1989

Radio Electronics

ELECTRONICS EXPERIMENTERS handbook™

JANUARY

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CIRCLE 21 ON FREE INFORMATION CARD

1989 ELECTRONICS EXPERIMENTER'S handbook

BUILD THIS


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TECHNOLOGY


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SURFACE-MOUNT TECHNOLOGY


page 107

CIRCUITS

NEW IDEAS

AND MORE

EDITORIAL

Diversity's the word!

Selecting the features that go into an annual like the **1989 Experimenter's Handbook** is no easy task. The editors must carefully examine the contents of a year's worth of magazines and make some tough decisions as to the relative "worth" of each article. Because an article's value depends to a large extent on who's doing the reading, we spend quite a bit of time thinking about *you*, the reader, and what you would most want to see.

Among our readers, two general characteristics are universal: You love to tinker, build, and experiment; and you are curious—not just about *how* things work, but also about *why* things work, and how you can make them work even better. That's where the similarities end: Among you are experienced engineers and students who are just starting out; computer whizzes and computer-phobics; audiophiles and automobile buffs; teenagers and retirees; and thousands of electronics technicians, servicemen, and hobbyists—all with their own tastes and preferences.

This years **Experimenter's Handbook** truly has something for everyone! Projects for the home—ranging from the simple *Phony Burglar Alarm* to *Phonlink*, a computerized home-control system. For your car, we have a digital dashboard, including a speedometer and tachometer to build and install. For video systems, there's our *Stereo-TV Decoder*, and a special SAP-decoder attachment for it. For improved signal reception, we present the *Miniature Wideband Amplifier* and for improved audio, a commercial zapper for your FM radio. For your test bench, build the *In-Circuit Digital IC Tester*. For holiday cheer, decorate the timely *Electronic X-Mas Tree*.

To satisfy your curiosity, we have articles on the latest in cellular-telephone technology and high-definition television. To stir your imagination we present a new theory about gravity and a glimpse of the automobile of the future. There's even a special section on Surface Mount Technology—including several SMT projects you can build yourself.

We've assembled a magazine brimming with information and challenges. Now it's your turn—to learn, to build on that knowledge, and to have a great time doing it!

—The Editors

1989 Electronics ELECTRONICS EXPERIMENTER'S handbook

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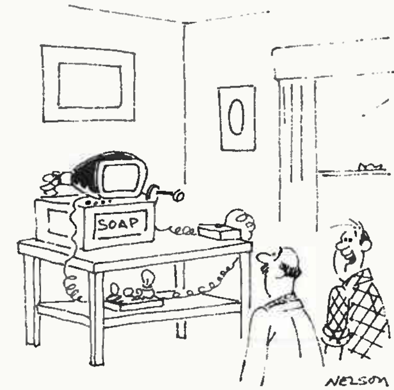
It started as a TV, then a computer. I thought, like wow, why not a stereo-satellite system too!



I built the TV myself from a kit.

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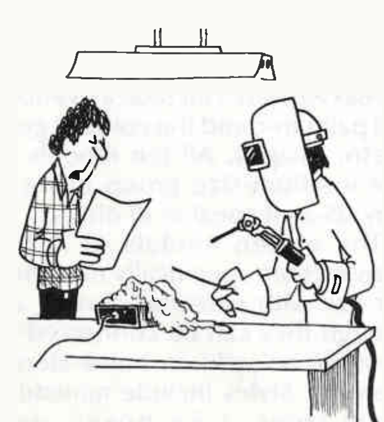
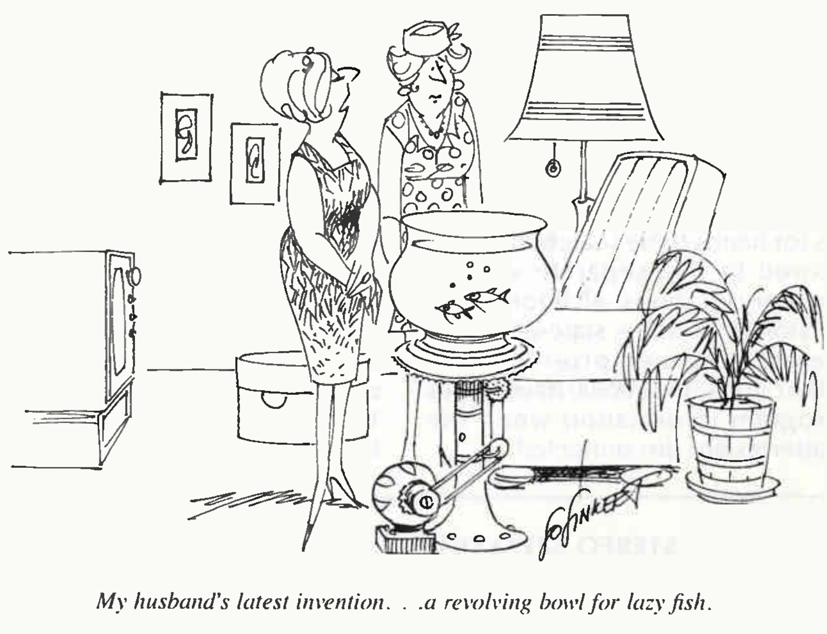
Yeah, yeah. . .it works! Now disconnect the battery!

SOUND FAMILIAR ??

You answer it! You couldn't wait to build a musical doorbell!



I'm not surprised that you're having problems. The plan says "solder"—not "weld"!



My husband's latest invention. . .a revolving bowl for lazy fish.

NEW PRODUCTS

CIRCLE 10 ON FREE INFORMATION CARD

PERSONAL SCANNING RECEIVER. AOR, Ltd's model *AR900* 100-channel hand-held receiver offers complete public-service band coverage. Frequency ranges of 25–54 MHz, 108–174 MHz, and 830–950 MHz allow coverage of all the police, fire, and emergency bands, as well as the new services now available above 800 MHz in 12.5-, 25-, and 30-KHz increments.

With the 25 front-panel keys, the user can program five banks of 20 channels, for a total of 100 channels. Pairs of upper and lower limits for bands to be searched can be stored in five separate search-memory locations. All information is stored in three state-of-the-art permanent memories. Unlike other units, the *AR900* never loses program information when the batteries are disconnected.

Other standard features on the model *AR9000* include first-channel priority, keyboard lockout, BNC-antenna connector, and a blue-green display that is back-lighted for night use. The LCD display offers 22 separate prompting annunciators to help the owner use the unit.

The scanning receiver weighs only 12 ounces, and measures 5¾ × 2⅛ × 1¾ inches. It can easily be carried in a pocket, with its standard belt clip, or in an optional leather case.

The *AR900*, including a 450 MAH rechargeable battery, an AC charger/adaptor, two antennas, and the belt clip, costs $299.00.—**Ace Communications, A Subsidiary of AOR, Ltd.**, Monitor Division, 10707 East 106th St., Indianapolis, IN 46256.

INFLATABLE STEREO SPEAKERS. Hyman Products' line of *Airwaves* speakers inflate anywhere, are easily portable, and require no batteries. They simply plug into personal stereos, boom boxes, and home stereos like conventional speakers.

Airwaves come in a variety of styles, including juke boxes, palm trees, a concert-style speaker, and cones and cubes decorated in colorful graphics. Three different size groups are available—Micro, Max, and Ultra Max.

Ultra Max *Airwaves*, the largest of the line, are offered in two styles. The Concert Speaker inflates to a 4 × 3-foot replica of a loudspeaker, and the 3½-foot Juke Box resembles a Wurlitzer. Both use a 2-way speaker system rated for 25-watts per channel (8 ohms).

CIRCLE 11 ON FREE INFORMATION CARD

Max *Airwaves* include a five-foot tall palm tree and the colorful geometric shapes. All ten models in the medium-size group use a 1-way, 25-watt speaker (8 ohms).

The eleven models of Micro *Airwaves* are specifically designed for use with personal stereos, although they can be connected to headphone jacks in home-stereo systems. Styles include miniature palm trees, juke boxes, and guitars, as well as cones, spheres, and cubes. The spheres measure 16 inches in diameter; all other Mi-

Electronics Paperback Books

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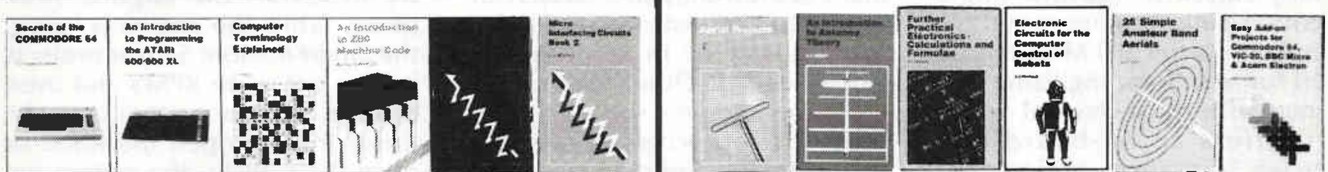

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Quality Paperbacks

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☐ **BP110—HOW TO GET YOUR ELECTRONIC PROJECTS WORKING ..... $5.75.** How to find the faults in your projects, repair them and get them working.

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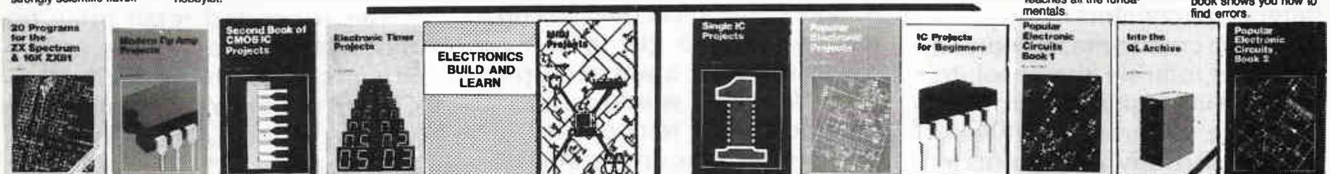
Affordable Prices



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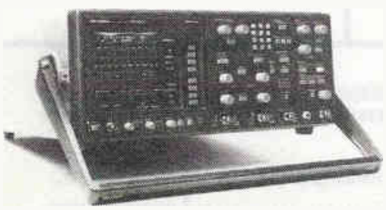
cros are 12 inches or less in their longest dimensions.

Ultra Max and Max *Airwaves* are sold individually, for the suggested retail prices of $80.00 and $30.00, respectively. Micro *Airwaves* are sold in pairs for a suggested retail price of $30.00.—**Hyman Products, Inc.**, 2392 Grissom Dr., St. Louis, MO 63146; 800-235-1542.

HIGH-RESOLUTION DIGITAL-STORAGE OSCILLOSCOPE. The Philips *PM 3320A* digital-storage oscilloscope, with 200-MHz bandwidth, real-time sampling rate of 250 MS/s, and 10-bit resolution, is ideally suited to capture single events. Using random repetitive sampling, its full 200 MHz can be used for waveform digitizing and storage. The dual-channel scope also offers an on-board Fast Fourier Transform option that gives the user an overview of the frequency spectrum of the incoming signal.

Two powerful acquisition modes are available to capture signal details exceeding preset limits: Save-on-Difference and Stop-on-Difference. Those features compare the incoming waveform with one in memory, and record the new waveform. The time of capture is noted as soon as a difference appears between the two signals due to jitter, spikes, or amplitude variations. The Absolute Min/Max function creates an historical record of a large number of traces, and can be used to set the Save/Stop-on Difference parameters.

Extensive cursor-measurement capabilities indicate the absolute level of the input signal to ground, the voltage difference between two channels at any given points in time (the *PM 3320A* automatically accounts for the attenuator settings), and the time difference between any points—even between two channels.



CIRCLE 12 ON FREE INFORMATION CARD

Other automatic-measurement functions are RMS voltage, percentage overshoot and preshoot for step functions, and continuously variable rise and fall times—including the two preset options of 10–90 percent and 20–80 percent for ECL applications. The *PM 3320A* also provides automatic pulse width, duty-cycle and phase measurements, division for ratio measurements, integration, and differentiation.

For ease of operation, the Autoset function automatically selects amplitude, timebase, and triggering for instant display of any input signal at the touch of a button. As many as 250 front-panel setups can be stored and instantly recalled—individually or in sequence—when needed. Other features include menu-driven softkey operation for direct access to over 200 subsidiary functions, an oversized CRT for enhanced on-screen display, and IEEE-488 or RS-232 compatibility for systems use and for hard-copy output to plotters and printers.

The Philips *PM 3320A* digital storage oscilloscope has a suggested list price starting at $8,990.00.—**John Fluke Mfg. Co., Inc.**, P. O. Box C9090, Everett, WA 98206; 800-443-5353, ext. 77.

REMOTE ENGINE STARTER. Clifford Electronics' *Smart Remote Starter* lets the owner start his car's engine and accessories from as far as 400 feet away, with a miniature remote control. He then has up to ten minutes to get to the car, which will have a warmed-up engine, defrosted windows, a comfortable interior temperature, and preset selections on the stereo.

The system—whose artificial-intelligence algorithm uses parallel processing with dual high-speed microprocessors—starts, supervises, and controls the starter, engine, brakes, transmission, and accessories. As soon as the remote control's digital-code signal is received (which the system acknowledges by flashing the car's parking lights), several safety checks are automatically performed. Once all safety checks pass, the engine is started, and any preset accessories are activated.

CIRCLE 13 ON FREE INFORMATION CARD

If the engine doesn't start, or starts and then stalls, the Auto-Restart feature will automatically try to restart the engine three times. While the engine is idling, the *Smart Remote Sensor* protects it from excessive RPM's and overheating. If anyone other than the driver tries to open the hood or drive the vehicle, the system immediately shuts down the engine. It will even prevent grinding of the starter if the driver inadvertently tries to start the engine when it's already running.

For safety reasons, the system is designed to work only on vehicles with automatic transmissions and electronic fuel injection. The system can recognize if anyone tries to use it on another type of vehicle, and will turn itself off.

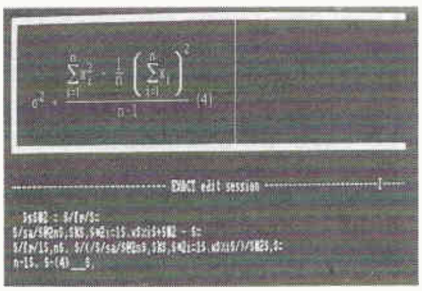
The *Smart Remote Starter* can easily be programmed to respond to as many as three additional Clifford remote controls, even if each one uses a different digital code or is of a different type.

The suggested retail price for the *Smart Remote Sensor*, including installation, is $550.00.—**Clifford Electronics**, Customer Service Department, 20750 Lassen St., Chatsworth, CA 91311

MATHEMATICAL-TYPESETTING. Technical Support Software's *EXACT 3.1* mathematical-typesetting program allows users to add complex mathematical expressions to documents produced in WordPerfect 5.0 or Microsoft Word 4.0.

EXACT is a RAM-resident program that cooperates with the user's word processor to allow creation of complex mathematical expressions. Because it automatically shares the screen and the printing function with the word processor, the manufacturer provides options to ensure word-processor compatibility. *EXACT 3.1* is also compatible with the latest releases of WordStar, Multimate, Displaywrite, Samna, and most other PC-based word processors. A free demo disk is provided, allowing users to test compatibility with their own word processors.

The program loads into RAM before the word processor. At any time during the creation of a document, the user can call a pop-up split-screen Edit Session. As the user types *EXACT* commands in the bottom screen, the mathematical expression is instantly created in the top screen. The act of editing the commands results in immediate update and redisplay of the mathematics.



CIRCLE 14 ON FREE INFORMATION CARD

A mathematical expression can be edited easily on screen by changing the command lines. Radicals, fractions, brackets, and tables automatically rescale when the material they contain is edited, so that the user immediately sees the effect of each change on the entire expression.

Once the expression looks right, the user exits the edit session and returns to the word processor. By positioning the cursor at the appropriate place in the text, the command lines created in the edit session are injected directly into the text. When printing, *EXACT* intercepts the print stream, scans it for *EXACT* commands, and sends a graphic image to the printer to construct the mathematical expressions.

Mathematical features include complete Greek-character sets in upper and lower case; unlimited levels of superscripts and subscripts; automatic equation centering, automatic positioning of equation numbers; and automatic creation of boxes, borders, script, and italic alphabets.

The software package includes 20 fonts with over one thousand symbols and characters. Any character can be rescaled up to 81 times its size. The package also contains a font editor that allows users to create their own characters and use them as easily as the standard fonts. *EXACT* can be used to remap the keyboard to allow typing in user-developed foreign fonts such as Russian or Hebrew.

Drivers are available for all common dot-matrix and laser printers. *EXACT* requires 64K to 128K of RAM, depending on the number of fonts loaded at one time. The program runs on IBM PC, AT, XT, and compatibles, with any graphics card. It is also available in the Hercules high-resolution format.

The suggested retail price for *EXACT 3.1* is $475.00.—**Technical Support Software Inc.**, 72 Kent St., Brookline, MA 02146.

NEW BOOKS

DIRECTORY OF AMERICAN RESEARCH AND TECHNOLOGY 1988; R.R. Bowker Company, Customer Service, P. O. Box 766, New York, NY 10011; 763 pages, including indexes; 8¾ × 11¼ inches; hardcover; $199.95.

Over 11,500 organizations at the forefront of scientific research—including almost 1,000 new research and development firms—are profiled in the 1988 edition of *Directory of American Research and Technology.* Detailed information is provided on corporate and university facilities, including parent organizations and their subsidiaries, in over 1,500 fields of scientific research. Listed alphabetically by company name, each entry provides address and phone number, research-staff size, and descriptions of all research and development activities. Facilities are identified as commercial, nonprofit, or privately financed. Three indexes are organized by personnel, geography, and classification.

Aimed at working scientists, R&D administrators, corporate recruiters, and business or research libraries, the directory also reflects the ever-changing world of industrial research by documenting emerging technologies and new research functions. Among this year's new entries are firms investigating internal hearing aids, holography, machine vision, satellite-TV systems, radar-warning devices, and electron sterilization systems.

SHORTWAVE DIRECTORY, by Bob Grove; Grove Enterprises, P. O. Box 98, Brasstown, NC 28902; approximately 500 pages, including glossary and cross-reference table; 8½ × 11 inches; softcover; $17.95 + $2.00 shipping in U.S.; + $7.50 shipping in Canada; other foreign countries add $7.50 (surface) or $25.00 (air).

The fourth edition of *Shortwave Directory* has been revised and expanded to include international broadcasting and Very Low Frequency (VLF). The book contains accurate, up-to-date frequency listings from 10 kHz to 30 MHz, and includes U.S. and foreign Air Force, Navy, Coast Guard, Army, Energy and State Departments, FBI networks, aircraft and ships, scientific installations, pirates and clandestines, space support, RTTY and FAX, INTERPOL, and English-language broadcasters worldwide.

Most stations are cross-referenced by agency and frequency for rapid identification of unknowns. The 1988 edition contains an exhaustive glossary of terms, acronyms, and abbreviations commonly encountered on the shortwave-radio bands.

HOW TO TEST ALMOST EVERYTHING ELECTRONIC, 2nd Edition, by Jack Darr and Delton T. Horn; TAB Books Inc., Blue Ridge Summit, PA 17294-0850; 175 pages, including index; 7¼ × 9¼ inches; softcover; $8.95.

Radio-Electronics' service editor, Jack Darr, teams with professional technician Delton T. Horn to produce this updated version of their 20-year-old *How to Test Almost Anything Electronic.* Some things remain the same: the basic principles of troubleshooting and interpreting test results; easy-to-follow instructions for using electronic test equipment; examples of typical circuit types. The descriptive overview of electronic test equipment, which includes ammeters, voltmeters, oscilloscopes, logic probes, analyzers, and more, has been updated to reflect the latest equipment. The book has been expanded to include new circuitry developments and the basics of digital electronics.

Most of the book details actual test procedures—including power-supply and DC-voltage tests, VOM and VTVM tests, signal tracing and alignment, oscilloscope and component tests, and TV tests. Those basic troubleshooting techniques are presented with the same emphasis on practical experience and common sense that has made Jack Darr's advice invaluable to technicians and servicemen for decades.

ENGINEERING EXCELLENCE, edited by Donald Christiansen; IEEE Publications Sales Office, 445 Hoes Lane, Piscataway, NJ 08855-1331; 263 pages, including index; 6 × 9¼ inches; hardcover; $24.55 for IEEE members, $32.75 for nonmembers; be sure to use code number *PC02188* when ordering.

At an international convocation in 1986, more than 20 eminent engineers, engineering managers, and sociologists met to consider how the varying cultural traditions in different countries might affect the quality of engineering and the way that engineers are managed and rewarded. The participants represented Japan, Germany, Holland, and the United States; the substance of their presentations forms the major part of *Engineering Excellence.*

The book provides engineering practitioners and entrepreneurs with interesting insights into the forces at work in the global high-technology marketplace. *Engineering Excellence* is divided into four sections. The first three cover the importance of the individual engineer, a comparison of engineering cultures, and institutional and organizational structures. The final section is a selection of writings comprising first-hand observations by engineering leaders who describe how they built successful technical organizations, and how they deal with pressures stemming from today's highly competitive global business climate.

RADIO WAVE PROPAGATION, by Lucien Boithias; McGraw-Hill, 11 West 19th St., New York, NY 10011; 330 pages, including appendixes, index, and bibliography; 6 × 9 inches; hardcover; $49.95.

Understanding propagation phenomena is crucial when planning communications links and designing systems to minimize interference. Aimed primarily at electrical and electronics engineers, *Radio Wave Propagation* provides a complete, practical overview of the field.

The first six chapters deal with line-of-sight propagation, beginning with open-space propagation and a discussion of major physical phenomena such as reflection, refraction, and scattering. Effects of the ground and the troposphere are also covered here.

The remainder of the text deals with propagation that is not line-of-sight, addressing the three main mechanisms allowing links to be established between two points which are not visible to each other: diffraction by hills, scatter by Earth's curvature and the troposphere, and reflection by the ionosphere. There is also a discussion of how to solve the problems of electromagnetic disturbance and interference from other transmissions and radiation.

MODERN RELAY TECHNOLOGY, by Hans Sauer; Aromat Corporation, Marketing Dept., 629 Central Avenue, New Providence, NJ 07974; 357 pages, including tables, references and indexes; 6 × 8½ inches; hardcover; $8.95, including shipping and handling.

This comprehensive reference book, translated from the original German by J.G. Naples, covers 240 relay types and 6,000 relay characteristics. It examines the history of relay technology, and looks at its future. Terms, definitions, and formulas are presented, followed by applications of electromechanical and solid-state relays. Those include measuring applications, time-delay relays, simple timing circuits; automatic control systems, and stepper relays. There are 50 illustrated tables, and translations of terminology into German, French, and Italian.

TOD T. TEMPLIN

STEREO TV DECODER

Build your own high-fidelity MTS decoder for the finest in TV enjoyment.

A RECENT SURVEY OF TELEVISION STATIONS across the U. S. and Canada reveals that more than 250 stations are now transmitting MTS stereo TV sound. So chances are good that at least one station in your area is transmitting stereo audio right now. You might think that you need a stereo TV or VCR to enjoy MTS, but consider this: For about $50 (for all new parts), you can build our add-on converter, which will work with virtually any TV or VCR. All components are readily available, and we've designed a PC board, which simplifies construction greatly. The circuit may be aligned by ear, although using an oscilloscope will give more precise results

Background

To understand how we can enjoy MTS sound, let's look back to when color-TV standards were formed. In 1953 the NTSC (*N*ational *T*elevision *S*ystems *C*ommittee) defined the standards for color-TV broadcasting that are now used in the U. S., Canada, Mexico, and Japan.

In the NTSC system, 6 MHz is allocated for each television channel, as shown in Fig. 1. Video information is transmitted on an amplitude-modulated carrier that extends about 4.2 MHz above the visual carrier. Mono audio is transmitted on a frequency-modulated carrier 4.5 MHz above the video carrier, with 100% modulation causing a 25-kHz deviation of that carrier. So a fully modulated mono signal causes the carrier to vary between 4.475 and 4.525 MHz around the carrier.

By subtracting 4.2 MHz (top of video) from 4.475 MHz (bottom of audio), we find that there is 275 kHz of unused spectrum. That space was originally allocated as a guard band by the NTSC. The reason the guard band was necessary was that the tube-based circuits of that era were less capable of keeping the audio and the video portions of the signal separate than modern solid-state circuits. It is that 275-kHz gap that allows us to have MTS sound today.

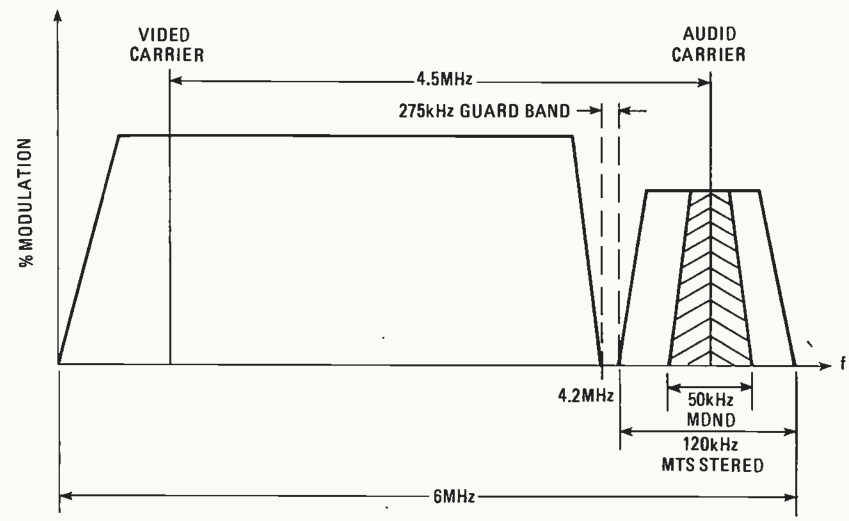


FIG. 1—STEREO-TV AUDIO requires about twice the bandwidth of a mono signal.

On March 29, 1984, the BTSC (the *B*roadcast *T*elevision *S*andards *C*ommittee, which is the present-day equivalent of the NTSC), proposed guidelines to the FCC (in BC docket 21323) for TV stations using the BTSC system of multichannel sound transmission. That docket contains general technical rules governing the use of the television audio baseband for use in the transmission of stereo television sound, as well as a second-language channel (SAP, for *S*econd *A*udio *P*rogram), and a professional channel. (The alternate services were discussed in "Stereo Audio for TV," **Radio-Electronics,** February and March 1985, and in "Stereo TV Decoder," in the March 1986 issue of **Radio-Electronics.**—*Editor*)

As in the NTSC system, the baseband mono audio signal (which is the equivalent of the L+R stereo signal) has a bandwidth of about 15 kHz. It is transmitted with 75 μs of pre-emphasis, and has a maximum deviation of 25 kHz.

At 15.734 kHz is the BTSC pilot tone. The pilot is locked to horizontal sync, and it is used to identify the signal as a BTSC transmission, thus informing the television receiver to switch from mono to stereo reception. The pilot has a 5-kHz deviation.

Then comes the stereo difference signal (L−R). It is amplitude modulated on a 31.468 kHz subcarrier, producing a double-sideband suppressed-carrier signal that spans about 30 kHz. That subcarrier frequency was chosen because it is exactly twice the NTSC horizontal sweep frequency, and is, therefore, easily synchronized during both transmission and reception.

NOISE REDUCTION

THE STEREO DECODER DESCRIBED IN THIS article doesn't use a true dbx decoder. When we first decided to build an MTS decoder, we contacted the engineers at dbx Corporation in an attempt to obtain engineering samples of their decoder IC's. As you may know, however, dbx Corporation does not sell those IC's to unlicensed persons or companies, and that includes hobbyists. We were discouraged, but decided to go ahead and build a converter without the dbx IC's, and see just how well it could be done.

The decoder presented here is the result of that effort, and we believe that it performs as well as many commercial units. In addition, none of the electronic components used are difficult to obtain. Also, due to a very flexible design, you can interface the decoder to almost any TV or VCR and obtain very good results. **R-E**

The L − R signal is also compressed by a complex noise-reduction technique known as dbx television noise reduction. (See the sidebar for more on dbx.) The level of the L − R signal is adjusted to produce 50 kHz of deviation.

At 78.67 kHz (five times the horizontal sweep rate) is the SAP subcarrier. It is limited to 10-kHz of deviation and is also dbx compressed.

Last, at 102.3 kHz (6.5 times the horizontal sweep), is the subcarrier for the professional channel. It is not compressed and is limited to about 3-kHz of deviation.

If the deviations of all sub-channels are added together, the total is 98 kHz (25 + 5 + 50 + 15 + 3). However, the total deviation is not allowed to exceed 73 kHz (50 + 15 + 3), because the sum of the deviations of the L + R and L − R signals is limited to 50 kHz. Although that total is greater than the deviation of a plain mono transmission, it fits into the guard band with room to spare.

If you're familiar with the stereo system used for FM radio transmissions, you'll notice that the stereo portion of the BTSC system is essentially the same as that used in FM radio, disregarding the SAP and professional channels. In fact, the main differences are the slightly different frequencies of the pilot and the L − R subcarriers. We can take advantage of those similarities by using an IC that is normally used to decode FM radio signals. Doing so simplifies our design and reduces costs considerably.

The circuit

A block diagram of the stereo-TV decoder is shown in Fig. 2. It shows the overall relationships between the separate sections of the circuit; Figures 3–6 show the details of each subsection.

