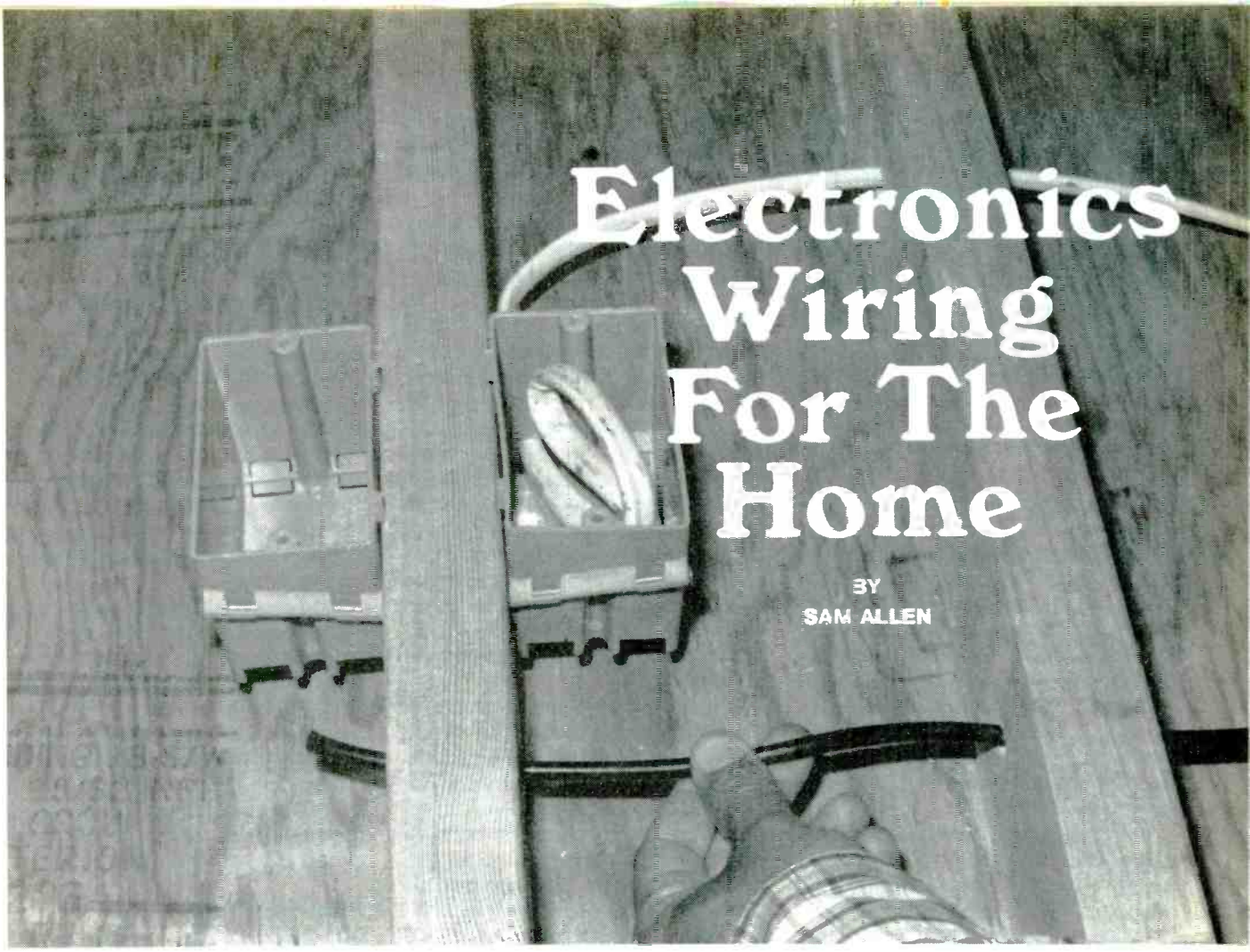

Electronics Wiring For The Home

BY
SAM ALLEN

Update your wiring for safety, and to make it easier to add new technologies to your household.

As an electronics hobbyist, you probably have installed wiring in your home for extension speakers, intercoms, antennas, or other electronic devices. Usually the wiring gets stapled to the baseboard or run under a carpet (a real "no-no" without the right cable) using any type of cable you have on hand. Next time you add some wiring to your home, you should consider doing a professional-quality job by following Code requirements and installing the wire in a way that will protect it and make it easy to make changes or additions. The investment in time could save you many, many hours in the future.

Code Requirements. All home-wiring standards are governed by the National Electrical Code (or by a local code that is usually based on the national code). If you follow the Code requirements, you will have a safe and effective wiring system.

The Code has been very lenient about low-voltage wiring in the past, simply stating that the wire should be "suitable" for the application. The 1987 National Electrical Code imposed restrictions on the types of cable that can be used and the 1990 Code expands upon the cable requirements.

The requirements are to ensure fire safety; the insulation of some cables is very flammable. Listed cables are rated for flame resistance and smoke production. For your own safety, you should use listed cables, although the Code allows for unlisted cables that are in an exposed location and are less than 10-feet long.

The Code is organized into a number of articles on various subjects. There are separate articles for audio, communication, remote-control, radio, television, CATV, and fiber-optic cables. In this discussion, I will give the National Electrical Code article numbers that apply to various types of electronics wiring so you can look up the complete requirements if you have a question. Most libraries will have a copy of the National Electrical Code and local codes in the reference section.

Limited-Power Circuits. A lot of electronics wiring fits into what the Code calls class-2 wiring, covered in Article 725. Class-2 wiring carries low voltage at limited amperage. Usually power is supplied from a transformer with a limited output. Dry-cell batteries can also be considered a limited-current source.

Generally, if the output of the device is less than 30 volts and the current is limited to less than 8 amps, you can use class-2 wiring. In certain applications, you can use class-2 wiring with voltages up to 150 volts when the current is limited to .005 amp or with power supplies that contain over-current protection circuitry. Consult the Code for further details on such circuits.

The Code requirements are lenient for class-2 wiring because the low voltage and limited amperage don't pres-

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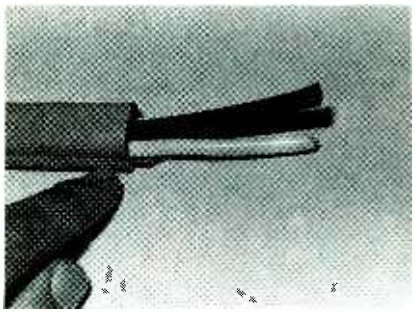


A surface raceway hides and protects electronics wiring. They provide a good way to add wiring to an existing building.

ent a fire or shock hazard. But there are a few requirements that you should always observe whenever you install class-2 wiring. First, class-2 wires should never be installed in an outlet or switch box that contains AC line-voltage wiring unless the box is designed with a barrier that separates the two systems. Second, never run class-2 wiring in the same conduit or raceway with AC line-voltage wiring, in fact keep class-2 wires at least 2 inches away from any other type of wiring in the home.

The Code makes a few exceptions to these rules; but in most cases, you're better off to just follow the rules, although sometimes you must take advantage of the exceptions. If you must attach a class-2 wire to a device that is powered by house current (a low-voltage control circuit to a relay for example), the Code will allow you to bring the class-2 wires into the same box solely for the purpose of making the connection. The wires must be separated by at least ¼ inch.

There is also an exception to the 2-inch separation rule: if either cable is enclosed in a raceway: If either cable is metal sheathed, metal clad, nonmetalic sheathed, or type-UF cable; if they are permanently separated by a porcelain tube, or in flexible tubing, then you can place them closer together. Today most homes are wired using nonmetallic-sheathed cable (Type NM, often referred to by the trade name *ROMEX*), and you can place class-2 cables closer than 2 inches to type NM cable. That would allow you to use the same hole in a stud for both NM cable and class-2 cable, but I prefer to drill separate holes anyway.

Cable used for class-2 wiring now must meet flame-resistance requirements. Cables that meet the requirement will be marked CL2 or CL2X. The latter is limited to use in one- or two-family dwellings.

Audio wiring is covered in Article 640. Most audio wiring is considered class-2, so you should follow the requirements given for class-2 cables.

The Code classifies telephone wiring, antenna lead-ins, and cable TV differently. Let's look at those next.

Telephone Wiring. Telephone wiring must now meet flame-resistance standards. Wiring that meets the standards will be marked CM or CMX. Type CM cables can only be used in one- or two-family dwellings. Telephone cables must be separated from full voltage wires as explained for class-2 wiring. In the past, splices and connections have been allowed anywhere, but the Code now recommends that they be made in a plastic or metal box. This is only a recommendation made in the Code, but it's a good idea to follow the advice anyway.

Telephone cables can be placed in the same conduit or box with class-2 cables, fiber-optic cables, and CATV cables, but not with AC line-voltage cables. The Code does make an exception for hybrid power/communications cabling that contain both house current and telephone cables in a single jacket. Those cables must be specifically listed for this application. Article 800 of the Code gives more details.

Receiving Antennas and Lead-Ins. Article 810 covers radio and television circuits. Cable TV is covered in article 820. On the outside of the building, lead-in wires must be positioned so that they cannot swing closer than 2 feet to wires carrying 250 volts or less and no closer than 10 feet to wires carrying more than 250 volts.

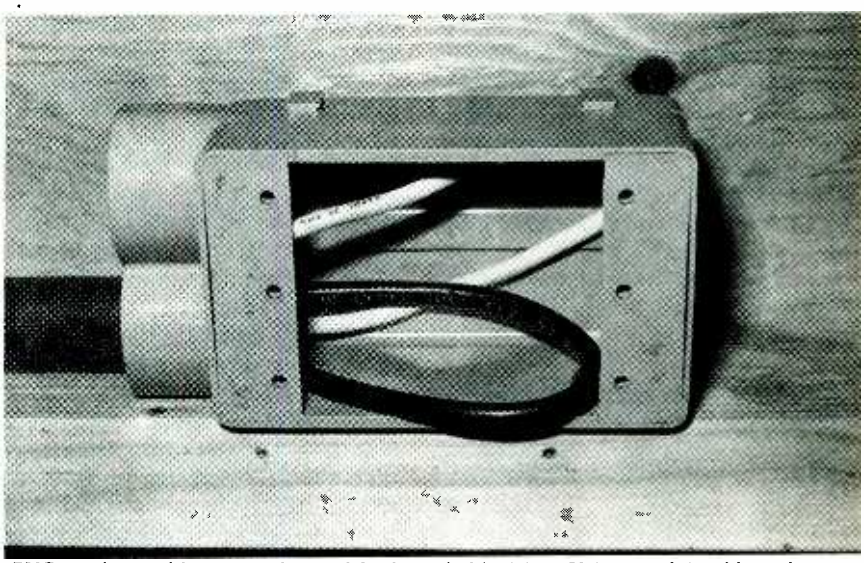
An important thing to know is that antenna masts should be grounded using wire that is not smaller than No. 10 copper, No. 8 aluminum, or No. 17 copper-clad steel or bronze.

A properly connected grounding terminal should be placed at the the point where the lead in enters the building. The grounding wire to it should run in a straight, direct path to the ground connection—usually a cold-water pipe.

Inside the building, the distribution wiring should not be placed closer than 2 inches to other wires. Further, antenna leads should not be placed in the same box with other wiring unless a barrier is installed in the box.

Coaxial cable used in cable-TV systems must be marked CATV on the outer jacket. Coax used for other purposes is usually listed CL2. Cable marked CATVX is allowed in one- or two-family dwellings. The outer shield must be grounded at the point the cable enters the building. Coaxial cable should not be placed closer than 2 inches to AC lines, but it can be run together with class-2 or telephone wiring.

Fiber-Optic Cables. Fiber-optic cables are becoming more prevalent all the time. Article 770 of the Code lists requirements for optical cables. The cables must be listed for flame resistance and marked OFC or OFN. There are three types of fiber-optic cables: Non-conductive cables (OFN) have no conductive material in them; conductive cables (OFC) have noncurrent-carrying conductive material added



PVC conduit and boxes can be used for household wiring. Using conduit adds to the construction cost, but it makes it easy to make changes or additions later.

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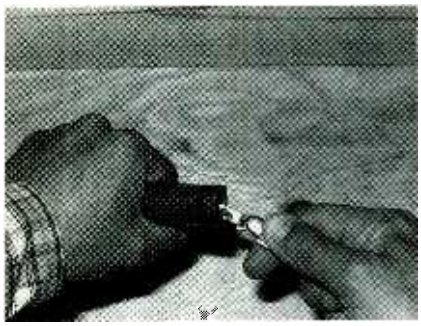


Remove the rough edges left on the conduit before you apply the glue. A small knife can be used for this job.

for strength or as a vapor barrier; and hybrid cables combine current-carrying conductors and optical fibers in the same cable. Hybrid cables are classified as electrical cables and must meet the requirements set for the conductors they contain; the other two types are not considered electrical cables, but they still must follow certain provisions of the Code.

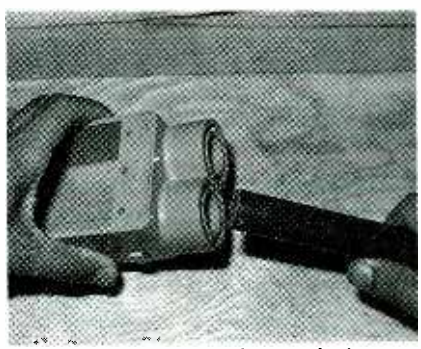
Non-conductive cables may be placed in the same raceway or cable tray with power cable of 600 volts or less, but conductive cables are not allowed in the same cable tray or raceway with power cables. Fiber-optic cables are not allowed in the same box as power circuits unless the function is directly associated with the circuit. But fiber-optic cables can be run together with class-2 cable, telephone cables, and CATV cable. The conductive materials in type OFC cable should be grounded.

Hierarchy of Cables. In addition to the types of cables already covered, there are multipurpose (MP), riser, and plenum cables. A riser is a vertical shaft inside a building that is used for distributing wiring and other utilities to various floors in a building. Riser cable must be more flame resistant than other types. Cable suitable for use in risers will have an R at the end of the cable marking. For example, communications cable for use in a riser will be marked CMR.

Plenum cable is used when the cable is run inside heating or air-conditioning duct work. Those cables must meet stricter standards for flame resistance and smoke production. Plenum cables will have P at the end of the cable marking. CMP for example would indicate communications cable that can be run in air-handling ducts.

You can always substitute a cable with better ratings for a lower grade cable, but not the other way around. That can reduce your inventory of cables. At the top of the hierarchy is multipurpose plenum cable (MPP). It can be substituted for any type of communication or class-2 cable. At the bottom of the hierarchy is type CL2X. That cable cannot be used for any purpose besides class-2 wiring in one- or two- family dwellings.

Table 1 shows the hierarchy of multipurpose, communications and class-2 cables. Cable substitution can be determined by using the chart: A cable can be used in place of any other cable that is to the right of it on the same row, below it in the same column, or to the right and below it. Starting at the top left of the chart, the first cable listed (MPP) can be used in place of any cable on the chart. Type CM can be used in place of CL2 because CL2 is in the same row to the right. It can also be



The conduit slips into a hole in the box. Follow the directions on the glue can when you apply the glue.

used in place of CMX, because it is in the same column but below it; and it can replace CL2X because it is below and to the right.

CATV and fiber-optic cables also come in plenum and riser types. The hierarchy of these types is listed in Tables 2 and 3, respectively. Read from the top down, a cable may be used as a substitute for any listed below, but not for those listed above it on the chart. Also, non-conductive cable can be substituted for conductive cable.

Installation Tips. If you have ever fished wires through a wall you have probably wished that homes were designed to make the job easier. Even if you wire a home wisely during construction, it is hard to plan for new technologies.

The normal practice when wiring a home for electronics is to staple wires to studs before the interior walls are covered; this method is fast and inexpensive but makes it hard to add wiring later. I have found that it is worth the extra time and expense to use conduit for electronics wiring, because you can easily slide in new wires at any time (we'll get into how to do that later).

If that is out of the question next time you make additions to the wiring in an existing structure, you can still fish wires through the walls or staple them to base boards, but be sure to use the proper cable. If you need to run cable under a carpet, only use type CMUC.

For a nice installation that allows for later expansion or cable replacement, use a plastic or metal raceway attached to the baseboard. A raceway protects and hides the cable. You can make later changes by pushing in new cable when necessary. Most electrical supply houses will carry this type of raceway and associated fittings.

If you are fortunate enough to be in the early stages of planning a new home, start thinking about wiring for any electronic systems you can anticipate. Make a list of all of them. The list might include: a TV-signal distribution system, telephone lines, intercoms, stereo extension speakers, computer cables, alarms, or remote-control circuits. Although your list will include all that you might want to install, keep in mind that new technologies will be developed after you finish the house.

It's a good idea to discuss your plans with your architect or contractor at this stage. He may have suggestions that will make the installation easier. Before the final plans are drawn, get a rough version of the floor plan of the house and mark the location of all of the

TABLE 1—CABLE HIERARCHY

MPP	CMP	CL2P
MPR	CMR	CL2R
MP	CM	CL2
	CMX	CL2X

TABLE 2—HIERARCHY OF CATV CABLES

CATVP
CATVR
CATV
CATVX

TABLE 3—HIERARCHY OF FIBER-OPTIC CABLES

Non-Conductive	Conductive
OFNP	OFCP
OFNR	OFCR
OFN	OFC

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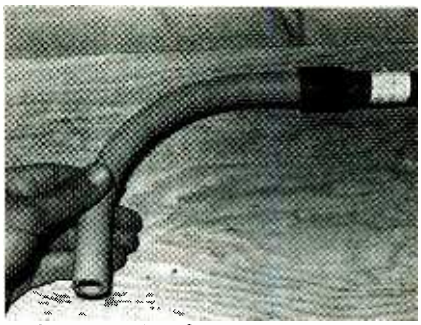
things you know you want; that way you can place a wiring box at the exact location. Now start thinking about system expansion. As a minimum, I would recommend a wiring box on each wall of each room likely to need electronics in the future. Rooms that you don't think will need wiring should have at least one box to allow for unexpected developments. I would also recommend several weatherproof boxes on the outside of the house.

In many cases you need a power outlet near the location of the main electrical box; for example, a central TV amplifier needs a power outlet and an antenna connection. Mark the location of these power outlets on the floor plan so your architect can draw them in on the electrical plan.