Let's start with the decoder section (shown in Fig. 3). It centers around IC1, a

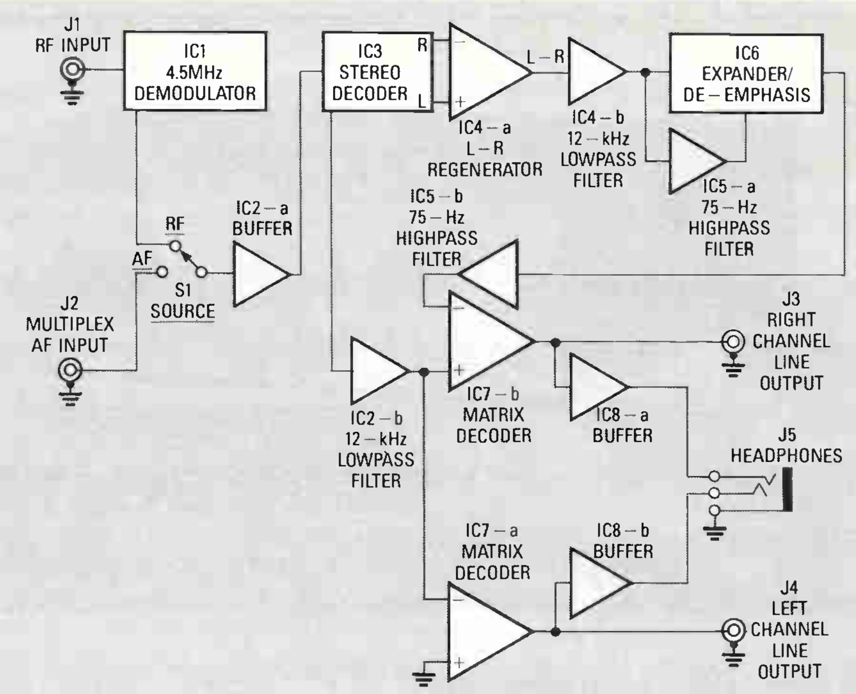


FIG. 2—EIGHT INEXPENSIVE IC'S are all it takes to provide a high-quality MTS decoder.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—120 ohms
R2, R7, R35, R37—10,000 ohms
R3, R23, R49, R53, R54—10,000 ohms, trimmer potentiometer
R4, R6, R11, R12, R42, R43, R44, R46, R48, R50, R51, R59, R60—100,000 ohms
R5—2200 ohms
R8—10 ohms
R9, R24, R31, R57, R58, R63—1000 ohms
R10, R16, R17, R28—3300 ohms
R13—330,000 ohms
R14, R15, R21, R62—4700 ohms
R18—12,000 ohms
R19—25,000 ohms, trimmer potentiometer
R20—4300 ohms
R22, R27—5100 ohms
R25—5,000 ohms, trimmer potentiometer
R26—1500 ohms
R29—30,000 ohms
R30—18,000 ohms
R32, R33, R39, R40—20,000 ohms
R34, R41, R55, R56—39,000 ohms
R36, R38—22,000 ohms
R45—68,000 ohms
R47—470,000 ohms
R52—100,000 ohms, dual-gang potentiometer
R61—330 ohms

Capacitors

C1, C4, C13, C32—0.01 µF, ceramic disk
C2, C9, C19—470 pF, ceramic disk
C3, C14—0.05 µF, ceramic disk
C5—5–60 pF, trimmer
C6—10 pF, ceramic disk
C7, C8, C10, C11, C27, C38, C47—1 µF, 50 volts, electrolytic
C12, C23, C25—0.0022 µF, ceramic disk
C15, C30, C34–C37—0.22 µF, ceramic disk
C16, C17—0.47 µF, ceramic disk
C18—0.0047 µF, ceramic disk
C20, C21—0.0015 µF, ceramic disk
C22, C24—0.0039 µF, ceramic disk
C26, C29—0.015 µF, ceramic disk
C28, C31, C39–C46—10 µF, 50 volts, electrolytic
C33, C50–C53—2.2 µF, 50 volts, electrolytic
C48—2200 µF, 50 volts, electrolytic
C49—470 µF, 50 volts, electrolytic

Semiconductors

IC1—MC1358 stereo demodulator
IC2, IC4, IC5, IC7, IC8—LM358 dual op-amp
IC3—LM1800 stereo decoder
IC6—NE570 compander
D1, D1—1N4002 rectifier diode
LED1, LED2—standard
Q1, Q3—2N3904 NPN transistor
Q2—2N3906 PNP transistor
Q4—2N2222 NPN transistor

Other components

F1—¼-amp, 250-volt fuse
J1–J4—RCA phono jack
J5—stereo headphone jack
L1—33 µH S1—SPDT toggle switch
S2—SPST toggle switch
T1—10.7 MHz IF transformer
T2—25-volt CT power transformer

Note: A drilled, etched, and plated PC board is available from T³ Research Inc., 5329 N. Navajo Ave., Glendale, WI 53217 for $10 plus $0.75 postge and handling. WI residents add 5% sales tax.

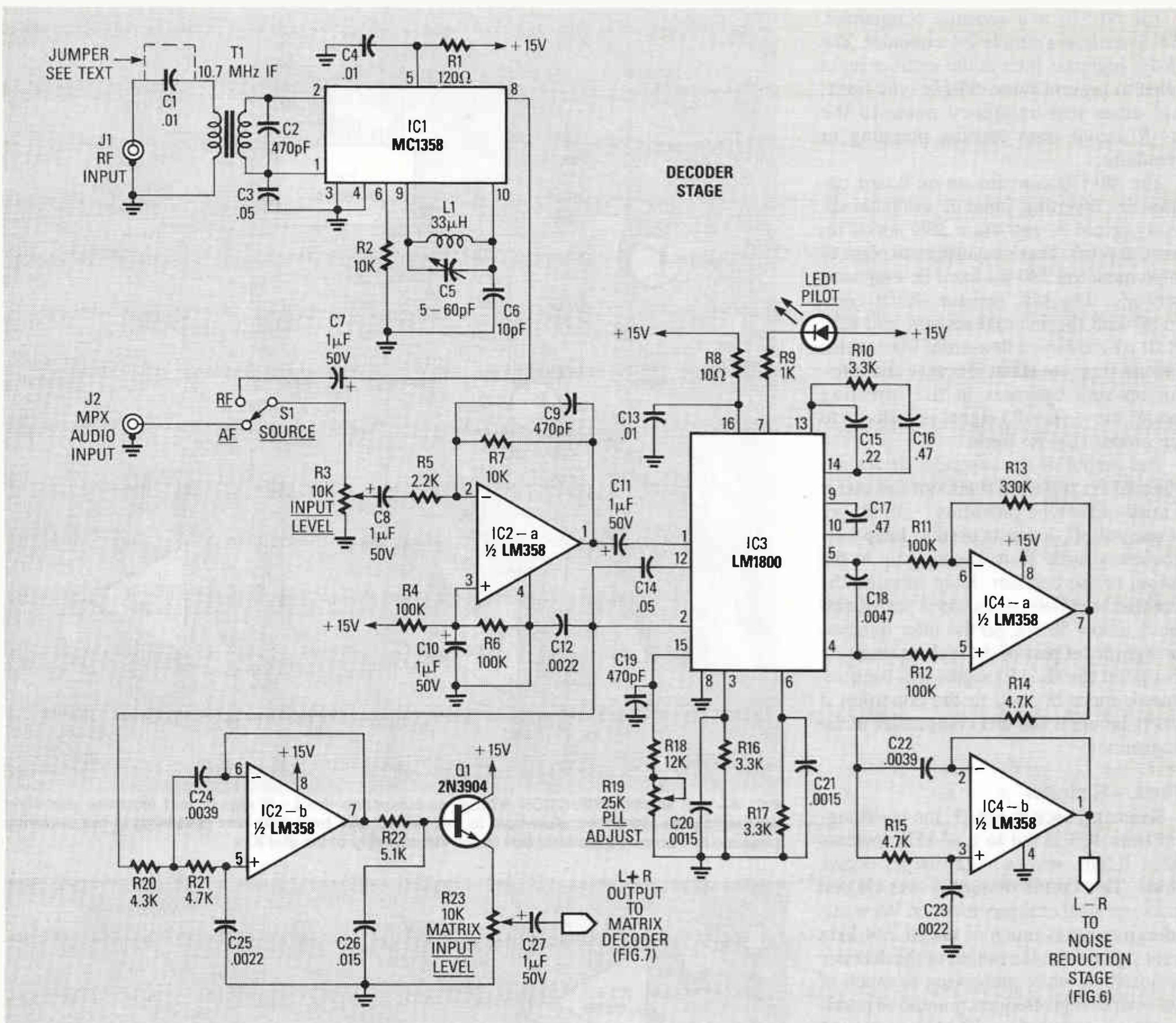


FIG. 3—THE DECODER STAGE converts the multiplexed audio signal into L + R and L − R signals.

standard 4.5-MHz audio demodulator that is used in many television receivers. The circuit is more or less what you find in the databook. The major exception is that the standard de-emphasis capacitor has been eliminated in order to ensure that the L − R signal is presented to the decoder. If present, the capacitor would roll off the high-frequency L − R signal.

The output of IC1 is routed to S1, which allows you to choose between the internally demodulated signal and an externally demodulated one. Buffer amplifier IC2-a then provides a low-impedance source for driving IC3, an LM1800 stereo demodulator. As with IC1, IC3 is used in a conventional manner. Our circuit differs from the cookbook circuit, however, in that the component values associated with the phase-locked loop have been altered so that the loop will lock on the 15.734-kHz MTS pilot rather than on the 19-kHz FM-radio pilot.

When IC3 is locked on a stereo signal, the outputs presented at pins 4 and 5 are the discrete left- and right-channel signals, respectively. In order to provide noise reduction to the L − R signal, we must re-combine the discrete outputs into sum and difference signals. Op-amp IC4-a is used to regenerate the L − R signal. It is wired as a difference amplifier, wherein the inputs are summed together (+L − R). Capacitor C18 bridges the left- and right-channel outputs of the demodulator. Although it decreases high-frequency separation slightly, it also reduces high-frequency distortion. After building the circuit, you may want to compare sound output with and without C18.

The L + R signal is taken from the LM1800 at pin 2, where it appears conveniently at the output of an internal buffer amplifier.

The raw L − R signal is applied to IC4-b, a 12-kHz lowpass filter. The L + R signal is also fed through a 12-kHz lowpass filter in order to keep the phase shift undergone by both signals equal. If only one were filtered, there would be a loss of high-frequency separation when the left and right channel signals were recovered.

Next, as shown in Fig. 4, the L − R signal is fed to Q2. That transistor has three functions. It allows us to add a level control to the L − R signal path; it provides a low source impedance for driving the following circuits; and it inverts the signal 180°. (Think of the signal at the collector of Q2 as −(L − R)). Inversion is necessary to compensate for the 180° inversion in the compander.

Next comes the expander stage; this is where we would use a dbx decoder if we could get one (see sidebar). At the collector of Q2 is a 75-μs de-emphasis network (R27 and C29) that functions just like the network associated with Q1 (in Fig. 3). Note that Q2 feeds both Q3 and IC5-a, a −12 db per octave highpass filter. The output of that filter drives the rectifier input of IC6, an NE570.

The NE570 is a versatile compander. We'll use it as a simple 2:1 expander. The 75-Hz highpass filter at the rectifier input helps to prevent hum, 60-Hz sync buzz, and other low-frequency noise in the L − R signal from causing pumping or breathing.

The NE570 contains an on-board op-amp; its inverting input is available directly at pin 5, and via a 20K series resistor at pin 6. That's a convenient place to implement the 390-μs fixed de-emphasis network. The 18K resistor (R30) combines with the internal resistor and C32 (0.01 μF) to form a first-order filter with a 390-μs time constant. Because the internal op-amp operates in the inverting mode, the −(L − R) signal is restored to the proper (L − R) form.

The output of the expander drives another 75-Hz highpass filter, but this one is a third-order type providing −18 db per octave rolloff. It too is used to keep low-frequency noise from showing up at the output of the decoder. Keep in mind the fact that television audio does not extend much below 50 Hz, so the filter removes no significant part of the audio signal. At this point the (L − R) signal has been restored, more or less, to the condition it was in before it was dbx companded at the transmitter.

The L + R signal

Referring back to Fig. 3, the L + R signal from IC3 is fed to a 12-kHz lowpass filter, IC2-b, with a −12 dB per octave slope. That cutoff frequency was chosen in a somewhat arbitrary manner. We wanted to remove as much of the 15.734-kHz pilot signal from the output of the decoder as possible, while preserving as much of the desired high-frequency audio as possible. So we settled on 12 kHz as a good compromise.

The output of the highpass filter is applied to a 75-μs de-emphasis network (R22 and C26). The L + R audio signal is now restored properly. We feed it through Q1, which is wired as an emitter follower to provide a high load impedance for the de-emphasis network and a low source impedance for level control R23. Next the L + R signal is fed to the matrix decoder, shown in Fig. 5.

Left and right recovery

Op-amps IC7-a and IC7-b are used to recover the individual channels. First, IC7-b is configured as unity-gain difference amplifier. The (L + R) is applied to its inverting input, and the (L − R) signal is applied to the non-inverting input. Therefore the output of IC7-b may be expressed as $-(L+R) + (L-R) = -L + L - R - R = -2R$. Similarly, IC7-a is configured as a mixing inverting amplifier. Here, however, both sum and difference signals are applied to the inverting input. So the output of IC7-a is −(L + R)

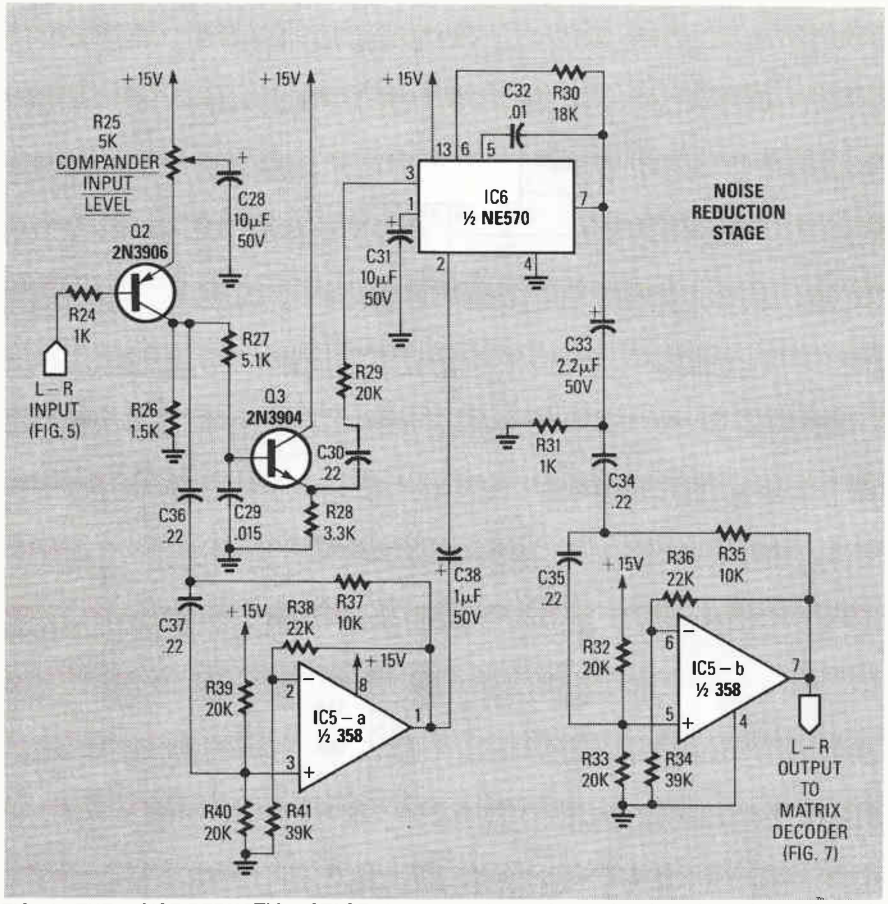


FIG. 4—THE NOISE-REDUCTION STAGE de-compands the L − R signal, and emulates dbx-style processing. As described elsewhere in this article (see box), true dbx procesing is not currently possible in a home-built circuit due to the inavailability of the dbx IC's.

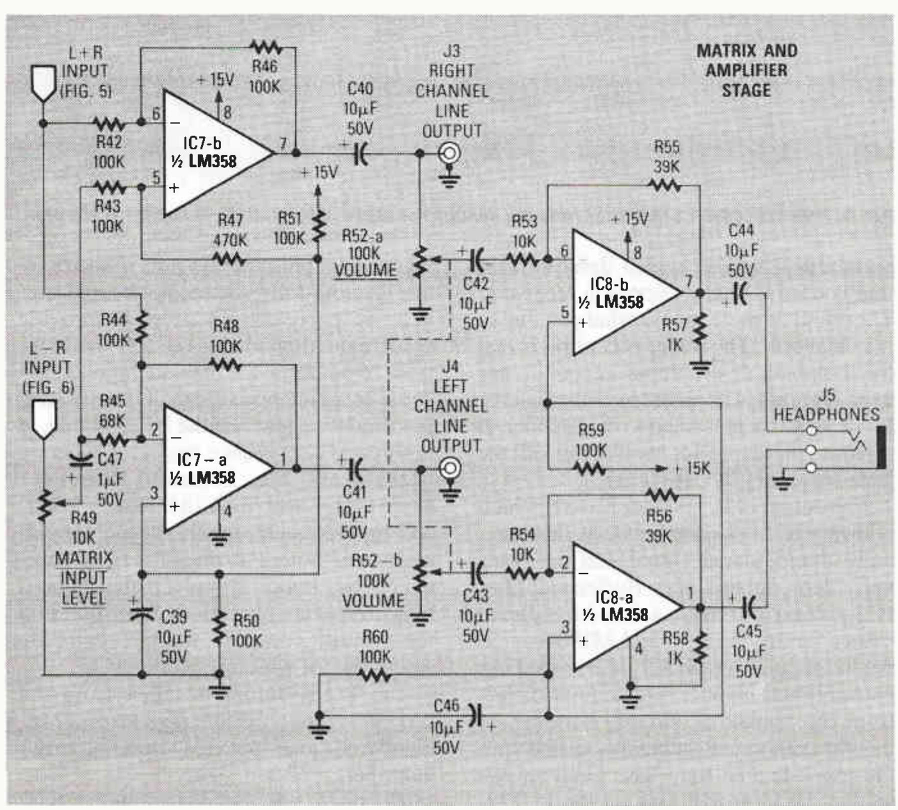


FIG. 5—THE MATRIX STAGE separates the L + R and L − R signals into the left- and right-channel components. Op-amp IC8 and associated components provide an optional headphone output. If you do not wish to drive a pair of headphones, or plan to use your amplifier's headphone jack for that purpose, all components to the right of jacks J3 and J4 can be deleted.

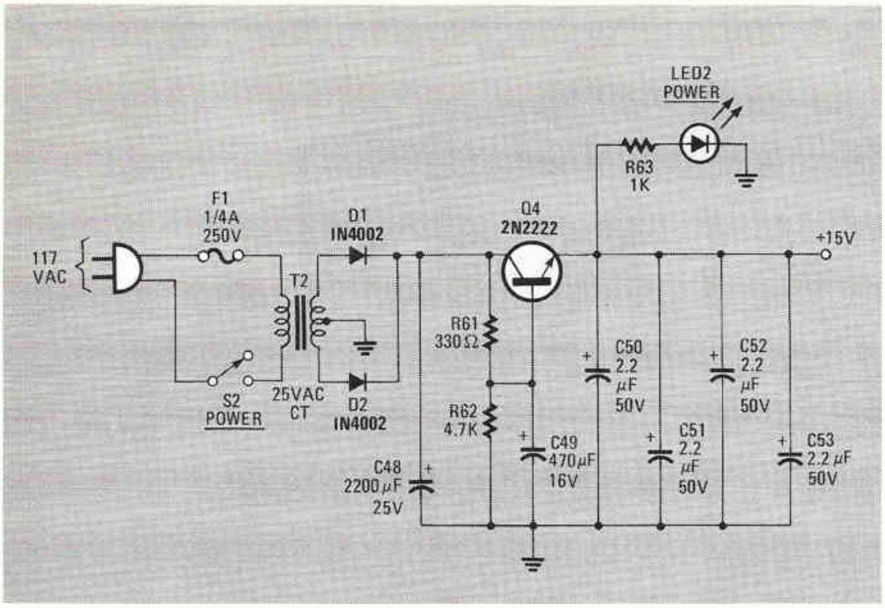


FIG. 6—THE UNREGUALTED POWER SUPPLY shown here provides extremely low ripple for the MTS decoder.

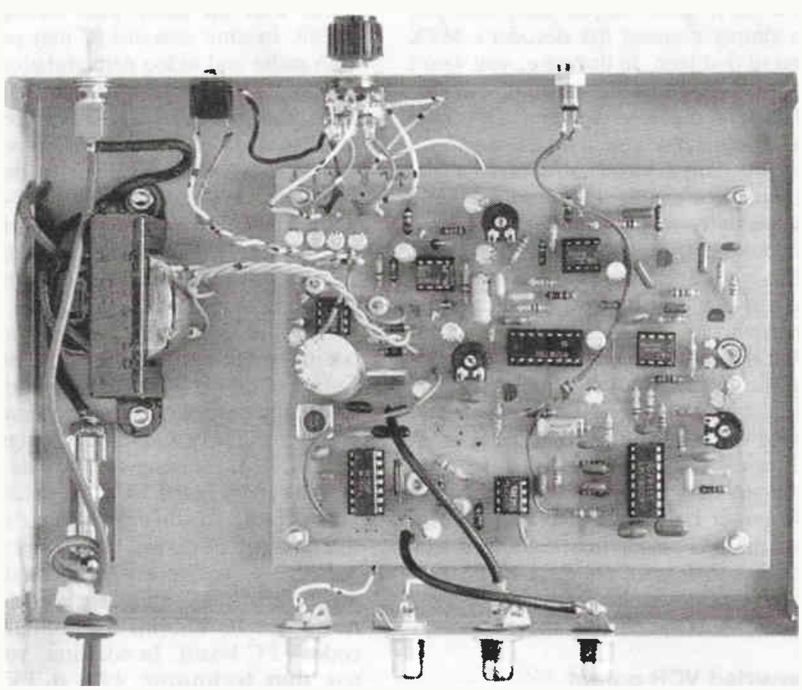
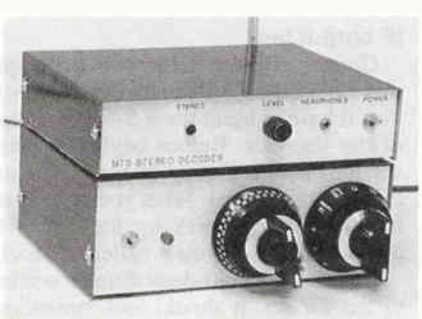


FIG. 7—THE COMPLETED STEREO DECODER BOARD. Next time, we'll show you how to build the circuit shown here.



AN OUTBOARD TUNER lets you use the circuit with a TV that lacks audio outputs. Next time, we'll see many other ways of using the circuit.

$-(L-R) = -L-R-L+R = -2L$. Because both channels have been inverted, the stereo relationship is preserved.

The two op-amps in IC8 provide an additional stage of amplification to drive a pair of stereo headphones. If you don't plan to use headphones, or if you are content to use only your stereo's headphone jack, all components to the right of line-output jacks J3 and J4 may be deleted.

The schematic of the decoder's power supply is shown in Fig. 6. It provides an unregulated 15-volt DC output. Transistor Q4 is used as a capacitance multiplier, to provide high ripple reduction. The four 2.2-μF capacitors (C50–C53) are distributed on the P.C board (which we'll show next time) to keep the impedance of the power-supply rails low. That's important to minimize crosstalk between different sections of the unit.

As shown in Fig. 7, most of the circuitry we've described mounts on a single PC board. Unfortunately, we've run out of space for this month. When we continue we will show you how to build the circuit, as well as several methods of connecting the unit to a TV or VCR. At that time, the PC pattern will be provided. If you wish to get a head start, and are planning to purchase a pre-etched board, you can order one from the source provided in the Parts List. **R-E**

COMPENSATION

THE MARCH 1985 ISSUE OF **RADIO-ELECtronics** has a good description of the dbx system, but we'll summarize the salient features here. Keep in mind the fact that dbx operates only on the stereo difference signal (L − R).

- The signal is compressed at transmission by a fixed ratio of 2 to 1.
- The signal is pre-emphasized by a combination of 75-μs and 390 μs networks.
- The signal is spectrally companded by a variable ratio that depends on broadband frequency balance and signal level.

Of those three functions, spectral companding is the most difficult to compensate for. We include de-compression circuits and the proper de-emphasis networks, but we decided not to include spectral de-companding in our decoder, based on the following rationale.

Spectral companding's primary function is to mask high-frequency noise when the signal is composed primarily of low frequencies at relatively low levels. It does so by adding a variable amount of high-frequency pre-emphasis at the proper times. If the signal contains relatively high signal levels across the entire audio spectrum, little spectral companding is performed. Fortunately, in the real world of television broadcasting, high-level signals that extend across the entire audio spectrum are fairly common, so little dbx companding actually is performed.

All television stations use sophisticated audio processing devices to boost the audio level during quiet program material, and to limit the level during loud material (like commercials). Those devices generally divide the spectrum into three bands, and each band is independently monitored by the processor to ensure that the levels in each band remain relatively high.

The end result is that overall modulation remains high across the entire audio spectrum for most types of program material. Therefore, the dbx circuitry would do little spectral companding, so we made no attempt to compensate. **R-E**

TOD. T. TEMPLIN

STEREO TV DECODER

Now that we know the theory behind MTS transmission and decoding, let's build a decoder!

Part 2 IN THE FIRST PART OF this article we showed the complete set of schematic diagrams (in Fig. 3–Fig. 6) while we discussed the decoder's theory of operation. However, due to a printing error, a line connecting R13, R14, and pin 7 of IC4 was deleted from Fig. 3, the decoder stage schematic. After you go back to your January issue and draw the line in, you'll be ready to start building. But before purchasing any parts, read the section on interfacing below; you may not need the board-mounted demodulator and its associated components, depending on how you interface the decoder with your TV or VCR.

To build the decoder, it's best to use a PC board. If you wish to etch your own, the foil pattern is shown in PC Service. Otherwise you can buy a board from the source mentioned in the Parts List.

However you obtain a board, before beginning construction, inspect it carefully for shorted and open traces, and make sure that the copper is clean. If necessary, rub it with steel wool and then clean it with soap and water.

When the board is in good shape, start stuffing it, as shown in Fig. 7 (which shows all board-mounted components) and Fig. 8 (which shows all off-board components and the three jumpers). First insert the low-profile components, and then work up to the larger components. Be sure to observe the polarity of all semiconductors and electrolytic capacitors—one mistake could be deadly!

When the board is stuffed, clean flux from the foil side and check your work once more. Then mount the board in a case, as shown in Fig. 9.

Interfacing

Before building the decoder, you should determine how you'll interface it with your TV or VCR. If your TV or VCR has a MPX audio-output jack, then you can simply connect the decoder's MPX input to that jack. In that case, you won't need to buy parts for, or build the 4.5-MHz demodulator. However, few late-model sets include such a jack, so you'll probably have to build and connect a special interface circuit. Doing so may void any warranty that is in effect, so don't undertake any modifications to your set unless you're quite sure you know what you're doing—or are willing to accept the consequences.

We'll present several ideas for interfacing the demodulator; whichever you chose, **be sure you never work on any device while it is plugged into a 117-volt AC power outlet.** Many TV chassis are extremely dangerous because they do not have power transformers to isolate them from the AC power line. Sets that lack such a transformer are said to be hot-chassis types, because there may be a 117 volts between the chassis and ground.

Converted VCR output

This is probably the most difficult option physically, because you must remove the case of your VCR and drill a hole in the rear panel to mount a small SPST switch. You must also locate the 75-μs audio de-emphasis capacitor in the tuner section, and lift the leg that goes to ground. To find that capacitor, you'll probably need a copy of the schematic diagram for the tuner section of your VCR. Your dealer's service department may have that information, and you may be able to ask a technician there for help in locating the capacitor.

The de-emphasis capacitor is always located close to the audio-demodulator IC. The capacitor forms part of a series RC network; one leg goes to ground, and the other is connected to a resistor that's in series with the audio path through the circuit. In some sets one IC may perform both audio and video demodulation.

After locating the proper capacitor, remove the grounded leg. Then prepare a piece of shielded cable that is long enough to reach from the capacitor to the rear-panel switch. As shown in Fig. 10-*a*, solder the shield to the hole from which the capacitor's leg was removed, and the center conductor to the free leg. Connect the other end to the switch.

Now, when the switch is in the STEREO position, the capacitor is disconnected from the circuit. That allows the high-frequency portion of the audio signal that contains the pilot and the L − R signals to pass through the remainder of the circuitry and appear at the VCR's regular audio output jack. Closing the switch returns the recorder to normal MONO operation.

Because we tapped the demodulated audio directly, IC1 and associated components can be eliminated from the decoder's PC board. In addition, **you can use that technique with a TV or a monitor, but only if it is not a hot-chassis type.**

IF output jack

Conversely, the following technique may be used on a TV with a hot chassis. You'll have to build the 4.5-MHz section of the decoder. Before beginning conversion, obtain a copy of the schematic diagram of your set. What you're looking for is a place to pick up the 4.5-MHz audio IF signal *before* it is demodulated.

Locate the audio-demodulator section of the TV set; it should look something like Fig. 10-*b*. In many cases, the circuit will look similar to the demodulator circuit in the decoder. Older sets will probably use a 4.5-MHz IF transformer

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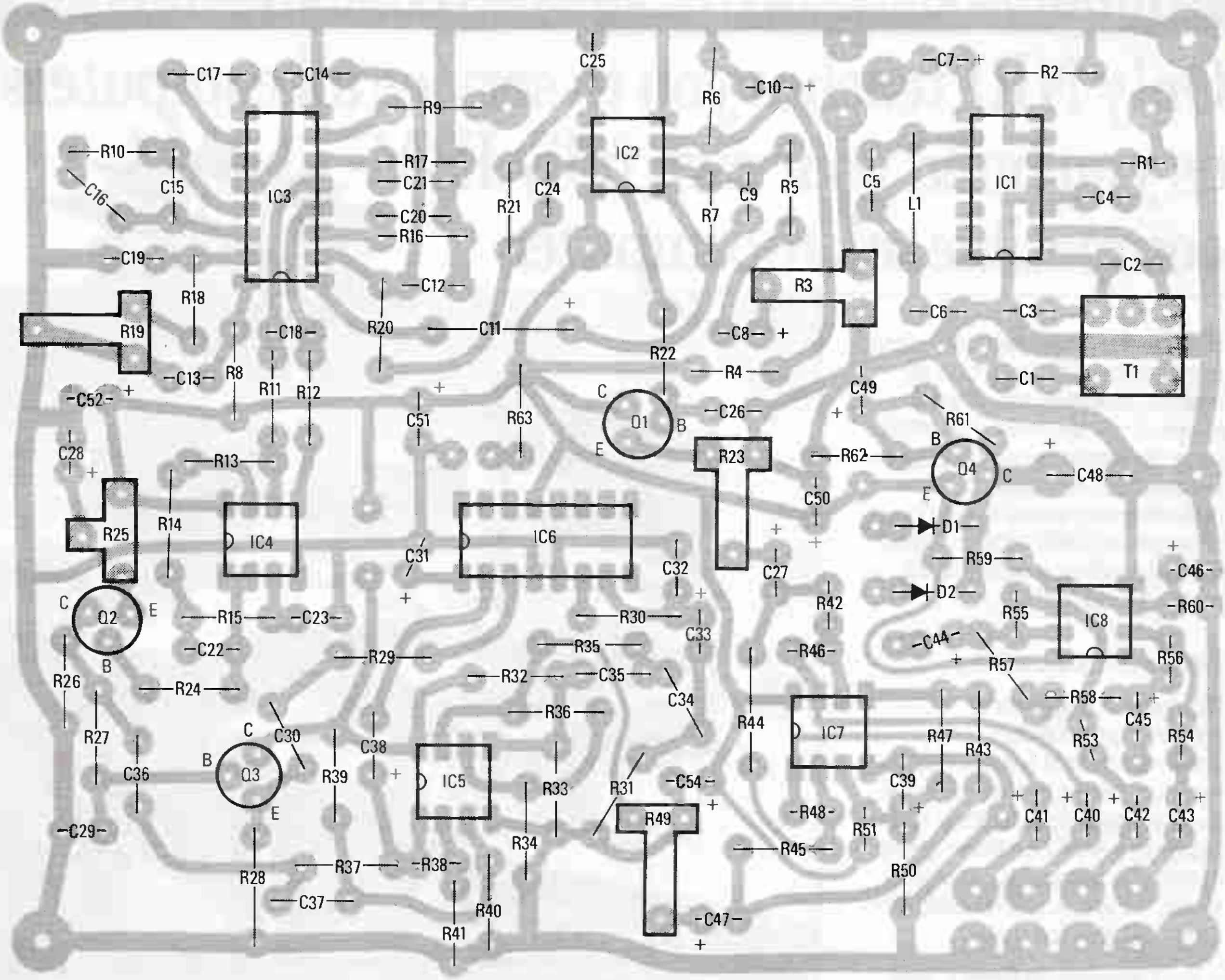


FIG. 7—MOUNT ALL ON-BOARD COMPONENTS on the MTS decoder's PC board as shown here.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—120 ohms
R2, R7, R35, R37—10,000 ohms
R3, R23, R49, R53, R54—10,000 ohms, trimmer potentiometer
R4, R6, R11, R12, R42, R43, R44, R46, R48, R50, R51, R59, R60—100,000 ohms
R5—2200 ohms
R8—10 ohms
R9, R24, R31, R57, R58, R63—1000 ohms
R10, R16, R17, R28—3300 ohms
R13—330,000 ohms
R14, R15, R21, R62—4700 ohms
R18—12,000 ohms
R19—25,000 ohms, trimmer potentiometer
R20—4300 ohms
R22, R27—5100 ohms
R25—5,000 ohms, trimmer potentiometer
R26—1500 ohms
R29—30,000 ohms
R30—18,000 ohms
R32, R33, R39, R40—20,000 ohms
R34, R41, R55, R56—39,000 ohms
R36, R38—22,000 ohms
R45—68,000 ohms
R47—470,000 ohms
R52—100,000 ohms, dual-gang potentiometer
R61—330 ohms

Capacitors
C1, C4, C13, C32—0.01 µF, ceramic disk
C2, C9, C19—470 pF, ceramic disk
C3, C14—0.05 µF, ceramic disk
C5—5–60 pF, trimmer
C6—10 pF, ceramic disk
C7, C8, C10, C11, C27, C38, C47—1 µF, 50 volts, electrolytic
C12, C23, C25—0.0022 µF, ceramic disk
C15, C30, C34–C37—0.22 µF, ceramic disk
C16, C17—0.47 µF, ceramic disk
C18—0.0047 µF, ceramic disk
C20, C21—0.0015 µF, ceramic disk
C22, C24—0.0039 µF, ceramic disk
C26, C29—0.015 µF, ceramic disk
C28, C31, C39–C46—10 µF, 50 volts, electrolytic
C33, C50–C53—2.2 µF, 50 volts, electrolytic
C48—2200 µF, 50 volts, electrolytic
C49—470 µF, 50 volts, electrolytic

Semiconductors
IC1—MC1358 stereo demodulator
IC2, IC4, IC5, IC7, IC8—LM358 dual op-amp
IC3—LM1800 stereo decoder
IC6—NE570 compander
D1, D1—1N4002 rectifier diode
LED1, LED2—standard
Q1, Q3—2N3904 NPN transistor
Q2—2N3906 PNP transistor
Q4—2N2222 NPN transistor

Other components
F1—¼-amp, 250-volt fuse
J1–J4—RCA phono jack
J5—stereo headphone jack
L1—33 µH S1—SPDT toggle switch
S2—SPST toggle switch
T1—10.7 MHz IF transformer
T2—25-volt CT power transformer

Note: A drilled, etched, and plated PC board is available from T³ Research Inc., 5329 N. Navajo Ave., Glendale, WI 53217 for $10 plus $0.75 postge and handling. WI residents add 5% sales tax.

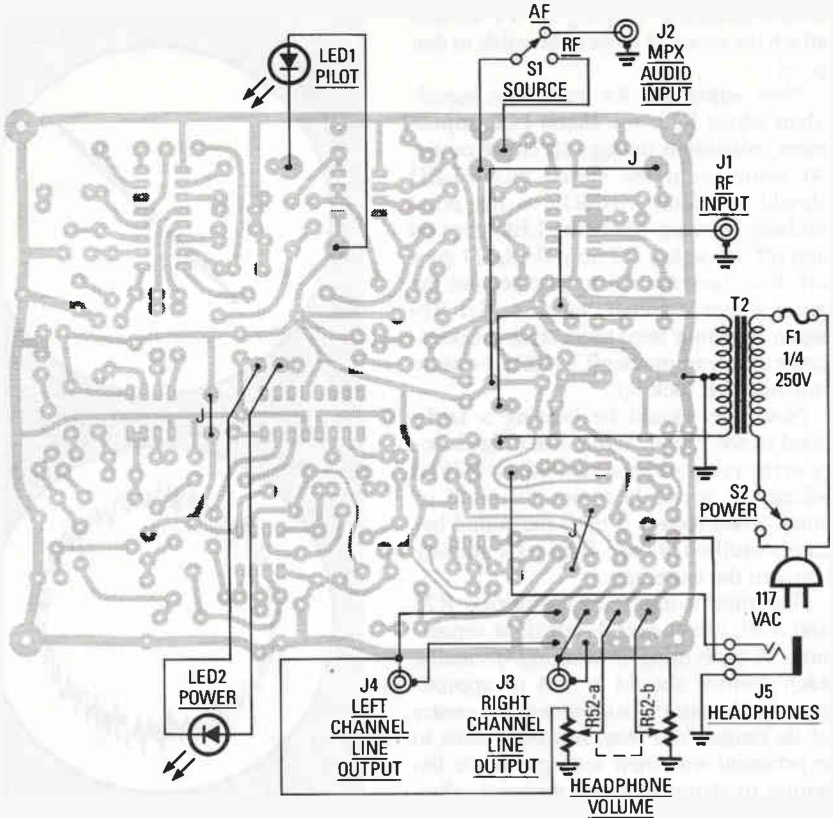


FIG. 8—THREE JUMPERS AND ALL OFF-BOARD components mount as shown here.

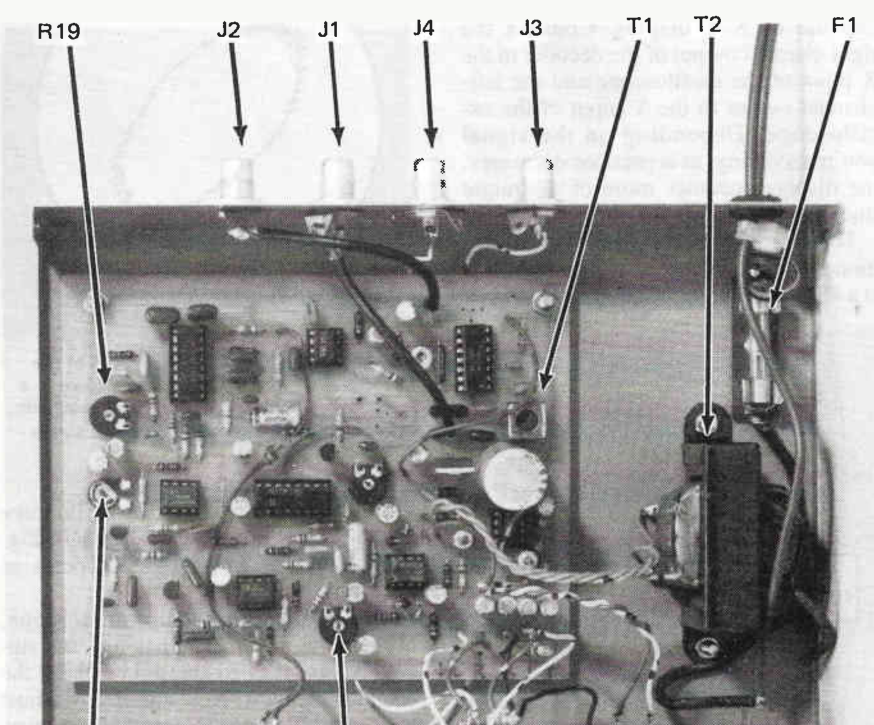


FIG. 9—THE COMPLETED DECODER appears as shown here. The board shown was an early prototype, so it doesn't match the parts-placement diagrams (shown in Fig. 7 and Fig. 8) exactly.

between the video and the audio demodulator sections; newer sets may use a ceramic filter.

In either case, solder one lead of a 100-pF capacitor to the output side of the transformer or filter. Cut a length of shielded cable that is long enough to reach from the capacitor to the rear of the set. Prepare one end by completely removing about one inch of the braid. Cover the part of the cable where the shield ends with tape or heat-shrink tubing. **There must be no possibility of the shield wire's touching any part in the TV.**

Now solder the center lead to the free end of the 100 pf capacitor. Dress the capacitor and the cable so that they don't touch any other parts. Locate a convenient, non-conductive place on the rear cover of the set and mount the RCA jack. **Do not mount the jack on any metal part of the set.** Finish the installation by soldering the 1-megohm resistor and the shielded cable to the jack.

RF probe

The RF probe is probably the best interface to use if you're not familiar with the inner workings of TV's and VCR's. Your set needn't be modified in any way, and you don't have to deal with high voltages. However, you'll almost certainly have to remove the cabinet in order to pick up the RF signal. In addition, you'll have to build the 4.5-MHz demodulator section of the decoder, but in that case, replace 0.01-μF input capacitor C1 on the decoder board with a wire jumper.

The basic idea is to build a small antenna that is tuned to 4.5 MHz and is placed as close as possible to the TV's audio demodulator. The antenna will pick up the RF signals that are naturally radiated in the set.

The circuit is very simple, as shown in Fig. 10-*c*. Use several drops of quick-set glue to hold the coil to a stick. Then solder the capacitor close to the body of the coil. Cover the assembly with heat-shrink tubing to help hold it together and to provide insulation. Cut a small hole in the tubing so you can adjust the trimmer capacitor. Then attach a length of shielded cable about six feet long, and terminate it with an RCA plug.

Finding the optimal location for the probe requires that the decoder be operational. On the other hand, you can't make the decoder operational without an input signal from the probe. That leaves you in a bit of a dilemma.

The best solution is to locate the audio demodulator in the television. Then use a rubber band or a piece of tape to secure the probe close to that portion of the circuit. Temporarily remove any shielding, if necessary. Now you should be able to get enough signal to align the decoder, after which you can go back and reposition the probe and adjust the setting of the trimmer capacitor for maximum signal strength.

In practice we have found that many sets, particularly older models and tube types, radiate so much RF that, after the probe is tuned, it can pick up enough signal to work as far as two feet from the set.

Alignment

The decoder was designed to be easy to align. The values of all components were selected so that by setting each adjustable part to the center of its range, it will be near its optimal setting.

Begin alignment by setting all potentiometers and trimmer capacitors to their center positions. Supply an input signal to the decoder by one of the circuits above. Be sure that you are tuned to a station that is transmitting a stereo signal. Most TV stations leave the pilot on all the time and transmit a synthesized stereo signal during shows that are not true stereo. You'll need to monitor the decoder's outputs via headphones or a stereo amplifier. If everything is working, you should hear some audio from the decoder, although it may be low in volume or highly distorted.

If you're using the on-board 4.5-MHz demodulator, you must adjust it first. Input transformer T1 is broadly tuned, so any adjustment to it will have little effect. Leave it centered, and adjust trimmer capacitor C5 for maximum audio output from the decoder.

If you're using the RF probe for input, you must adjust it while the television is operating, so **be extremely careful not to touch anything inside the TV set.** While carefully holding the probe in a position where you can hear some signal, adjust the probe's trimmer capacitor for maximum output. Then move the probe around to find the point where the signal level is strongest. Unplug the TV set and attach the probe as close as possible to that point.

Now adjust R3 for maximum signal. Then adjust R19, the stereo PLL adjustment, rotating it through its entire range. At some point the stereo PILOT LED should come on. Set R19 to the point midway between where the LED goes on and off. Re-adjust R3 until the LED goes off, then increase R3 to just beyond the point where it comes back on. Set R19 again. You may need to increase the resistance of potentiometer R3 a little to ensure reliable PLL lock up.

Now you should be hearing a fairly good stereo signal. While listening closely to the program material, adjust R25 to where the sound becomes distorted or noisy. Then reduce it until the sound becomes muffled or dull. Then set it midway between the extremes.

The matrix-input-level controls, R23 and R49, affect overall left/right separation. If everything is working normally, each control should be set to approximately the same position near the center of its range. You may, however, wish to experiment with their settings. While listening to stereo program material, alternately adjust each to obtain the greatest apparent separation.

Another method of adjusting R23, R25, and R49 requires an oscilloscope capable of X-Y display. Connect the right-channel output of the decoder to the X input of the oscilloscope and the left-channel output to the Y input of the oscilloscope. Depending on the signal you're receiving, as separation decreases, the display becomes more of a straight line that tilts one way or the other.

For example, as shown in Fig. 11-*a*, a mono signal will appear as a straight line at a 45-degree angle. A good stereo signal fills all four quadrants of the oscilloscope display about equally, as shown in Fig. 11-*b*. A mostly L − R signal appears as shown in Fig. 11-*c*.

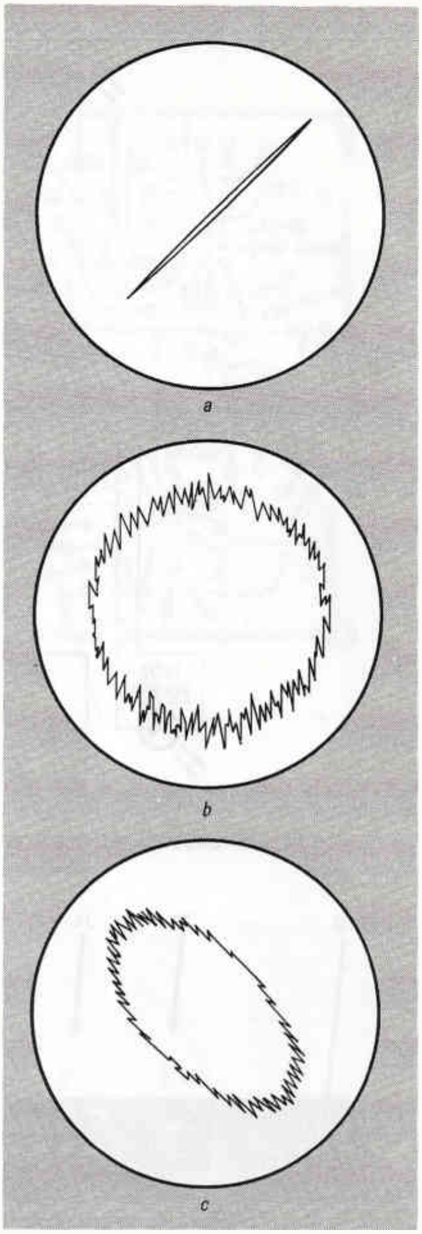


FIG. 11—OSCILLOSCOPE DISPLAYS of the decoder's left and right outputs. Shown in *a* is a mono signal (L + R); in *b* is a signal with proper left/right separation; in c is a signal with too much L − R.

To adjust the decoder with a scope, observe the pattern and listen to the signal. Adjust R25 to the point where the sound is cleanest. Now alternately adjust R23 and R49 for the most circular display. With patience and experience with different types of program material, you'll quickly learn how the controls affect the sound, and thus find the best setting for each.

When you're satisfied with your adjustments, assemble the decoder and your TV set, sit back, and enjoy the new stereo-TV shows. **R-E**

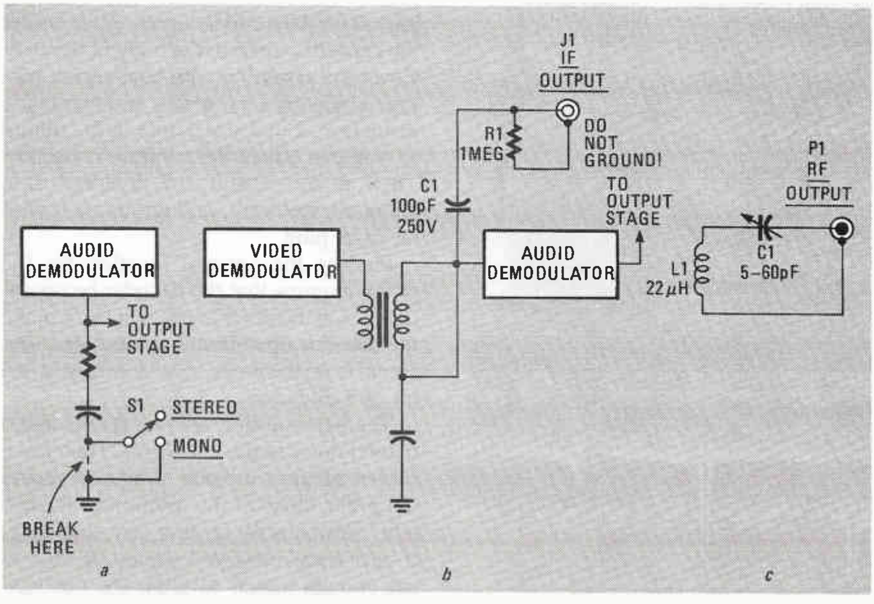


FIG. 10—INTERFACING THE DECODER to a TV or VCR can be accomplished in various ways: via the audio demodulator (*a*), at the output of the video demodulator (*b*), or indirectly via an RF probe (c).

BUILD THIS

TOD T. TEMPLIN

SAP ADAPTER

Add a second-audio-program adapter to your MTS stereo decoder!

IN THE PREVIOUS ARTICLE WE SHOWED YOU how to build an MTS stereo decoder. Another TV-audio signal that's also worth decoding is called the *S*econd *A*udio *P*rogram or SAP channel.

Besides its primary use as a second-language audio channel, the SAP channel is also being used in some interesting and novel ways. Some TV stations are transmitting continuous weather and news (unrelated to the main visual program), public service information, and station self-promotional activities. Also, as an aid to the visually impaired, some programs use the SAP channel for a narration that describes the actions, scenery, clothing, and other items related to the visual aspects of the program.

Although the SAP channel is not being used by every station in every part of the country, its use is spreading quickly. That's because more and more television broadcasters are beginning to realize the competitive advantage and the commercial potential of having a second audio program piped into viewer's homes.

The SAP channel is a 78.670-kHz frequency-modulated subcarrier on the main-audio carrier. The subcarrier frequency is phase-locked to exactly five times the horizontal-sync rate. That eliminates beating of the SAP subcarrier with those of the stereo-pilot signal, the L − R stereo subcarrier, and the professional channel (which is used by the broadcaster for private communication), all of which are multiples of, and phase locked to the horizontal sync. SAP modulation is limited to 10 kHz of total deviation and uses the dbx noise reduction system to improve weak signal reception.

The SAP decoder is designed to plug directly into the circuit board of our stereo-TV decoder. It shares the baseband signal source, the 15-volt power supply, and half of the NE570 compander IC with the original circuit. (The stereo decoder used only half of that IC, where it was labeled IC6. The SAP decoder makes use of the other half of that IC, which is labeled IC3-b in the SAP decoder circuit.)

Circuit description

The schematic for the SAP decoder is shown in Fig. 1. The baseband-audio input comes from the pole of switch S1 in the stereo decoder, and is coupled to IC1 (a CA3089) via a 78.6 kHz bandpass filter that consists of capacitors C1 and C2, and inductor L1. IC1 is a combination IF amplifier and quadrature detector normally used for FM-radio systems operating with an IF of 10.7 MHz. However, the device works equally well at 78.6 KHz, and was chosen over a PLL device because its three internal stages of IF limiting amplifiers allow it to operate over a wide range of input-signal levels without any need for adjustment. Capacitors C6 and C7, and inductor L2 tune the detector section to 78.6 KHz, while C5 provides the necessary 90-degree phase shift for proper quadrature detector operation. Resistor R1 serves to slightly lower the Q of the detector circuit to ensure adequate bandwidth of the recovered audio. The output voltage at pin 13 of IC1 is proportional to the level of the incoming signal. When the voltage at the wiper of potentiometer R3 reaches a predetermined threshold level, Q1 conducts, grounding pin 5 of IC1, enabling IC1's mute function.

Detected audio output from pin 6 of IC1 goes to IC2-a which is configured as a 12 kHz, −12-dB-per-octave, low-pass filter. It's the same circuit that is used in the MTS stereo decoder design and serves to reduce noise above 10 kHz. The output of IC2-a appears across potentiometer R10, which provides a means of adjusting the drive level into IC3-b, the 2:1 compander. Again, as in the main stereo decoder circuit, no attempt has been made to compensate for the spectral-companding component of the dbx-encoded signal. Rather, a straight 2:1 expansion with fixed 390-microsecond de-emphasis is used.

Audio from the wiper of R10 is split into two paths: a high-pass filter (C14 and R8) provides a path to the rectifier input of the compander, and a bandpass filter (R9, C16, and C15) that feeds the audio input of the compander. The time constant of the compander circuit is controlled by C17; lowering its value increases the speed of the circuit's attack and decay times. A fixed 390-microsecond de-emphasis network is formed by C18 and R11 in conjunction with IC3-b. Corrected audio appears at pin 10 of IC3-b and is coupled to IC2-b, an output buffer amplifier.

Audio from pin 6 of IC1 is also coupled to an audio high-pass filter (R5 and C10) and fed to an audio rectifier (D1, D2, and C11). When a SAP signal is detected by IC1, it is rectified by D1 and D2; the resultant DC charges C11. An increasing positive voltage at the base of Q2 causes its current flow to decrease, so the voltage at Q2's collector also decreases. That in turn causes the base voltage of Q3 to drop, which causes Q3 to conduct, thereby lighting the LED.

Construction

The SAP adaptor is built using a 16-pin wire-wrap IC socket for IC3. To add the

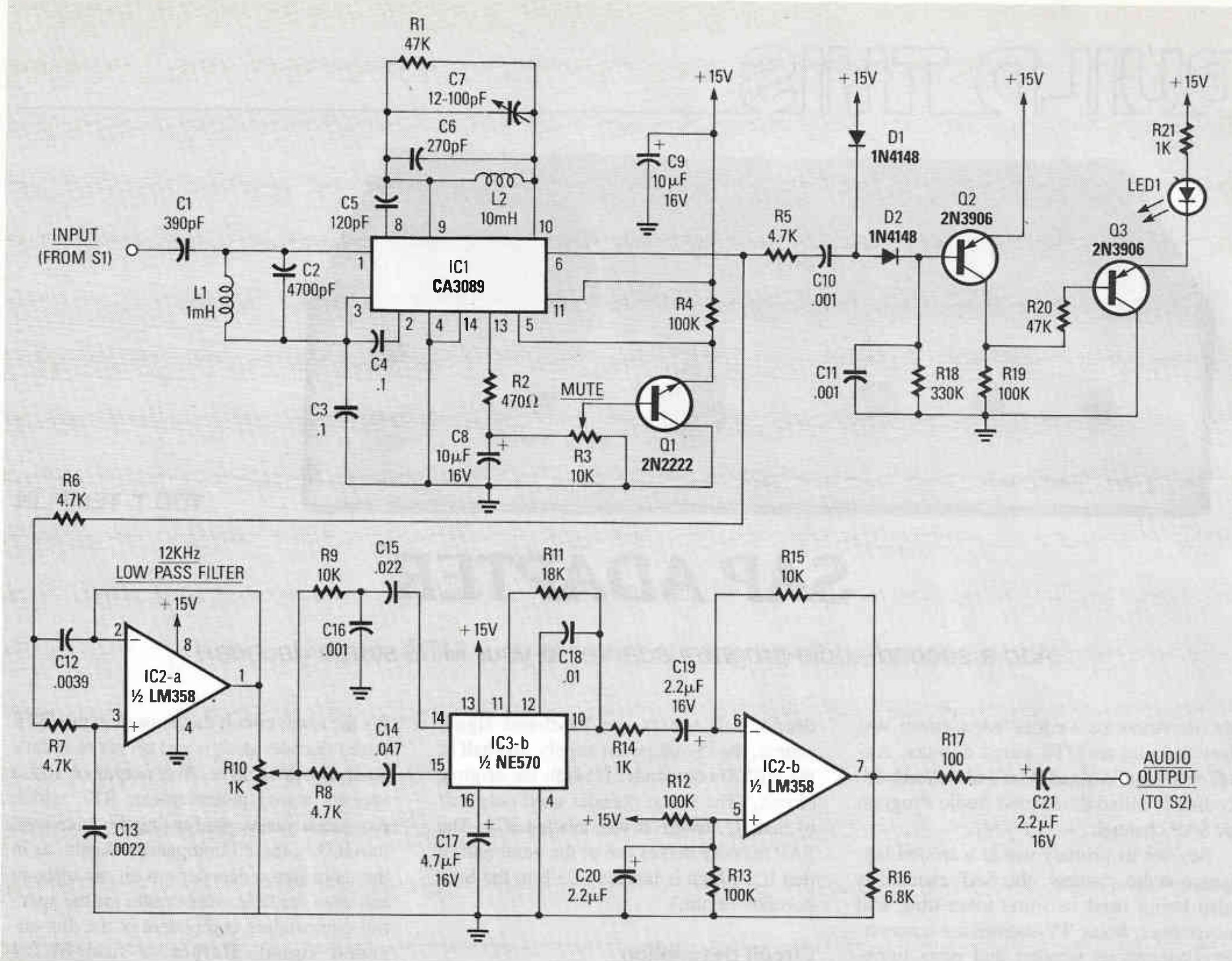


FIG. 1—THE SAP ADAPTER SCHEMATIC. Easily added to your stereo decoder, it will allow you to hear the SAP channel.

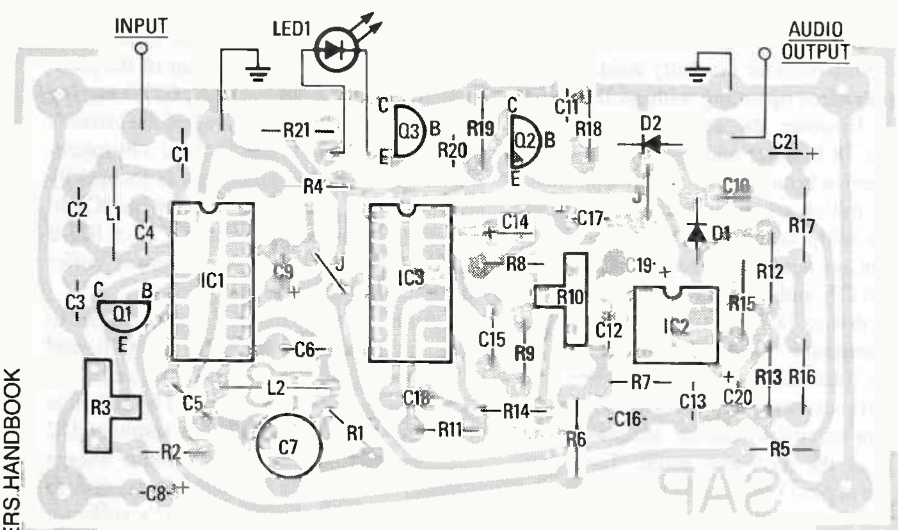


FIG. 2—FOLLOW THIS DIAGRAM for correct placement of the SAP board's components.

SAP adaptor to the original circuit board, IC6 (the NE570) is removed from its socket on the stereo board and placed in the wire-wrap socket on the SAP circuit board (where it is now labeled IC3-b). Then the wire-wrap socket is plugged back into the IC6 socket on the main board. Now the power supply and the compander IC is shared by both circuits. That type of construction method simplifies the interconnections and greatly reduces the cost of the SAP adaptor.

With the exception of using a wire-wrap IC socket for IC3, building the SAP adaptor is straightforward. Install the components on the circuit board as shown in Fig. 2. Be careful to check the polarity of all diodes, transistors, IC's, and especially the electrolytic capacitors.

Figure 3 shows a completed SAP board. A DPDT switch (S2) must be added to the chassis of the stereo decoder to allow switching the output jacks of the decoder between STEREO and SAP reception. Wiring details for S2 are shown in Fig. 4. Allow appropriate lengths of wire for connecting the SAP board to the input to S1, the output of S2, and the LED, which are all on the front panel as shown in the photograph.

In order for the SAP board to be installed "piggy back" on the main board, none of the components on the main board should be taller than ⅝ inches. That should be no problem, with the exception of C49. If C49 is too tall, you may need to either use a

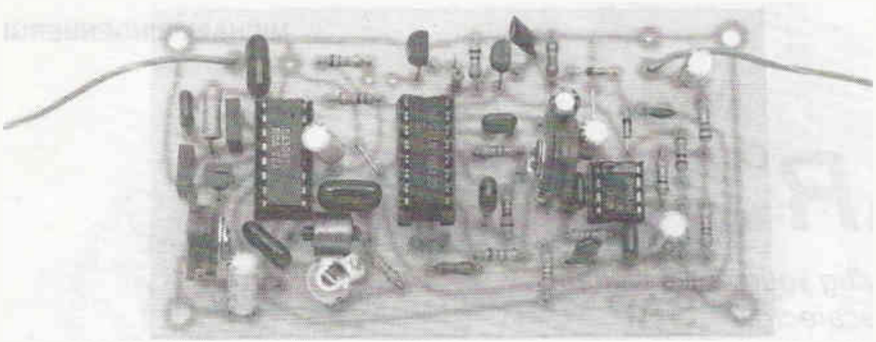


FIG. 3—THE COMPLETED SAP BOARD. Notice that only two wires have to be connected to the stereo decoder.

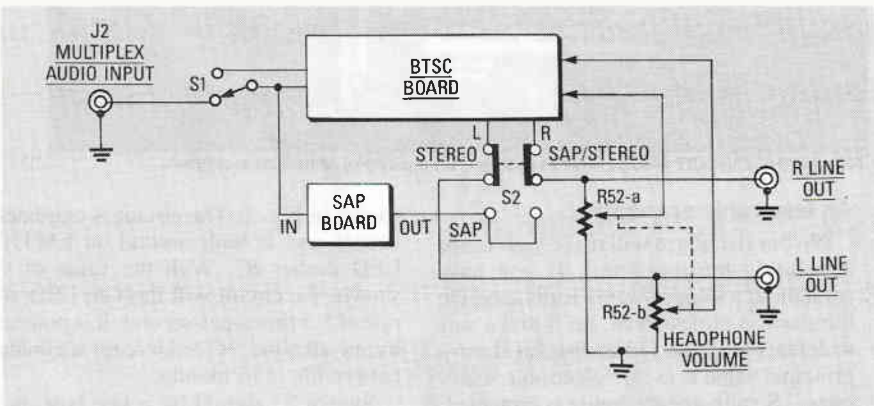


FIG. 4—THIS IS HOW S2 is connected into the system to allow for switching between SAP and stereo decoding.

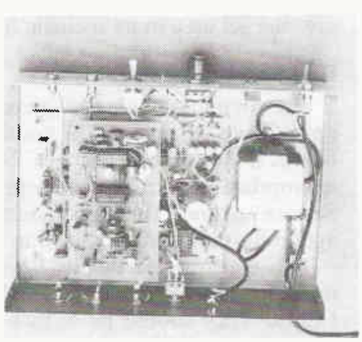


FIG.5—THE SAP BOARD MOUNTS directly onto the BTSC board. Notice the modifications (extra switch, wiring, LED, etc.) that have been made to the chassis in order to accommodate the SAP decoder.

smaller capacitor, or turn C49 on its side.