When you are wiring a new building, you'll have access to the interior of the walls and floors so you can hide the wiring inside the walls. You can run the cables through holes drilled in the studs and joists or staple them along the side of studs; keep the cables at least 2 inches from the finished surface of the wall so that misguided nails driven through the studs won't damage the cable. Use plastic or metal boxes at cable terminations.

For the ultimate in wiring, use conduit. PVC conduit is easy to work with so the job can be a do-it-yourself project. The main idea is to get the wires through the walls and into an area that is easily accessible. If you have an unfinished basement or attic, you can run conduit from a box in the wall to the unfinished area, and back up to where you need it. If the basement will be finished, run the conduit to a central location where you can mount a distribution panel.

When it comes time to choose a contractor, talk with him about your plans; if you want to do the work yourself, be sure to work out the details with him. You will need to be prepared to do the work quickly when needed so you won't hold up other subcontractors. Most of your work must be done after the rough electrical work, but before the interior walls are covered. If you plan ahead and have the materials on hand, you can do the work in one or two days. If it is possible to buy the cable, conduit, and boxes through the electrical subcontractor, you will probably be able to get a better price than you can at a retail outlet. You will need to provide him with a complete list of the supplies needed. If you prefer, you can have the work done by the electrical contractor.



A factory-made 90° bend eliminates the need for a conduit bender. Just cut the conduit to length and glue the parts together.

Distribution Panel. The distribution panel needs to be centrally located. A closet or utility room is an ideal location. If there isn't a closet, build a box with a door to enclose the panel. Have the electrician install a power outlet nearby.

After the drywall or plaster is finished, attach a piece of plywood to the wall. This will give you a firm mounting for any equipment installed on the panel.

PVC Conduit. If you choose to run conduit from the distribution panel to the wall boxes, you can use EMT or PVC conduit. EMT is metal thin-wall conduit; it takes experience and special bending tools to do a good job with EMT. PVC conduit is probably easier for the do-it-yourself installer because you simply cut it to length with a hack saw and glue it into special fittings. Conduit is available in several sizes. Choose a size large enough to allow for additional wires later. You will need PVC wall boxes, fittings, and a can of PVC cement.

Begin at the box location. Drill a hole through the sole plate of the wall into the space between the joists below. Next cut a short length of conduit using a hacksaw. Use a knife to remove the rough edges left by the saw. The piece needs to be long enough to reach from the bottom of the box through the floor with an inch or two extra. Using the applicator attached to the lid of the cement can, wipe some cement inside the fitting on the box and around the outside of the conduit end. Push the conduit into the box with a slight twisting motion, then hold it in place for a few seconds as the cement grabs.

Now slip the free end of the conduit through the hole in the sole plate. Mount the box to a stud. Since you should be doing your work after the electrician has done the "rough in" (the basic wiring required in your house) you can measure the height of the boxes that are installed in the house to make sure yours match. Also notice how far the electrician has extended the front of the box past the edge of the stud. That distance will vary depending on the type of wall covering that will be installed.

Most of the boxes will be close to floor level, but a box for a wall phone, an intercom, or light switch should be placed at a convenient height higher on the wall. Boxes for extension speakers may be placed close to the ceiling.

If the house has a second story, you can run a length of conduit out the top of the distribution box to a box directly above on the next floor. Keeping the conduit runs straight and short simplifies installation and makes it easier to push the wires in.

Install all of the boxes, then move to the basement. Boxes in basement walls should have the conduit run out of the top and into the space between the joists above. When all of the boxes are installed, you can make the conduit runs to the distribution panel. Keep the runs as straight as possible and run them alongside a joist. You won't need to do any drilling unless there is some solid bracing in the way. Glue a 90° fitting to the stub of conduit that extends through the floor from the box. Then glue in a section of conduit running toward the distribution panel.

If a run is too long, you will need to glue several lengths together using couplings. Cut the last piece to length before gluing it to the coupling. Use PVC straps to attach the conduit to the joists. When the conduit needs to run across at a 90° angle to the joists, you can attach the conduit to the bottom of the joists. That is easier than drilling through the joists. Group all of the conduits together and run them next to a wall or support beam; that will make it easier for the carpenters to box over and conceal the conduit run.

Antenna Mast. A provision for an outside antenna is a nice feature to add to the system. Use 1-¼-inch EMT thin-wall metal conduit for that. It is one job that should be done early in the framing of the house, as soon as the decking for the roof is on but before the roofers come.

Choose a location for the antenna that is directly above a wall and close to the distribution panel. Drill a hole through the sole plate of the wall and

(Continued on page 112)

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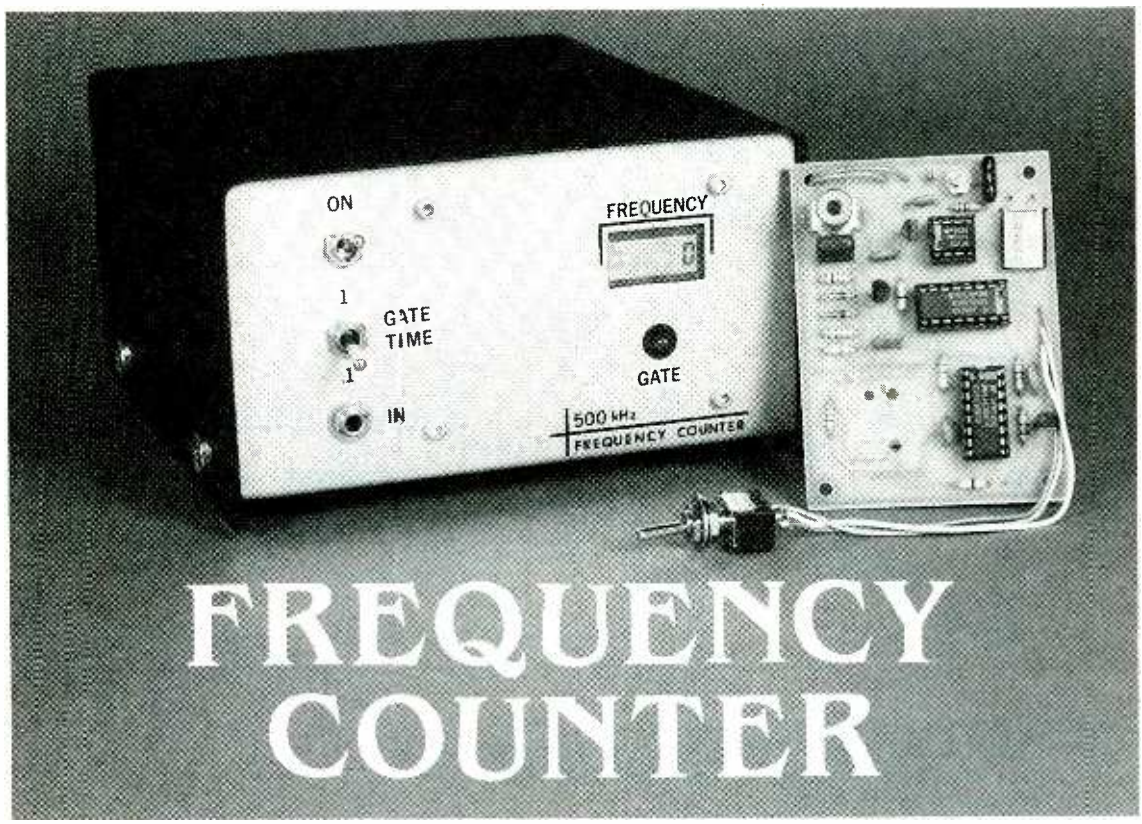
Super Simple



FREQUENCY COUNTER

If you work with digital circuits, you know how aggravating it can be to check for timing signals without a frequency counter. Don't you think it's about time you added one to your test bench?

BY STEVEN J. STRONCZEK,
WA9IDZ

A frequency counter is a useful tool for troubleshooting, aligning, or evaluating various electronic equipment or projects. However, for the average hobbyist, the commercially available units may be priced beyond reach. But, for under $40. (or less with studious shopping), you can build this *Super-Simple Frequency Counter* for a mere fraction of the cost of commercially available equipment.

With an upper-frequency limit of 500 kHz (shown on a 6-digit display in hertz), the Super-Simple Frequency Counter has very good accuracy. On the lower end of the scale, the counter will display as little 1 Hz with reasonable accuracy. The counter may be used as a stand-alone test instrument or incorporated into some existing or future project to provide an accurate frequency readout.

If the range of the counter in its present form is not wide enough for you, you can always add a prescaler (essentially a frequency divider) to its front end, thereby widening the range of frequencies that can be measured by the circuit. Prescalers are available in DIP IC form, in versions designed for frequencies that extend into the gigahertz region. Such circuits usually require some sort of pre-conditioning circuitry (often buffers and/or amplifiers).

The printed-circuit board for the counter measures a scant 2¼ by 3 inches, so it will easily fit into the enclosure of existing projects. The project can be incorporated into gear such as wide-range audio oscillators or function generators; or it may be used to set an RF signal generator to a 455 kHz IF.

The counter's input sensitivity is on the order of several hundred millivolts, but it will accept peak-to-peak voltages as high as 20 volts. Voltages higher than that may also be measured by feeding the input signal across a resistor divider network to reduce the input signal voltage to within the operating range of the counter. Conversely, if greater input sensitivity is needed an amplifier may be added to the front-end of the counter to give a little boost to the signal.

Circuit Description. Figure 1 is a schematic diagram of the Super-Simple Frequency Counter. At the heart of the unit is MOD1, a Red Lion Sub Cub series component counter that has a built-in 6-digit LCD display and all the necessary driver circuitry to operate the display. The Sub Cub is supplied in two versions with .2- or .35-inch digits designated Sub Cub I or Sub Cub II, respectively. The counter is packaged in a clear plastic housing with elastomeric contacts for connection to the outside world. The component's housing snaps

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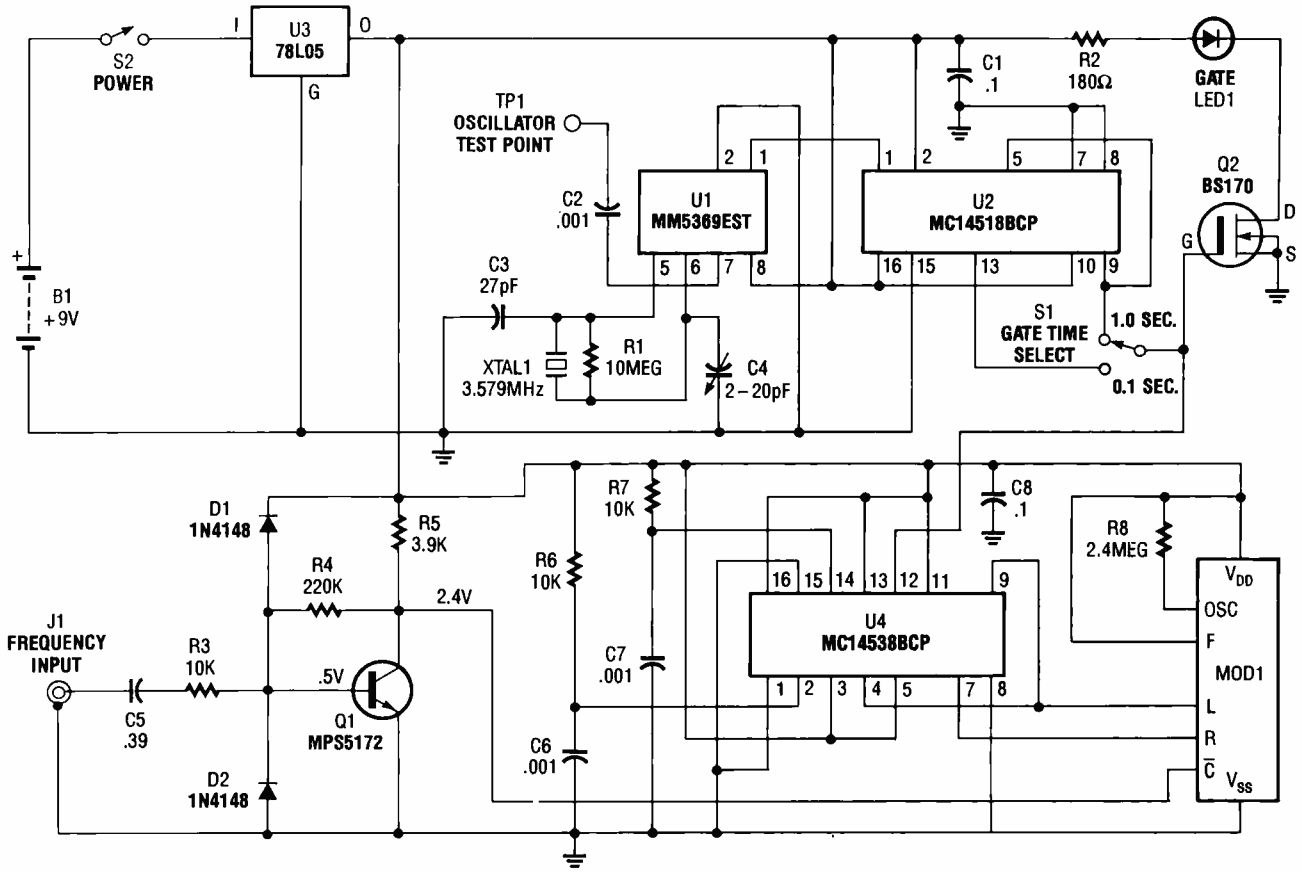

Fig. 1. The Super-Simple Frequency Counter is built a around three IC's—an MM5369EST/N 17-stage oscillator/divider (U1), an MC14518B dual synchronous up counter (U2), and an MC14538BCP dual precision monostable multivibrator (U4)—and a Red Lion Sub Cub 1, counter module (MOD1).

onto the foil side of a PC board, where the connectors contact the PC-board foil.

In any frequency-measuring application, an accurate standard or time base must be provided for a measurement comparison. The time base used in the Super-Simple Frequency Counter is provided by a quartz crystal and an MM5369EST/N 17-stage oscillator/divider. (When collecting the parts for the project be sure to specify the MM5369-EST/N version, which has a 100-Hz output. The MM5369-AA/N version has 60-Hz output and will cause an incorrect frequency display.)

The MM5369EST/N contains an oscillator and a frequency-divider chain, which divides the oscillator signal to provide a square-wave reference signal. A 3.579-MHz crystal is used to stabilize the oscillator frequency. The oscillator's output is internally divided (by almost 35,800) to obtain a 100-Hz output. It is interesting to note that any error in oscillator frequency is also divided by the same factor resulting in an accurate time-base frequency. For example, even if the oscillator was 1 kHz off frequency, the time-base output would be off by less than .03 Hz—since it is possible to obtain oscillator accuracies to within tens of hertz or closer, a very accurate time base results.

The 100-Hz time-base signal is applied to the input of U2, an MC14518B dual synchronous up-counter. Each counter in that IC package is configured to divide by ten. Dividing the 100-Hz signal by 10, produces a 10-pulse-per-second time base; further division of the signal (by the second counter in U2) produces a 1-pulse-per-second time base. Those gate times are selectable via the GATE TIME switch, S1.

The selected gate time is fed to U4, an MC14538BCP dual precision monostable multivibrator, each monostable being governed by the RC networks, consisting of R6/C6 and R7/C7, connected to pins 2 and 14, respectively. The values specified for those components have been chosen to provide output pulses that are short in time with respect to the time-base pulses applied to the input of the one-shots. The outputs of U4 are applied to the L and R inputs of MOD1, as a timing gate.

The gate opens at the beginning of the time-base period, allowing MOD1 to accumulate the input pulses. At the end of the timing period, the gate closes, MOD1 then latches, resets, and displays the accumulated pulses. The counter module, MOD1, requires a backplane oscillator to function. The backplane oscillator is internal to MOD1 and requires only a single timing resistor (R8).

The signal to be read is first buffered by transistor Q1. The buffer stage is used to protect MOD1 from static charges and high-voltage input signals, and the moderate gain provided by the buffer increases input sensitivity. The buffer along with a pair of 1N4148 general-purpose diodes connected across the input are used to protect the MOS IC's from static discharge.

A visual indication of the measurement gate time is provided by LED1. When the gate LED blinks, it indicates that the frequency display has been updated. That's useful when measuring slowly changing frequencies. The GATE indicator (LED1) is driven by VMOS transistor, Q2, by connecting its gate directly to the time-base output. A VMOS transistor is a physical variation of the MOSFET die and is used due to its high

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PARTS LIST FOR THE SUPER-SIMPLE FREQUENCY COUNTER

SEMICONDUCTORS

U1—MM5369EST/N 17-stage oscillator/divider (100 Hz out)
U2—MC14518BCP dual up-counter, integrated circuit
U3—78L05 low-power 5-volt regulator, integrated circuit
U4—MC14538 BCP dual precision monostable multvibrator, integrated circuit
MOD1—Red Lion Sub Cub I, counter module
Q1—MPS5172 NPN silicon transistor
Q2—BS170 N-channel VMOS transistor
D1, D2—1N4148 general-purpose, small-signal, silicon diode
LED1—Jumbo red light-emitting diode

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1—10-megohm
R2—180-ohm
R3, R6, R7—10,000-ohm
R4—220,000-ohm
R5—3900-ohm
R8—2.4-megohm

CAPACITORS

C1, C8—0.1-μF, ceramic-disc
C2, C6, C7—0.001-μF, ceramic-disc
C3—27-pF, NPO, ceramic-disc
C4—2–20-pF, trimmer
C5—0.39-μF, ceramic-disc

ADDITIONAL PARTS AND MATERIALS

S1, S2—Single-pole, double-throw, toggle switch
Printed-circuit materials, enclosure, phone jack and mating plug, battery(s), battery holder and connector, wire, solder, hardware, etc.

Note: The following parts for the Super-Simple Frequency Counter are available from SHF Microwave Components (7102 West 500 South, Laporte, IN 46350): etched, predrilled printed-circuit board (part FC-PCB) for $7.50; a kit of parts, including printed-circuit board and all parts (except enclosure, battery holder, power switch, phone jack and plug) for $43.50. All prices include shipping within the continental U.S. Indiana residents must include appropriate sales tax.

input resistance coupled with its ability to sink high output currents.