Transfer IC6 (NE570) from the main board to the IC3 socket on the SAP board. Line up the pins of the wire wrap socket on the SAP board with the holes of IC6's socket on the main board. Then install the entire assembly as if it were just one large IC. Figure 5 shows how the completed decoder looks with the SAP board in place. The wire-wrap socket will serve to support the entire SAP board. Be sure that there aren't any components from the main board touching the foil patterns on the SAP board. Connecting the input, output, and LED finishes the conversion.

Setup

Install the completed stereo decoder in your system as described in the stereo-decoder article. If your decoder was working properly before you installed the SAP adaptor, it should still be working the same with the adaptor installed. If not, recheck your work to locate the problem. Tune to a station that you know is transmitting a SAP signal. Set R10, the compander-input-level adjustment, to mid position. Set R3, the mute-detector-level adjustment fully clockwise as viewed from the front. If a SAP signal is present you should now hear it and LED1 should light.

Adjust trimmer C7 for the cleanest sounding signal. Then adjust R3 counter-clockwise until the signal just disappears, and then slowly turn it clockwise until the signal just re-appears. Switch between a station with SAP and one without SAP. The adaptor should mute when no SAP signal is received. If it doesn't, it may be necessary to slightly readjust R3 for consistent muting.

With the addition of the SAP adaptor to your stereo TV decoder, you are now ready to enjoy the complete range of audio services that are currently available on broadcast television. **R-E**

All resistors are ¼-watt, 5% unless noted
R1, R20—47,000 ohms
R2—470 ohms
R3—10,000 ohms, vertical trimmer potentiometer
R4, R12, R13, R19—100,000 ohms
R5–R8—4700 ohms
R9, R15—10,000 ohms
R10—1000 ohms, vertical trimmer potentiometer
R11—18,000 ohms
R14, R21—1000 ohms
R16—6800 ohms
R17—100 ohms
R18—330,000 ohms
All capacitors 5% tolerance unless otherwise noted
C1—390 pF, disc or mica
C2—0.0047 µF, metal film
C3, C4—0.1 µF, metal film or disc
C5—120 pF, disc or mica
C6—270 pF, disc or mica
C7—12–120 pF, trimmer capacitor (7mm, 3 pin)
C8, C9—10 µF, 16 volts, radial electrolytic
C10, C11, C16—0.001 µF, metal film or Mylar
C12—0.0039 µF, metal film or Mylar
C13—0.0022 µF, metal film or Mylar
C14—0.047 µF, metal film or Mylar
C15—0.022 µF, metal film or Mylar
C17—4.7 µF, 16 volts, radial electrolytic
C18—0.01 µF, metal film or Mylar
C19–C21—2.2 µF, 16 volts, radial electrolytic
Semiconductors
IC1—LM3089 IF amplifier
IC2—LM358 low-power dual op-amp
IC3—NE570 or NE571 compander IC
Q1—2N2222 NPN transistor
Q2, Q3—2N3906 PNP transistor
D1, D2—1N4148 switching diode
LED1—Red LED
Other components
L1—1 mH inductor
L2—10 mH inductor
Miscellaneous: 1 8-pin IC socket, 1 16-pin IC socket, 1 16-pin wire-wrap IC socket (see text), wire, etc.
Note: A kit containing a printed circuit board for the SAP adaptor and L1, L2, and C7 is available for $7.75 from T3 Research, Inc., 5329 N. Navajo Ave., Glendale, Wisconsin 53217-5036. Wisconsin residents must add appropriate sales tax.

BUILD THIS

PHONY BURGLAR ALARM

MICHAEL RINGENBERGER

Scare off burglars without emptying your wallet with this simple, inexpensive electronic "scarecrow."

IT'S A SAD COMMENTARY THAT THESE days a burglar alarm is becoming as common a household "appliance" as a refrigerator or a dishwasher. But burglar alarms are not inexpensive. Most will cost a few hundred dollars, and some elaborate systems could cost a thousand dollars or more.

If your household possessions are simply not worth that kind of outlay, there is a very inexpensive alternative. Most burglars are burglars because it's the easiest way they know of to make a fast buck. When they look for a house to ransack, they try to find the easiest target. The trick, then, is to make your house *look* like it is protected by a sophisticated alarm system. That can be done for less than $20 with the circuit described here.

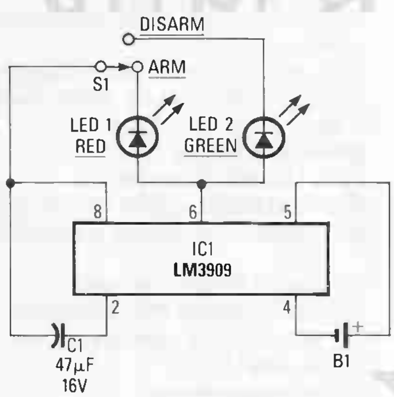


FIG. 1—IT'S NOT A REAL BURGLAR ALARM, but this "electronic scarecrow" can do almost as good a job as a real one when it comes to scaring away a burglar.

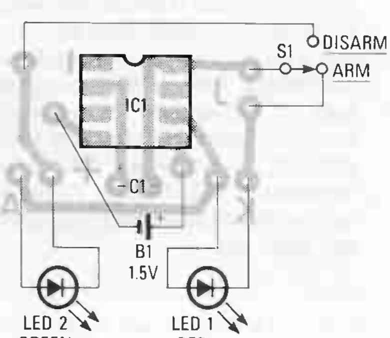


FIG. 2—THE CIRCUIT CAN BE BUILT on a tiny PC board. The pattern is provided in our PC Service section.

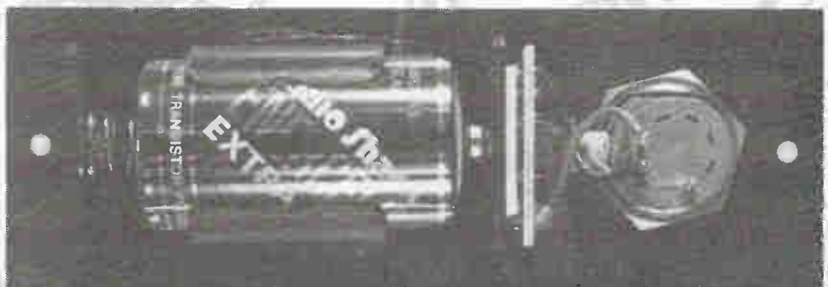


FIG. 3—THE CIRCUIT SHOULD be assembled on a piece of anodized aluminum.

An electronic scarecrow

No burglar alarm will make your home absolutely burglar proof. If you have something a burglar wants badly, and the burglar is a professional, he'll find a way to defeat the alarm. Otherwise, an alarm's principal value is as an "electronic scarecrow." Seeing that the house is protected, a burglar will move on to easier pickings.

How does a burglar know that there is an alarm? Most alarm systems have their sensors hidden from view, so frequently the only sign of an alarm system is a status display located near the entrance. That display usually consists of a red and a green LED that show whether or not the system is armed.

By now you may have guessed where we are headed: Since the presence of an alarm-status display alone is enough sometimes to scare off a burglar, why not set up a dummy display and do away with the rest of the system? That's precisely what our circuit does. Of course it won't give you the degree of security that a real alarm-system would, but its cost is much, much lower.

The schematic diagram of the circuit is shown in Fig. 1. The circuit is extremely simple and is built around an LM3909 LED flasher IC. With the value of C1 shown, the circuit will flash an LED at a rate of 5.5 times-per-second. It is powered by an alkaline "C"-size cell; estimated battery life is 15 months.

Switch S1 should be a key type as is typically found in burglar-alarm installations. The switch should be mounted on the dummy status-display's front panel to give the set up a more realistic look.

PARTS LIST

C1—47 µF, 16 volts, electrolytic
IC1—LM3909 LED flasher IC
LED1—green jumbo LED
LED2—red jumbo LED
S1—SPST, key switch
B1—1.5 volts, "C" cell
Miscellaneous: PC or perforated-construction board, anodized aluminum panel, battery holder, wire, solder, etc.

Building the circuit

The circuit is simple enough to be built on a piece of perforated construction board. If you wish to use a PC board, an appropriate pattern is shown in our PC Service section. The parts-placement diagram for the board is shown in Fig. 2.

Two construction details bear special mention. One is the lead length of the LED's. They should be ¼-inch long to allow for flexibility when mounting the board (more on that in a moment). Secondly, the lead length of C1 should be kept to an absolute minimum. Be sure that the bottom of that electrolytic capacitor is flush with the board.

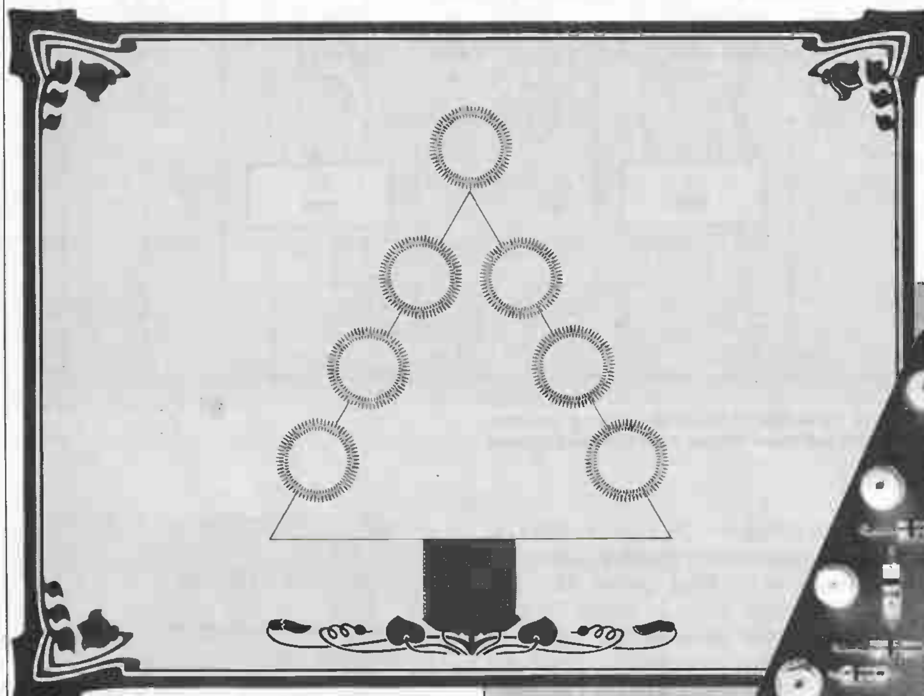
The circuit is mounted on a piece of anodized aluminum. Size is not critical, as long as it is appropriate for the task. The author's prototype was 1½ × 4 inches. The other side of the aluminum piece will serve as the dummy status-panel.

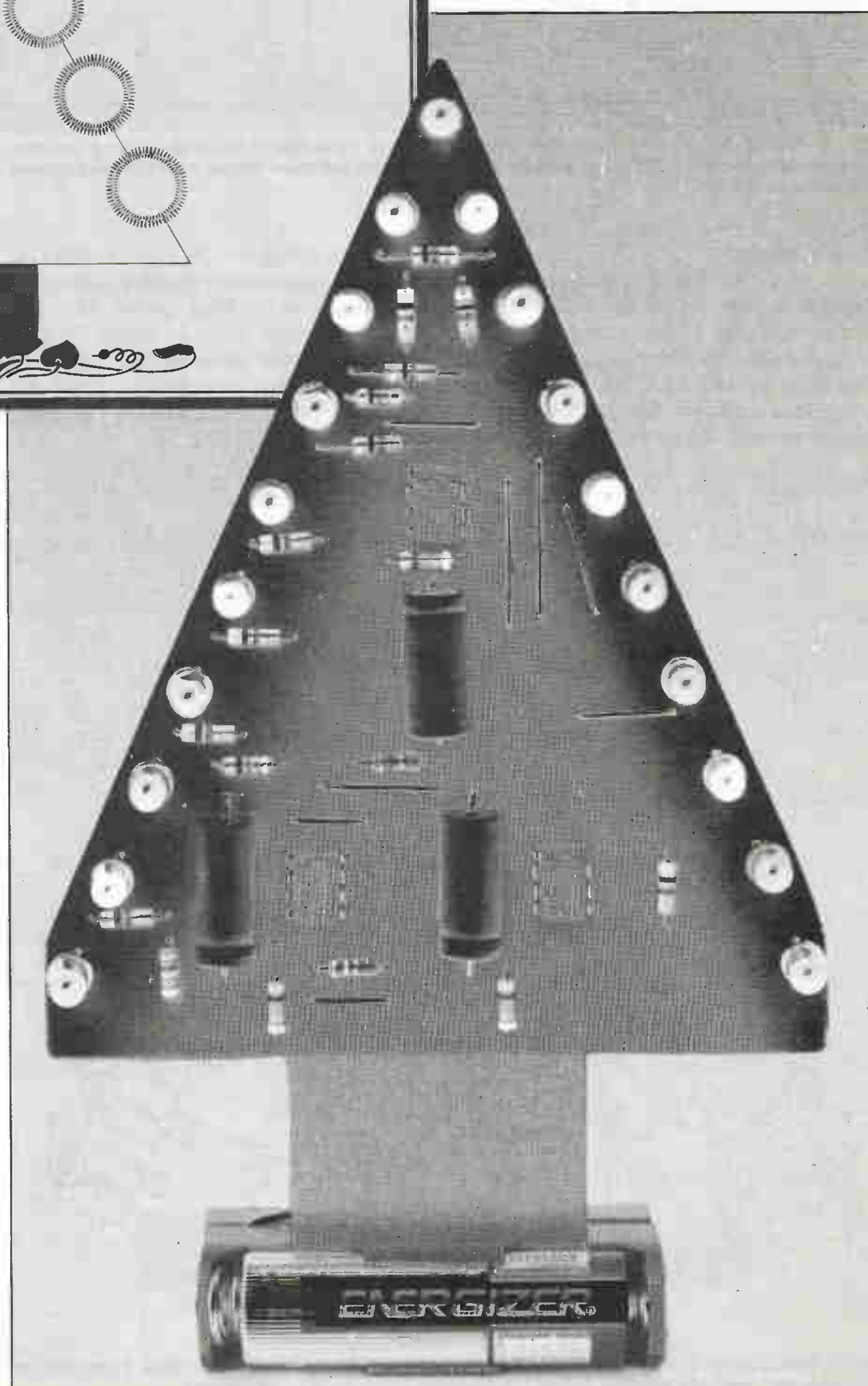
Begin by drilling holes for the two LED's and the key switch; also drill two mounting holes. Be careful, as a neat, "professional" looking job will help enhance the effect. Next, secure a "C"-cell

continued on page 150

THOMAS L. JOZWIAK

ELECTRONIC XMAS TREE





This pocket-size electronic Christmas tree will give your holiday lighting a new and festive look.

FOR ABOUT $10 YOU CAN BUILD A UNIQUE high-tech Christmas tree that will add a new and festive look to both your home and office holiday decorations. And because it's powered by two AA batteries, if you can't be home for the holidays you can pack one along in a suitcase to remind you of your loved ones.

The electronic Christmas tree is really a 6½-inch high tree-shaped printed-circuit board that's outlined by what appears to be randomly-blinking red, green, and yellow LED's. The tree's trimming is the components for the electronic circuit that makes the LED's wink and blink. The Christmas tree's base consists of two AA-size battery holders cemented together with the tree's PC board sandwiched between the two. A little imaginative spray painting before the components are installed puts a realistic finishing touch to the Christmas-tree project.

Because the LED's are continuously cycled *on* and *off*, two alkaline batteries provide more than 300 hours of continuous operation: that's enough to provide almost two full weeks of window display or entertainment before the batteries need to be replaced.

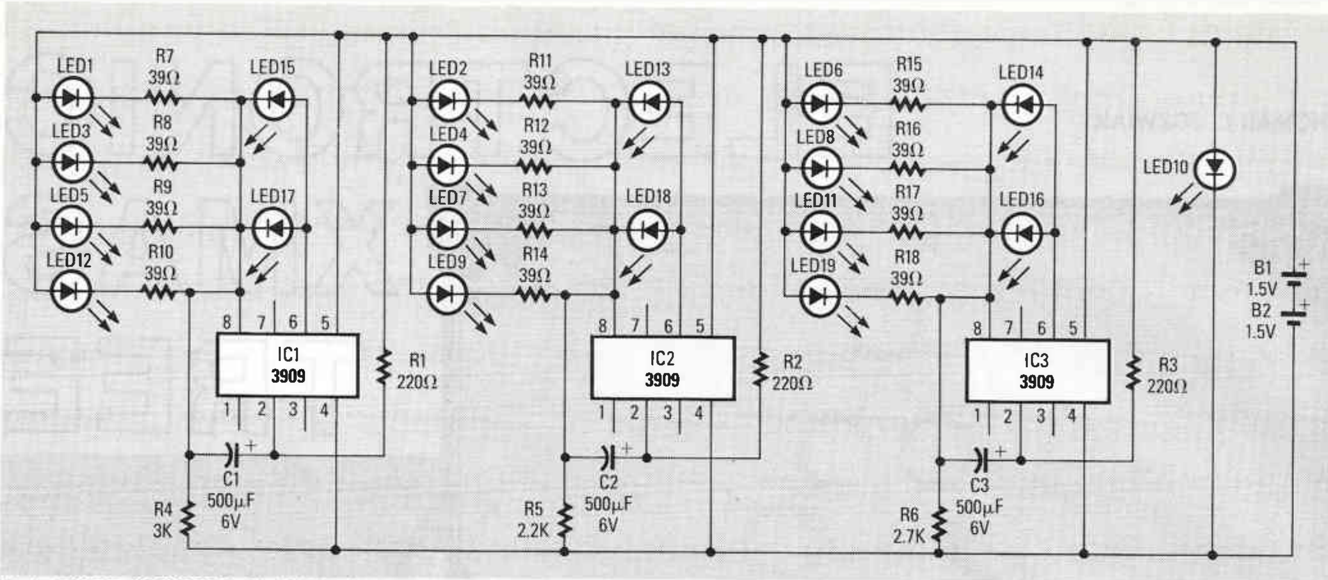


FIG. 1—THREE INDIVIDUAL FLASHER CIRCUITS having unrelated flash rates create a pseudo-randown blinking of the LED's because the LED's from each individual circuit are intermixed around the edges of the tree.

How it works

As shown in Fig. 1, three individual flashing circuits that use an LM3909 LED flasher/oscillator IC create the appearance of a pseudo-random firing order. The combination of C1/R4, C2/R5, and C3/R6 control the blink rate, which is between .3 and .8 second, while the inherent wide tolerance range (−20% to +80%) of standard electrolytic capacitors add to the irregularity of the blink cycles. The continuous current drain is about 10 mA; however, if you decrease the values of R4–6 or C1–3 in order to to increase the blink rate, the current will then increase proportionately.

PARTS LIST

All resistors are ¼-watt, 5%.
R1–R3—200 ohms
R4—3000 ohms
R5—2200 ohms
R6—2700 ohms
R7–R18—39 ohms
Capacitors
1–C3—500 μF, 6 volts, electrolytic
Semiconductors
IC1–IC3—LM3909, LED flasher
LED1, LED4, LED7, LED13, LED 16, LED 19—Red, diffused 5-mm LED
LED2, LED5, LED6, LED11, LED14, LED17—Yellow, diffused 5-mm LED
LED3, LED6, LED9, LED12, LED15, LED18—Green, diffused 5-mm LED
LED10—Red flasher LED (Radio Shack 270-401 or equivalent)
Other Components
B1, B2—1.5-volt AA alkaline battery
Miscellaneous: battery holders, PC board, wire, solder, etc.

Note: An etched and drilled PC board is available for $11 postpaid from Fen-Tek P.O. Box 5012, Babylon, NY 11707-0012. NY residents must add appropriate sales tax.

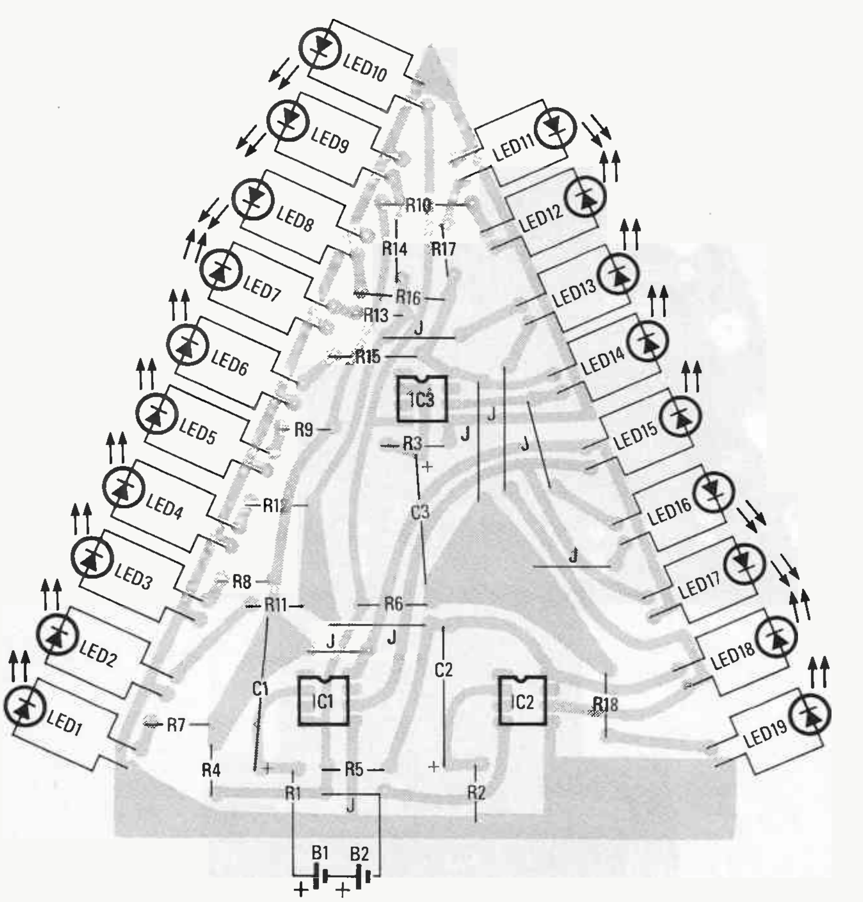


FIG. 2-TAKE EXTRA CARE THAT THE LED'S are installed with the correct polarities. If you want to decorate the "tree", do it before drilling the mounting holes for the components.

Note in partcular that external current-limiting resistors aren't needed for LED13 through LED18; the resistors are built into the IC's. LED10, which serves as the tree's "star," is a special kind of flashing LED that blinks continuously at a fixed rate.

Power can be turned off by simply removing either battery, or by slipping a small piece of paper between any battery and either of its battery-holder terminals. Of course, a switch can also be added.

continued on page 162

THE BLUE BOX AND MA BELL

When blue and red meant the trashing of Ma Bell

HERB FRIEDMAN, COMMUNICATIONS EDITOR

BEFORE THE BREAKUP OF AT&T, MA BELL was everyone's favorite enemy. So it was not surprising that so many people worked so hard and so successfully at perfecting various means of making free and untraceable telephone calls. Whether it was a *Red Box* used by Joe and Jane College to call home, or a *Blue Box* used by organized crime to lay off untraceable bets, the technology that provided the finest telephone system in the world contained the seeds of its own destruction.

The fact of the matter is that the Blue Box was so effective at making untraceable calls that there is no estimate as to how many calls were made or who made them. No one knows for certain whether Ma Bell lost revenues of $100, $100-million, or $1-billion on the Blue Box. Blue Boxes were so effective at making free, untraceable calls that Ma Bell didn't want anyone to know about them, and for many years denied their existence. They even went as far as strong-arming a major consumer-science magazine into killing an article that had already been prepared on the Blue and Red boxes. Further, the police records of a major city contain a report concerning a break-in at the residence of the author of that article. The only item missing following the break-in was the folder containing copies of one of the earliest Blue-Box designs and a Bell-System booklet that described how subscriber billing was done by the AMA machine—a booklet that Ma Bell denied ever existed; Fig. 1 proves otherwise. Since the AMA (*A*utomatic *M*essage *A*ccounting) machine was the means whereby Ma Bell eventually tracked down both the Blue and Red Boxes, we'll take time out to explain it. Besides, knowing how the AMA machine works will help you to better understand Blue and Red Box "phone phreaking."

FIG. 1—THE BOOKLET THAT NEVER EXISTED. Although its existence was denied, the front (*a*) has a photograph of an AMA tape, while the back (*b*) has the Bell System logo.

Who made the call?

Back in the early days of the telephone, a customer's billing originated in a mechanical counting device, which was usually called a "register" or a "meter." Each subscriber's line was connected to a meter that was part of a wall of meters. The meter clicked off the message units, and once a month someone simply wrote down the meter's reading, which was later interpolated into message-unit billing for those subscriber's who were charged by the message unit. (Flat-rate subscriber's could make unlimited calls only within a designated geographic area. The meter clicked off message units for calls outside that area.) Because eventually there were too many meters to read individually, and because more subscribers started questioning their monthly bills, the local telephone companies turned to photography. A photograph of a large number of meters served as an incontestable record of their reading at a given date and time, and was much easier to convert to customer billing by the accounting department.

As you might imagine, even with photographs billing was cumbersome and did not reflect the latest technical developments. A meter didn't provide any indication of what the subscriber was doing with the telephone, nor did it indicate how the average subscriber made calls or the efficiency of the information service (how fast the operators could handle requests). So the meters were replaced by the AMA machine. One machine handled up to 20,000 subscribers. It produced a punched tape for a 24-hour period that showed, among other things, the time a phone was picked up (went off-hook), the number dialed, the time the called party answered, and the time the originating phone was hung up (placed on-hook).

One other point, which will answer some questions that you're certain to think of as we discuss the Red and Blue boxes: Ma Bell did not want persons outside their system to know about the AMA machine. The reason? Almost everyone had complaints—usually unjustified—about their billing. Had the public been aware of the AMA machine they would have asked for a monthly list of their telephone calls. It wasn't that Ma Bell feared errors in billing; rather, they were fearful of being buried under an avalanche of paperwork and customer complaints. Also, the public believed their telephone calls were personal and untraceable, and Ma Bell didn't want to admit that they knew about the who, when, and where of every call. And so Ma Bell always insisted that billing was based on a meter that simply "clicked" for each message unit; that there was no record, other than for long-distance calls, as to who called whom. Long distance was handled by, and the billing information was done by an operator, so there was a written record Ma Bell could not deny.

The secrecy surrounding the AMA machine was so pervasive that local, state, and even federal police were told that local calls made by criminals were untraceable, and that people who made obscene telephone calls could not be tracked down unless the person receiving the call could keep the caller on the line for some 30 to 50 minutes so the connections could be physically traced by technicians. Imagine asking a woman or child to put up with almost an hour's worth of the most horrendous obscenities in the hope someone could trace the line. Yet in areas where the AMA machine had replaced the meters, it would have been a simple, though perhaps time-consuming task, to track down the numbers called by any telephone during a 24-hour period. But Ma Bell wanted the AMA machine kept as secret as possible, and so many a criminal was not caught, and many a woman was harried by the obscene calls of a potential rapist, because existence of the AMA machine was denied.

As a sidelight as to the secrecy surrounding the AMA machine, someone at Ma Bell or the local operating company decided to put the squeeze on the author of the article on Blue Boxes, and reported to the Treasury Department that he was, in fact, manufacturing them for organized crime—the going rate in the mid 1960's was supposedly $20,000 a box. (Perhaps Ma Bell figured the author would get the obvious message: Forget about the Blue Box and the AMA machine or you'll spend lots of time, and much money on lawyer's fees to get out of the hassles it will cause.) The author was suddenly visited at his place of employment by a Treasury agent.

Fortunately, it took just a few minutes to convince the agent that the author was *really* just that, and not a technical wizard working for the mob. But one conversation led to another, and the Treasury agent was astounded to learn about the AMA machine. (Wow! Can an author whose story is squelched spill his guts.) According to the Treasury agent, his department had been told that it was impossible to get a record of local calls made by gangsters: The Treasury department had never been informed of the existence of automatic message accounting. Needless to say, the agent left with his own copy of the Bell System publication about the AMA machine, and the author had an appointment with the local Treasury-Bureau director to fill him in on the AMA machine. That information eventually ended up with Senator Dodd, who was conducting a congressional investigation into, among other things, telephone company surveillance of subscriber lines—which was a common practice for which there was detailed instructions, Ma Bell's own switching equipment ("crossbar") manual.

TABLE 1—CCITT NUMERICAL CODE

Digit	Frequencies (hz)	
1	700 + 900	
2	700 + 1100	
3	900 + 1100	
4	700 + 1300	
5	900 + 1300	
6	1100 + 1300	
7	700 + 1500	
8	900 + 1500	
9	1100 + 1500	
0	1300 + 1500	
Code 11	700 + 1700	FOR INWARD OPERATORS
Code 12	900 + 1700	FOR INWARD OPERATORS
KP	1100 + 1700	PRIME (START OF PULSING)
KP2	1300 + 1700	TRANSIT TRAFFIC
ST	1500 + 1700	START (END OF PULSING)

The Blue Box

The Blue Box permitted free telephone calls because it used Ma Bell's own internal frequency-sensitive circuits. When direct long-distance dialing was introduced, the crossbar equipment knew a long-distance call was being dialed by the three-digit area code. The crossbar then converted the dial pulses to the CCITT tone groups, shown in Table 1, that are used for international and trunkline signaling. (Note that those do not correspond to *Touch-Tone* frequencies.) As you can see in that table, the tone groups represent more than just numbers; among other things there are tone groups identified as KP (*prime*) and ST (*start*)—keep them in mind.

When a subscriber dialed an area code and a telephone number on a rotary-dial telephone, the crossbar automatically connected the subscriber's telephone to a long-distance trunk, converted the dial pulses to CCITT tones, set up electronic cross-country signaling equipment, and recorded the originating number and the called number on the AMA machine. The CCITT tones sent out on the long-distance trunk lines activated special equipment that set up or selected the routing, and caused electro-mechanical equipment in the target city to dial the called telephone.

Operator-assisted long-distance calls worked the same way. The operator simply logged into a long-distance trunk and pushed the appropriate buttons, which generated the same tones as direct-dial equipment. The button sequence was KP (which activated the long-distance equipment), then the complete area code and telephone number. At the target city, the connection was made to the called number but ringing did not occur until the operator there pressed the ST button.

The sequence of events of early Blue Boxes went like this: The caller dialed information in a distant city, which caused his AMA machine to record a free call to information. When the information operator disconnected, he pressed the KP key on the Blue Box, which disconnected the operator and gave him access to a long-distance trunk. He then dialed the desired number and ended with an ST, which caused the target phone to ring. For as long as the conversation took place, the AMA machine indicated a free call to an information operator. The technique required a long-distance information operator because the local operator, not being on a long distance trunk, was accessed through local wire switching, not the CCITT tones.

Call anywhere

Now imagine the possibilities. Assume the Blue Box user was in Philadelphia. He would call Chicago information, disconnect from the operator with a KP tone, and then dial anywhere that was on direct-dial service: Los Angeles, Dallas, or anywhere in the world if the Blue Boxer could get the international codes.

The legend is often told of one Blue Boxer who, in the 1960's, lived in New York and had a girl friend at a college near Boston. Now back in the 1960's, making a telephone call to a college town on the weekend was even more difficult than it is today to make a call from New York to Florida on a reduced-rate holiday using one of the cut-rate long-distance carriers. So our Blue Boxer got on an international operator's circuit to Rome, Blue Boxed through to a Hamburg operator, and asked Hamburg to patch through to Boston. The Hamburg operator thought the call originated in Rome and inquired as to the "operator's" good English, to which the Blue Boxer replied that he was an expatriate hired to handle calls by American tourists back to their homeland. Every weekend, while the Northeast was strangled by reduced-rate long-distance calls, our Blue Boxer had no trouble sending his voice almost 7,000 miles for free.

Vacuum tubes

Assembly plans for Blue Boxes were sold through classified advertisements in the electronic-hobbyist magazines. One of the earliest designs was a two-tube portable model that used a 1.5-volt "A" battery for the filaments and a 125-volt "B" battery for the high-voltage (B+) power supply. The portable Blue Box's functional circuit is shown in Fig. 2. It consisted of two phase-shift oscillators sharing a common speaker that mixed the tones from both oscillators. Switches S1 and S2 each represent 12 switching circuits used to generate the tones. (*No, we will not supply a working circuit, so please don't write in and ask—Editor.*) The user placed the speaker over the telephone handset's transmitter and simply pressed the buttons that corresponded to the desired CCITT tones. It was just that simple.

Actually, it was even easier than it reads because Blue Boxers discovered they did not need the operator. If they dialed an active telephone located in certain nearby, but different, area codes, they could Blue Box just as if they had Blue Boxed through an information operator's circuit. The subscriber whose line was Blue Boxed simply found his phone was dead when it was picked up. But if the Blue Box conversation was short, the "dead" phone suddenly came to life the next time it was picked up. Using a list of "distant" numbers, a Blue Boxer would never hassle anyone enough time to make them complain to the telephone company.

The difference between Blue Boxing off of a subscriber rather than an information operator was that the Blue Boxer's AMA tape indicated a real long-distance telephone call—perhaps costing 15 or 25 cents—instead of a freebie. Of course, that is the reason why when Ma Bell finally decided to go public with "assisted" newspaper articles about the Blue Box users they had apprehended, it was usually about some college kid or "phone phreak." One never read of a mobster being caught. Greed and stupidity were the reasons why the kid's were caught.

It was the transistor that led to Ma Bell going public with the Blue Box. By using transistors and RC phase-shift networks for the oscillators, a portable Blue Box could be made inexpensively, and small enough to be to be used unobtrusively from a public telephone. The college crowd in many technical schools went crazy with the portable Blue Box; they could call the folks back home, their friends, or get on a free network (the Alberta and Carolina connections—which could be a topic for a whole separate article) and never pay a dime to Ma Bell.

simply monitored the booth. Ma Bell might not have known who originated the call, but she did know who got the call, and getting that party to spill their guts was no problem.

The mob and a few Blue Box hobbyists (maybe even thousands) knew of the AMA machine, and so they used a real telephone number for the KP skip. Their AMA tapes looked perfectly legitimate. Even if Ma Bell had told the authorities they could provide a list of direct-dialed calls made by local mobsters, the AMA tapes would never show who was called through a Blue Box. For example, if a bookmaker in New York wanted to lay off some action in Chicago, he could make a legitimate call to a phone in New Jersey and then Blue Box to Chicago. His AMA tape would show a call to New Jersey. Nowhere would there be a record of the call to Chicago. Of course, automatic tone monitoring, computerized billing, and ESS (*E*lectronic *S*witching *S*ystems) now makes that all virtually impossible,

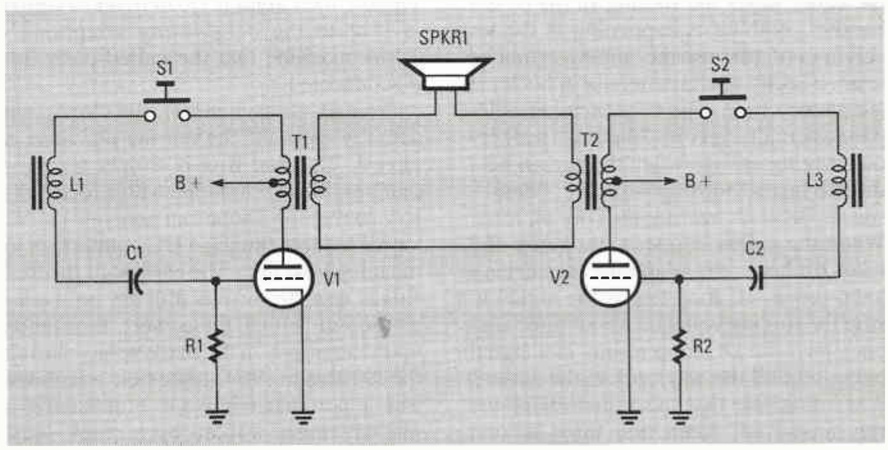


FIG. 2—A POPULAR BLUE BOX DESIGN used two phase-shift oscillators, vacuum tubes, and a simple speaker connection that mixed both oscillators into a single two-tone output.

Unlike the mobsters who were willing to pay a small long-distance charge when Blue Boxing, the kids wanted it, wanted it all free, and so they used the information operator routing, and would often talk "free-of-charge" for hours on end.

Ma Bell finally realized that Blue Boxing was costing them *Big Bucks*, and decided a few articles on the criminal penalties might scare the Blue Boxers enough to cease and desist. But who did Ma Bell catch? The college kids and the greedies. When Ma Bell decided to catch the Blue Boxers she simply examined the AMA tapes for calls to an information operator that were excessively long. No one talked to an operator for 5, 10, 30 minutes, or several hours. Once a long call to an operator appeared several times on an AMA tape, Ma Bell simply monitored the line and the Blue Boxer was caught. (Now do you understand why we opened with an explanation of the AMA machine?) If the Blue Boxer worked from a telephone booth, Ma Bell

but that's the way it was.

You might wonder how Ma Bell discovered the tricks of the Blue Boxers. Simple, they hired the perpetrators as consultants. While the initial newspaper articles detailed the potential jail penalties for apprehended Blue Boxers; except for Ma Bell employees who assisted a Blue Boxer, it is almost impossible to find an article on the resolution of the cases because most hobbyist Blue Boxers got suspended sentences and/or probation if they assisted Ma Bell in developing anti-Blue Box techniques. It is asserted, although it can't be easily proven, that cooperating ex-Blue Boxers were paid as consultants. (If you can't beat them, hire them to work for you.)

Should you get any ideas about Blue Boxing, keep in mind that modern switching equipment has the capacity to recognize unauthorized tones. It's the reason why a local office can leave their subscriber *Touch-Tone* circuits active, almost inviting you to use the *Touch-Tone* service. A few days after you use an unauthorized *Touch-Tone* service, the business office will call and inquire whether you'd like to pay for the service or have it disconnected. The very same central-office equipment that knows you're using *Touch-Tone* frequencies knows if your line is originating CCITT signals.

The Red Box

The Red Box, later to be called a Black Box, was primarily used by the college crowd to avoid charges when frequent calls were made between two particular locations. Unlike the somewhat complex circuitry of a Blue Box, a Red Box was nothing more than a modified telephone; in some instances nothing more than a capacitor, a momentary switch, and a battery.

As you recall from our discussion of the Blue Box, a telephone circuit is really established before the target phone ever rings, and the circuit is capable of carrying an AC signal in either direction. When the caller hears the ringing in his or her handset, nothing is happening at the receiving end because the ringing signal he hears is really a tone generator at his local telephone office. The target (called) telephone actually gets its 20 pulses-per-second ringing voltage when the person who dialed hears nothing—in the "dead" spaces between hearing the ringing tone. When the called phone is answered and taken off hook, the telephone completes a local-office DC loop that is the signal to stop the ringing voltage. About three seconds later the DC loop results in a signal being sent all the way back to the caller's AMA machine that the called telephone was answered. Keep that three-second AMA delay in mind. (By now you should have a pretty good idea of what's coming!)

Figure 3 shows the simplified functional schematic of a telephone. Switch S1 is the hook switch. When S1 is open (on-hook) only the ringer circuit consisting of C1 and BELL1 is connected across the line. Capacitor C1 really has no purpose in the ringing circuit; it only serves to keep DC from flowing through BELL1. When the local telephone office feeds a 20-pps ringing signal into the line it flows through C1 and a ringer coil in BELL1. A vibrating device attached to BELL1 strikes a small bell—the ringing device. When the phone is answered by lifting the handset from its cradle, switch S1 closes (goes off-hook) and connects the handset across the telephone line. Since the handset's receiver and transmitter (microphone) are connected in series, a DC path is established from one side of the line to the other—what is called completing a DC loop with the central office. The DC current flowing in the loop causes the central office to instantly stop the ringing signal. When the handset is replaced in its cradle, S1 is opened, the DC loop is broken, the circuit is cleared, and a signal is sent to the *originating* telephone's AMA machine that the called party has disconnected.

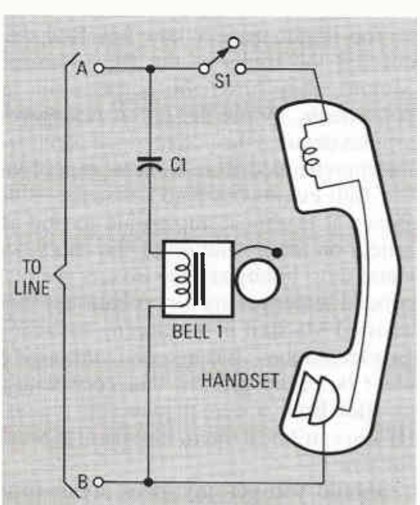


FIG. 3—A SIMPLIFIED TELEPHONE circuit. The handset is connected across the line when hook switch S1 is closed. The handset closes the DC loop with the telephone company's switching equipment.

Now as we said earlier, the circuit can actually carry AC before the DC loop is closed. The Red Box is simply a device that provides a telephone with a local battery so that the phone can generate an AC signal without having a DC connection to the telephone line. The earliest of the Red Boxes was the surplus military field telephone, of which there were thousands upon thousands in the marketplace during the 1950's and 1960's. The field telephone was a portable telephone unit having a manual ringer worked by a crank—just like the telephone Grandpa used on the farm—and two D-cells. A selector switch set up the unit so that it functioned as a standard telephone that could be connected to a combat switchboard, with the DC power supplied by the switchboard. But if a combat unit wasn't connected to a switchboard, and the Lieutenant yelled "Take a wire," the signalman threw a switch on his field telephone that switched in the local batteries. To prevent the possibility of having both ends of the circuit feeding battery current into the line in opposite polarity—thereby resulting in silence—the output from the field telephone when running from its internal batteries was only the AC representing the voice input, not modulated DC.

Figure 4 is the functional simplified schematic for a field telephone (**do not attempt to build that circuit**). Momentary switch S4 is not part of the field telephone, it is added when the phone is converted to a Red Box; so for now, consider that S4 does not exist. Once again, S1 is the hook switch. When S2 is set to N (NORMAL) and S1 is closed, DC flows from line A through T1's secondary (S), through S2-a to S2-b, through T1's primary (P), through the handset, through S2-c, to line B. There is a complete DC path across the line, and if the unit is connected across a conventional subscriber telephone line it will close the DC loop from the local office.

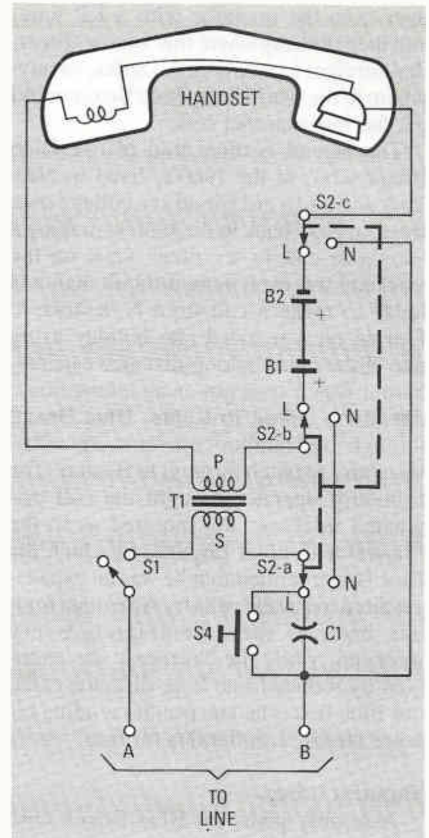


FIG. 4—A SIMPLIFIED RED BOX. Switch S2 lifts the handset from the telephone line and connects two D-cells as a local power supply. The circuit is DC-isolated from the telephone line even when hook switch S1 is closed.

To use the field telephone as a Red Box, switch S2 is set to L (LOCAL). Switches S2-b and S2-c connect batteries B1 and B2 in series with the handset and the transformer's primary, which constitute an active, working telephone circuit. Switch S2-a connects T2's secondary to one side of the telephone line through a non-polarized capacitor (C1), so that when hook-switch S1 is closed, T1's secondary cannot close the DC loop.

Press once to talk

The Red Box was used at the receiving end; let's assume it's the old homestead. The call was originated by Junior (or Sis) at their college 1000 miles from home. Joe gave the family one ring and then hung up, which told them that he's calling. Pop set up the Red Box by setting S2 to LOCAL. Then Junior redialed the old homestead. Pop lifted the handset when the phone rang, which closed S1. Then Pop closed momentary-switch S4 for about a half-second, which caused the local telephone

continued on page 129

BUILD THIS

Miniature Wideband Amplifier

JOHN CLAWSON

From DC to 450 MHz, 20-dB gain in the palm of your hand.

FROM DC THROUGH TO THE MOBILE RADIO and TV frequencies, there's always need for some amount of additional amplification. In particular, when it comes to TV reception just a *smidgen* extra gain can make the difference between looking at a snowstorm or a decent picture having rock-stable color.

Often, obtaining enough of a signal for a good TV picture means using some kind of deep-fringe antenna and a preamplifier. The problem is, however, that *stable* preamplifiers don't come cheap unless you build them yourself, and even then you might spend countless days, nights, and weekends getting one to work without producing more *spuri* (spurious signals) than it does TV signal.

But spurious signals are nonexistent in the wideband high-frequency amplifier shown in the photographs; yet it rivals commercial units in both performance and reliability—but without their formidable price tags. While a commercial counterpart might easily sell for $100 or more, our version, shown in Fig. 1, can be built for about $12. How can a commercial-quality amplifier be built so inexpensively? The answer to that question is found in a new breed of integrated circuit, the Signetics NE5205, a UHF amplifier with a fixed gain of 20 dB.

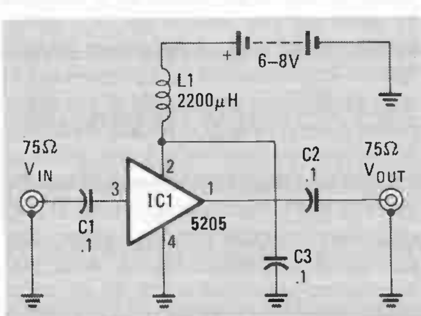


FIG. 1—EXCEPT FOR THE COUPLING and decoupling capacitors, IC1 is a complete wideband amplifier having a fixed gain of 20 dB to 450 MHz. No external compensation is required.

Signetics offers the NE5205 in two kinds of housings: the TO-46 metal can shown in Fig. 2-*a*, and the SO-8 DIP shown in Fig. 2-*b*. Unlike earlier monolithic amplifiers, the NE5205 does its job without external compensation networks and matching transformers. What's left is an experimenter's dream: an inexpensive black-box amplifier that can be plugged into practically any circuit. Put into other words, a gain-block.

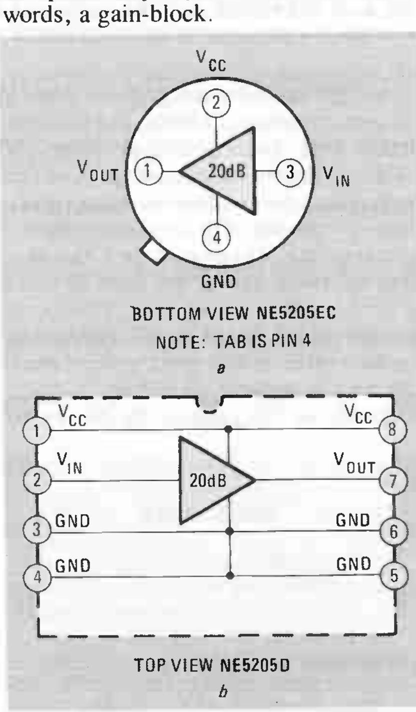


FIG. 2—THE NE5205 IS AVAILABLE in two configurations: a pinout for a conventional TO-46 metal can whose tab provides the ground connection is shown in *a*. An SO-8 DIP pinout is shown in *b*. The grounded metal case of the TO-46 version extends the response from 450 MHz to 650 MHz.

Before going into construction details, let's go over some of the NE5205's specifications, because they will give you a better feeling for the IC and its performance.

Let's start with amplification, because how well the NE5205 does that job will greatly influence how it is used. To begin with, there's 20 dB of fixed insertion gain that is essentially ruler-flat to 450 MHz. The grounded case of the TO-46 version extends the response to −3 dB at 650 MHz. Unlike some theoretical or optimized values, 20 dB is a real-world figure that is not swamped in a sea of noise. For example, the NE5205 can be used as a 50- or 75-ohm line amplifier; yet even with such a low impedance it preserves a remarkably low +4.8 dB NF (*N*oise *F*igure) at 75 ohms, +6.0 dB at 50 ohms. Input and output VSWR (*V*oltage *S*tanding *W*ave *R*atio) for both impedances remains below 1.5:1 to 450 MHz.

Twenty decibels is a hefty boost, but as Murphy's Law would have it, with 20 dB of gain available you will undoubtedly need 21 dB. How, then, do you provide the extra gain? As shown in Fig. 3, simply cascade two NE5205s for a total gain of 40 dB. Notice the conspicuous absence of compensation. Although providing a total of 40 dB gain, the amplifier is still our basic wideband amplifier circuit; only an extra IC, a choke, and two capacitors have been added.

Also notice that again we are saved from circuit complexities by using only AC coupling capacitors rather than reactive networks. That is amazing, considering that chaining even the most docile conventional high-frequency amplifier can often severely strain stability.

Circuit operation

Referring back to Fig. 1, the wideband amplifier uses only five components. External signals enter pin 3 of IC1 via AC coupling capacitor C1. Following amplification, the boosted signals from IC1 pin 1 are coupled to the output by capacitor C2. Capacitor C3 decouples the DC power supply, while RF current is isolated from the power supply by RF choke L1.

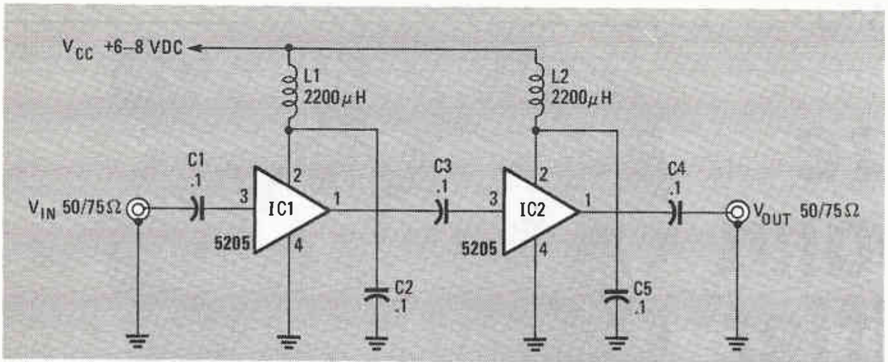


FIG. 3—SINCE THE NE5205 FUNCTIONS as a gain block, two or more can be easily cascaded to provide additional amplification. In this circuit, which uses two NE5205s, the overall gain is 40 dB.

strip are given in PC Service. The recommended printed-circuit board material is double-clad 0.060-inch G-10 epoxy board. The pattern shown is intended for 75-ohm operation. For alternate impedances (Z_O) or different thicknesses of G-10 board, you will need to change both the input and the output trace widths; refer to the chart shown in Fig. 4, which shows the characteristic impedance *vs.* signal-trace width required for various G-10 thicknesses. For example, a 50-ohm Z_O (characteristic impedance) and a 0.031-inch G-10 board requires a signal trace width of approximately 0.050-inch.

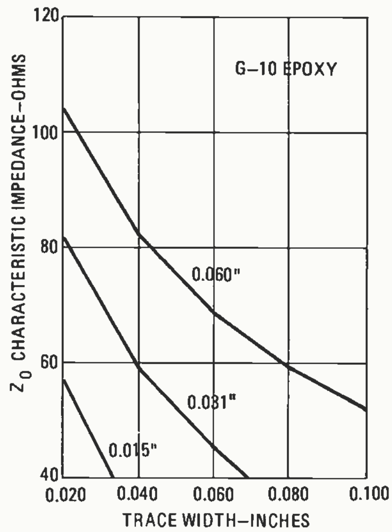


FIG. 4—USE THIS CHART to determined microstrip trace width for various impedances and thicknesses of G-10 epoxy board.

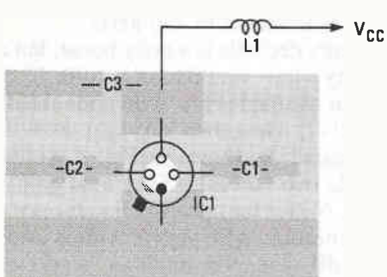


FIG. 5—THIS IS THE COMPONENT LAYOUT for the basic amplifier. All components are on the soldering side of the board.

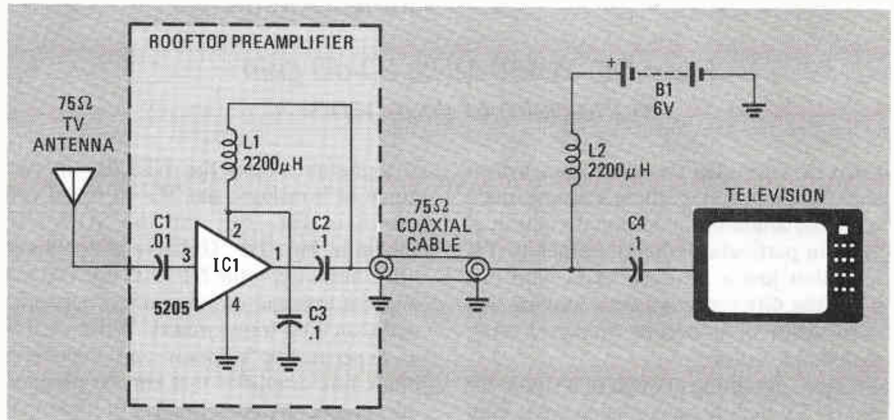


FIG. 6—IF THE POWER SUPPLY is fed through the signal-carrying coaxial cable, the amplifier can be mounted in a weatherproof enclosure directly at the antenna.

The NE5205's low current consumption of 25 mA at 6 volts DC makes battery-powered operation a reality. (Although the device is rated for a 6- to 8-volt power supply, 6 volts is recommended for normal operation.) Six volts provides an internal bias of 3.3 volts, which permits a 1.4-volt peak-to-peak output swing for video applications.

Construction

Below 150 MHz, just about any kind of point-to-point wiring assembly can be used if the leads are made as short as possible, if you don't run the output and input wires close together, and if you remember to ground the metal case.

But the amplifier will perform better at frequencies above 30 MHz, and most certainly with fewer problems above 150 MHz, if built on a microstrip. A *microstrip* is a microwave low-loss transmission line. It consists of a conductor above a groundplane, analogous to a two-wire line in which one of the lines is represented by the groundplane. Obviously, printed-circuit board that is copper-clad on both surfaces will make an ideal medium for a homebrew microstrip.

Full-scale PC patterns for the micro-

PARTS LIST

IC1—NE5205EC wideband high frequency amplifier (Signetics)
C1, C2, C3—0.1 µF, multilayer ceramic chip capacitor, 10%, 100-WVDC (Stetner Electronics KEFQ1210
L1—RF choke, 2200µF, 10%, Ferrite core (Digi-Key M8153 or equivalent)

Note. The following are available from John Clawson, P.O. Box 225, Tillamook, OR 97141: NE5205EC, $8.50; NE5205D, $6; set of three 0.1-µF chip capacitors, $3; Printed circuit board, $3.25. Shipping and handling $3.25 per total order. Foreign orders add $4.75. U.S. funds only. Oregon residents add appropriate sales tax. Check or M.O. only.

Since IC1's TO-46 case is grounded, don't be concerned about providing an insulated hole through the groundplane. You can leave the underside copper complete and simply drill a 3⁄16-inch hole through from the top side of the board.

If you want to expand the foil pattern to include another NE5205, keep all new signal paths short and as straight as possible. The groundplane should be extended beyond each edge of any added traces by no less than the trace width.

The parts-placement pattern is shown in Fig. 5. Prior to assembling the etched and drilled PC board, be sure that all circuit traces are free from residue, burrs, and obstructions.

Except for one lead of RF choke L1, all components are mounted directly on the soldering side of the board. L1 is attached by soldering one lead to the V_{CC} plane and the other lead to the power source. The 3⁄16-inch diameter hole is intended to hold the NE5205 very snugly. If you experience a great deal of difficulty installing IC1, slightly enlarge the hole using a small round file or a slightly larger drill bit. Be sure that the the metal flange on the TO-46 case doesn't touch the V_{CC} plane, and that IC1 is properly oriented. After you have correctly positioned the IC, solder its leads to their appropriate traces, keeping length to an absolute minimum. Then make a good electrical connection be-

continued on page 129

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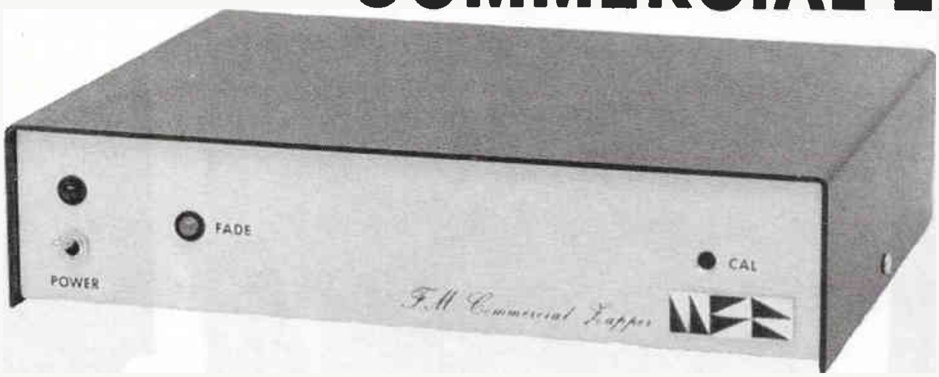
COMMERCIAL ZAPPER FOR YOUR RADIO



MARK RUMREICH

Bothered by commercial interruptions on FM? Kill 'em with this zapper.

MANY SMALL OFFICES USE FM EASY-LISTENING stations to supply background music. Often, the commercials broadcast by those stations are unobjectionably loud. If you'd like to restore peace and quiet to your office, just connect our commercial killer in your receiver's tape-monitor loop. The circuit automatically senses large changes in volume and reduces output accordingly. In addition, it's easy to build, and inexpensive.

How it works

The commercial killer monitors the incoming signal and reduces output according to how much the input resembles a commercial (we'll discuss how it makes its decision in a moment). In reducing output, the commercial killer takes account of the past few seconds of signal in determining how much to reduce output. Doing so reduces the number of errors and creates a smoother overall effect as it fades out of commercials and fades into music. It is less objectionable to miss the first few seconds of music than to hear the first few seconds of a commercial, so the commercial killer has different attack and decay times.

Whether a signal is "commercial-like" is determined by the rate of large volume transitions. Because music (especially that on "light" stations) is typically composed of a number of instruments playing more or less continuously, the volume (or envelope) stays fairly constant over a short period of time. In a typical commercial, however, the instantaneous volume changes rapidly over time as the announcer pauses between words, and as various additional sound sources are mixed in and out.

Music with much dynamic range (rock and roll, for example) has a high rate of large volume transitions, so the commercial killer probably will trigger erroneously with that type of music.

Figure 1 shows a block diagram of the commercial killer. A summing amplifier adds the left- and right-channel inputs. The summing amp has adjustable gain so that you can find the optimum signal level for the station you use the commercial killer with.

Next comes an envelope detector, which produces a waveform that represents the instantaneous volume of the signal. A comparator (with hysteresis) produces a transition whenever the output of the envelope detector goes either above or below pre-set thresholds. The output of the comparator is conditioned via the transition converter, which produces a pulse of fixed width and amplitude for each transition of the comparator. Those pulses feed a "leaky integrator," whose output determines the gain of the left and right VCA's (*V*oltage *C*ontrolled *A*mplifiers). The output of the leaky integrator is a DC voltage whose value depends on the pulse rate from the transition converter.

The VCA's are what actually reduce the output signals during commercials. An LED connected to the VCA's provides a visible indication of the amount of volume reduction taking place.

Figure 2 shows the schematic of the circuit. Diodes D5–D8 form a bridge rectifier that feeds Zener diode D9, which provides a regulated single-ended 16-volt supply for the circuit. Because a single-ended supply is used, a reference voltage (V_{REF}) is generated via the voltage divider composed of R36 and R37 and transistor Q3. That reference voltage is used to bias the op-amps precisely.

Op-amps IC1-a and IC1-b function as buffers that drive both the summing amp (IC2-a) and the VCA's (IC1-c and IC1-d). The outputs of IC1-a and IC1-b are, of course, biased to the reference voltage. To achieve maximum dynamic range, a positive envelope detector follows the

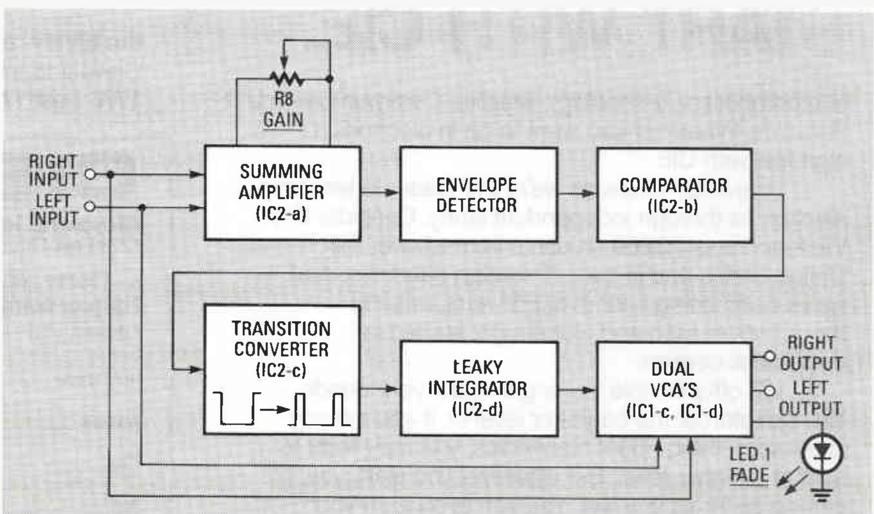


FIG. 1—BLOCK DIAGRAM OF THE COMMERCIAL KILLER: The envelope of the signal is used to vary the pulse rate from IC2-c. The pulses are integrated; the resulting signal controls the gains of a pair of VCA's.