Power for the circuit is provided by feeding a 9-volt battery source through U3, an MC78L05 3-terminal 5-volt regulator, to provide a regulated +5-volt DC power source. If power consumption is a factor in your application, LED1 along with R2 and Q2, may be omitted, thereby reducing current consumption to less than 5 mA.

Assembly. The author's printed-circuit pattern for the Super-Simple Frequency Counter is shown in Fig. 2. As mentioned earlier, there are two versions of the counter module. The pattern in Fig. 2 is designed for the Sub Cub I module. For those etching their own printed-circuit boards, 1/16-inch thick printed-circuit board material recommended. If you choose not to etch your own board, one may be purchased from the supplier listed in the Parts List.

For those making their own printed-circuit board, when drilling the mounting holes for the counter module, be sure to use the correct size drill bits. The polarizing hole requires a number 42 (.093 inch) or 3/32-inch drill bit. The two mounting holes require a number 31 drill size (.120 inch). Use of a 1/8-inch (.125) drill bit may make the hole too large and the counter will not stay put after being snapped in place.

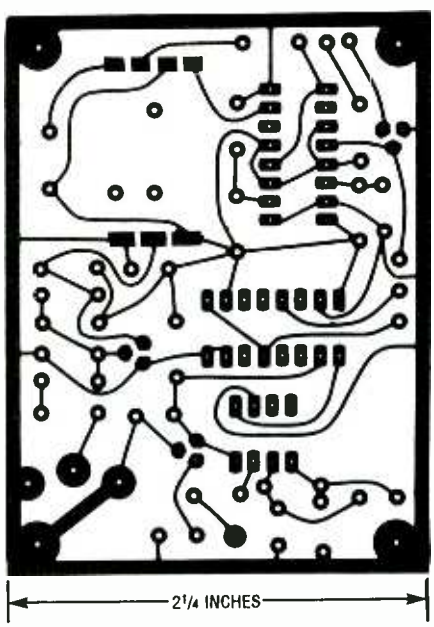

Fig. 2. The author's prototype of the counter was built on a small printed-circuit board, the template for which is shown here.

Once you've obtained the parts and the printed-circuit board, construction can begin. Start by installing the two jumper connections (as shown in Fig. 3), followed by the passive components (resistors and capacitors), followed by the semiconductors. IC sockets are recommended for all of the IC's.

Note that counter module MOD1 and LED1 (which are shown with dashed lines) are not mounted to the component side of the board. MOD1 is snapped into position, with its elastomeric connectors making electrical contact to the pads on the foil side of the board.

It is a good idea to observe the necessary precautions regarding static discharge when installing the IC's, including the counter module. The VMOS transistor, Q2, is also a static-sensitive component. Static stations with wrist straps and earth grounds are usually the exception rather than the rule in most home workshops. A method that has been successfully and effectively used is to mount static-sensitive components last with the board on a sheet of aluminum foil. Place the PC board, soldering station, tools, and the components on the foil before removing the components from their conductive foam or tube packaging.

Then while resting at least some part of your hand or arm on the foil, the components may be picked up and removed from their protective packaging and placed on the foil with their leads contacting the conductive surface. The board may then be handled and the components installed. If you have a soldering station that has a grounding point, it too may be attached to the foil with a clip lead. If you have a soldering iron in a stand, simply place it in a convenient spot on the foil before starting assembly.

The author used a miniature phone jack for J1, but any suitable jack can be used. The jack can be of the printed-circuit or panel-mounted type, depending on your application. An extra pad (marked with an asterisk) is provided for terminals of the printed-circuit type.

If the jack is to be remotely located, use a short piece of miniature coaxial cable to connect J1 to the printed-circuit board. The coaxial cable shielding is soldered to the grounded lug of the phone jack. A convenient length of similar coaxial cable is used to make the test lead, using a mating phono plug. A couple of alligator clips or miniature hook connectors can then be attached to the other end of the coaxial test lead.

The circuit can be housed in any type of enclosure of your own choosing. The author's unit was housed in a metal enclosure, measuring 3 by 5⅞ by 5¼ inches. Prepare the enclosure by mak-

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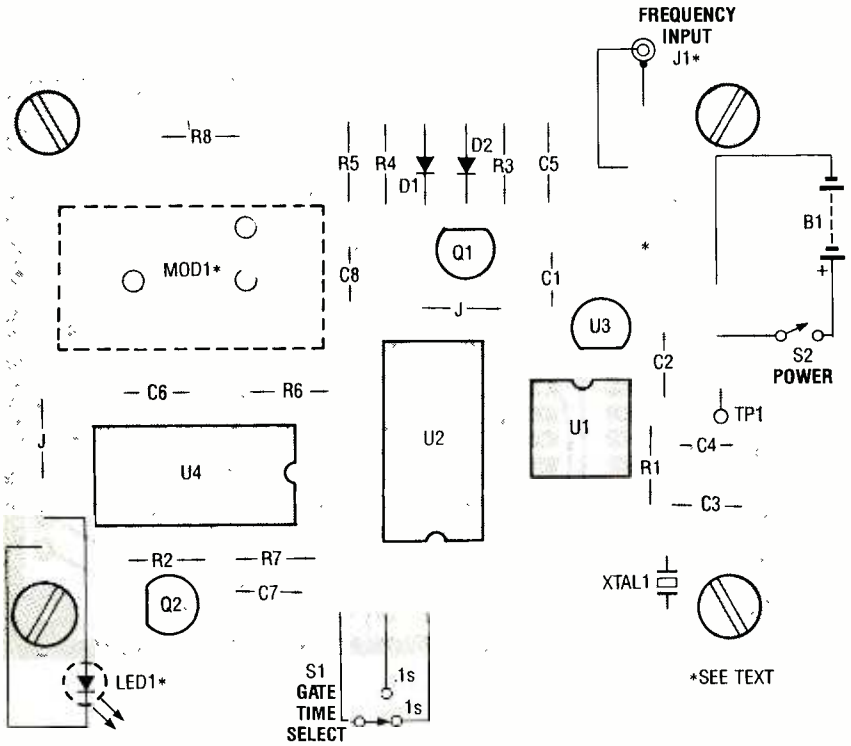
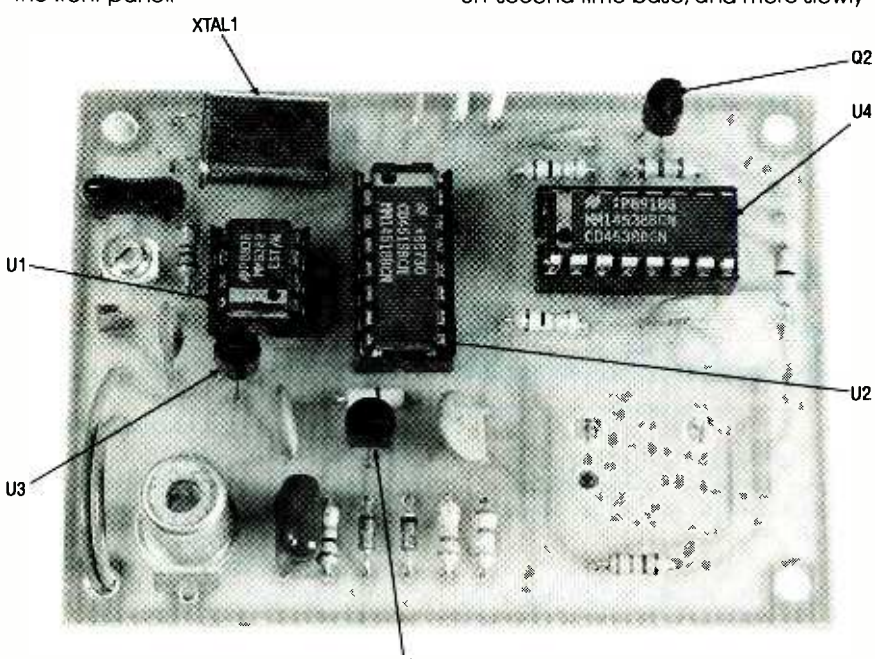


Fig. 3. Here is a parts-placement diagram corresponding to the foil pattern shown in Fig. 2. Mounting the components to the board is straightforward, but be aware that LED1 and the counter module (which are indicated by the dashed lines) are mounted on the foil side of the board.

ing a cutout in the front panel for the display, and drilling 4 holes for the input jack, the two switches, and the LED indicator. Labels can then be added to the front panel.

When the assembly is complete, apply power to the counter. The GATE indicator (LED1) should blink in step with the time base selected (rapidly for the 0.1-second time base, and more slowly for the 1-second time base). The counter circuit should draw no more than about 25 mA when the gate LED is illuminated (assuming that you've included it in your circuit). The gate-time switch is used to select the amount of time the counter accumulates input pulses to be counted and displayed. With the switch in the 1-second position, the counter will have the highest accuracy and display the frequency measured to the nearest cycle. With the switch in the 0.1-second position, the counter will display the frequency measured to the nearest ten cycles. The one tenth position will also provide the fastest measurement update, which is useful when measuring a rapidly changing frequency.



Note that the counter module (MOD1) and LED are conspicuously absent from the component side of the board; those components are mounted to the foil side. The counter module is simply snapped into position, with electrical contact being made through its elastomeric connectors. The LED, on the other hand, is simply tack-soldered to the foil side of the board.

Calibration. There are several methods that will produce varying degrees of accuracy when calibrating the reference oscillator. The first and best method is to use a frequency counter of known accuracy. Connect the counter input to the oscillator test point (TP1). The trimmer capacitor, C4, is then adjusted for exactly 3,579,545 Hz at TP1. If a counter is not available, the 60-Hz line frequency may be used to check the counter's operation. A small power transformer with a 5- to 10-volt secondary is used to obtain the 60-Hz line frequency sample. Connect the transformer secondary to the counter input, J1. Set the oscillator trimmer to the center of its range.

With a one second gate time, the counter display should indicate 60 Hz. Accurate calibration of the counter is not possible using a relatively low-frequency such as 60 Hz. It is possible to verify that the counter is operating correctly and that the displayed frequency is reasonably close. An alternate calibration method would be to use an accurate shortwave or ham receiver that tunes the 80 meter (3.5 MHz) band.

The receiver should have a digital frequency readout. Set the receiver to receive 3.5795 MHz and turn the BFO on. The frequency counter's time-base oscillator may be heard in the receiver speaker as the oscillator trimmer, C4, is adjusted through its range. Set trimmer C4 for zero beat in the receiver's speaker.

It may be necessary to use a piece of wire as an antenna for the receiver. One end of the wire should be connected to the receiver antenna terminal and the other end placed near the

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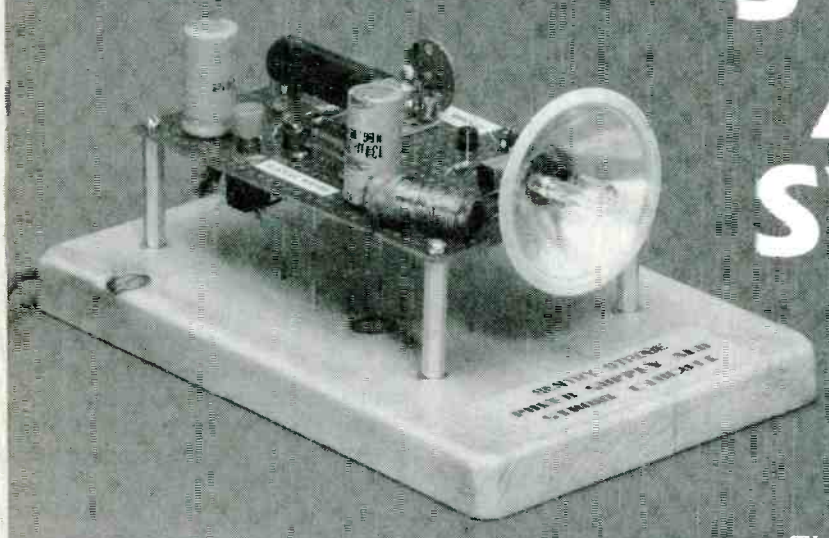
THE SENTRY STROBE ALERT SYSTEM

BY ANTHONY CHARLTON



This strobe circuit does more than just flash; it can be used to call your attention to a ringing phone, entry into a secured area, temperature conditions, and more!

For some metaphysical reason, the phone seems to ring most often when a person is a dozen or so steps away getting groceries out of the car, weeding the vegetable garden, or in the shop running a power saw. Sometimes you hear the phone ringing—then comes the mad dash as you race to answer before the caller hangs up. Similarly, if I had a quarter for every TV dinner that has burnt while I was engaged in some project in the workshop, I would certainly be a rich man!

I've always wanted a gizmo to attach to an appliance or the telephone to let me know it needs attention. One of those loud, startling bells was out of the question, and besides, they're ineffective if noisy equipment is operating. The *SentryStrobe* presented in this article was developed as an answer to that need. A Xenon lamp is used to produce eye-catching flashes, offering a silent but highly effective visual indicator.

The unit may be placed anywhere; inside the house (such as in a noisy garage workshop), in an industrial work area (such as a machine shop), or out-of-doors. People with hearing impairments will find the SentryStrobe a real boon too, as it can offer the security of not missing important alerts.

You can even turn the project into a burglar alarm that will scare the daylights out of any thief! The strobe can be configured to respond to virtually any type of sensor. Later we'll show you how to adapt the circuit to various types of sensor inputs, but first let's explain how the strobe, and its power supply circuit operates.

How It Works. Figure 1 is a schematic diagram of the SentryStrobe. The circuit is activated by a special device called an LED/photoresistor isolator (U1), which is a combination of a light-dependent resistor (LDR) and LED in a single package. That device was chosen because of its high isolation (2000 volts) characteristic, which is necessary because the strobe part of the circuit is directly connected to the AC line.

A voltage divider is formed by R2, U1's internal resistance, and R3. When U1's internal LED is off, U1's internal LDR has a very high resistance—on the order of 10 megohms. The output voltage of the divider under that condition is

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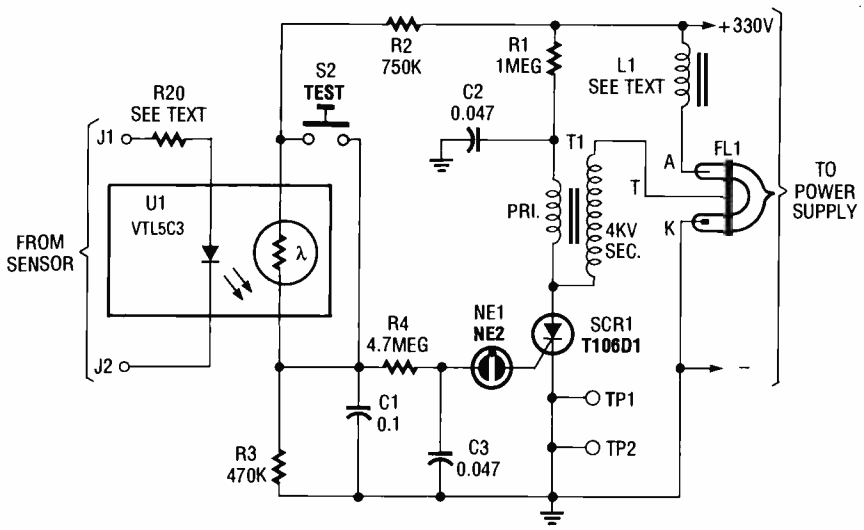

Fig. 1. The SentryStrobe is built around a trigger transformer, a Xenon flash lamp, an SCR, and a neon lamp (which is used to trigger the SCR). A VTL5C3 optoisolator/coupler accepts trigger inputs from an external signal source to fire the strobe circuit.

very low. Thus, the voltage applied to NE1 is considerably below its ignition voltage of approximately 90 volts DC.

The optoisolator's internal LED is activated by a DC signal supplying 20 mA. The external sensor(s) that supply the signal are connected to the strobe part of the circuit at J1 and J2. The resistance at J1, R20, limits the current through U1's internal LED to a maximum of .20 mA. That resistance varies in value with different sensor types.

When the internal LED lights, the LDR's resistance decreases to around 5k. Under that condition, about 125 volts DC is applied across C1, R4, and C2—more than enough to ignite NE1. The neon lamp periodically fires and extinguishes as capacitor C3 charges through R4, and discharges via NE1 and the SCR gate. (What we have here is a "relaxation oscillator," which is one of the simplest oscillators around.) Resistor R4 restricts the current input to C3, and thereby controls the firing rate of NE1—about three times per second. The discharge through NE1 is applied to the gate of SCR1.

SCR1, a sensitive-gate unit, snaps on immediately when NE1 conducts, which completes the ground circuit for transformer T1 (a 4-kV trigger transformer). As SCR1 toggles on and off in time with the firing of NE1, capacitor C2 (connected in parallel with T1's primary) charges via R1, and then discharges very rapidly through T1's primary winding. The on/off action of SCR1 generates a rising and collapsing field about T1's primary winding, which induces a 4-kV pulse in its secondary winding. That voltage pulse is applied to the trigger input of FL1, a Xenon flashlamp, ionizing the xenon gas inside, and rendering it highly conductive to current flow.

In order to ignite a Xenon flashlamp, you need to meet two conditions. First, the Xenon gas must be ionized (which is accomplished via the circuit in Fig. 1). Next, there must be a large capacitor to store energy at a high enough voltage to sustain the arc inside the flashlamp after it is triggered. A power supply is also needed to charge that capacitor. The circuit at Fig. 2 provides that function with a minimum of parts.

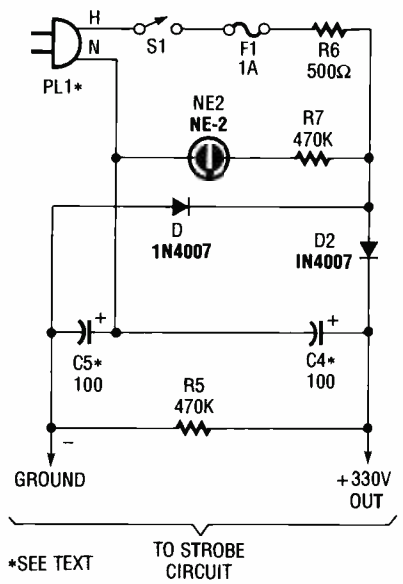

Fig. 2. The power supply for the SentryStrobe is a simple voltage doubler/rectifier circuit, which provides 330 volts DC to the primary winding of the trigger transformer in the strobe circuit.