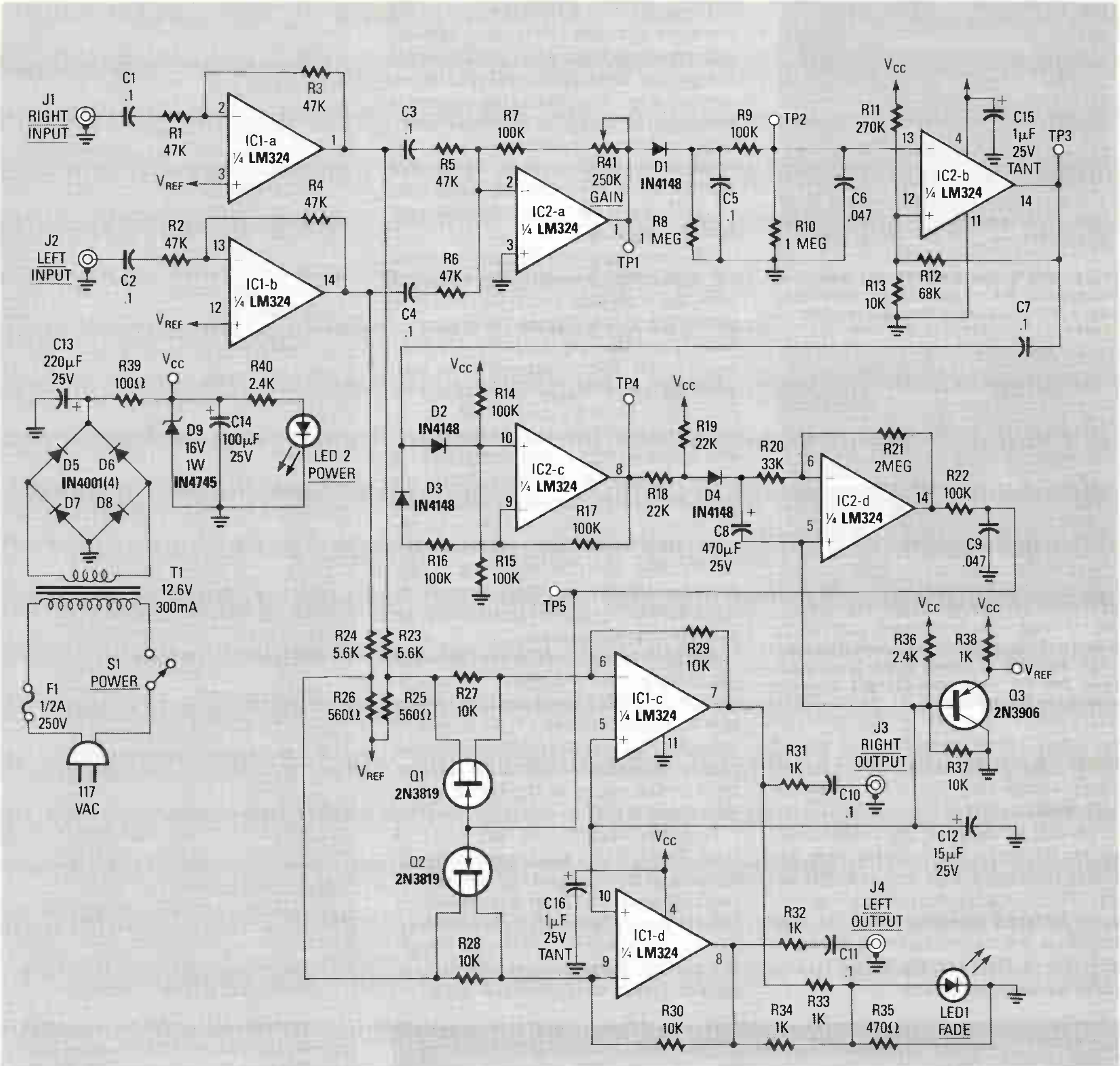


FIG. 2—THE COMMERCIAL KILLER'S SCHEMATIC: Q3 provides a reference voltage for the op-amps; Q1 and Q2 control the gain of IC1-c and IC1-d.

FIG. 3—THE SPIKES represent L + R audio, and the smooth trace, the output of the envelope detector.

summing amp (IC2-a); that allows the summer to be referenced to ground (not V_{REF}). The envelope detector has a second-order network optimized for normal audio material.

Figure 3 shows typical waveforms at the output of the summing amplifier (TP1), and the corresponding waveform at the output of the envelope dectector (TP2). The spiked traces represent the audio signal, and the smooth trace riding above them, the envelope. The summer's channel is set for 1 volt/division, and the envelope detector for 0.5 volt/division. The timebase is 20 ms/division.

Referring back to the schematic (Fig. 2), IC2-b is used as a comparator. As mentioned earlier, the comparator has two thresholds; the signal must cross both before the output changes from positive to negative (or vice-versa). The equations describing the lower and upper threshold voltages (V_{LO} and V_{HI}, respectively) as functions of the supply voltage and bias resistors are as follows:

$$A = (R12 \times R13) / (R12 + R13)$$

$$V_{LO} = (A \cdot V_{CC}) / (A + R11)$$

$$B = (R11 \times R12) / (R11 + R12)$$

$$V_{HI} = (R13 \cdot V_{CC}) / (R13 + B)$$

In this case, $V_{LO} \approx$ 0.5 volts and $V_{HI} \approx$ 2.48 volts.

Figure 4 shows the envelope-detector's output (TP2) at 0.5 volts/division and the comparator's output (TP3) at 2 volts/division (both at 20 ms/division). The square waveform in the center of the photo is the comparator's output; the other waveform is the envelope detector's output. Notice that the comparator does not respond to

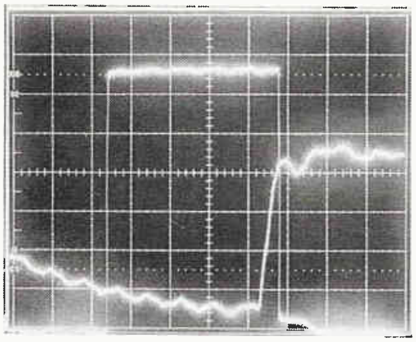


FIG. 4—THE SQUARE WAVEFORM represents the output of the comparator; the other waveform is the output of the envelope detector.

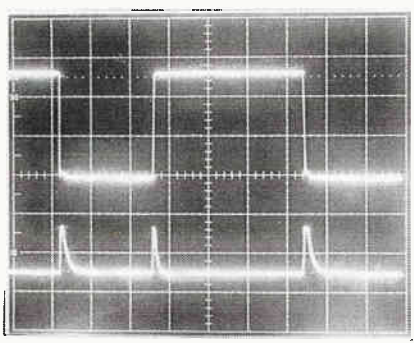


FIG. 5—THE COMPARATOR'S OUTPUT is shown in the upper trace; the output of the transition converter is shown in the lower trace. Every time the comparator changes state, another pulse is generated.

the minor transitions in the early part of the waveform; the comparator's output changes state only after both thresholds have been crossed.

Because the inverting input of the comparator is used for threshold detection, the output is inverted with respect to the input. The comparator responds to specifically designed threshold levels, so it is important that the output of the summing amp provide that level. We'll show how to make the adjustment later.

Figure 5 shows a typical output of the transition converter (TP4) along with the corresponding input from the hysteresis comparator, in the upper and lower traces, respectively. The transition-converter waveform is shown at 5 volts/division, with the bottom graticule at 0 volts; the timebase is 100 ms/division. Notice that the baseline is approximately eight volts ($V_{CC}/2$); that is due to the bias at the non-inverting input of IC2-c.

The leaky integrator (IC2-d) produces a DC voltage that depends on the pulse rate from the transition converter. When no pulses are present, diode D4 is reverse-biased, and the output of IC2-d will be equal to the voltage present at its non-inverting input, V_{REF}. When pulses arrive, diode D4 is forward-biased, so the voltage across capacitor C8 increases. The output of IC2-d then decreases by a factor of about 60 (R21/R20). When the pulse rate is high, the output voltage will be between six and nine volts, thereby providing minimum gain from the VCA's. But when the pulse rate is low, capacitor C8 will discharge through resistor R20 to V_{REF}, thereby restoring the gain op-amp to maximum.

The trick about the VCA circuits is that a matched pair of N-channel JFET's act as voltage-controlled input resistors. When gate-to-source voltage (V_{GS}) is near 0 volts, the FET acts as a small resistor, and gain is maximum—about 5 dB with respect to the output of the buffer stages (IC1-a and IC1-b).

However, when V_{GS} is less than −3 volts, the FET acts as a large resistor, so the gain of the op-amp is minimized—it provides about 20 dB of attenuation. In order to provide good left/right matching, the two FET's should have similar voltage and current characteristics, especially at drain-to-source voltages of 0.6 volts.

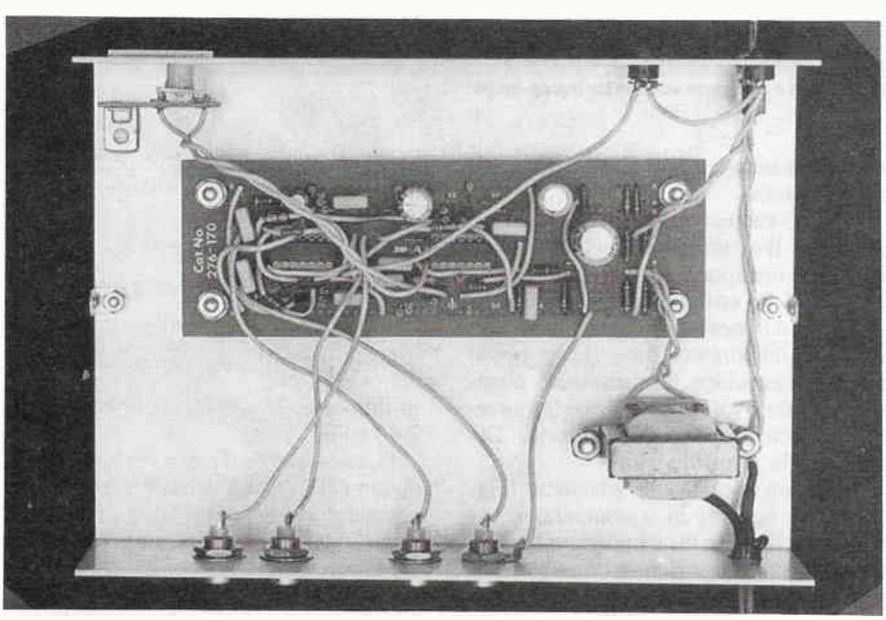


FIG. 6—THE AUTHOR'S PROTOTYPE was built on a piece of perfboard using point-to-point wiring. Keep your lead lengths short, and be careful with the 117-volt primary circuit.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—R6—47,000 ohms
R7, R9, R14–R17, R22—100,000 ohms
R8, R10—1 megohm
R11—270,000 ohms
R12—68,000 ohms
R13, R27–R30, R37—10,000 ohms
R18, R19—22,000 ohms
R20—33,000 ohms
R21—2 megohms
R23, R24—5600 ohms
R25, R26—560 ohms
R31, R33, R34, R38—1000 ohms
R35—470 ohms
R36, R40—2400 ohms
R39—100 ohms
R41—250,000 ohms, trimmer potentiometer

Capacitors
C1–C5, C7, C10, C11—0.1 µF, ceramic disc
C6, C9—0.047 µF, ceramic disc
C8—470 µF, 25 volts, electrolytic
C12—15 µF, 25 volts, electrolytic
C13—220 µF, 25 volts, electrolytic
C14—100 µF, 25 volts, electrolytic
C15—1 µF, 25 volts, tantalum

Semiconductors
IC1, IC2—LM324 quad op-amp
D1–D4—1N4148 signal diode
D5–D8—1N4001 rectifier diode
D9—Zener diode, 16 volt, 1 watt (1N4745 or similar)
LED1, LED2—standard
Q1, Q2—2N3819 N-channel JFET
Q3—2N3906 (or similar)

Other components
J1–J4--Chassis-mount RCA connectors
F1—Fuse, 0.5 amp, 125 volts AC
S1—SPST, 1 amp, 125 volts AC
T1—Transformer, 12.6 volts, 300 mA (Radio Shack 273-1385 or similar)

NOTE: The following are available until April 1989 from MFR Engineering, 5333 N. Guilford, Indianapolis, IN 46220: Etched and drilled circuit board, $15; matched set (Q1 and Q2) $3. All prices postpaid. Indiana residents must add applicable sales tax.

Construction hints

Figure 6 shows the author's prototype, which was built on a piece of prototype board. The author used two LM324 quad op-amps, because they're inexpensive and easy to obtain. However, slightly better frequency response and signal-to-noise ratio may be obtained by replacing the buffer op-amps (IC1-a—IC1-d) with low-noise JFET op-amps (TL074's, for example). Do not replace IC2-a—IC2-d with "high-performance" op-amps. The LM324 has the unique property of output swing to ground required in this application. Whichever op-amps you use, make

continued on page 130

Concerned about acid rain? This inexpensive monitor will keep you informed.

WALTER D. SCOTT

ACID RAIN MONITOR

THE EFFECTS OF ACID RAIN HAVE BEEN widely debated, often with little hard evidence to back up either side's point of view. Actually, it's not difficult to provide hard evidence. A simple one-transistor circuit can be used to sense the acidity of local rainfall (and other liquids). Accuracy is as good as the source used to calibrate the meter. The project can be built for about $30 using all new parts; many of the parts are of the junkbox variety, so with just a little bit of luck the cost could be even less.

The sensor can be mounted in a remote location; it has a built-in solenoid-operated drain valve. The meter indicates acidity in terms of pH, which refers to the concentration of hydrogen ions in a solution. The meter's range is from 7 (neutral) to 2.5 (highly acidic).

How it works

The schematic diagram of the circuit is shown in Fig. 1. A simple bridge rectifier and 12-volt regulator powers the MOSFET sensing circuit. The unregulated output of the bridge rectifier operates the drain solenoid via switch S1. The sensor itself is built from two electrodes, one made of copper, the other of lead. In combination with the liquid trapped by the sensor, they form a miniature lead-acid cell whose output is amplified by MOSFET Q1. The maximum output produced by our prototype cell was about 50 μA.

MOSFET Q1 serves as the fourth leg of a Wheatstone bridge. When sensed acidity causes the sensor to generate a voltage, Q1 turns on slightly, so its drain-to-source resistance decreases. That resistance variation causes an imbalance in the bridge, and that imbalance is indicated by meter M1.

Construction

The circuit is simple, but the sensor must be built exactly as shown for calibration to be accurate. As shown in Fig. 2 and Fig. 3, the electrodes must have a diameter of ¼ inch, and they must be spaced ⅜ inch apart in a plastic funnel with a handle to ensure accurate calibration. The positive electrode is a 1½" length of ¼" copper tubing. The negative electrode is a strip of lead that is formed to the same size and shape as the copper electrode. You should be able to get lead strip from a sporting-goods store; it's used to make fishing sinkers. Otherwise, try a junkyard.

Use flux-less solid-core solder to make connections to the electrodes, and waterproof all exposed joints and wiring. Seal the electrodes in the bottom of the funnel by melting the plastic with a soldering iron, or plug the funnel with epoxy putty. Use a good-quality waterproof cable to connect the electrodes and solenoid to the control box.

The solenoid assembly must be waterproof, otherwise, water may leak into the solenoid housing and cause a short. But first, remove the valve and coat the plunger with grease, preferably silicone, for temperature resistance. Also, coat all metal solenoid parts with acrylic spray or clear lacquer. Then epoxy the solenoid's valve to the funnel stem through a 1" washer with a drain hole. Mount the solenoid in a 35mm film canister or other waterproof container. It may be necessary to trim off some of the valve's exit tube in order to fit it inside the 35mm film canister.

The method of fitting the solenoid to the cap of the film canister and the mount-

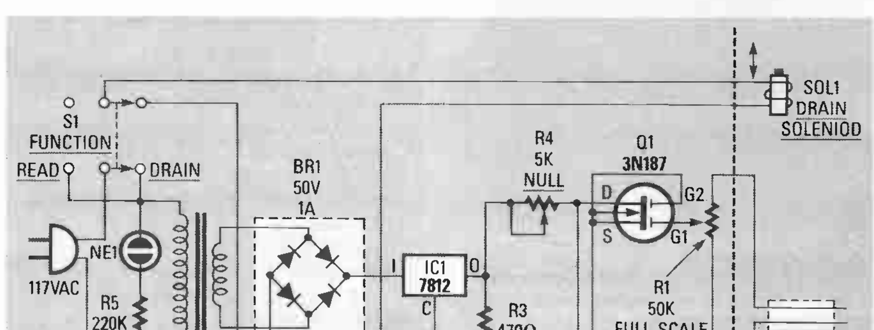


FIG. 1—THE DRAIN-TO-SOURCE RESISTANCE of Q1 varies depending on the acidity of the sample presented to Q1's gate circuit. That variable resistance varies the current flowing through the bridge; that current is proportional to pH.

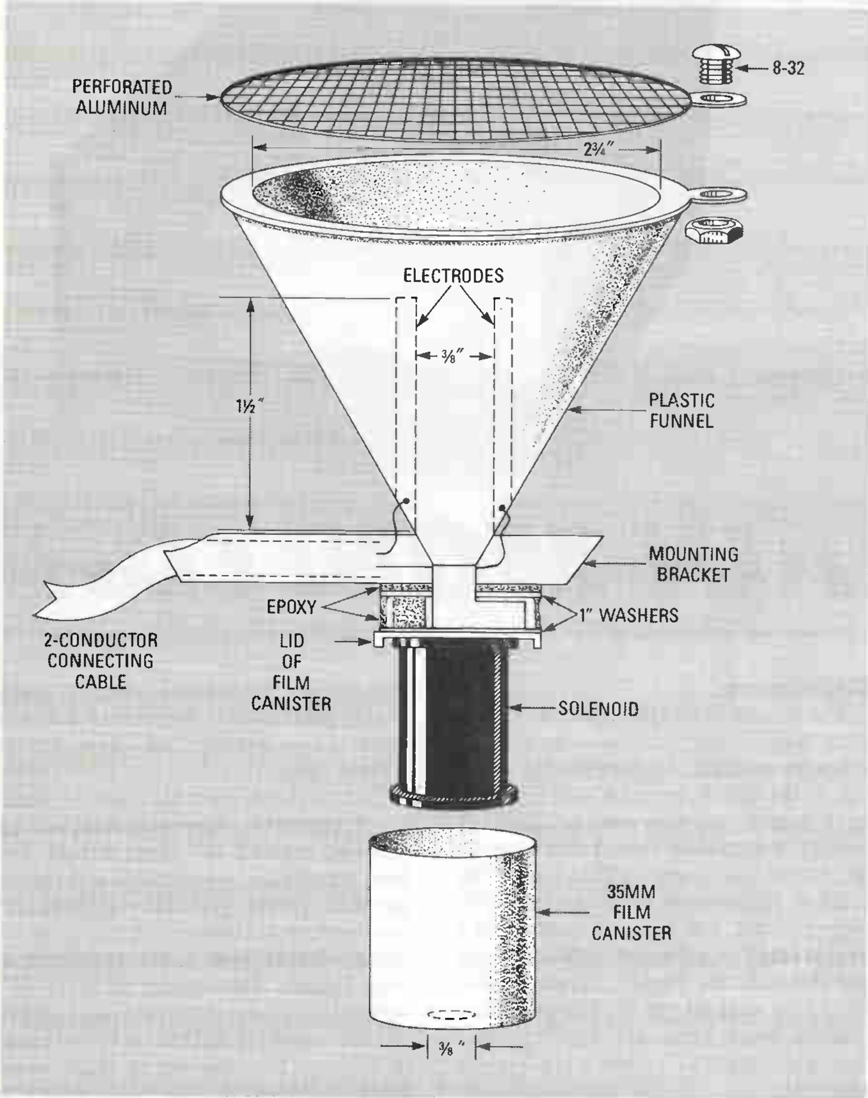


FIG. 2—TWO ¼-INCH ELECTRODES, made of copper and lead, are mounted inside the funnel, spaced ⅜-inch apart. A solenoid valve attached to the mouth of the funnel is used to drain it as necessary.

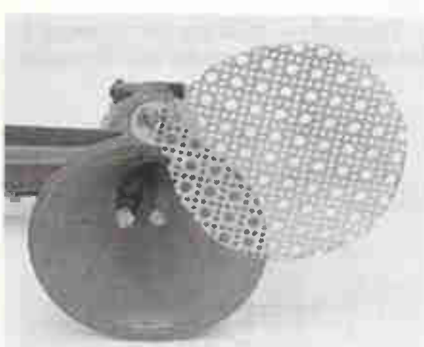


FIG. 3—CLOSE-UP OF THE FUNNEL assembly: the screen keeps foreign matter, which could affect pH, out of the funnel.

ing bracket will depend on the type of solenoid you have. Use epoxy, screws, or both.

As shown in Fig. 4, a swing-away filter cut from perforated sheet aluminum is bolted to the funnel's handle. In addition to preventing drain-clogging or electrode-shorting by air-borne particles, the screen prevents false pH readings that might be caused by pine needles, oak leaves, or other acidic contaminants. You should also coat the filter with lacquer to prevent aluminum-oxide contamination. Plastic screening is also available and may be used.

All parts were mounted and wired point-to-point on a piece of perfboard; the perfboard was then mounted in a case, as shown in Fig. 5.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—50,000 ohms, pc-mount, linear potentiometer
R2, R3—470 ohms
R4—5000 ohms, PC-mount, linear potentiometer
R5—220,000 ohms

Capacitors

C1—470 µF, 35 volts, electrolytic

Semiconductors

IC1—7812, 12-volt regulator
Q1—3N187 MOSFET transistor
BR1—50-volt 1-amp bridge rectifier

Other components

M1—100-µA panel meter
NE1—Neon lamp
S1—DPDT, 117-volt, toggle, center off
SOL1—12-volt DC solenoid valve
T1—12-volt 450-mA power transformer

TABLE 1—CALIBRATION

pH	µA
3	82
3.5	76
4	68
4.5	64
5	61
5.5	59
6	56
6.5	53

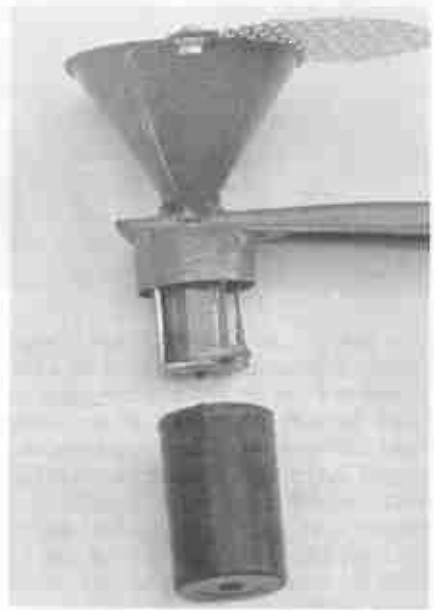


FIG. 4—A 35mm FILM CANISTER provides a water-tight enclosure for the solenoid valve.

Calibration

Our prototype was calibrated against a professional pH meter using precisely-diluted sulphuric acid (which is, by the way, a major ingredient of industrial pollution.) After setting the zero and full-scale points, you can calibrate the meter using Table 1. Otherwise, you can, as we did, measure known solutions with your meter and a professional meter, and mark your meter's scale accordingly.

The first step is to null the meter; 0 µA represents neutrality, a pH of 7. With the sensor connected through the same cable that will be used for the final installation, set R1 for lowest resistance and fill the receptor funnel with distilled water. Adjust R4 until the meter reads exactly zero.

You'll need to connect a 1.5-volt battery in series with a 5,000-ohm linear potentiometer to calibrate the remaining

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DIGITAL TACHOMETER FOR YOUR CAR

Monitor your car's engine speed with digital accuracy and analog readability.

ROSS ORTMAN

UNTIL RECENTLY, THE DIGITAL dashboard has been seen only in movies and custom show cars. Automobile manufacturers now incorporate digital displays in selected models, but only as an extra-cost option. But that leaves the rest of us in the dark—literally! So here's an inexpensive, easy-to-build tachometer that displays engine speed in both analog and digital form. The circuit is versatile enough to be adapted for use as a speedometer; we'll show how to do so in a future issue.

Why did we provide both analog and digital displays? Mainly because a digital readout can be harder to read and interpret under rapidly changing engine speeds than an analog dial. After the circuit is calibrated, you can get a good idea of engine speed just by glancing at the gauge. After calibration, the digital readout will display accurately from 0 to 9990 RPM in increments of 10 RPM.

Theory of operation

The tachometer works by counting pulses from the distributor points for a period of time, and then scaling and displaying that number. The digital display has three significant digits; the forth (and least significant) digit always displays "0," so that RPM's can be read from the display directly.

Breaker-point frequency is determined by this formula:

$$f = RPM \times (\text{Number of cylinders} / 120)$$

For example, with a speed of 600 RPM on an eight cylinder engine, breaker-point frequency is $600 \times (8/120) = 40$ Hz. At 3000 RPM, it is 200 Hz.

Now let's use the 600-RPM value to establish how to display the correct value on the tachometer. With an input frequency of 40 Hz, the display must read 600. Because the least-significant digit is zero and the counter section controls only the three active digits, we need to end up with a value of 60 in our counter. With a time-base of 0.5 second (2 Hz), 60 pulses must be read within 0.5 second. Dividing 0.5 by 60 gives us 8.33 ms; the reciprocal of that is 120 Hz—the value we must feed the counter section to obtain the correct reading. So we must multiply the 40-Hz incoming frequency by 3. The circuit that does that will be described later.

Following the same procedure, we find that, to obtain accurate readings for 4-, 6-, and 8-cylinder engines, the input frequency must be multiplied by a value of 6, 4, or 3, respectively.

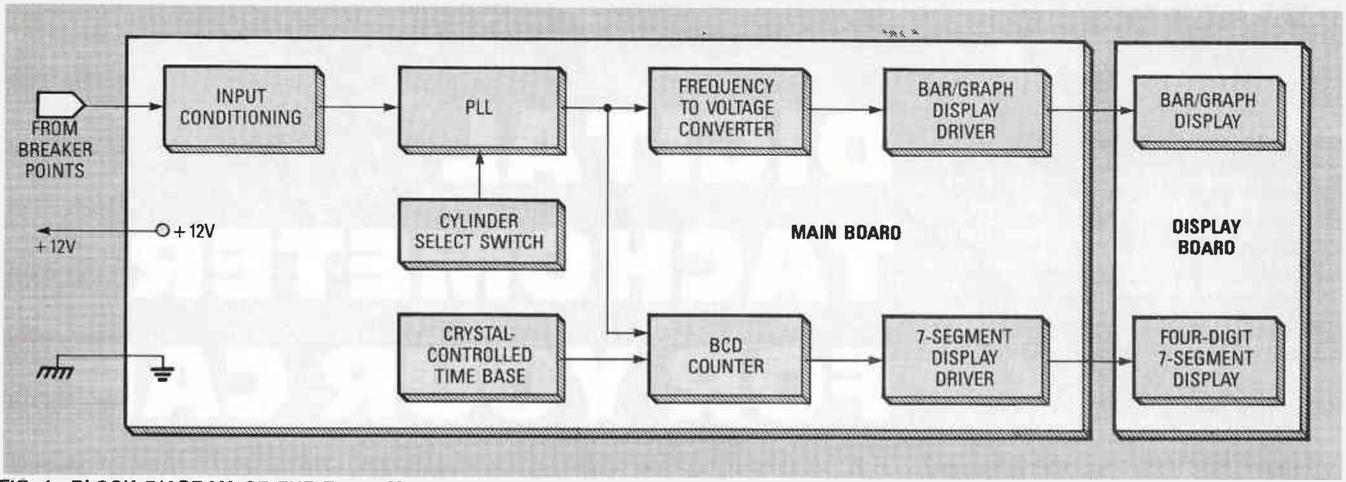


FIG. 1—BLOCK DIAGRAM OF THE TACHOMETER: The PLL scales the breaker-points signal for display directly in RPM.

Circuit overview

A block diagram of the circuit is shown in Fig. 1. After conditioning the noisy input signal, a PLL (*P*hase-*L*ocked *L*oop) is used to multiply the incoming frequency by the value set by the cylinder-select switch (S1). The output of the PLL drives both the analog and digital sections that follow.

The BCD counter is the heart of the digital circuit; it counts the multiplied input signal. After a predetermined sampling interval, a latch pulse latches the number present in the counter at that instant. Immediately following the latch pulse, a clear pulse resets the counter so that counting may start from zero for the next sampling period. The readout is updated every 0.5 second. Figure 2 shows the circuit's timing diagram.

The latch and clear pulses that control the counter are derived from a crystal-controlled oscillator. The oscillator uses a 3.58-MHz TV color-burst crystal to generate a 0.5-second gate time that is stable over a wide range of temperatures.

To produce the analog display, the output of the PLL section is converted to a voltage by a frequency-to-voltage converter. That relative voltage is then displayed on a row of twenty LED's that are driven by a pair of bar/graph display-driver IC's.

Circuit description

The input-conditioning circuit, PLL, and timebase are shown in Fig. 3. Pulses from the points (or tachometer hookup on an electronic ignition system), are fed through a coaxial cable to the input circuit. Waveshaping is accomplished by rectifying the pulses, filtering out spikes, and squaring the signal up by using a comparator with hysteresis. The input circuit limits the amplitude of the 200–300-volt pulses from the points to about nine volts in order to avoid damaging the PLL. Negative pulses are clipped by D1, and positive pulses are filtered by C1 and C2.

Pulses are next squared by IC1, an LM741 op-amp that functions as a comparator. The comparator uses positive feedback via resistor R6 to produce hysteresis, which helps square up the signal.

The PLL section is made up of IC5 (a 4046), its associated circuitry, and IC6, a 4018 presettable divide-by-*n* counter. The setting of IC6 is what determines the PLL's multiplication factor. If IC6 is set to divide by 3, the output frequency of the PLL section will be locked at 3 times the input frequency. Switch S1 determines the number by which IC6 will divide the PLL's output frequency.

The clock is built around an MM5369 17-stage programmable oscillator/divider (IC2); it uses a 3.58 MHz crystal to produce an output of 60 Hz. The 60-Hz output is then divided down to 2 Hz by IC3. The 50-millisecond latch pulse is produced by IC7-a; a delayed version of that pulse is generated by C11, C12, R14, R15, IC7-b, and IC7-c. The delayed pulse functions as the clear signal that was described earlier.

Now let's examine the digital display section (shown in Fig. 4). Counting, latching, and display multiplexing is done by IC9, an MC14553 three-digit BCD counter. The common-cathode LED segments are driven by IC8 (a 74C48); the LED's common cathodes are driven by the three PNP transistors (Q1–Q3).