PARTS LIST FOR THE SENTRYSTROBE

SEMICONDUCTORS

U1—VTL5C3 Vactrol photocoupler, (EG&G Vactec) integrated circuit
SCR1—T106D1 4-amp, 400-PIV, sensitive-gate, silicon-controlled rectifier
D1, D2—1N4007 1-amp, 1000-PIV, general-purpose rectifier diode

RESISTORS

(All fixed resistors are ¼-watt, 5% units, unless otherwise noted.)
R1—1-megohm
R2—750,000-ohm
R3—470,000-ohm
R4—4.7-megohm
R5—470,000-ohm, ½-watt
R6—500-ohm, 25-watt, power resistor
R7—470,000-ohm, ½ watt
R20—see text

CAPACITORS

C1—0.1-µF, 250-WVDC polyester
C2—0.047-µF, 400-WVDC polyester
C3—0.047-µF, 250-WVDC polyester
C4, C5—100-µF, 250-WVDC electrolytic

ADDITIONAL PARTS AND MATERIALS

L1—See text
F1—1-amp fuse
FL1—Xenon flashlamp, U-shaped, 45 W/s
NE1, NE2—NE-2 neon lamp
S1—SPST snap switch
S2—SPST normally-open pushbutton switch
T1—4-kV trigger transformer
Perfboard materials, non-conducting enclosure, AC molded power plug with line cord, optional reflector, wire, solder, hardware, etc.

It is important to remember that the circuit is connected directly to the AC line. Resistor R6 is included in the circuit of Fig. 2 to limit the amount of line current available to the circuit. The value of R6 may be decreased if you intend to modify the circuit for more flash power. **Warning:** Even though the circuit is fuse-protected, the circuit can still be dangerous if handled carelessly.

When the AC line voltage is applied to the circuit in Fig. 2, it is stepped-up (about 2.8 times) by a voltage-doubler circuit consisting of D1, D2, C4, and C5. Diodes D1 and D2 (in addition to their other duties) rectify the incoming AC line voltage, which is then stored as DC in the two large capacitors (C4 and C5), and provides an output of about 330 volts DC, which is an ideal voltage level to ignite the flashlamp.

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Note that a second neon lamp, NE2, is included in the circuit as a safety feature, and is there to remind you when the unit is plugged in and full AC line voltage is present.

Flashlamp FL1's luminescence is directly related to the total capacitance and voltage rating across it. Since C4 and C5 are identical units and are connected in series, their combined capacity is one-half the value of either unit, while the voltage across both is doubled. Be sure to use exactly the same size and type capacitor for each. And it is a good idea to test each part for its actual value, rather than rely on its specification. Do not to use those that differ by more than ±20%.

To determine the flashlamp's output in watt/seconds (W/s), use:

$$W/s = .5\ (C \times V^2)$$

where C is the total capacitance across FL1 in microfarads and V is the voltage across FL1 in kilovolts (kV). Thus, plugging in 50 μF for C and with 330 volts across the lamp, you get about 2.5 W/s of output. In practice, the actual light output is somewhat less; that's because the lamp flashes quickly in this design, which does not allow the capacitors to charge fully between flashes. Remember the SentryStrobe is designed primarily for intermittent operation, and the lamp should not run until it's super heated, or its life expectancy will be diminished.

If the lamp gets too hot, increase the value of R4 to 10 megohms to reduce the flash rate. Alternately, you can either reduce the capacitance of C4 and C5, or use a lamp with a higher W/s rating. Note that decreasing the values of C4 and C5 will have no effect on the circuit other than its light output.

It is interesting to note that FL1 consumes all the energy in the two capacitors in about 1/10000th of a second. For that brief interval, FL1 is as bright as a 35,000 watt lamp! That extreme brightness makes the lamp easy to see, especially on overcast days or at night.

Your application will determine the amount of light needed, as well as the required duty cycle of the lamp. For instance, if the project is used in place of a telephone-ring detector, it likely will flash only a few seconds at a time and not have a chance to overheat. If it is used as a thunderstorm alert, it may have to flash much more brightly and for longer periods at a time. In the latter case, the component and power supply ratings will have to be beefed up.

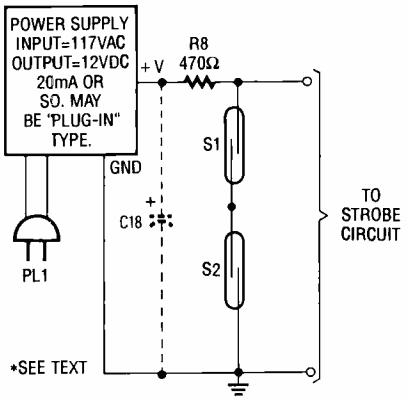

Fig. 3. The SentryStrobe can easily be configured as a burglar-alarm by connecting the appropriate sensor/power supply combination to the input of the strobe circuit. A closed-loop circuit, consisting of a couple of magnetic reed switches and its own power supply (like that shown here) can be used to monitor specific areas of your home or the entire house.

PARTS LIST FOR THE INTRUDER DETECTOR

R8—470-ohm ¼-watt, 5% resistor
R20—330-ohm ¼-watt, 5% resistor
C18—220-μF, electrolytic capacitor, see text
S1, S2—Normally-closed magnetic-reed switches, see text
12-volt DC, 20-mA or more power-supply or plug-in transformer, optional back-up battery, wire, solder, hardware, etc.

Greater light outputs are possible by using larger capacitors for C4 and C5 to store more energy. For instance, substituting two 750-μF capacitors will give a light output per flash of about 20 W/s. The limit of the flashlamp specified in the Parts List is 45 W/s per 15-second shot, or less when flashed at a higher rate. Lamps up to 500 W/s are available from the supplier in the Parts List.

You may use photoflash capacitors to store the energy for FL1. However, if you do, a choke will be required between the anode of the lamp and the positive side of the power supply. The reason for that is that photoflash capacitors are low-inductance devices when compared to ordinary electrolytic types. As a result, FL1 will flash with a short, powerful pulse generating a lot of ultraviolet light.

That invisible light reduces the output of FL1, and the fast flash conspires to shorten the flashlamp's life. The author used a home-made choke that was comprised of 70 turns of #22 magnet wire wound on a ferrite core (like that used in AM radios with built-in antennas). The home-made choke provided an inductance of 25 millihenries (mH), which is adequate for the series-wired 130-μF photoflash capacitors used in the prototype.

If you require such a choke, it is suggested that you use 0.2 to 0.5 mH of inductance per microfarad of capacitance across FL1. A good test is to watch the flashlamp from a distance of 20 feet during the daytime hours. If it is blinding white, your choke is large enough, but if it has a blue tint, add more inductance. Finally, do not omit R5—a 470k, ½-watt resistor connected across C4 and C5; that resistor is used to bleed off the heavy charge on the large capacitors when the project is unplugged.

Power Supply Assembly. The author's prototype was assembled on a 6- × 3½-inch section of perfboard, with point-to-point wiring used to join the circuit elements. Once you've obtained all the parts, begin construction with the power supply, using Fig. 2 as a guide. Fuse F1 should preferably be a fast-blow type. When installing R6, keep about a ¼-inch space between R6 and the circuit board to allow that unit to dissipate heat freely.

Be sure to use a polarized plug on the line cord, and wire it (as shown) so that the hot side of the plug (the smaller terminal) is connected to R6, F1, and S1. Once the power supply is complete, it's a good idea to make a visual check of the assembly to see if there are any errors in construction—misconnected components, solder bridges, and the like. If no construction errors are found test the circuit by plugging the power supply into a polarized outlet, and flipping on S1. Neon lamp NE2 should come on immediately.

Measure the voltage across C5 and C6. You should get about 330 volts DC. Then test the voltage across each capacitor separately. The readings across the individual units should be about half the total applied voltage and within ±20% of each other. If they differ significantly, suspect that one of the capacitors is defective, or is of substantially different value than its companion. Replacement is warranted if the individual voltages across the two are not within ± 20% of each other.

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There is a shock hazard associated with this type of circuit. You must be especially careful to wire the power-supply circuit as shown with the neutral prong of a polarized plug mating with the neutral side of the AC wall socket. Be sure to mount the SentryStrobe in a non-conducting case—especially if the project is to be located outside, where it may be exposed to adverse weather conditions.

If everything checks out okay, it is time to move on to the strobe section of the project.

Strobe Assembly. Assembly of the strobe portion of the project is relatively straightforward, except for the flashlamp, which we'll get to in a moment. The concern of the moment is the high-voltage output of T1. The secondary leads must be kept away from the other components so as not to destroy them. Fortunately, the output of T1 is too weak for people to feel. But do allow adequate spacing around T1's secondary and the +330-volt line. With certain trigger transformers, the pinout may be confusing. Make sure the proper windings are connected to conform to the schematic diagram shown in Fig. 1.

Note that the flashlamp, FL1, is a polarized component. That means that it's cathode lead must connected to ground, and its anode connected to the +330-volt line. The cathode is easily identified by a small cylinder of sintered, gray-colored metal bonded to it. In the authors prototype, the flash lamp was mounted to a small section of perfboard; a reflector was then fitted to the board to concentrate the light.

You may also install a colored filter or lens over the reflector to tint the concentrated flash. Light-colored filters are best, as dark ones tend to absorb the infrared energy generated by the lamp. After mounting FL1 to the perfboard, do not clip its leads. They will be used to connect the flashlamp to the rest of the strobe circuit.

To test the strobe section of the circuit, connect it to the power supply that you've just built. Energize the circuit and press S2. The lamp should flash at about 3 Hz. Troubleshooting the circuit, if required, is fairly simple. Problems usually appear in the area connected with SCR1. Another sore spot lies with the trigger transformer not supplying enough energy to ionize the lamp's Xenon gas. A few simple tests will tell you if T1 and SCR1 are functioning correctly.

First take a disc capacitor with a high voltage rating—400-WVDC or so—and with a capacitance of a few hundred picofarads or more. Unplug the circuit, disconnect the trigger lead to FL1, and connect one end of the capacitor to the high voltage output lead of T1. Attach a neon lamp to the free end of the capacitor. Now connect the remaining lead of the neon lamp to circuit ground. Power up the circuit, and press S2. The test lamp should give a weak flash each time NE1 flashes. If it does not, suspect SCR1 or T1 to be defective.

If that checks out, test SCR1 by first opening the circuit between TP1 and TP2 and connect a speaker across TP1 and TP2. Press S2, TEST; that should cause NE1 to flash. Each time NE1 flashes, the speaker should emit a distinct click. Lack of a click means either the SCR is defective, or the primary of T1 is open.

You can also check T1 with an ohmmeter. Its primary should give a very low resistance reading (on the order of a fraction of an ohm); the secondary should give a reading of several tens of ohms. If both tests pass, and the lamp still doesn't flash, suspect the lamp itself or its accompanying section of perfboard to be the culprit. Problems of the latter type can be frustrating to solve, because the circuit appears to be functioning correctly, but the lamp just won't flash.

Usually the trouble can be traced to a short across the lamp leads, passing the charge from T1 to ground. Make sure the lamp and board are clean, dry, and free of solder-flux residue. The wire going to FL1 must be in good condition. Sometimes slipping a piece of heat-shrink tubing over the lead, or taping it, will solve an elusive problem.

Problems related to flash speed are often due to a low (or high) line voltage in your area, or to variations in the ignition voltage of the neon lamp—not all neon lamps are created equal! The author noted while assembling some prototypes that the values of R2 and R3 needed to be adjusted to compensate for the different firing points of individual neon lamps, so be prepared to experiment.

After the flashlamp part of the circuit is verified as working properly, you may test FL1 to see if it overheats. Press S2 and hold it for about a minute, while checking the flashlamp. Even during normal operation, the lamp will get very hot, but if it gets so hot that the flash rate begins slowing down, skips, or halts altogether, the lamp is overheating. A thermometer is handy for testing the circuit, especially if it has a small probe. The temperature with continuous flashing should not exceed 250°F.

PARTS LIST FOR THE FAULTY FURNACE DETECTOR

SEMICONDUCTORS
U2—MC7812ACT 12-volt, 1-amp, precision voltage regulator, integrated circuit
U3—LM335 voltage-mode temperature sensor, integrated circuit
U4—LM311 high-performance voltage comparator, integrated circuit
Q1—2N3906 or equivalent general-purpose PNP silicon transistor
LED1—Extra bright light-emitting diode

RESISTORS
(All fixed resistors are ¼-watt, 5% units, unless otherwise noted.)
R9—10,000-ohm, 1%, metal film
R10—200-ohm, cermet 20-turn potentiometer
R11—2940-ohm, 1%, metal film
R12—10,000-ohm
R13—100,000-ohm
R14—3300-ohm
R15—1000-ohm
R16—10,000-ohm, sealed, single-turn potentiometer
R20—1000-ohm

CAPACITORS
C7—1-μF, 50-WVDC, electrolytic
C8,C11—0.1-μF, ceramic-disc
C9, C10—10-μF, 6.8-WVDC, Tantalum

ADDITIONAL PARTS AND MATERIALS
Perfboard materials, enclosure, 8-pin IC socket, AC molded power plug with line cord, thermometer (for calibration), probe case, wire, solder, hardware, etc.

The circuit is now ready to accept the output of a suitable sensor. Once again, be sure that the sensor output does not exceed 20 mA to prevent damage to U1. Input resistor R20 is placed in the circuit to limit the level of current flowing to the input of U1. The value of that component is selected to match the type of sensing circuit connected to the SentryStrobe's sensor input.

Sensor Suggestions. There are many types of sensors that can be attached to your SentryStrobe. For instance, you might want to attach a toxic-gas sensor, like the one that appeared in "Build An Exhaust Monitor For Your Car" (**Popular Electronics**, June 1990), to detect carbon monoxide and other deadly gases.

Or perhaps you're into gardening,

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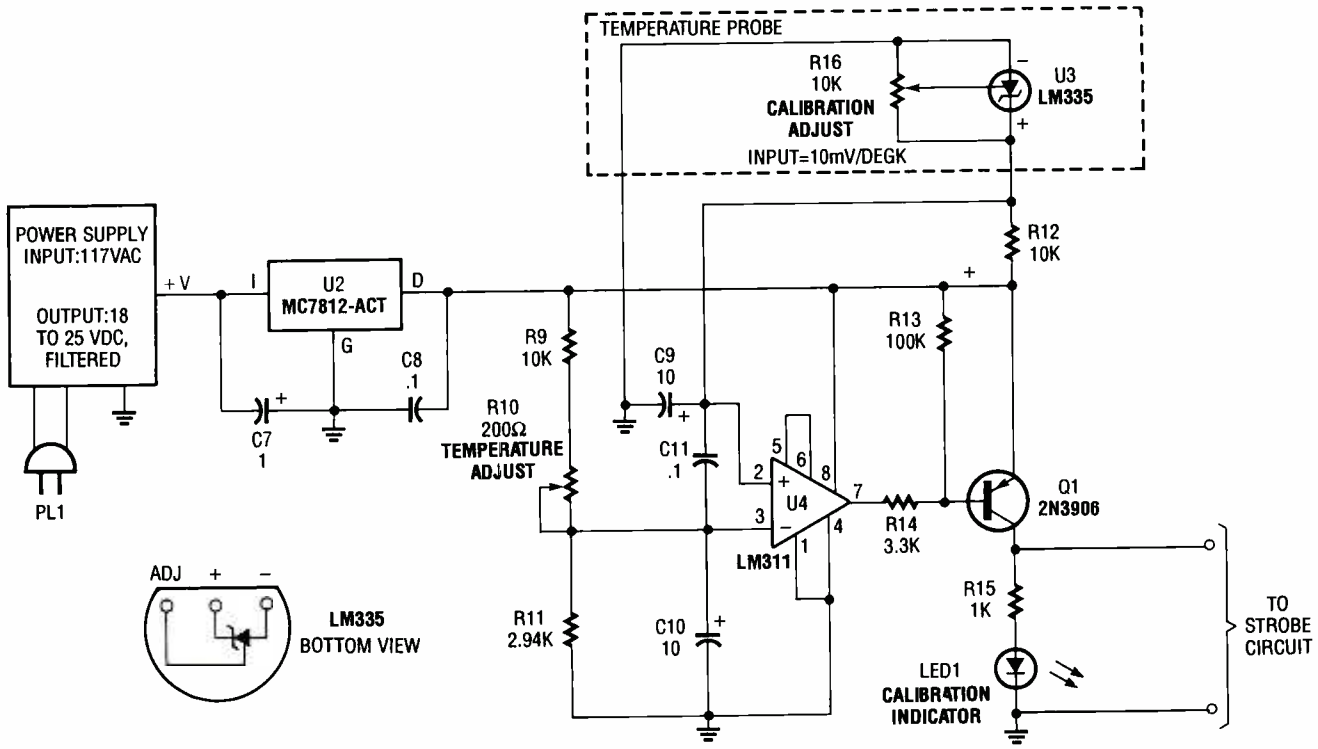

Fig. 4. This circuit—built around an LM355 precision temperature sensor, an LM311 voltage comparator, and an MC7812-ACT 12-volt 1-amp voltage regulator—can be used to monitor temperature changes at a given site, and trigger the strobe circuit when preset conditions are met.

and "vegetable-eatin' critters" have been celebrating the "feast of plenty" in your backyard at night. Rigging the SentryStrobe to a simple microphone circuit or capacitance sensor can provide a way for animals to trip the project. Perhaps a strong blast from a flashtube will frighten them off.

Yet another application of the circuit might be to use it in conjunction with a thunderstorm-sensing apparatus like "Sferic-Level Monitor" (**Popular Electronics**, August 1989). Let's look at some other sensors in more detail.

Intruder Sensor. The magnetic reed switches shown in Fig. 3 are the simplest type of sensor that can be used to turn the SentryStrobe into an intruder alarm. Any number of sensors can be connected in series. A small amount of power is run through the alarm loop, whose normal path is through the normally-closed, magnetic-reed switches (S1 and S2). When any switch is opened by an intruder, current is no longer shunted to ground. As a result, the current flows through U1, causing the SentryStrobe to immediately begin flashing. The magnetic-reed switches can be replaced by a relay, or a normally-closed pushbutton switch, which could then be used as a "panic button."

The power supply for the circuit in Fig. 3 is not critical. A plug-in wall transformer with a 12-volt regulated output at 20 mA or so is ideal. However, you may use any low-voltage power supply that you might have on hand. If you use an unregulated plug-in power supply, be aware that such units often run several volts in excess of their published specifications, which could easily exceed the safe operating parameters of the optocoupler. The current fed to the input of U1 should be limited to no more than 20 mA.

It will be necessary to determine an appropriate value for R20. To do so, first determine the approximate resistance required to limit the input current to 20 mA using Ohms law. Then place a resistor of the nearest standard value in series with a milliammeter, an LED, and the sensor power supply. If the meter indicates an input current of 20 mA or less, use that value; if a higher current is indicated, substitute the next higher standard value resistor for R20, and take another current reading. Its better to take the time to go through this procedure than to risk the much more expensive optocoupler.

The power supply output should be filtered; a 220-μF electrolytic capacitor of the appropriate voltage rating is recommended for C18. A battery back-up is recommended for maximum security to frustrate the would-be intruder should he attempt to defeat the alarm by cutting off the AC power.

Faulty-Furnace Sensor. Another application for the SentryStrobe is to monitor furnace operation. For example, imagine you are vacationing in the middle of February. At your residence up north, the weather is close to zero degrees, and snowing. The furnace quits, and the house temperature drops rapidly. The falling temperature is detected by a low-temperature sensor. The unusual coolness activates the temperature-monitoring circuit, which then triggers the SentryStrobe. The flashing signals your neighbor to call the furnace repairman before the water pipes freeze and break. You just saved yourself a $1000 plumbing bill.

Figure 4 shows a precision, adjustable, low-temperature sensing circuit that's built around three inexpensive integrated circuits—an LM355 precision temperature sensor, an LM311 voltage comparator, and an MC7812-ACT 12-volt 1-amp voltage regulator.

The regulator (U2) feeds a constant voltage to the temperature sensor (U3), whose output voltage changes propor-

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tionally to temperature—exactly 10-mV-per-degree Kelvin (10 mV/°K). Integrated circuit U3 can be thought of as a precision Zener diode whose reverse breakdown voltage (Zener voltage, V_Z) is temperature dependent—as temperature goes up, the unit's Zener voltage goes up.

The Zener voltage of U3 is fed to the non-inverting input of U4 at pin 2. The inverting input of U4 at pin 3 is tied to an adjustable voltage-divider, consisting of R9, R10 (precision 20-turn potentiometers), and R11. Resistors R9 and R11 are precision 1% tolerance units that exhibit virtually no change in resistance with temperature changes.

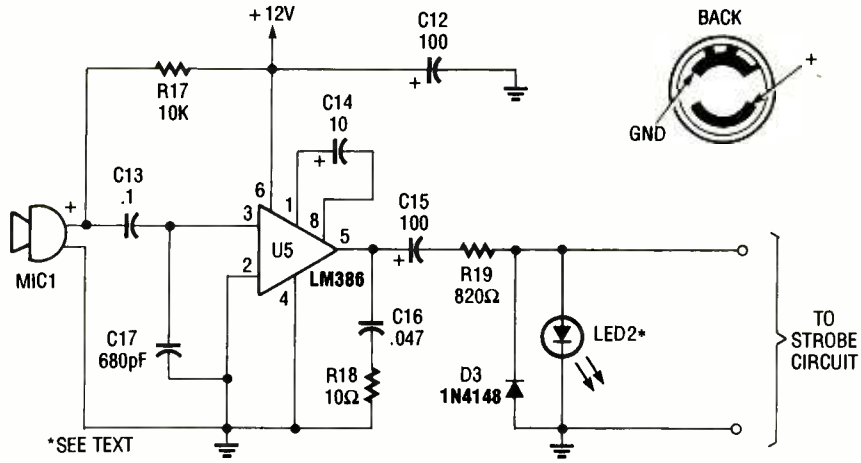

Fig. 5. This simple circuit allows the strobe circuit to be used as a sound detector; such a circuit might be used to detect sounds within a covered area, indicating that the perimeter has be breached.

PARTS LIST FOR THE SOUND AND RINGER SENSOR

SEMICONDUCTORS

U5—LM386 low-voltage audio-power amplifier, integrated circuit
D3—1N4148 general-purpose small-signal silicon diode
LED2—Extra-bright light-emitting diode

CAPACITORS

C12, C15—100-µF, 16-WVDC, electrolytic
C13—0.1-µF, ceramic-disc
C14—10-µF, 25-WVDC, electrolytic
C16—0.047-µF, ceramic-disc
C17—680-pF ceramic-disc

ADDITIONAL PARTS AND MATERIALS

R17—10,000-ohm, ¼-watt, 5% resistor
R18—10-ohm, ¼-watt, 5% resistor
R19—820-ohm, ¼-watt, 5% resistor
R20—see text
MIC1—Electret condenser microphone cartridge (Digi-key P9956 or equivalent)
Perfboard materials, enclosure, regulated 12-volt power source, wire, solder, hardware, etc.

Note: The following parts are available from Allegro Electronic Systems (Dept. XFT, 3 Mine Mountain Road, Cornwall Bridge, CT 06754): U-shaped 45 W/s Xenon flashlamp $4.95, (order part XFT-45U); 4 kV Trigger Transformer, $2.05 (order part TR4-FX); VTL5C3 Vactrol integrated circuit with data, $3.95. Please add $3.50 per order for shipping and handling. All Connecticut residents, please add appropriate sales tax.

All other integrated circuits, 1% resistors, and several other components are available from Digi-Key (P.O. Box 677, Thief River Falls, MN 56701-0677). The magnetic reed switches, LED's plug-in transformers, and other components are available from All Electronics (P.O. Box 567, Van Nuys, CA 91408.

Free technical assistance for this project and a catalog of related parts are available by calling 203-672-0123 from 9 AM to 12 noon E.S.T. weekdays.

Since the accuracy and stability of the regulator (U2) determines the accuracy of the circuit. A pair of capacitors, C7 and C8, are attached to the input and output of U2 to dampen unwanted oscillations that might develop.

Calibration. It is important to note that the Kelvin (K) scale starts at *absolute zero* (−273.15°C), and a 1°K change in temperature equals precisely a 1°C change. On the Kelvin scale, the freezing point of water (32°F or 0°C) is 273.15°K. At the exact freezing point of water, U3's Zener voltage (V_Z) will be V_Z = 10 mV × 273.15°K or 2.7315 volts.

Obtain a good quality thermometer and digital voltmeter. Place the sensor (U3) in a medium at exactly 25°C (77°F). Be sure not to get R16 soaked. Adjust R16 so that the voltage at the cathode (pin 2) of U3, and thus the comparator, is exactly 2.98 volts. Once calibrated, U3 is accurate to ±1°C.

Now R10, TEMPERATURE ADJUST, must be set to the trigger-point temperature chosen for the SentryStrobe. Let's say that we want the circuit to trigger the strobe at 40°F. The trigger point (40°F) correlates to 4.4°C. Add 273.15 to the centigrade temperature to obtain temperature in Kelvin degrees; 4.4°C + 273.15 = 277.55°K. That value can be rounded off to the nearest tenth or 277.6°K. Multiply that value by .01 and you get 2.776, which we'll round off to 2.78. Adjust R10 for 2.78 volts at pin 3 of U4. (Potentiometer R10 is adjustable from 2.72 to 2.86 volts, which corresponds to 30°F to 55°F.) Now whenever the temperature falls below 40°F, the SentryStrobe will start flashing.

Since component tolerances, volt-

(Continued on page 107)

The LM355 (U3) is mounted in a probe located at the point you wish to monitor. The probe housing should allow the end of U3 to stick out a bit so that it can contact the medium to be monitored. The wires connected to U3 should be sealed in silicone RTV to form a leak-tight container, making it immune to high humidity or water immersion. The CALIBRATION potentiometer, R16, should be located inside the case with the rest of the electronic circuitry; it should require no further adjustment after the initial calibration.

Shielded cable must be used if U3 is to be located more than a few feet from the rest of the circuit to prevent the wire from acting like an antenna for radio-frequency interference.

In this application, the strobe's input resistor, R20, should be 470 ohms. Capacitors C9 and C10 are solid Tantalum units, which were chosen for their low-leakage characteristics. Those capacitors provide a delay that allows the circuit to ignore minor temperature fluctuations. Capacitor C11 is placed close to U4 to dampen oscillations that may occur.

Under normal room-temperature conditions, U3 keeps the voltage at pin 2 of U4 high, placing pin 2 at a higher potential than pin 3. That forces the output of U4 at pin 7 high. That high is fed to the base of Q1 through R14, keeping it at cutoff. As the temperature decreases, U3 causes the voltage presented to pin 2 of U4 to decrease. When the voltage at pin 2 drops below the reference voltage applied to pin 3, the output of U4 swings negative, causing Q1 to conduct. That, in turn, triggers the strobe.

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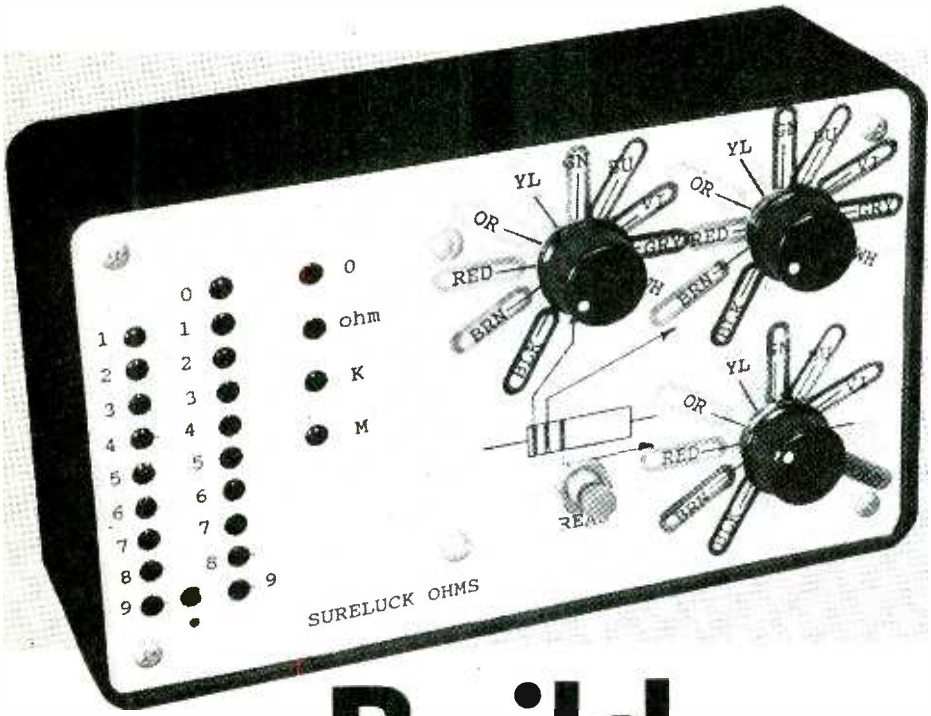

Build "Sure-Luck" Ohms

If selecting a required resistor solely by color code is giving you headaches, or if you simply don't know the code well enough to use it accurately, check out Sure-luck Ohms—the easy-to-build color-code sleuth!

BY CHARLES D. RAKES

Do you experience the "color-code blues" every time you search through your junkbox for a resistor? And do you make like a magician and vanish when a color-code question comes your way? Have you tried to teach a budding electronic enthusiast the resistor color code without resorting to some off-color memory scheme? If so build our *Sure-luck Ohms* color-code decoder and never ever again suffer from those resistor color-code blues.

Why, might you ask, should I go to the trouble of building an electronic gadget to read resistor color-code values when I can use a chart or color-code wheel? For one thing our Sure-luck Ohms is easier to read and the resistor values are indicated in OHMS, K ohms, and MEG ohms without showing all of those zeros that complicate the process when using a chart or wheel. If you can read numbers from 0 to 9 and know that "k" is the prefix for 1000, and "M" is the prefix of 1,000,000, you will not have any problem converting the colors on a resistor into a resistance value.

Take a look at any construction project, in this publication and most others, and you will find in the parts list and on the schematic diagram that the resistor values are usually shown in their shortest possible form. A two-thousand-two-hundred ohm resistor (2,200) will be shortened to read 2.2k and a two-million-two-hundred-thousand ohm resistor (2,200,000) will read 2.2 megohms. And that's what the circuitry in Sure-luck Ohms does to make decoding the color code on a resistor's body a snap.

About The Circuit. The schematic diagram for Sure-luck Ohms is shown in Fig. 1. The circuit is little more than a well-thought-out switching arrangement—built around three single-pole 10-position (SP10T) rotary switches—that are used to decipher the resistor color code that's stamped in the unit's body. To operated Sure-luck Ohms, the three switches are rotated to match the resistor's three colors. A pushbutton READ switch is then used to apply power to the circuit, and light the proper LED's to indicate the resistor's value. In between the switches and LED's is a bit of "diode-transistor logic" that turns on a flashing decimal point LED, the OHM LED, the K, or the M LED as reauired.

The function of S1 is the simplest of the three selector switches. When S4 is pressed, battery power is applied through a 470-ohm current-limiting resistor (R1) and the wiper of S1 to the selected LED to indicate the first digit of the resistor's value.

The second rotary switch, S2, selects the LED for the resistor's second digit. The first position on all switches is marked black indicating a zero. Since S1 selects the resistor's first digit, a zero LED isn't needed, but in the second and third digit, the zero is necessary. If a resistor has a color code of brown-black-red, S1 will be in the brown (number 1) position and the S2 will be in the black (zero) position, and S3 will be in the red (number 2) position. But for the circuit to show a reading of 1k, the zero LED for the second digit must not light. That's where Q1 and D1–D3 come into play.

The wiper of S3 connects the 9-volt bus to the number-2 (red) position and on to the base of Q1 through D1. That turns Q1 on, clamping the voltage across the zero LED to ground, keeping it from lighting. The positive voltage at position 2 of S3 also supplies current

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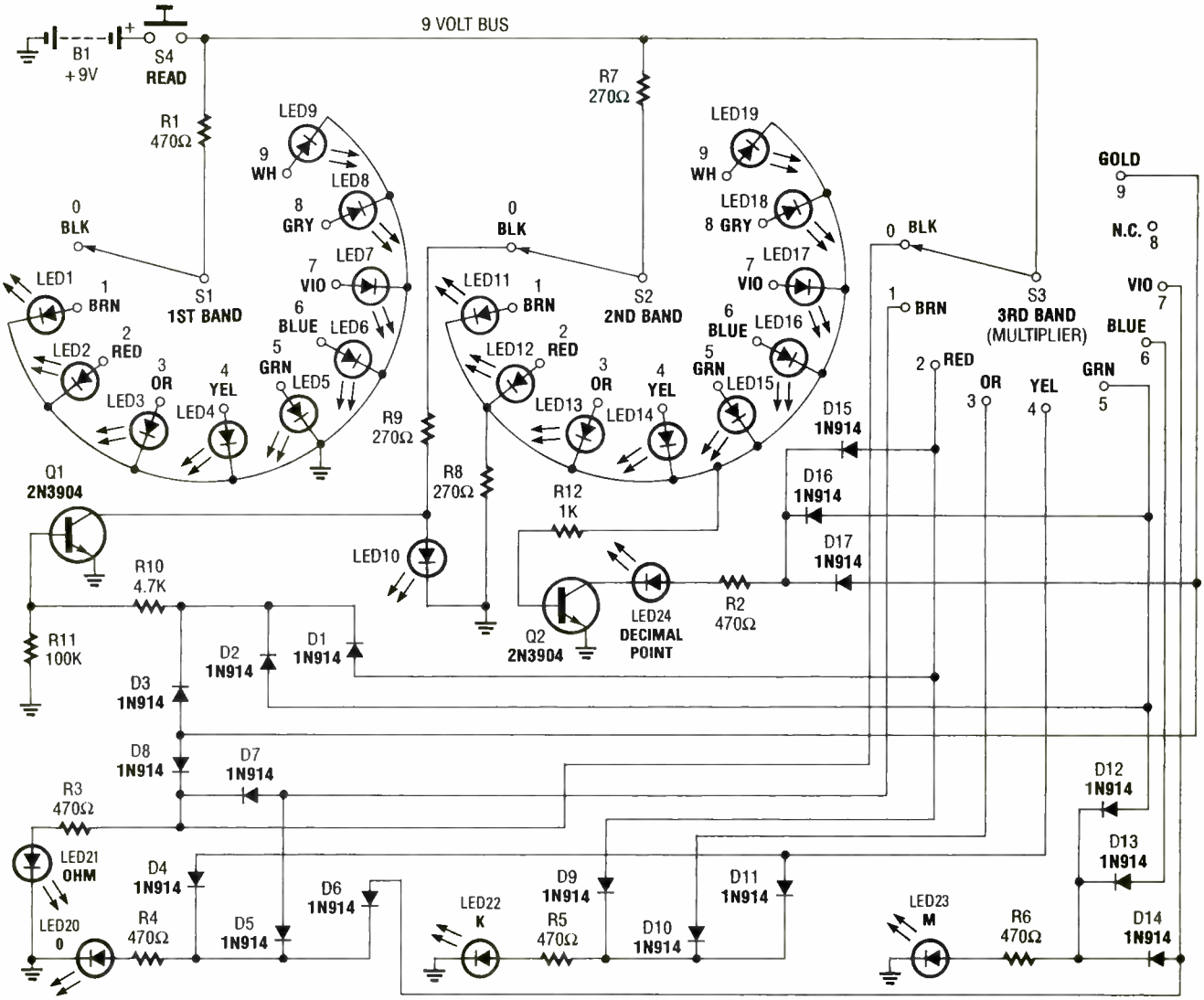

Fig. 1. Sure-luck Ohms is little more than a well-thought-out switching arrangement—comprised of three single-pole 10-position (SP10T) rotary switches—and LED's to decipher the resistor color code that's stamped on a resistor's body.

through D9 to turn on the OHM LED. Of course the READ switch must be activated for the LED's to light.

If the resistor had been a 1.5k (brown-green-red) instead of a 1k, the wiper of S2 would be on the number 5 (green) position. Current would then flow through R7, LED15, R8, R12, and the base-emitter junction of Q2, turning it on and bringing the cathode of LED24 to ground. The wiper of S3 supplies a 9-volt source to its number-2 (red) position and on through D15, R2, and on to light the blinking, decimal-point indicator LED24.