The analog display (shown in Fig. 5) is based on a frequency-to-voltage converter IC12, an LM2917. It produces a voltage that is proportional to the frequency of the signal fed to its pin-1 input. That voltage is fed to the two bar/graph display drivers, IC10 and IC11, through potentiometer R34, which allows the display to be calibrated. The display drivers are cascaded to drive the 20 discrete LED's. Cascading is accomplished by referencing IC11's internal comparator reference voltage to the final reference voltage of IC10. Resistor R29 limits the amount of current the drivers must dissipate.

Construction

The tachometer is built on two PC boards, a display board, and a main board. The display board (Fig. 6) contains four seven-segment LED displays, twenty discrete LED's, and several current-limiting resistors. The main board (Fig. 7) contains the remainder of the circuitry. The PC boards can be made using the foil patterns shown in PC Service, or a set of boards with plated-through holes can be bought from the supplier mentioned in the Parts List. If you etch your own boards, be sure to solder both sides of the board wherever necessary. If possible, use machined-type IC sockets that don't have plastic bodies, as they can be soldered on both sides of the board easily.

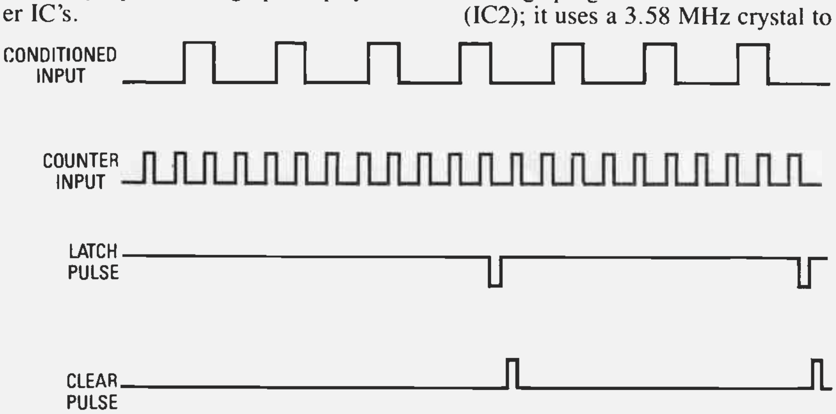


FIG. 2—THE SIGNAL FROM THE POINTS is multiplied by the PLL and counted until a latch pulse is received. The counter is then reset.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—4700 ohms
R2, R3, R5, R12, R14, R15, R30, R33—10,000 ohms
R4, R7, R8, R10—100,000 ohms
R6—470,000 ohms
R9—22 megohms
R11—2.2 megohms
R13—1 megohm
R16, R17, R18, R27—1000 ohms
R19–R25—220 ohms
R26, R31—470 ohms
R28, R36—22,000 ohms
R29—50 ohms, 5 watts, wire-wound
R32—33,000 ohms
R34—10,000 ohms vertical trimmer pot
R35—2200 ohms

Capacitors

C1—0.22 µF disc
C2—0.022 µF disc
C3—0.01 µF disc
C4—10 µF, 16 volts, electrolytic
C5—33 pF disc
C6—22 pF disc
C7, C8, C15—1 µF, 16 volts electrolytic
C9—0.1 µF disc
C10—0.05 µF disc
C11, C12, C13—0.µF 001 disc
C14—0.022 µF mylar

Semiconductors

IC1—LM741 op-amp
IC2—MM5369 17-stage oscillator/divider
IC3—CD4518 dual synchronous up counter
IC4—CD4081 quad AND gate
IC5—CD4046 micropower phase-locked loop
IC6—CD4018 presettable divide-by-*n* counter
IC7—CD4001 quad NOR gate
IC8—74C48 BCD to 7-segment decoder/driver
IC9—MC14553 three-digit BCD counter
IC10, IC11—LM3914 bar/graph display driver
IC12—LM2917N frequency-to-voltage converter
D1–D3—1N4004 rectifier
D4—1N4739A, 9.1 volts, 1 watt Zener
D5—1N4148 switching diode
D6—1N4001 rectifier
Q1–Q4—2N3906 PNP transistor
LED1–LED10—0.125" green diffused LED
LED11–LED16—0.125" yellow diffused LED
LED17–LED20—0.125" red diffused LED
DISP1–DISP4—7-segment common-cathode display (Panasonic LN516RK, Digi-Key P351. P352, P353, & P354 may also be used.)

Other components

S1—DP3T slide switch (CW Industries GPI154-3013, Digi-Key SW115-ND)
XTAL1—3.58 MHz color-burst crystal
F1—1 amp slo-blow automotive fuse
P1, P2—0.1" 2-pin Molex connector

See page 150 for ordering information.

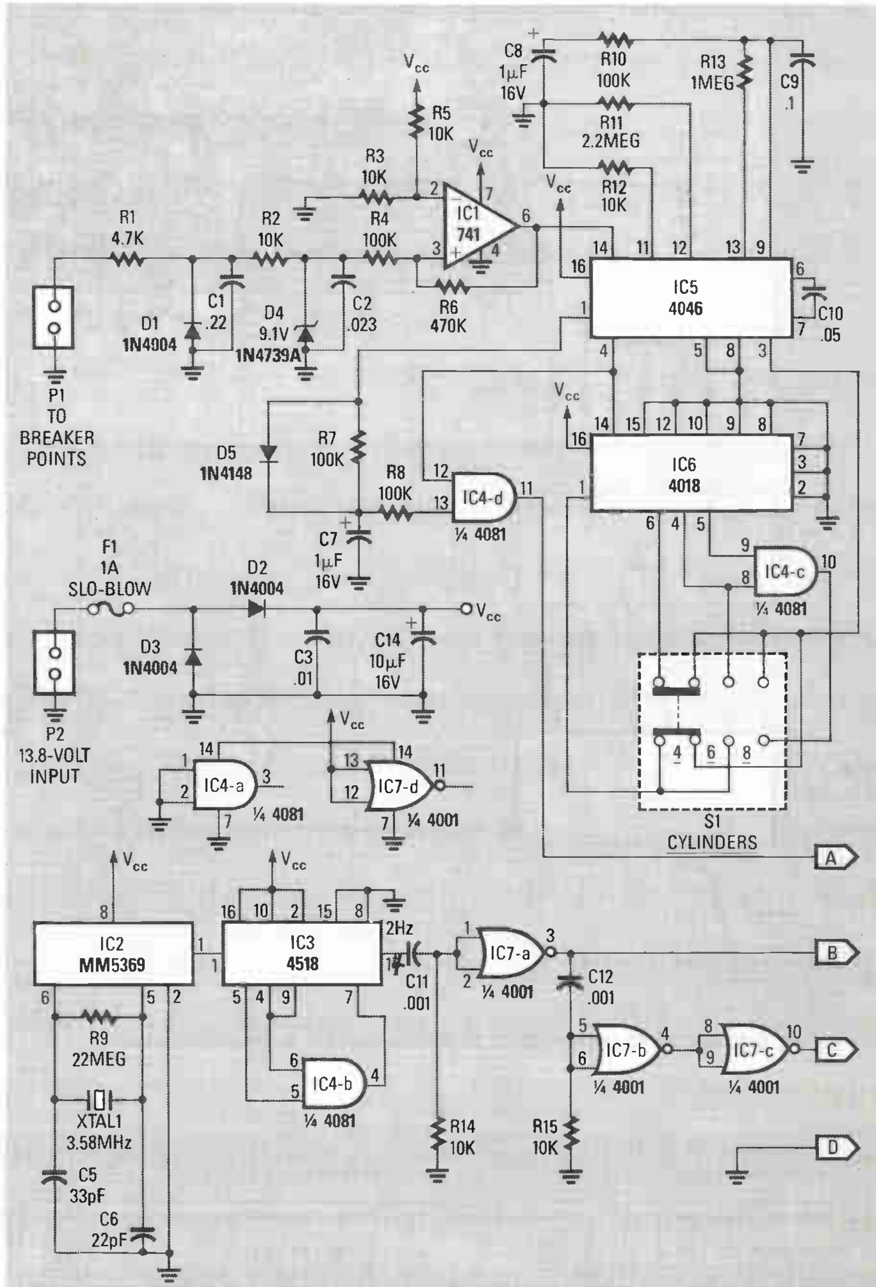


FIG. 3—THE TIMEBASE, INPUT CONDITIONING, and PLL circuits are shown here. Op-amp IC1 functions as a comparator that squares up the input signal for processing by the PLL.

When stuffing the display board, begin with the eight resistors and the three jumpers; then install the four seven-segment displays. Next, insert the twenty LEDs into their respective holes. Pay close attention to the polarity of the LED's. The cathode (or flat side) goes toward the row of holes at the lower edge of the board. After the LEDs have been set in place, carefully turn the board over and lay it down on a flat sturdy surface. Now position the LED's and the displays so they are the same height above the board. If they're not, the LED's must be inserted into their mounting holes further. After the LED's and displays are at the same approximate height, solder one lead of each LED to the board. Then turn the board over and align the LED's so they stand up straight and follow a smooth curve. Now, finish soldering the LED's and set the display board aside.

The next step is to stuff the main board. Begin with the smaller parts: resistors and diodes. Next install the IC's. Because they're mainly CMOS IC's, the use of sockets is recommended, but not essential. If you don't use sockets, insert the IC's carefully, and solder only a few legs at a time to keep heat to a minimum. If sockets are used, install them now and insert the IC's later. Doing so will lessen any chances of static damage. Remember, if you don't use boards with plated-through holes, you'll have to solder most components on both sides of the board.

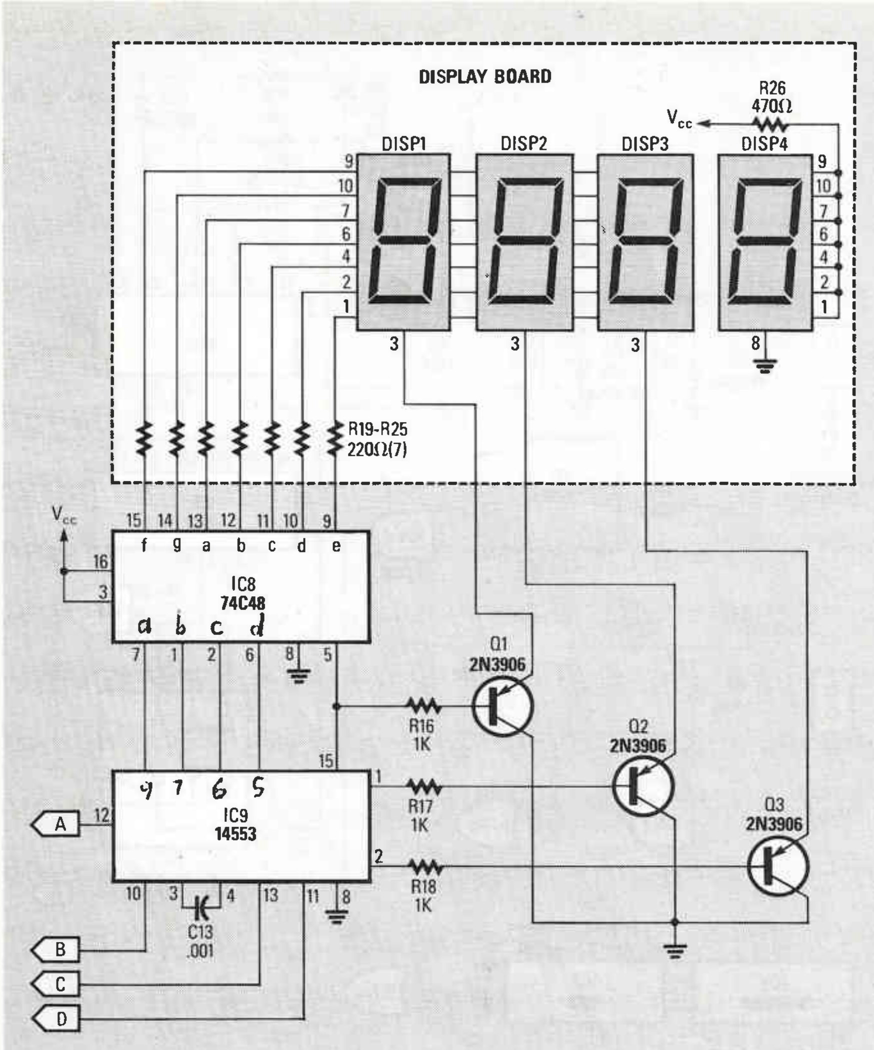


FIG. 4—THE TACHOMETER'S DIGITAL DISPLAY is a conventional decoder/driver circuit.

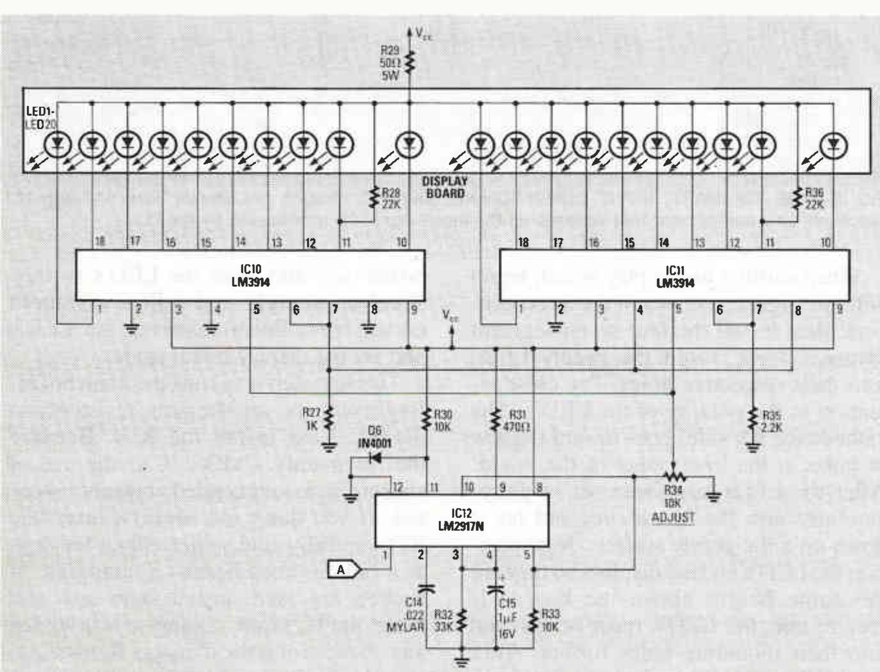


FIG. 5—THE TACHOMETER'S ANALOG DISPLAY is built around a frequency-to-voltage converter (IC12) that drives two bar/graph drivers (IC10 and IC11).

Install the remaining components (capacitors, connectors, and transistors). The base or center leg of each 2N3906 is bent toward the flat side of the package; the transistor should rest about ¼ inch off the board. Install the remaining parts on the board and double-check both boards for errors.

Mechanically, the boards are mounted back to back, separated by ¼-inch stand-offs. Note that each PC board has a row of 35 holes along the lower edge. The boards were designed so that corresponding holes in each should be connected electrically using short pieces of bare wire. Trimmed resistor legs work admirably. If troubleshooting should prove necesssary, you can separate the boards by bending those wires carefully.

Before soldering the wires, connect the boards together using stand-offs and #6 hardware. Assemble the boards with the foil side of each facing that of the other. Then lay the assembly down and insert a bare wire through each hole in the top board and into the corresponding hole in the bottom board. Insert and solder several wires at a time; continue until all wires have been inserted and soldered.

Testing

After the two boards are stuffed and connected together, apply 12 volts to P2 using a power supply or battery. The three right-hand digits should display zero's, and the left hand digit should show nothing. Also, no LED's should be lit. Now, using an audio-frequency function generator, apply a 9-volt peak-to-peak 40-Hz squarewave to the junction of D4 (the 9.1-volt Zener diode) and R2. If your generator cannot supply a squarewave with a DC offset, you may have to feed the test point through a 1K resistor and use a higher-amplitude signal.

Set the cylinder-select switch to 8. The readout should now display something close to 600. Change the cylinder-select switch to 6; the display should read 800. Last, set the switch to 4; the display should read 1200.

Now we'll calibrate the analog display. Set the cylinder-select switch to the setting you plan to use. Next, set the generator to the frequency that will produce the "redline" RPM reading for your engine (i. e., the speed above which the manufacturer recommends you not run the engine.) For an eight-cylinder engine, that speed is typically 5000 RPM. When the redline reading is obtained on the digital readout, adjust R34 so the first red LED lights up. The tachometer is now calibrated and ready for installation.

Installation

First decide where the tachometer will be installed. You'll have to find a spot that provides a good view, that doesn't interfere with pre-existing components, and

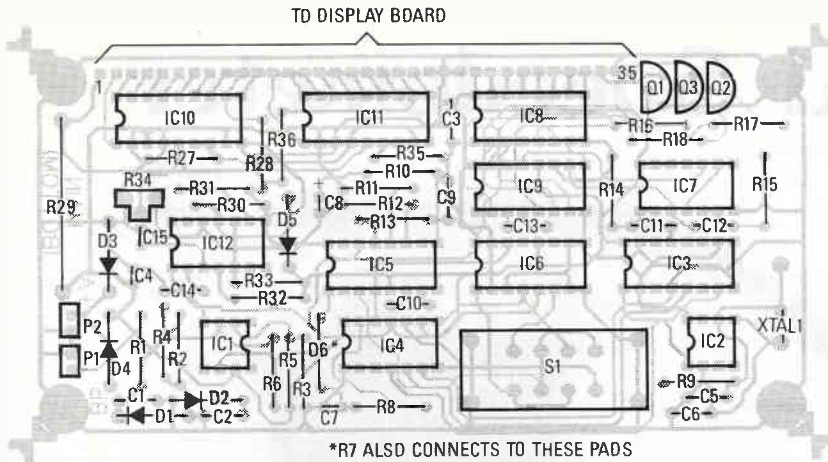


FIG. 6—STUFF THE TACHOMETER'S MAIN BOARD as shown here. Use clipped resistor leads to make the connections to the display board.

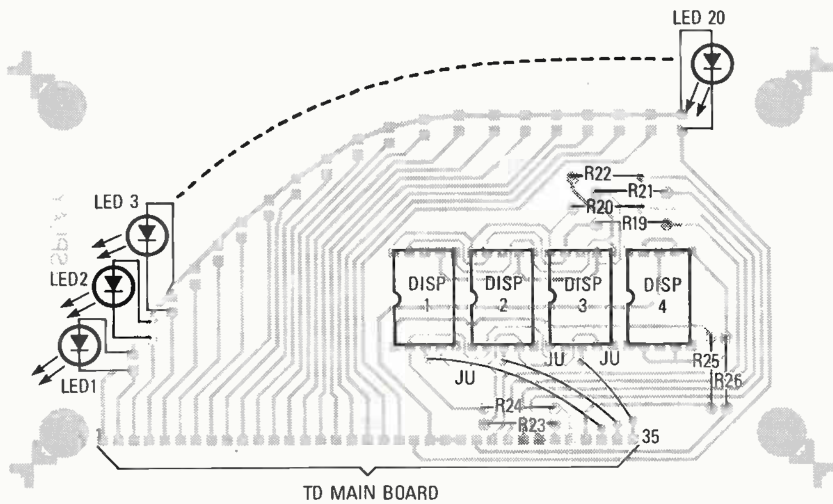


FIG. 7—STUFF THE DISPLAY BOARD as shown here. The flat side of each LED should point toward the bottom of the board. The two boards are sandwiched together, and corresponding pads on the boards are connected with short pieces of stiff wire.

one that you can get to without being a Chinese contortionist!

When a suitable mounting site has been chosen, run a wire from your ignition system to the PC-board assembly. Three possible wiring schemes for different types of ignition systems are shown in Fig. 8-*a*, Fig. 8-*b*, and Fig. 8-*c*. Whatever type of ignition system you have, run a piece of coaxial cable from the distributor points or tachometer hookup to the mounting location. An easy and reliable way to make the connection is to attach the center conductor of the coax to the terminal labeled DIST or - on the ignition coil. Many electronic ignition systems also use a conventional coil, and the connection is made in the same manner as to a distributor/points system. Some electronic ignition systems do not use a conventional coil, so the connection must be made by fastening the center conductor of the coax to the terminal marked TACH.

After putting a connector on the opposite end of the signal coax, connect the power wires. Connect the black wire to chassis ground and the red one to a source that is on only when the ignition key is in the ON position.

Now you're ready to install the tachometer. A case can be built from just about any type of material, but an attractive, durable front panel is important. The use of bronze-colored Plexiglass for the front panel will not only protect the displays, but also make them more visible. Don't use red filter plastic because it will wash out the green and yellow LED's of the bar/graph display. To enhance appearance further, the front panel can be masked on the inside to allow only the LED's and displays to show, thus hiding the rest of the display board. Masking can be done by taping over the area through which the displays will show, and painting the uncovered area black. You may also want to label the front panel using using white dry-transfer lettering.

After building your enclosure, mount the PC-board assembly in it, and then install the enclosure in your vehicle. Be sure to install it and the connecting wires so they will not present a safety hazard. Now plug in the power and signal connectors. The installed digital tachometer is now ready to display your engine's speed with both digital accuracy and analog readibility.

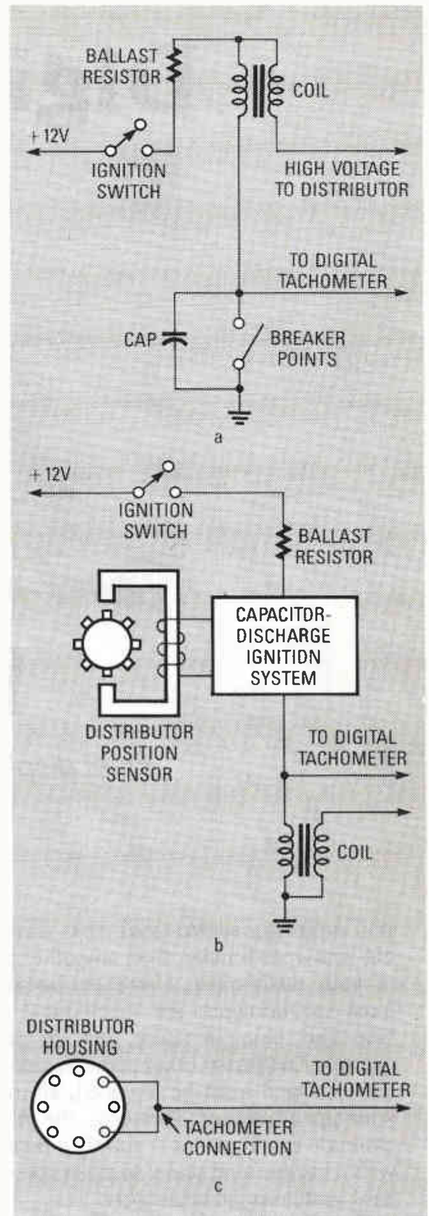


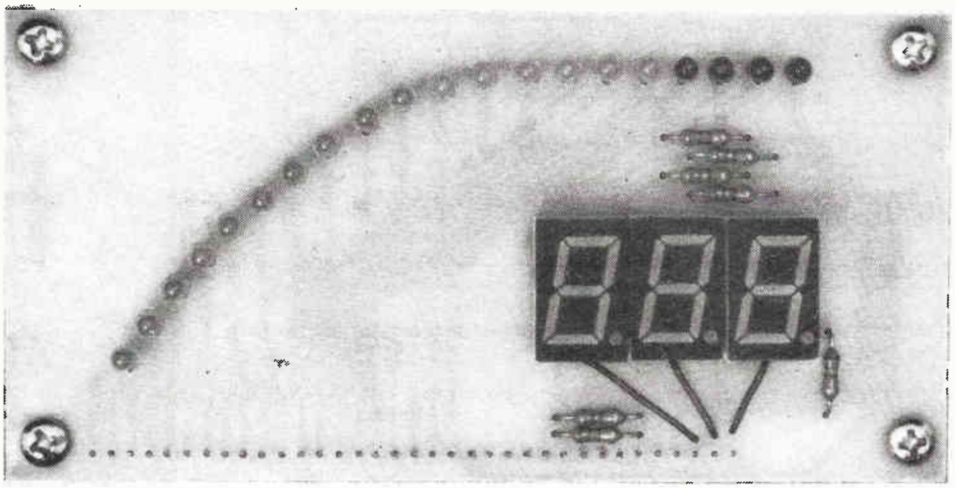
FIG. 8—TO INTERFACE THE TACHOMETER, follow one of these circuits. A conventional (Kettering) ignition system is shown in (*a*), a capacitor-discharge system in (*b*), and a General Motors hook-up in (*c*).

Conclusions

The circuit can be used in a car, truck, boat, or wherever an accurate and reliable tachometer is needed. If you're interested in adding other digital display equipment to your car, see the July, August, and September 1983 issues of **Radio-Electronics.** Those issues contain circuits for displaying voltage, water temperature, and oil pressure in digital form. In addition, the circuit shown here can also be adapted for use as a speedometer.

See page 150 for an important update! **R-E**

Digital Speedometer



for your Car

Dual display delivers both an accurate digital readout and a rapid-read analog display.

ROSS ORTMAN

YOU PROBABLY SPEND MORE TIME WATCHING your speedometer than any other part of your dashboard. However, because most speedometers are mechanical devices and analog in nature, they are prone to error. And just as other parts of your car wear out and must be replaced, so must your speedometer. Besides, the most common speedometer is simply a pointer with a background scale; so exact speed is hard to determine accurately.

Our digital speedometer will accurately display vehicle speed both on a three-digit seven-segment display for precise speed readings, and on a quick easy-to-read analog bar-graph display. The speedometer can be calibrated to read in miles per hour or in kilometers per hour, whichever is preferred. In addition, the bar-graph's "red line" can be set to any desired speed—probably 55 mph.

Theory of operation

The digital speedometer operates by monitoring the speed of driveshaft rotation (on a rear-wheel-drive vehicle) or one of the transaxle output shafts (on a front-wheel-drive vehicle.) Rotational speed is monitored by sensing four magnets (that are secured to the driveshaft or output shaft) with a pickup coil that is mounted to the chassis or body of the automobile. As each magnet passes the pickup coil, a pulse is generated and sent to the digital speedometer, which then counts the number of pulses that occur during a preset time interval and converts this number to display the vehicle's actual speed. The pickup coil and magnets are commercial units that are available from many auto-parts stores.

Because the speedometer uses magnets

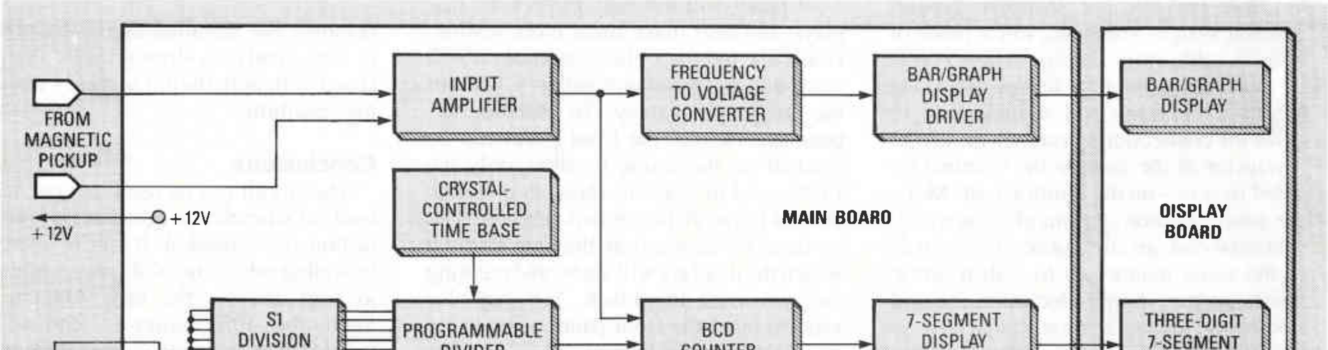


FIG. 1—BLOCK DIAGRAM OF THE SPEEDOMETER: The input amplifier conditions the signal from the magnetic pickup for processing by the counting and display circuitry.

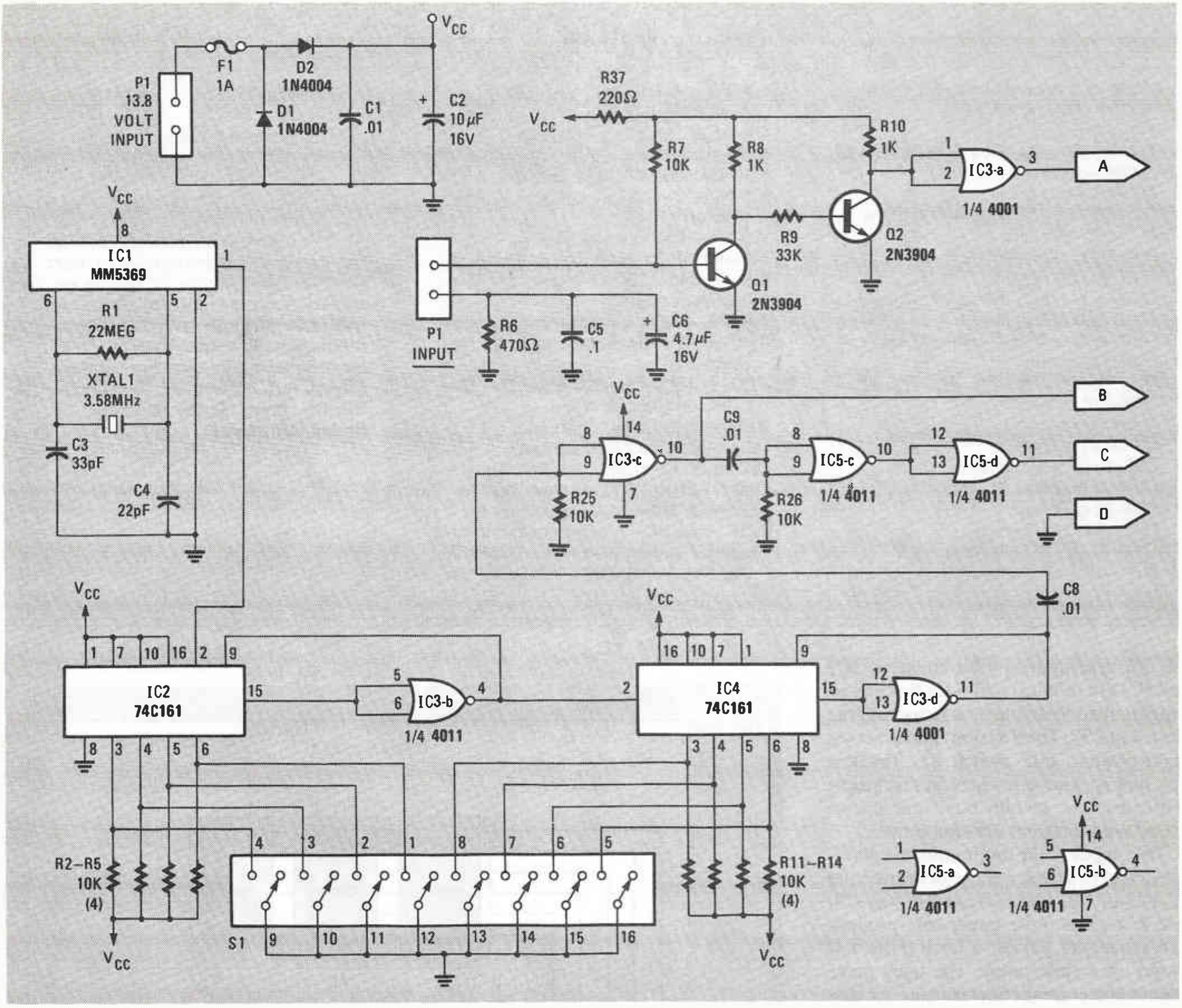


FIG. 2—THE INPUT AMPLIFIER AND TIMEBASE circuitry are shown here. DIP switch S1 sets the divide ratio for calibrating the speedometer.

for sensing (just as many aftermarket cruise-control devices do), dirt, moisture, and weather will not affect its operation. Also, because the speedometer is digitally calibrated, it will remain accurate in all conditions ranging from the coldest winter morning to the hottest summer day.