The third zero (LED20), as well as the K (LED22) and M (LED23) indicators, are controlled by switch S3 and their simple diode logic.

Construction. In the author's unit, the majority of the components are circuit-board mounted and housed in a 6¼ × 3¾ × 1 15/16-inch plastic cabinet. The circuit is by no means complicated or critical, and can be built breadboard style if you wish. However, to simplify assembly and reduce the possibility of error, printed-circuit construction is recommended. Figure 2 shows a template for the printed-circuit layout used by the

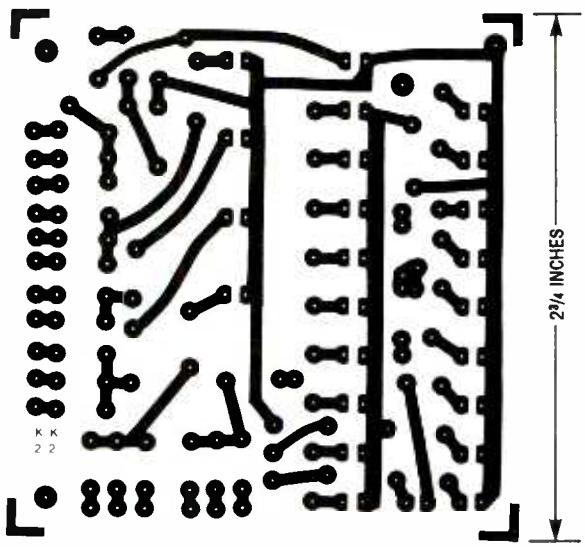

Fig. 2. To simplify assembly and reduce the possibility of error, printed-circuit construction is recommended. Here's a template for the circuit-board layout used by the author.

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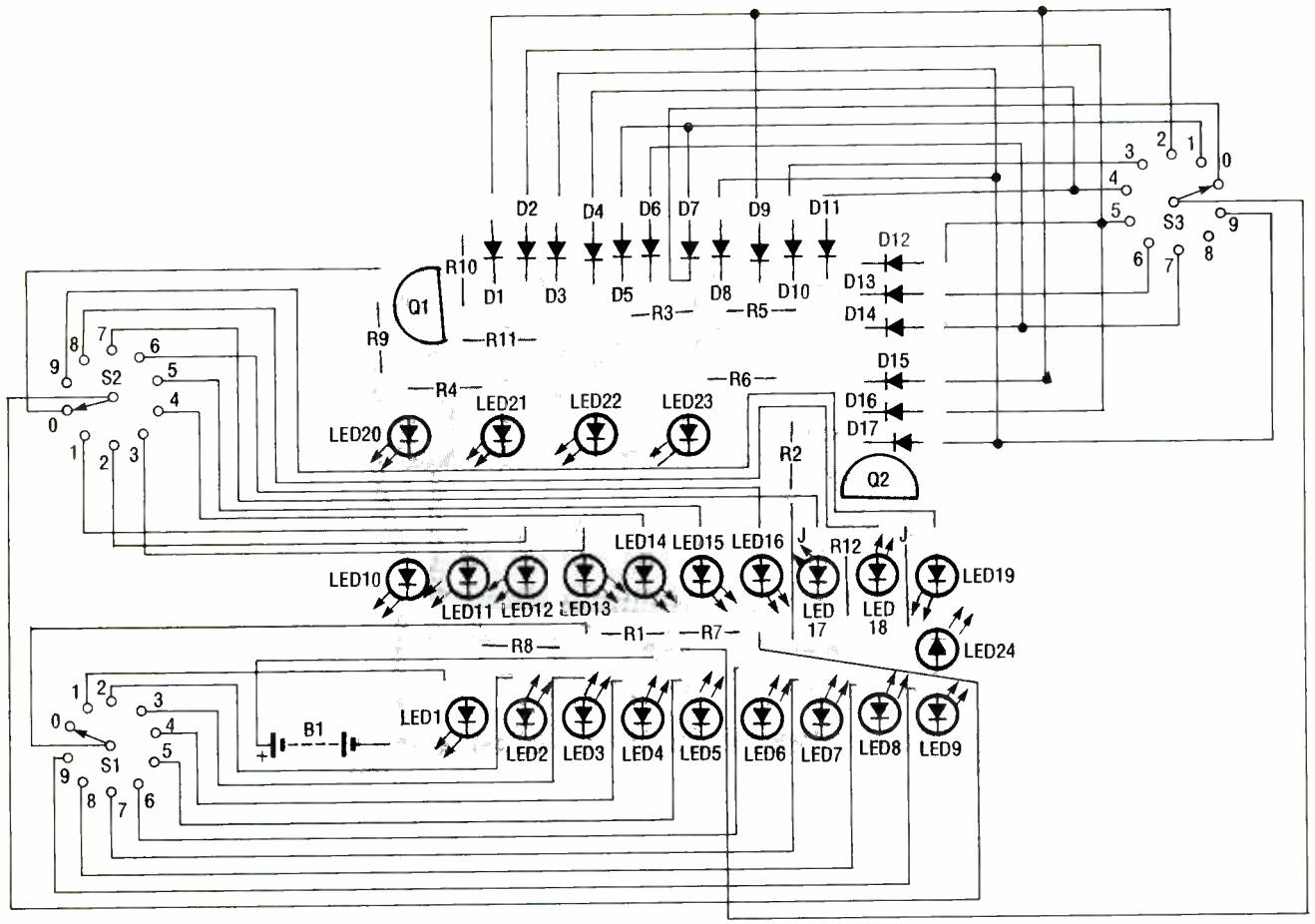
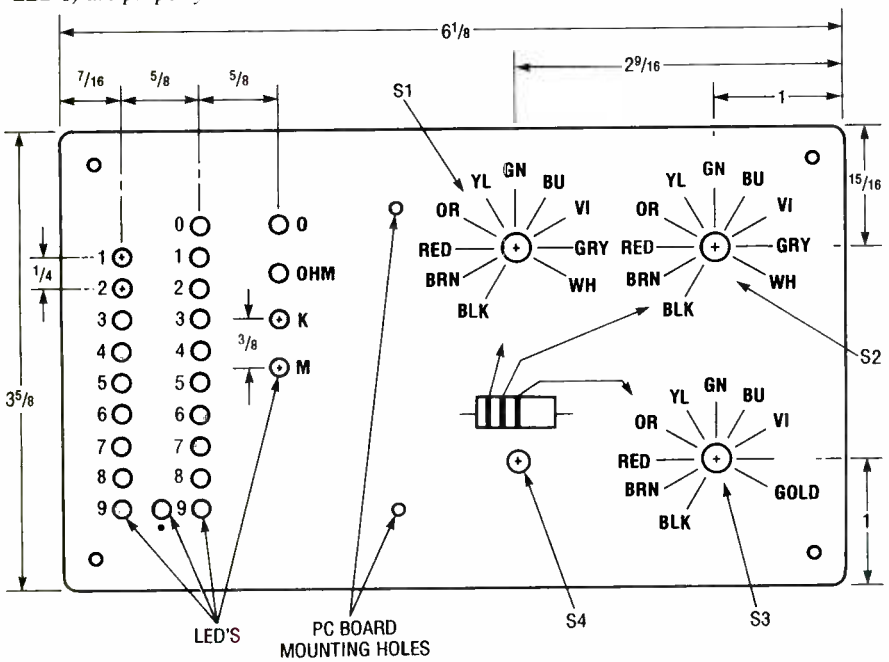


Fig. 3. Assemble the printed-circuit board using this illustration as a guide. When mounting the components to the board, be sure that the polarized parts (diodes and LED's) are properly oriented.



ALL DIMENSIONS IN INCHES

Fig. 4. Once the board has been assembled, prepare the front panel of the enclosure using this layout as a guide. Note that the front panel of the enclosure has 24 holes spaced to match the LED's mounted on the board.

author. Regardless of the method of construction taken, you should be able to build your own for under $20, or even less if you maintain a well stocked junkbox.

Assemble the printed-circuit board using Fig. 3 as a guide. When mounting the components to the board be sure to orient the polarized parts (diodes and LED's) as shown. Note that all the LED's, except LED24, are mounted with their cathodes facing the left edge of the board. Also note that the cathodes of all of the LED's in row 1 and all but one in row 2 are common. The anode of LED24 is facing the left edge of the circuit board.

If you want to save a dollar, you can substitute a regular LED for the flashing unit used for the decimal point, LED24. All 17 of the 1N914 diodes are mounted on the board with their anodes connected to the pads that are located along the outside rim of the printed-circuit board. A jumper from the cathodes of D7 and D8 to S3 position zero (0) will have to be added for the OHM LED to light when decoding resistor values of 100 ohms and less. There's no hole in the circuit board for that jumper so just tack a wire on the back side of the board at the junction of R3, D7, and D8. Also note that there are two additional short jumpers on the board.

Using color-coded wiring between the board and the switches will help

(Continued on page 114)

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LAVA LAMP

(Continued from page 27)

shown in Fig. 1. It should be about 10-inches high, although the taller the bottle the better. Fill it partially with brine, add about 150 milliliters of benzyl alcohol (dyed red), and then fill the bottle up with brine. Leave about 1-inch of air on top to buffer expansion; note that the bubble size is influenced by the amount of air space.

Open a 1 pint (or larger) tin can, remove the lid completely, and remove the contents. Clean the can thoroughly and cut (or drill and file) a hole in the bottom. That hole should be as large as possible, but a metal lip must remain; that lip will be used to support the beverage bottle chosen when the can is inverted. Be sure to remove any sharp edges from the hole before proceeding.

Cut a circular piece of wood, about 4–5-inches in diameter, from a piece of scrap plywood of suitable size. Mount a ceramic light fixture at the center of the board. Drill a hole in the side of the can (toward the open, top end) that's large enough for a power cord. Fit the hole with a grommet, feed a length of power cord through the hole, and connect the wire to the terminals on the fixture. Screw a 40-watt bulb into the fixture. Invert the can (open end down), place it over the fixture and bulb, and center it. Glue the can to the board using epoxy cement.

Create a gasket from a thin piece of foam rubber and place it on the can's lip. The gasket's function is to keep light from escaping around the bottom of the bottle. Place the bottle on the can assembly, plug in the light source, and soon your lamp should be bubbling away.

Improvements. If your bottle is tall enough, or you don't have the lamp running all the time, your Lava Lamp may work well exactly as described. However, the key to the lamp's operation is the temperature within the bottle. It is best to operate the unit at the lowest temperature possible since at lower temperatures, separation appears to be best and sticking to the walls is reduced. And if things get too warm, after a while the benzyl alcohol will simply accumulate at the top. That's particularly likely to happen if the bottle is too short.

There are a couple of ways of combating this. One is to use a cooling fan at the top. Another is simply to turn off the lamp and let things cool down. But perhaps the best approach is to use a simple lamp-dimmer circuit to regulate the temperature. One suitable circuit is shown in Fig. 2, but just about any lamp dimmer could be used. With the lamp dimmer, the unit can be turned on at full brilliance to get things warmed up, and then the wattage can be reduced to the point where things run continuously.

If the lamp doesn't get things going fast enough to suit you, almost instant warming up can be had by means of a hot-air blower or hair drier. The hot air should be directed only toward the red layer of benzyl alcohol that sits on the bottom when the lamp is cool.

If available, a trace of antioxidant, such as BHT or BHA, can be added. In some of my experiments, I used some fluorescein sodium, a pink dye that gives the salt water a beautiful greenish color that contrasts even better with the red. ■

BUG OFF

(Continued from page 62)

(ouch!) no matter what its hearing range may be.

Also note the power supply; Two batteries in parallel are a good idea because, unlike common 555 circuits, the two oscillators are both supply-voltage dependent. A drop in voltage will reduce the unit's effectiveness. Besides, if you're out in the wild, you'll want the device to work a long time with little tending.

Construction. I wire-wrapped my Bug-Off because of the circuit's simplicity. I started by placing the IC socket for U1 on a small piece of perfboard sized to accommodate it, a 16-pin IC socket (which I'll explain in a little bit), and the two 9-volt batteries. I then wired the pins of the 14-pin socket as shown in Fig. 3A (note that the figure shows the wire side).

I used an unusual wiring technique for the rest of the Bug-Off circuit. I cut the leads of all the discrete components and inserted them into a 16-pin wire-wrap socket (see Fig. 3B). It makes for neat, and sparing use of perfboard surface area. That's important to make the unit easily portable. When preparing your own DIP socket, you might need to bend the capacitors back against the other components. It'll depend on the size of your project box. Once the components are in the socket, install the socket on the board. You can use Fig. 3B as a wiring-side diagram as long as you position D1 correctly. First wire the support-component jumpers, and then run the necessary wires to the IC.

Make appropriate holes in the unit's case for the switch and piezo element. Put them in place and wire them to the board and the battery clips (note that BZ1 goes to the switch and pin 9 on the IC). Before you close up the case, you should test the unit. Get two good batteries, preferably from the same package to help ensure their internal resistances are the same. Connect them to the circuit, and flip the power switch on. If you place your ear very close to the transducer, you should hear a hard-to-notice high-pitched whine.

If the tone is easily audible, then the VCO is not operating in the right range. That could be due to a poor battery, mis-wiring, poor component connections, or poor component tolerances. I would check for each in the order just listed. If you can't hear the tone at all, don't worry; your component tolerances might be pushing the frequency up, or, more likely, your hearing may be poor at such frequencies. That's very common and nothing worth worrying about. To make sure the unit is operating, press your finger against the leads of C2. That should cause its tone to drop to a more noticeable frequency.

Frills. You can soup-up the unit by running it off of a wall adapter for indoor use. However, without some amplification, the unit will have a limited range. You can use a good-size switching transistor running full-open to slam the crystal up and down at higher voltage levels to do just that. Just be sure you don't alter the operating voltage of the oscillators.

It's perfect for sleeping-bag use, especially if a clip or velcro is added to hold it in place. The pest repeller should provide you with many carefree hours to enjoy nature's bounty, or just a little patio R&R, without pesky bugs spoiling the fun. You can leave your battery of repellents and bite disinfectants home on that next family outing because you have Bug-Off. ■

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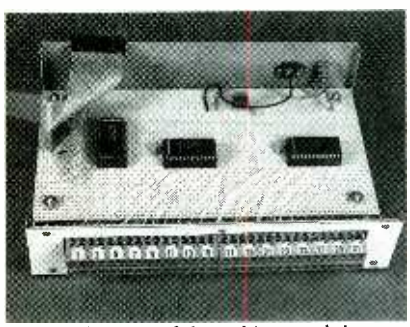
(Continued from page 39)

also notice that pins 1 and 10 are connected only to each other, so the two wires are simply twisted together inside the cabinet—and that's two less wires that have to be connected to the board.

All of the connections on the board were wire wrapped, with the following exceptions: the row of connected pins coming from the ribbon cable were soldered together using bus wire, and the connections to the power jack and on/off switch were made with heavier wire. As for the outputs, a 6-inch length of wire-wrap wire was attached to each pin and left hanging for the moment. After all of the connections are checked out, the board can be put aside.

The next step is to fabricate the rear panel. First, the terminal strips are mounted on the cut-off piece of perfboard. Each terminal strip consists of 16 contacts, so pairs of two were used for each one. All of the ground leads were connected together with bus wire, leaving a free pin for each IC output.

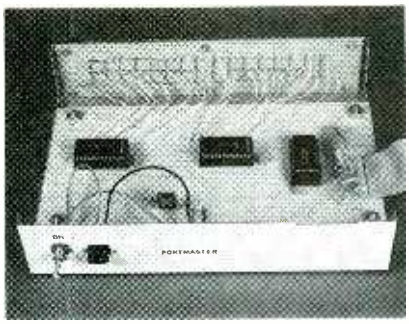
The openings in the front and rear of



Here is the rear of the cabinet and the inside-front. If terminal strips aren't your cup of tea, you can use any sockets or plugs you wish.

the cabinet were started with pilot holes, and cut out to size with a nibbling tool. A bit of metal was also cut away for the ribbon cable to enter the unit. After properly fitting the rear panel in the opening cut in the cabinet, six small screws secured it in place. Next, the perfboard was mounted in place using standoffs, and the power jack and switch were connected. A ground wire from the board was then soldered to the bus-wire ground on the rear panel.

The last step, which is probably the most tedious, is to solder each wire-wrap lead from the IC outputs to the corresponding pin on the terminal strip.



Here is the front of the cabinet and the inside-rear. As you can see it takes relatively few components to achieve a lot.

After inserting the IC's in the sockets, be sure to test all of the outputs to be make certain that they're done correctly.

As finishing touches, rubber feet were put on the bottom of the cabinet, and electrical tape was wrapped around the bus wire as extra insulation where it leaves the cabinet.

Some Modifications You Can Make. It is assumed that data is reaching the device at a relatively slow rate, so the Portmaster has been designed to function asynchronously. Thus, the computer is always free to proceed with whatever tasks it must perform without interference from the unit. Because of that, you must make sure the computer doesn't transmit characters at too rapid a rate (as mentioned before), although it is unlikely.

If that solution is inadequate, the low-power Schottky chips can be replaced by faster chips of other TTL-compatible architectures, provided that their pinouts are the same and that all the IC's (except the 7805 voltage regulator) are changed accordingly.

Setting-up the System. Turn the computer off and plug the Portmaster's DB-25 connector into the parallel port. Plug the wall-transformer power supply into a surge-protected AC socket and connect its output plug to the Portmaster. Connect the devices to be controlled to the unit's outputs, making sure that the outputs have been properly configured for each device (AC/DC/momentary/toggled). Turn the unit on and power-up your computer.

Assuming you wish to enter and use the program supplied in Listing 1, be sure to use the initialization portion to test the operation of both the unit and your software. Strobe all outputs and check the connected devices' response. If everything checks out, your system is ready for use. ■

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SPEAKERS

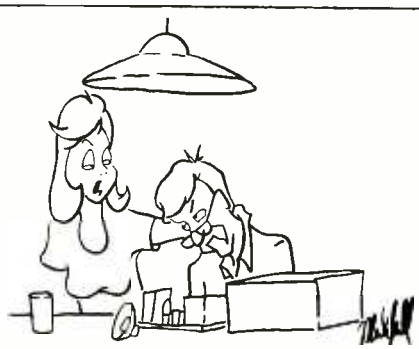
(Continued from page 34)

test. What you're trying to verify is that the crossover works as expected.

While slowly varying the frequency from one half to two times the low crossover frequency, measure the AC voltage at the woofer terminals. That voltage should start dropping just below the crossover frequency, and should drop rapidly above it. Do the same with the midrange. It should have a low voltage at half the lower crossover frequency, rising as the frequency increases, then leveling out above the crossover frequency. Check the midrange and tweeter sections in the same way, but this time varying the frequency from half to twice the upper crossover frequency. Any wiring errors you may have made can be discovered by these tests. (I once blew an amplifier by mis-wiring a crossover network so that it presented too low an impedance to the amp; a 15-minute test is cheap insurance.)

If you are really interested in crossover design, there has been a lot of valuable work published in the *Journal of the Audio Engineering Society* in the last few years. Much of this is summarized in Vance Dickason's *Loudspeaker Design Cookbook*, published by the Marshall Jones Company of Francestown, N.H. There's also some good info in Badmaieff/Davis', *How to Build Loudspeaker Enclosures*, published by Howard Sams.

Well, I guess you're wondering about my young friend and his girl's ex-speaker system. Once he found out what the problem was, he decided to use a simple capacitive crossover like the one that was originally in the system, but he did buy 100-volt capacitors. Then he decided to add midrange units. He wasn't very good with a saber saw. Oh well .... ■



"Why can't you be obsessed with cars like a normal man?"

ELECTRONIC FISHING LURE

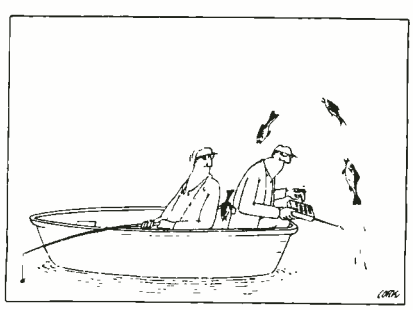
(Continued from page 56)

The battery should be held in place by the clip. If not, remove the battery and adjust the bends at points A and B so that when the battery is slipped into place, it "clicks." Once you have the battery clip working correctly test the assembly. To test it, simply tie it to a string and spin it around. Make sure there are no breakables or anyone else in the room. If the battery doesn't fly out, you've made a good clip and can continue on to complete the lure, if not adjust the bends until you get it right.

Take a ½-inch piece of ¼-inch wide cellophane tape and wrap around the wire as shown in Fig. 1 at the point labeled "insulator." Make the wrap several layers thick. Next wrap the negative leg of the LED or the micro lamp around the cellophane-tape insulator. Flow some solder on the windings on the side that contacts the battery. Solder the other wire to the clip just beyond the cellophane-tape insulator.

The lamp or LED can be mounted to face in a variety of directions—for example, pointing directly out away from the battery or, perhaps, pointing toward the hook end of the lure. The switch is the essence of simplicity—a thin piece of plastic or film slid between the battery and battery-contact lead of the LED. Cut the plastic or film into a strip about ⅛-inch wide and an inch or two long.

Use. Use the lure as a spinner bait by attaching a treble hook to the loop at point E and your fishing line at the other end. Cast it out, let it sink a little, and reel it in with a jerking motion. If you are a bait fisherman, especially one who likes to fish at night, position the lamp to point towards the loop at point E. Fasten a leader with hook on loop-point E, bait the hook with a live minnow, and your bait will be swimming in the spotlight. ■



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VAN DE GRAAFF

(Continued from page 59)

A powerful static charge builds up on the spherical terminal. In a dark room, you will be able to see long, thin, bluish bolts of artificial lightning jump between the upper terminal and the base. It's a fantastic sight!

Experiments. Gaseous tube illumination and spark production are only two of the many interesting things you can do with your Van de Graaff generator. Here are just a few of the others:

- Obtain some foam plastic packing material and break it up into small pieces. Turn on your generator and allow it to run for a few moments. Now, drop the plastic bits, one by one, on top of the spherical terminal. They land on the aluminum, sit there for a second, and then shoot off! Some of the plastic may fly for a distance of one or two feet. When the material makes contact with the terminal, it picks up an electric charge. Since like charges repel, the plastic is thrown off the surface of the sphere.
- Find some very thin aluminum foil and carefully cut it into strips about ¼- to ½-inch wide and about 8 inches long. Tape the strips to the top of the terminal. Make sure the foil is making good electrical contact with the aluminum sphere. Turn on the generator. The strips will be repelled from the terminal and from each other. Now approach the sphere slowly with the palm of your hand. The strips will be attracted magically to your fingers!
- You can also use your generator to create what is sometimes called an "electric wind." Locate a narrow metal rod about 9- or 10-inches long. Tape one end of the rod to the top of the spherical terminal. Make sure that this end of the rod is entirely covered with tape, and, once again, check for a good electrical contact. Turn on the machine. Next, light a household candle and approach the free end of the rod with the candle flame. As molecules of ionized air rush from the metal tip, the flame will be blown to one side.

These experiments just scratch the surface of what you can do with your generator. The book, *Nature's Electricity* by C.K. Adams (Tab Books, Blue Ridge Summit, PA 17294) contains many other interesting experiments that can be performed with your Van de Graaff generator, as well as other static-electricity experiments. ■

CUSTOM CASES

(Continued from page 68)

Another method for attaching the lid is to glue small blocks to the bottom of the lid, and drill and tap the blocks attached to the lid. Mounting screws are inserted through the sides of the enclosure into the blocks attached to the lid (as shown in Fig. 5) to hold the lid panel in place.

After the enclosure is completed, allow about 24 hours for curing and then carefully file off any rough edges and protrusions. The sharp corner edges can be beveled using a fine-grit sandpaper.

Any plastic battery holders, which are available for all battery sizes from "N" cells to "D" cells, can be cemented to the inside of the enclosure with fast-curing epoxy. Lightly sand the bottom surface of the battery holder and the place where it is to be mounted. That gives the epoxy a better gripping surface. To complete the enclosure, stick-on rubber or plastic feet can be applied to the bottom corners.

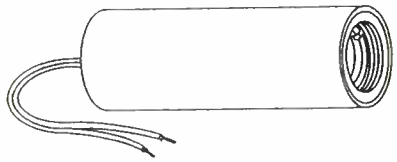
This And That. Working with plastics, you will find that new designs for those special projects can be made easily with just a little thought before actually cutting the parts. It's always a good idea to "build" the enclosure on paper first to avoid unpleasant surprises. It should be noted that the specified thickness of plastic sheet is not always true. For instance, an eighth-inch thick sheet may vary as much as 20%. To avoid problems from thickness tolerances, purchase enough of the plastic sheet to make all the parts from the same piece. The piece can then be measured and the dimensions of the enclosure adjusted to take into account variances in thickness.

An extra advantage of the plastic enclosure is that it can be made using colored plastic, so that the finished enclosure doesn't need painting or finishing of any kind. And if your project has a digital readout, the entire top panel can be made of translucent plastic so the readouts can be seen without the need of a cutout window.

Small holes for wires can be drilled without too much pain using standard drill bits. And there are bits designed specifically for plastics work, which have long tapered tips (similar in shape to a tapered reamer), and will not grab as it goes through the sheet. ■

LASERS

Visible Laser Diode Modules



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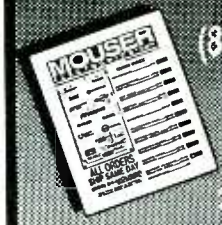

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PEH 92

CLASSIC MILK DROP

(Continued from page 42)

power as before. Place it near the pen light and aim it downward toward the plate.

Your camera should have a macro-focusing lens with at least a 100-mm focal length. The falling milk splashes, and the longer focal length will keep the lens surfaces at a relatively safe distance. Load the camera with ISO/100-speed film.

Turn off the room lights and open the burette slightly to allow one drop to fall about every one to two seconds. Move the burette until you see the shadows of the falling drops cross the photocell. The flash should fire as each drop passes. Adjust the delay knob until you see

This milk crown—a drop of milk actually splashing off a solid surfcae—is but one example of an action that requires split-second timing to capture on film.

the "crown" splash. Your vision persistence will hold the image long enough to see the splash clearly.

Once you have the delay set to your liking, simply set your camera's shutter to "B" and open it just long enough to record the next splash. Set the aperture as small as possible for maximum depth of field. Don't let more than a thin layer of milk accumulate in the plate. Too much milk makes the "crowns" less spectacular. To get a cone-shaped splash, make the milk deeper.

Timing is quite important to catch the splash. Since the tolerance of electrolytic capacitors tends to be pretty wide, you may need to make R3 a bit larger or smaller to get the proper time delay. Otherwise, you can raise or lower the height of the burette until you see the splash. ■

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SENTRYSTROBE

(Continued from page 98)

meter accuracies, and circuit tolerances will vary from project-to-project, we strongly recommend that you familiarize yourself with the accuracy of your particular setup before trusting it totally. To check your sensor's accuracy, place ice and water in a thermally insulated container (such as a Thermos), and adjust R10 for a 33°F trip point (2.74 volts). Immersing the probe in the ice/water mixture should cause LED1 to come on almost immediately. If LED1 does not light, adjust R10 until it just does. That gives you an indication of exactly where 32°F is and an indication of the accuracy of the circuit's response.

The circuit can be modified to react to any temperature between −10°C (14°F) to 100°C (212°F), by varying the ratio of divider resistors R9 and R11, and changing the value of R10. The circuit can also be modified to alert you to "over" temperature conditions, by simply reversing the pin-2 and -3 connections of U4. That tells U4 to trip when the probe encounters a temperature greater than the corresponding voltage provided by the fixed voltage divider. A relay or other device may be wired to signal additional equipment when the alarm condition occurs.

Sound and Ringer Sensor. Another way that the strobe circuit might be triggered is through an audio-detector circuit like that shown in Fig. 5. An electret microphone MIC1 picks up the sound, which is amplified via the microphone's internal FET transistor. The transistor requires a few milliamps of bias current (supplied through R17). The amplified signal is then fed into U5, an LM386 low-voltage, audio-power amplifier. The amplifier's voltage gain is fixed at 200 by the unit's internal components and feedback capacitor C14.

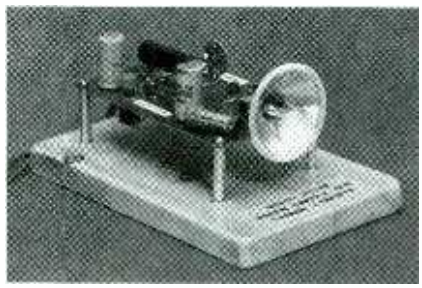
A 680-pF bypass capacitor (C17) at the input of U5 ensures that it does not amplify ultrasonic acoustical energy from MIC1. Capacitor C16 and resistor R18 form a snubber circuit that prevents oscillations from occurring at U5's output. Capacitor C15 blocks the DC content of U5's output (which is biased internally at half the supply voltage).

Sound energy picked up by MIC1 and amplified by U5 appears as an AC signal to diode D3. That unit clips the negative swing of that AC signal, leaving a positive DC voltage of varying amplitude. That voltage is fed through a current limiting resistor, R19, to the strobe circuit via J1 and J2. In this application, R20 (in Fig. 1) should be eliminated, or jumpered out of the circuit.

The LED in Fig. 5 is optional, and must be removed when the sensor is placed in service, or else U1 (in Fig. 1) will receive insufficient current to trigger it. The LED can be helpful, however, in locating the mike in the best spot for sound pickup.

When assembling the circuit, the leads of MIC1 should be kept short. If the leads are long, unwanted oscillations may occur. Keep the 12-volt power source close to the amplifier board. A regulated power source is required to keep U5 from amplifying unwanted power-supply ripple along with the desired signal. Place MIC1 near the object to be monitored, such as a telephone.

A loud sound, such as a telephone ringing will now activate the strobe circuit. Occasionally, spurious sounds such as loud conversation or power equipment will trigger the strobe. To eliminate false triggering, place MIC1 inside a small case, a 35-mm film holder works well; insulate the sides of MIC1 with a sound dampening material, such as cotton or polyester wool, and place the assembly near the object to be monitored. The case will now serve to focus sound entering its front, and eliminate pick-up from the sides.



The author's prototype of the SentryStrobe was mounted on stand-offs to block of wood for testing. The dark object between the two capacitors is the 500-ohm, 25-watt ceramic power resistor (R6) used in the power-supply circuit.

We hope you enjoy the SentryStrobe. It will maintain a vigil over almost any type of equipment, and will alert you to either normal or abnormal functioning of the monitored condition, depending on how it's wired.

We welcome communication regarding this project, and also suggestions as to how to use and improve it. Send your correspondence to Allegro Electronic Systems at the address provided in the Parts List. ■

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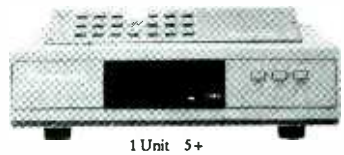

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DIGITAL LOCK

(Continued from page 65)

23, the third key wire to pin 22, and the fourth key wire to pin 21. As an example, consider the jumper arrangement shown in Fig. 2; that arrangement gives an access code of 7410. Notice that all other key wires are connected to U1's reset terminal at pin 2 through jumpers. Therefore, if a "wrong" key is pressed, U1 is reset awaiting the first digit of the code. That helps ensure that random key pressing will not open the lock.

By using a socket and header for the jumpers, you can change the code by just unplugging and replacing the header. You can have different codes for different purposes, or different times of the day, by just inserting a header programmed with different jumpers.

equipped with a solenoid-operated strike mechanism.

The relay supplied with the Digital Entry Lock Kit (see Parts List) has both normally-open and normally-closed contacts, which can be coupled to an external circuit or external latching relay for any number of applications requiring security-protected operation, not necessarily momentary.

For example, suppose you wanted to keep your computer (or other AC operated device) from being used by unauthorized parties. Just have the Digital Entry Lock's relay contacts close an external latching circuit, as shown in Fig. 6. Plug what you want protected into the switched socket. To unlatch (power off), press the normally-closed pushbutton. Be sure the contacts of the external relay in the latching circuit can handle

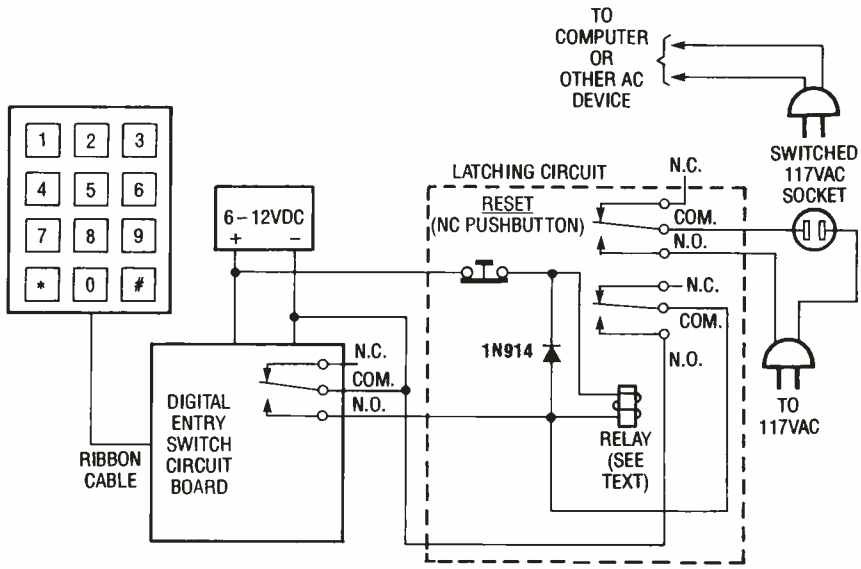

Fig. 6. The Digital Entry Lock can also be used to prevent unauthorized use of equipment, such as a computer (as shown here), or it can just as easily be used to keep someone from shutting down a device during some critical operation.

Applications. My application, as previously mentioned, was to control my garage-door opener. A block diagram of that set up is shown in Fig. 5. In most cases, all that is required is that the normally-open relay contacts of the Digital Entry Lock be connected in parallel with the existing "manual" door switch.

When the relay closes it's the same as if you pressed the manual switch. If your door opener needs more time to properly operate, increase the value of C2, or press and hold the first digit after hitting the fourth digit.

Obviously, the Digital Entry Lock could be used for an electric gate, or a door the AC current of the controlled device.

The circuit works equally well at preventing equipment from being shut down by unauthorized parties; that's done by wiring one terminal of the 117-volt AC socket to the normally-closed contact of the latching circuit instead of the normally-open contact. In that case, pressing the reset button would turn the device on.

A momentary-closure, switching format can be used to arm and disarm many alarm systems. With a little imagination you'll find the Digital Entry Lock can be used for a variety of applications. How many can you think of? ■

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BINARY CLOCK

(Continued from page 54)

frame. The rear Plexiglas only needs one hole for the power input cord from the wall-plug transformer, and four corner mounting holes.

I built another Binary Clock into the round clear plastic container that originally packaged about a pound of nuts. It hangs in my kitchen, and never fails to elicit the question, "What's that?" When I try to explain binary code, their eyes glaze over and their mouths drop as they try to figure out how to tell me I'm strange. But the best response I ever gotten was, "Hey, Fred, why don't you get a wrist watch, like everyone else?"

Reading Your Binary Clock. The binary numbering system is the simplest way to represent a number or quantity since it uses only two symbols: 0 and 1. Using only those two symbols, you can write the equivalent of any decimal number that uses ten symbols: 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0.

The big advantage of the two-number binary system is that computers, calculators, and other electronic instruments can easily represent 0's and 1's with switching circuits that can be on or off, high or low.

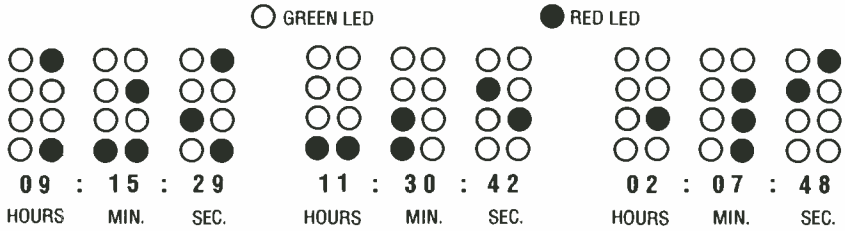

Fig. 6. Here are a few examples to help acquaint you with reading the clock display.

The Binary Clock uses vertical columns of LED's to display time in binary-coded decimal form, to represent decimal numbers. Looking at Fig. 5, you'll see that the hours, minutes and seconds are each represented by two vertical columns, each with four LED's.

When an LED is green, it represents 0—no value. When it is red, it represents a decimal count based on its position from the bottom. The lowest LED represents the numeral 1, the next up represents 2, the next up represents 4, and the top one represents 8. The numeral 3 is represented when both 1 and 2 are red; 5 is represented when 4 and 1 are red at the same time; 6 is represented when 4 and 2 are red; 7 is represented when 4, 2, and 1 are red; 9 is represented when 8 and 1 are red.

To read each column, start from the top and go down, looking for red LED's. Add the values of the red LED's together for the total for that column. Practice by reading the seconds column on the far right as the clock is running.To read the total time displayed by the Binary Clock, start with the left column, which is tens of hours. It will either show 1 or 0 (red or green) in the 1's row, since this is a 12-hour clock. The next column to the right is hours, and can total from 0 to 9. Next count the tens of minutes, minutes, tens of seconds, and finally seconds. To help you learn how to read the display, several examples are shown in Fig. 6. See, it's not so hard! Now try to explain it to someone! ■

SIMPLE COUNTER

(Continued from page 92)

oscillator test point on the frequency-counter board.

The frequency to be measured may now be applied to the counter input, J1. The frequency may be obtained from a wide-range audio generator, a low-frequency RF oscillator, or even a breadboarded 555 timer configured for astable operation. The waveform of the input frequency is not critical for most measurements.

The input voltage required for reliable measurements is slightly more for higher frequencies than that required for lower frequencies. If the input voltage is too low, the displayed frequency will appear to fluctuate between wildly different values or not read at all.

Several units of this design have been built for different applications. All of them have worked with no problems. As with all projects, if problems do occur, check the power supply for the proper voltage first. Then check for +5 volts at the +V terminals of all IC's. Finally, inspect the board for solder bridges, misoriented parts, etc. ■

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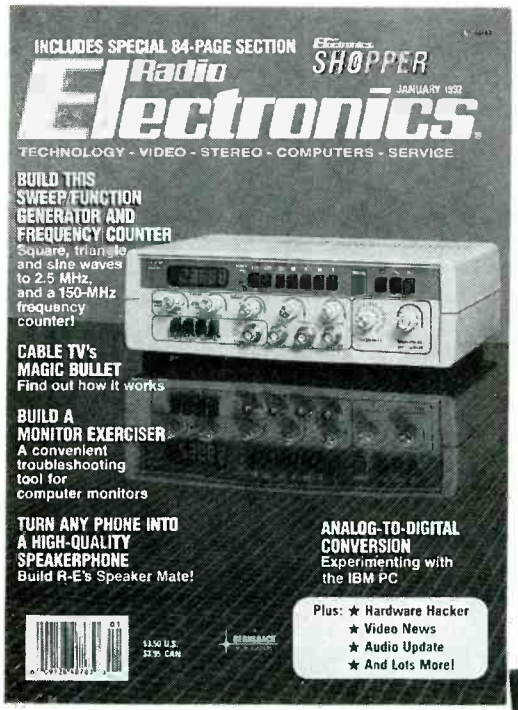

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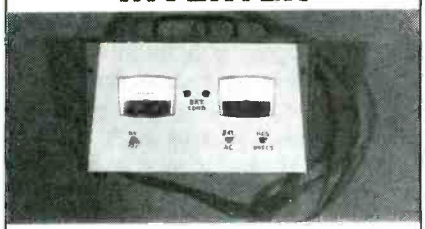

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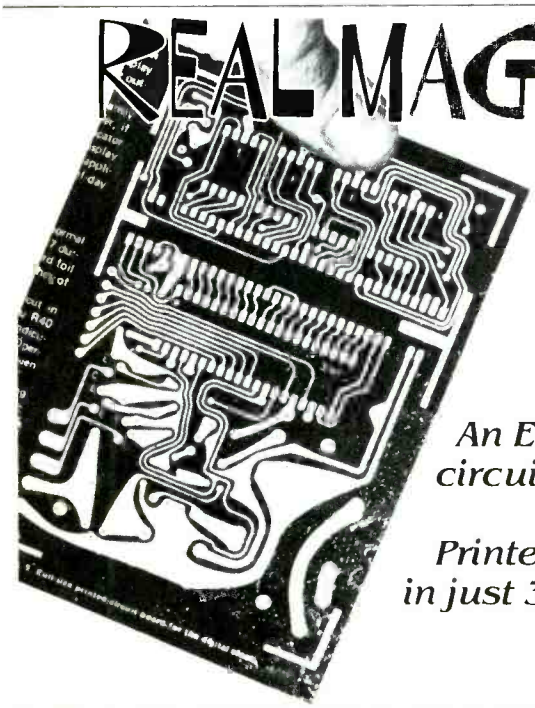

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PIRATE RADIO

(Continued from page 84)

With these tips in mind, logging many shortwave pirates is certainly possible. Pirate listening is semi-structured, not completely haphazard.

Pirate-station programming, on the other hand, represents a mixed bag of American and "alternative" cultures. Some of the active music/talk format stations include WJDI, WLAR, WENJ, WHBH, WKZP, WYMN, Samurai Radio, Radio Mexico, Secret-Society Radio, and East-Coast Pirate Radio. The comedy-oriented stations include RCCI, Voice of Laryngitis, Voice of Stench, WXZR, RFM, Voice of Monotony, and Secret Mountain Laboratory. Radio Garbonzo and Radio Clandestine spoof legal and offshore broadcasters. The Voice of Tomorrow and Free-Radio One are right-wing political stations, while odd music/politics/comedy formats are featured on KNBS and Radio USA.

Most pirates have their mail forwarded through one of several mail-drop addresses (see Table 2) to conceal transmitter locations. Obviously, all letters from the stations would be postmarked from their respective hometowns, so pirates send the letters back to the maildrops before being mailed out again. In order for the system to work, listeners must include three first-class postage stamps or two International Reply Coupons (IRC's). Some stations don't bother to reply to people who don't include proper postage.

Since many pirates are shortwave listeners themselves, they often respond favorably to friendly, personal letters. Some reporting techniques work especially well. For example, including your telephone number on all letters may net a few calls from station operators. Other listeners have had success by sending a cassette recording of the broadcast they'd heard, along with a few extra stamps. Occasionally, stations will record a studio copy of the program onto the tape and return it. Pennants, stickers, T-shirts, and other "goodies" have been received by listeners who send in exceptional reports.

Considering FCC activity, equipment failure, and occasional operator burnout, it's no wonder that the pirate scene is constantly changing. In order to avoid the FCC, stations alter their broadcasting schedules and try different frequencies. The only way to keep abreast of the current situation is to belong to a newsletter. The Association of Clandestine Radio Enthusiasts publishes a timely monthly bulletin ("The ACE"). Sample copies are available for $2 from P.O. Box 11201, Shawnee Mission, KS 66201.

Those near the East Coast can tune in the amateur radio ANARC SWL net on 7240 kHz LSB every Sunday morning at 10 AM Eastern time. The amateur network reads shortwave loggings of all sorts on the air. Numerous bits of pirate information are given and sometimes pirates even check in to inform those listening of a future broadcast.

Pirate radio may never change the world, but most pirates serve at least, to make shortwave listening more interesting. Certainly, there's a voice on the airwaves somewhere to proclaim the ideals of almost everyone who cares enough to listen. ■

ELECTRONICS WIRING

(Continued from page 88)

another hole through the top plate of the wall and another through the roof; all three holes should be in line if possible. Push the conduit up through the top plate and the roof, adding sections with couplers as necessary. Push the conduit through the roof until there is about 4 feet extending past the roof deck, then put the bottom end into the hole through the sole plate and lower the conduit one foot. That should still leave about 3 feet of conduit extending above the roof. Anchor the conduit firmly to the roof trusses using straps and screws. You can finish the work on the antenna mast after the roof is shingled.

The Code requires that the antenna mast be grounded. Attach a grounding clamp to the conduit. Connect No. 10 copper wire to the ground clamp and take the straightest and shortest path to the pipe that serves as the electrical-system ground. Attach a ground clamp to the pipe next to the one used for the electrical system and connect the antenna ground to it. Don't use the same clamp that the electrical ground used, but be sure to connect your clamp to the same pipe. After the roofers are done, attach a weather head to the top of the conduit. That is a cap that fits over the end to keep rain out.

The conduit is strong enough to serve as the mast for small antennas and the downlead that enters the weather head and feeds down to the distribution panel. Larger antennas will require a separate mast, but you can still use the conduit to feed the downlead.

Finishing Touches. When you have completed your work, you can relax until the house is finished. You don't need to install anything else until the interior walls are finished.

When you start to install your own electronics in the house, you will first need to pull wires through the conduit. An electrician's fish tape is an essential tool at this stage.

Start at the first box and feed the fish tape through the conduit until the end appears at the box at the other end. If more than one wire will be fed to that box initially, pull all of the wires at the same time. Attach the wire to the hook on the end of the fish tape by bending a loop in the wire, and secure it with vinyl tape. Pulling in the wires takes two people, one to feed the wire in and straighten out kinks and snarls, and another to pull on the fish tape. When the ends of the wires appear at the box, pull out enough extra to make up the connections, then remove the fish tape.

There are a wide variety of faceplates made to fit standard-size electrical boxes. They range from antenna connections to speaker terminals. If you can't find one that fits your needs, you can use a blank cover and drill holes for the type of connector you need. Cover any unused boxes with blank covers.

After the initial installation, you will be happy with things for a month or two, then you will think of some new project that will make life more convenient, like a closed-circuit TV camera in the back yard to keep an eye on the kids. Well, all you need to do is open the closest box and push in the wire.

If the time comes when a single fiber optic cable delivers voice, video, and computer information to your home, all you will need to do is have the installer route it through one of the outside boxes of your system into the distribution panel. Put the associated electronics on the distribution panel and pull cables to the monitors located throughout your home. ■

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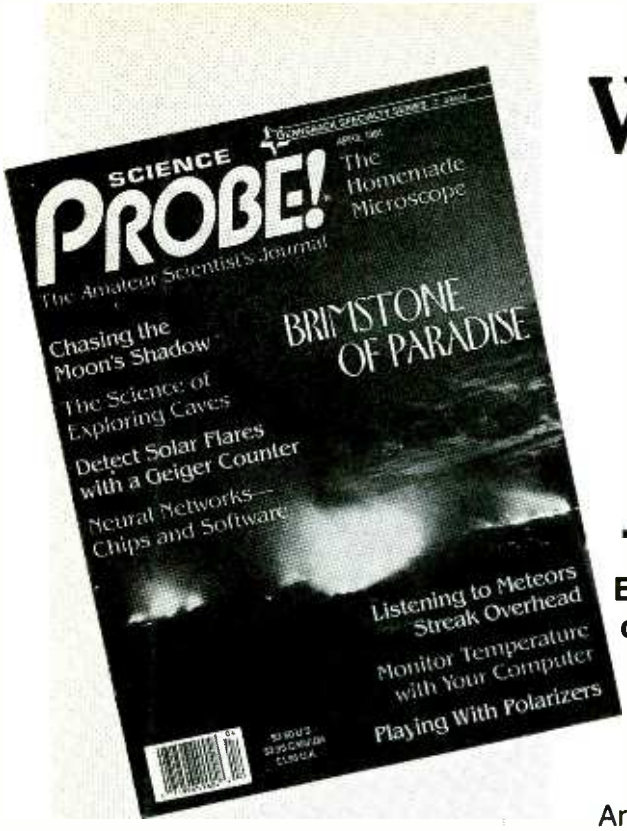

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SURE-LOCK OHMS

(Continued from page 101)

simplify the job of keeping track of where you are and where you are headed. The rotary switches in the prototype are actually 12-position switches, which for some reason are easier to locate than 10-position units, but either will do.

Once the board has been assembled, prepare the front panel of the enclosure using the layout shown in Fig. 4. The 24 holes in the front panel of the enclosure are spaced to match the spacing of the LED's that are mounted on the board.

In the author's arrangement, the LED's do not extend through the front panel of the enclosure, but instead are mounted so that the crest of the LED lenses rest on the inside surface of the enclosure at the proper positions so that lighted LED's can be seen. The off-board components, which consists of four switches (three rotary and one pushbutton), are positioned on the front panel as shown in Fig. 4.

There are several schemes that can be used to label the front panel of the enclosure—anything from rub-on letters to cut-out letters and numbers glued in place. The ten colors used to mark the switch positions can be made with marking pencils. After finishing with the front panel's lettering and coloring, give it a good coat of clear plastic spray.

Check Out And Use. To check the circuit's operation, first set the three rotary switches (S1–S3) to black-black-black and press S4. The 0 (LED10) and OHM LED's should light. Switch S1 to brown and LED1, LED10, and the OHM LED should light. Set S1 to brown, S2 to green, and S3 to red and you should read 1.5k with the decimal point indicator, LED24, flashing. Keep checking each switch out one position at a time to be sure there are no wiring errors between the switches and circuit board.

Position 9 (GOLD) on S3 does not indicate the resistor's tolerance, but is used to decode a resistor of 10 ohms or less. You won't come across such values too often, but when you do the circuit will read them, too.

You can also work backwards: If you need a particular value of resistance, but do not know the color code for that value, the circuit can be used to figure it out. Simply press switch S4 and hold while rotating switches S1–S3. For instance, let's say you need a 1.2k resistor. Simply rotate S1 until the 1-position LED, which is located in the rightmost column, lights; then do the same for S2 until the 2-position LED lights; and finally rotate S3 until the K LED lights.

Finding the color codes of resistors with values of a hundred-thousand ohms is only slightly more difficult, because the 0 LED must be taken into account. For example, if a 750k resistor is needed, you would rotate S1 and S2 as described above, but S3 must be rotated until both the K and 0 LED's light—that's 75 followed by 0 for 750, and the K to indicate that that number is multiplied by 1000 for a total value of 750,000 or 750k.

You'll soon discover that old timers and new comers alike will find Sure-luck Ohms a valuable ally in decoding those hard to remember color-code values. ■

PARTS LIST FOR SURE-LUCK OHMS

SEMICONDUCTORS

Q1, Q2–2N3904 or 2N2222 general-purpose NPN silicon transistor
D1–D17—1N914 general-purpose small-signal silicon diode
LED1–LED23—Jumbo red LED
LED24—Flashing (Radio Shack 276-036) or standard LED, see text

RESISTORS

(All resistors are ¼-watt, 5% units.)
R1–R6—470-ohm
R7–R9—270-ohm
R10—4700-ohm
R11—100,000-ohm
R12—1000-ohm

ADDITIONAL PARTS AND MATERIALS

B1—9-volt transistor-radio battery
S1–S3—SP10T or SP12T rotary switch, see text
S4—SPST normally-open pushbutton switch
Printed-circuit board materials, enclosure, battery holder and connector, knobs, wire, solder, hardware, etc.

Note: The following items are available from Krystal Kits, P.O. 445, Bentonville, AR 72712. A kit containing the circuit board and all parts (excluding the cabinet, switches, knobs, and flashing LED) is available for $14.95 postage paid; the circuit board only is available for $7.95 postage paid. Arkansas residents please add applicable sales tax.

VCR REPAIRS

(Continued from page 47)

lems in the tape path is a loop of tangled tape sticking out of the cassette when it's ejected. If that only happens on rare occasions, it may be caused by a problem in the cassette itself. But if it occurs on a regular basis, then suspect a slipping belt or idler. After the tape stops, the P guides retract and the tape is rewound a little to pull the loose loop back into the cassette. If the drive belt or idler to the reel hubs is slipping, then the tape may not fully rewind into the cassette before the eject sequence starts. You can correct this problem as described earlier.

If the VCR "eats" a tape when it malfunctions, you can sometimes still salvage the tape, at least for one more play so you can dub a copy. There is a small latch release button on the left side of the cassette near the door hinge. Press in on the latch release and lift up the door. Now put your finger into one of the reel holes on the bottom of the cassette and turn the reel to rewind the tape into the cassette. Try to smooth out any wrinkles or creases as you go.

Some tape damage isn't obvious unless you open the door on the cassette. A crinkled or scalloped edge on the top or bottom edge of the tape can be caused by a misaligned guide or an oil seal on the capstan that has moved out of position. First look at the capstan. If there is a small plastic disc on the shaft, that may be the problem. The plastic disc is an oil seal. It should be positioned directly on top of the bearing. If it rides up the capstan, it will rub against the tape and crinkle the edge. To solve this problem, push the oil seal back down to its original position.

If the capstan is fine, play a tape with the VCR case open and observe what happens. The edges of the tape may be rubbing against something, or one of the guides may be out of alignment. Adjust the guilty part.

Scratches that run along the length of the tape are usually caused by a foreign particle on some part of the tape transport. Using a cleaning tape may solve the problem. If not, visually inspect all of the guides and rollers. Use a cotton-tipped swab moistened with rubbing alcohol to remove any dirt or accumulations you find. Don't use alcohol or cotton swabs on the video head. Use only head cleaner and special head-cleaning swabs for that. ■

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PHB

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The professional discussions seen on the TV screen in your home reveals how to detect and disable wiretaps, midget radio-frequency transmitters, and other bugs, plus when to use disinformation to confuse the unwanted listener, and the technique of voice scrambling telephone communications. In fact, do you know how to look for a bug, where to look for a bug, and what to do when you find it?

Bugs of a very small size are easy to build and they can be placed quickly in a matter of seconds, in any object or room. Today you may have used a telephone handset that was bugged. It probably contained three bugs. One was a phony bug to fool you into believing you found a bug and secured the telephone. The second bug placates the investigator when he finds the real thing! And the third bug is found only by the professional, who continued to search just in case there were more bugs.

The professional is not without his tools. Special equipment has been designed so that the professional can sweep a room so that he can detect voice-activated (VOX) and remote-activated bugs. Some of this equipment can be operated by novices, others require a trained countersurveillance professional.

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This advertisement was not written by a countersurveillance professional, but by a beginner whose only experience came from viewing the video tape in the privacy of his home. After you review the video carefully and understand its contents, you have taken the first important step in either acquiring professional help with your surveillance problems, or you may very well consider a career as a countersurveillance professional.

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