Referring to the block diagram shown in Fig. 1, pulses from the magnetic pickup are amplified and shaped by the input circuitry. Because all input pulses may not be the same amplitude (due to different magnet strengths and possible distance variations between the magnets and the pickup coil), input-pulse shaping increases the speedometer's accuracy by eliminating multiple counts, missed counts, or both.

The conditioned input pulses are sent to the counter and then to the digital and analog displays. The counting section counts the number of input pulses for a period of time that is determined by the setting of the programmable timebase.

Let's take an example of how the timebase is set for a particular vehicle. On most vehicles, the gear ratio in third (or high) gear is 1:1. In other words, driveshaft speed is equal (or very close) to engine speed. On an eight-cylinder engine, the engine is running at approximately 2200 RPM when the vehicle's speed is 60 mph. With 2200 RPM as our driveshaft speed, we know that the input-pulse rate to the speedometer will be 8800 pulses per minute (2200 RPM times four magnets). Dividing that number by 60 gives us our input frequency in Hertz, in this case, 146.66 Hz.

We now determine that the time for one complete pulse cycle is 6.818 ms (1 ÷ 146.66 Hz). In order to display 60 mph on our digital readout, we must count 60 of those 6.818-ms pulse cycles. That gives us a timebase of 0.41 seconds (60 × 6.818 ms), or 2.44 Hz.

The analog display indicates relative speed by converting the input frequency to a voltage that is then processed for display by the bar-graph display driver IC's (IC8 and IC9).

Circuit description

Referring to Fig. 2, the pickup coil is connected to P1 of the digital speedometer via a twisted-pair cable and a 0.1" female Molex connector. One side of the coil assembly is AC coupled to ground through C5 and C6, and the other side is passed on to the input amplifier, which is composed of Q1, Q2, and the associated bias resistors. The pickup coil is biased slightly positive to ensure that Q1 turns on reliably. After buffering by IC3-a, the input signal is ready for processing by the counting section of the speedometer.

The 60-Hz signal is generated by IC1, an MM5369 17-stage programmable oscillator/divider, and its support components. Here, IC1 uses a 3.58 MHz colorburst crystal to produce a stable and accurate 60-Hz reference.

The programmable divider uses two

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—22 megohms
R2–R5,R7,R11–R14,R25,R26,R30, R32—10,000 ohms
R6,R33—470 ohms
R8,R10,R22–R24,R27—1000 ohms
R9—33,000 ohms
R15–R21,R37—220 ohms
R28—22,000 ohms
R29—50 ohms, 5 watts, wire-wound
R31—220,000 ohms
R34—10,000 ohms, vertical trimmer potentiometer
R35—2,200 ohms
R36—22,000 ohms

Capacitors
C1—0.01 μF disc
C2—10 μF, 16 volts, electrolytic
C3—33 pF disc
C4—22 pF disc
C5,C12—0.1 μF disc
C6—4.7 μF, 15 volts, electrolytic
C7—0.001 μF disc
C8,C9—0.01 μF disc
C10—0.022 μF mylar
C11—1 μF, 16 volts, electrolytic

Semiconductors
IC1—MM5369 17-stage oscillator/divider
IC2,IC4—74C161 synchronous binary counter
IC3,IC5—4001 quad NOR gate
IC6—MC14553 three-digit BCD counter
IC7—74C48 BCD to 7-segment decoder/driver
IC8,IC9—LM3914 dot/bar display driver
IC10—LM2917N frequency-to-voltage converter
D1,D2—1N4004 rectifier diode
D3—1N4001 rectifier diode
Q1,Q2—2N3904 NPN transistor
Q3–Q5—2N3906 PNP transistor
LED1–LED10—0.125" greeen diffused
LED11–LED16—0.125" yellow diffused
LED17–LED20—0.125" red diffused
DISP1–DISP3—7-segment common-cathode display (Panasonic LN516RK, Digi-Key P351; P352, P353, & P354 may also be used)

Miscellaneous
F1—1 amp slo-blow fuse
S1—eight-position DIP switch
P1,P2—0.1" 2-pin Molex connector
XTAL1—3.58-MHz color-burst crystal

Other components
L1—pick-up coil (ARA part #2701278), magnets, strap mount (ARA part #2701279), wire, solder, PC boards, etc.

Note: ARA cruise control parts are available through your local automotive supply house. They may also be ordered as follows from Dakota Digital, R.R. 5 Box 179E, Sioux Falls, SD. See page 150 for additional ordering information.

74C161 synchronous 4-bit counters (IC2 and IC3) to produce a divider that can be programmed to divide by a factor ranging from 4 to 256. The division ratio is set via eight-position DIP switch S1. The text box that appears elsewhere in this article indicates how switch positions correspond with different division ratios.

The output of the programmable divider is fed to two pulse generators consisting of: IC3-c, C8, and R25; and IC5-c, C9, and R26. The pulse generators produce two sequential pulses; a latch pulse followed by a clear pulse. The latch pulse latches the current counter value for display, and the clear pulse resets the 14553 counter (IC6, shown in Fig. 3) so that it begins counting from zero for the next sample period.

The heart of the digital display section (shown in Fig. 3) is IC6, an MC14553 three-digit BCD counter. That IC counts the incoming signal for the duration of the timebase and outputs the value through IC7, a 74C48 BCD to 7-segment decoder, and on to displays DISP1, DISP2, and DISP3. Resistors R15–R21 limit the amount of current that passes through the displays. The three digits are multiplexed by Q3, Q4, and Q5.

The analog display section (shown in Fig. 4) consists of IC10, an LM2917N frequency-to-voltage converter, and its associated components. That IC produces a DC voltage that is proportional to the frequency of the input signal. That relative voltage is then used to drive two cascaded LM3914 bar-graph display drivers (IC8 and IC9), which, in turn, drive the 20-element discrete LED display. The analog display is calibrated simply by setting potentiometer R34.

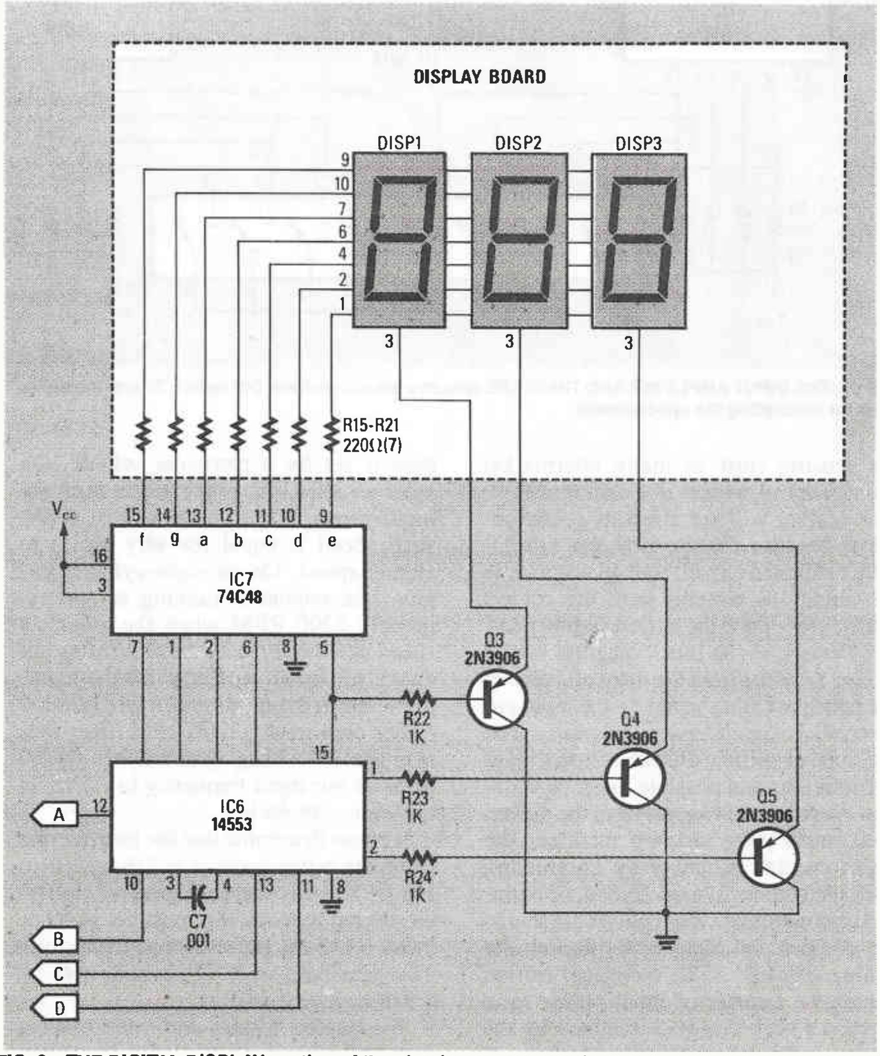


FIG. 3—THE DIGITAL DISPLAY section of the circuit uses a 14553 (IC6) to count pulses, and a 74C48 (IC7) to display the count.

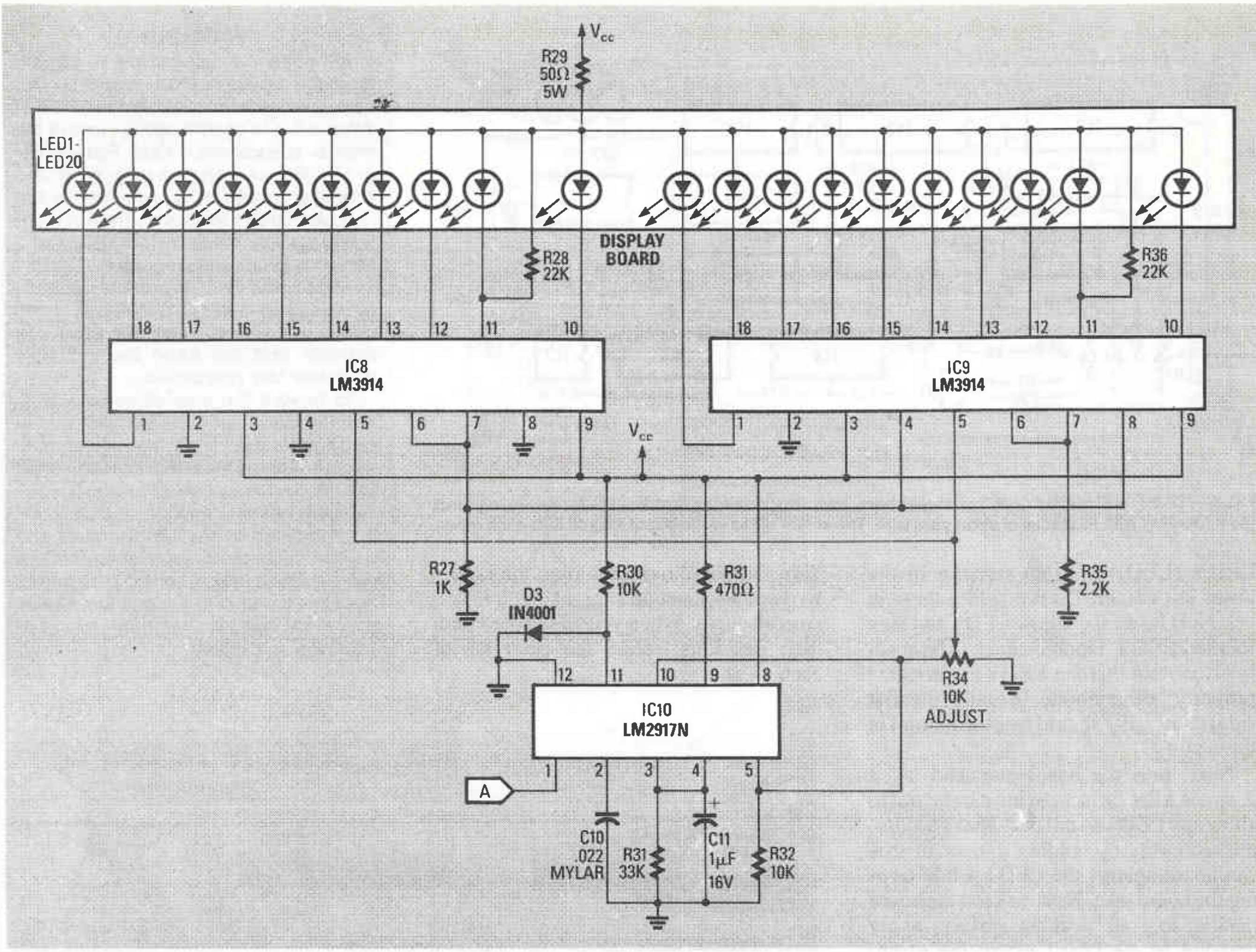


FIG. 4—THE ANALOG DISPLAY uses a frequency-to-voltage converter (IC10) to convert the counted pulses into displayable form.

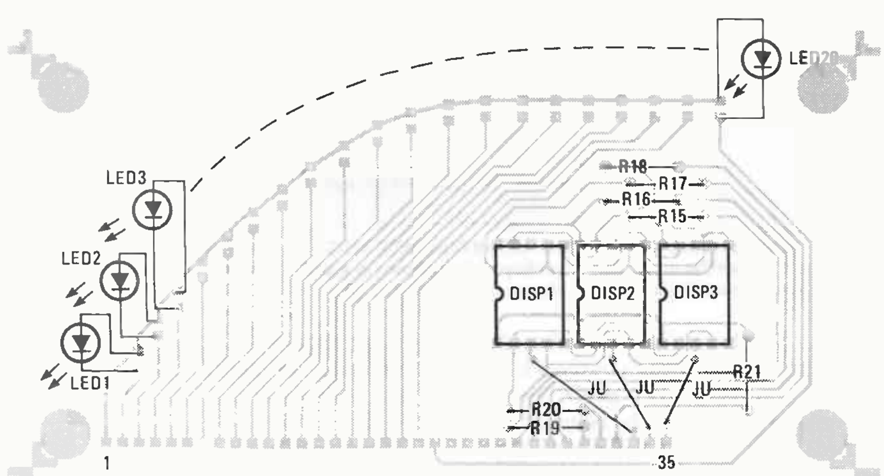


FIG. 5—STUFF THE DISPLAY BOARD as shown here. Don't forget to install the three jumpers. The flat sides of all LED's should face the row of holes at the bottom of the board.

Construction

Construction of the digital speedometer is nearly identical to that of the digital tachometer presented last month. The circuit is built on two PC boards: a display board and a main board. The two boards are connected by 35 jumpers.

The display board contains the seven-segment readouts, the twenty LED's and several resistors; the main board contains everything else. The display board is single-sided; the main board is double-sided. The PC boards can be made using the foil patterns shown in PC Service, or they may be purchased from the supplier mentioned in the Parts List. If you etch your own boards, be sure to solder both sides of the main board.

Begin stuffing the boards with resistors, diodes, and other low-profile parts. Refer to Fig. 5 and Fig. 6 for part locations. If you are using IC sockets, which we recommend, install them next. If you don't use sockets, install the IC's last and solder only a few legs of each IC at a time to prevent overheating. Whether sockets are used or not, observe CMOS handling precautions: use a ground strap, ground your soldering iron, and work only on an anti-static surface.

Continue installing the rest of the parts, including the DIP switch, the capacitors, and the crystal, on the main board. The transistors are installed with the base or center leg bent toward the flat side of the body of the device. Install each transistor about ¼ inch above the board.

When stuffing the display board, begin by inserting and soldering the three seven-segment displays. And don't forget to install the three jumpers located just below the displays. Then insert the discrete LED's into the board with ten green

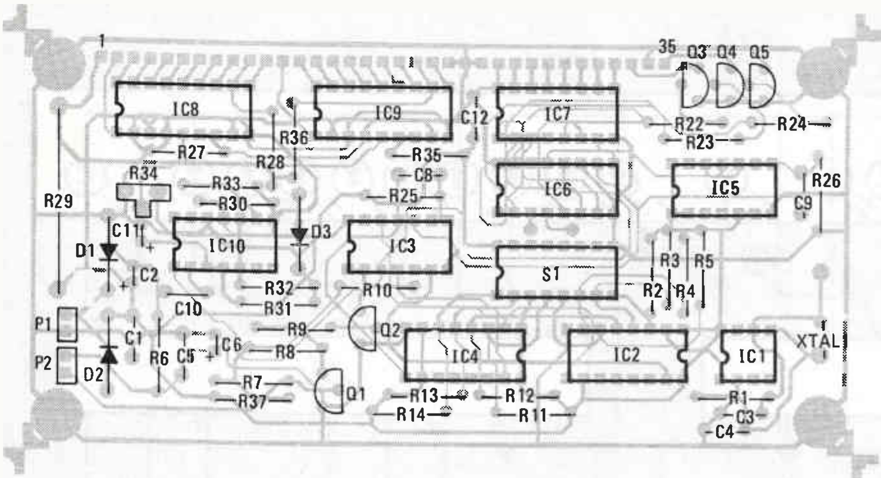


FIG. 6—STUFF THE MAIN BOARD as shown here, and, after checking both boards for errors, connect them together with 35 pieces of short bare wire. The solder sides of the board should face each other.

LED's (LED1–LED10) starting in the lower left corner. Do not solder them in yet. Next insert six yellow LED's and then four red LED's. Double-check to be absolutely certain that the LED's are oriented properly; the cathode (usually the flat side) of the LED should face the bottom of the board.

Next, turn the board over and lay it down on a flat surface, being careful not to allow any LED's to fall out. That's accomplished easily by holding a piece of stiff cardboard against the LED's while turning the board over. Now, to keep the board parallel to your working surface, apply pressure to the board where the seven-segment displays are mounted, and solder one lead of the end and middle LED's. Next, carefully look across the surface that the board is lying on to see whether the LED's are at the same height as the seven-segment displays. If not, correct their positions and then continue soldering one lead each of the remaining LED's.

Turn the board over and align the LED's so that they stand up straight and follow a smooth curve. When you're satisfied with their positions, solder the other leg of each LED.

WARNING

Although the speedometer can be mounted above, below, or inside the dashboard, some conditions must be met if the unit is to be installed in place of the original speedometer. First, Federal law prohibits any tampering with the odometer section of the speedometer and imposes harsh penalties on those in violation of that law. That does not mean that a person is forbidden to replace the original speedometer with the digital speedometer presented here. However, if the device is installed, it must be done in a manner that will keep the vehicle's odometer fully operational.

To replace the original speedometer with the digital speedometer, remove the face plate and pointer of the original, making sure that you leave the original gearing and odometer mechanism intact. The digital speedometer can then be installed in the space left by the old face plate and pointer. Also, the original speedometer cable must be left connected; to remove it is also a violation of Federal law. Check your state laws, too, as they may have additional restrictions.

SWITCH SETTINGS

For a front-wheel-drive vehicle, the transaxle output shaft's speed can be determined from this formula:

$$DF = 5.355 \cdot R$$

where DF is the division factor, and R is the radius of the front wheel. For a rear-wheel-drive vehicle, the driveshaft's speed can be estimated from the engine speed. If you have an overdrive transmission, use the gear ratio found in the owner's manual to convert the engine speed to the driveshaft speed. The output of each programmable divider (IC2 and IC4) can be determined from the chart below. The total division factor provided by the two IC's is the product of the individual DF's provided by each separately.

For example, a 10" wheel requires a division factor of $5.355 \times 10 = 53.55$. We could approximate that value by setting IC2 to divide by 5 and IC4 to divide by 10. To do so, the DIP switch would be set like this: 01001001.

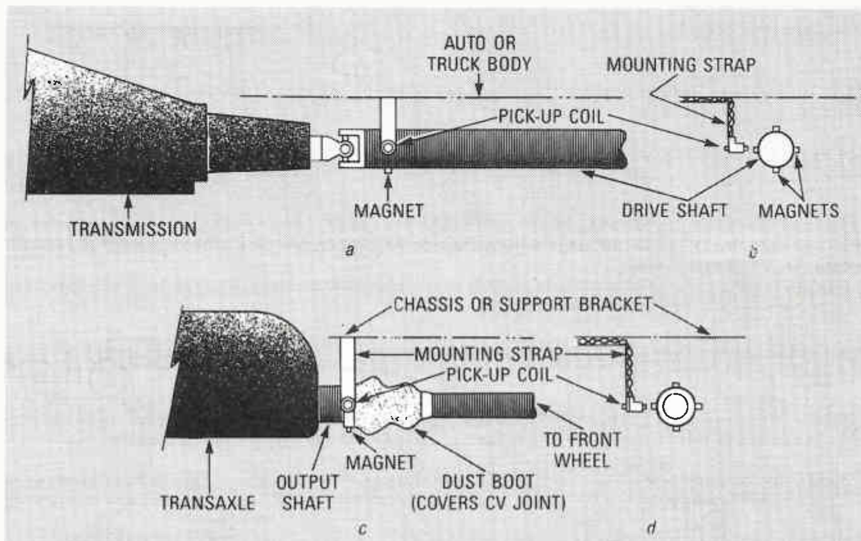


FIG. 7—MAGNET AND PICKUP-COIL MOUNTING METHODS: For a car with a transmission and driveshaft, mount the magnets and pickup coil as shown in *a* and *b*, respectively. For a car with front-wheel drive, mount those parts as shown in *c* and *d*.

After you have installed and soldered all components, check your work carefully for errors. Fix any errors, and then complete the assembly by connecting the boards, mechanically and electrically, to each other. Mount the boards back to back (foil side to foil side) with #6 hardware. The boards must be spaced at least ¼-inch apart using spacers or standoffs. Keep in mind that the board will be mounted to the dashboard (or custom-built case) by the same bolts that hold the boards together.

After the two boards are mechanically secured to each other, run short pieces of solid bare hook-up wire between corresponding pads on the two boards. Make sure that the wires are straight and do not touch each other. The boards can be "folded apart" for troubleshooting or repair, if necessary.

Bench testing

The next step is to test the speedometer to ensure that it is completely operational before installing it in an automobile. Apply twelve volts to power connector P2, which is located on the main board. Note that the positive pin is the one closest to five-watt resistor R29. After power is applied, the two right-hand digits should display zeros, and none of the LED's should be lit.

If your displays differ, check the supply

continued on page 130

The Electronic Industries Association/Consumer Electronics Group has recently completed the first in a series of videocassette training tapes.

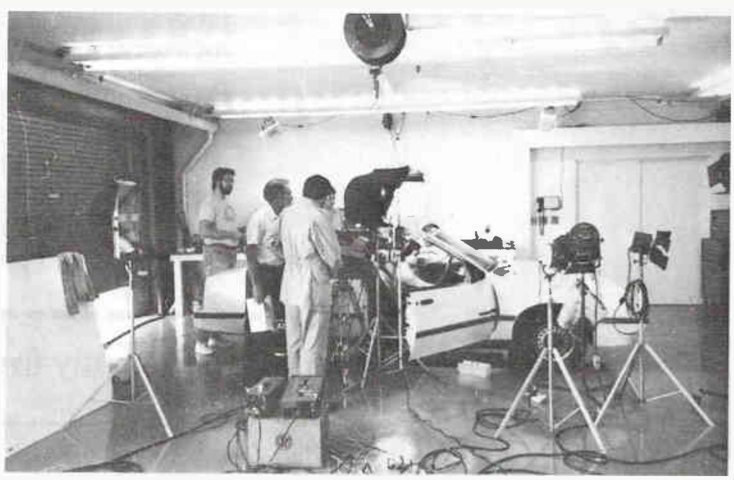
EIA/CEG ANNOUNCES COMPLETION OF NEW "BASIC CAR AUDIO INSTALLATION" VIDEO TAPE

If you are thinking of "cashing in" on the profits in the ever growing car audio service business, the troubleshooting–service–installation–and removal of car audio products is a large, non-competitive profit center for your service facility. This thirty minute video introduces you to the ever increasing complex world of car stereo installation. It guides the new installer or owner in the correct layout and design of a car stereo installation facility, covering basic as well as specialized tools needed for the installation business.

This informative videotape is also an excellent aid to the electronics technician in that it gives the correct procedure for removing and replacing "any" car radio from the dashboard of any car and shows the installer's, salesperson's and customer's role in the installation and sale of car audio products.

KEY TOPICS COVERED IN THIS VIDEO

- The design and layout of a car stereo installation center.
- Basic and specialized tools needed for car audio installation work.
- Safety in the shop.
- How to treat the customer's car, from pre-installation checkout to demonstrating to the customer the completed job.
- The proper procedure for installing car audio equipment.
- The technical resources available for information about specific types of vehicles, dashboard dismantling, speaker sizes and antenna locations.
- Speaker wiring types found in the automobile. Common and floating ground systems—how to differentiate. Proper wiring procedures used in the car.



The cost of the videocassette is $30.00. Use the order form below to order yours now!

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Soldering:

OLD TECHNIQUES & NEW TECHNOLOGY

It takes a more than just solder to make reliable connections.

VAUGHN D. MARTIN

SOME CLAIM IT WAS GUGLIELMO MARCONI himself who said "Soldering is an art"—as he used a blowtorch and a five-pound bar of lead to assemble the transmitter that finally broadcast a radio signal across the *big pond*. While we no longer use a plumber's blowtorch for precision soldering, it often appears that we haven't progressed to anything that is significantly better. More times than we care to remember, the causes of defects in projects, retrofits, and upgrades have been directly traced to poor solder connections: either too much or too little solder, cold solder joints, or simply the wrong kind of solder, de-oxidizer, or wetting agent.

So it is in the spirit of "Soldering is an art" that we'll take a close look at soldering techniques: everything from assembling a simple "one-evening" commercial kit to making repairs using conductive plastic.

Conventional soldering techniques

Exactly what is soldering, anyway? Conventional soldering is the bonding together of two or more metal parts with a tin-lead alloy (the solder itself). It is the least expensive, yet most reliable method of connecting electronic components. In a good solder joint, solder molecules actually mix with the molecules of the metal being soldered—what is called *wetting*.

The tools for making solder connec-

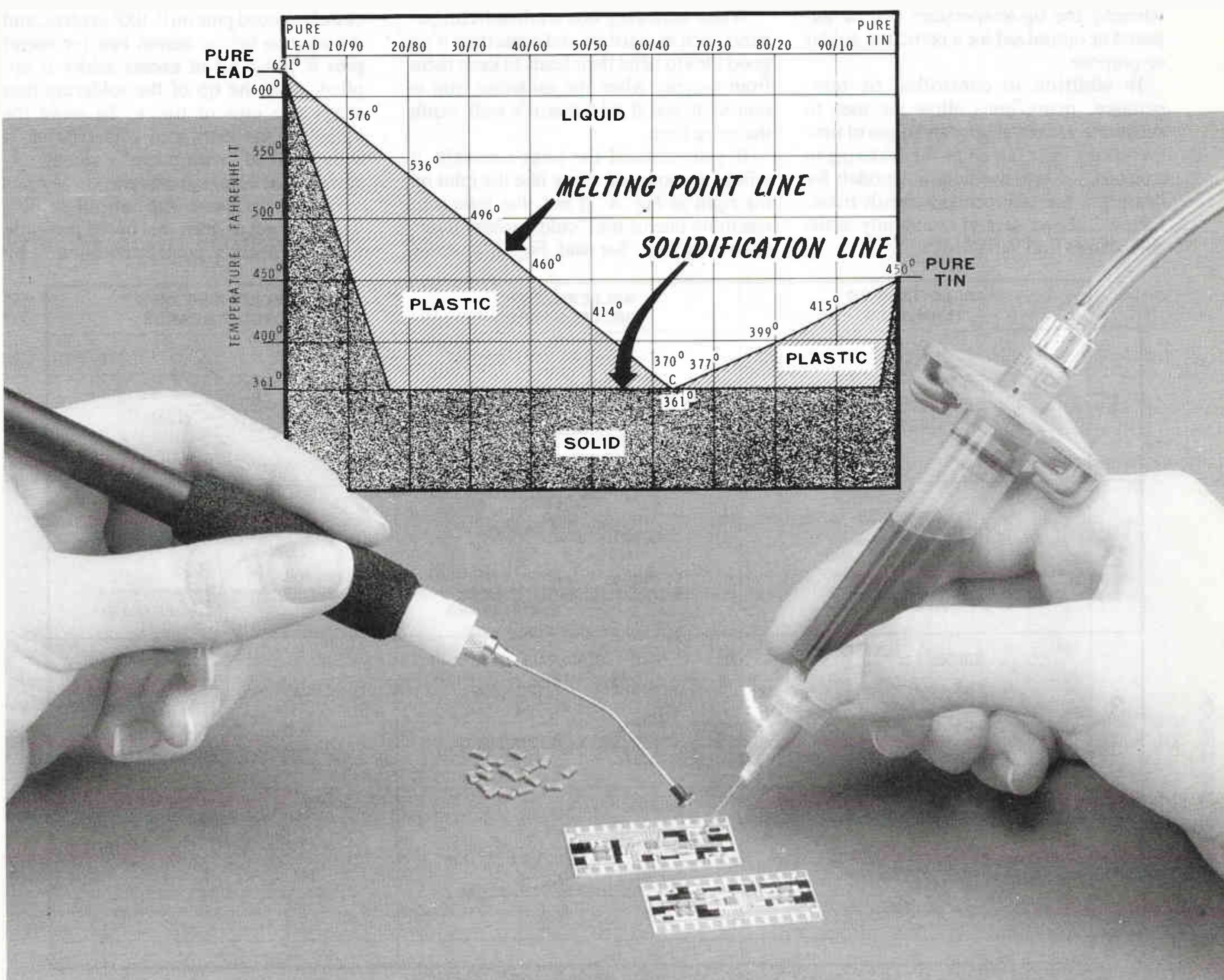


FIG. 1—ADJUSTABLE-HEAT soldering irons allow you to adjust the tip-temperature adjustment. Other soldering irons have a single controlled tip-temperature.

tions to electronics equipment come in a variety of styles, sizes, and shapes of *guns*, *irons*, and *pencils*—a soldering pencil being a low-wattage, usually pencil-size soldering iron. Although most have fixed tip-temperatures, some, such as the unit shown in Fig. 1, have a means whereby the tip-temperature can be adjusted or optimized for a particular solder or purpose.

In addition to controlled tip-temperature, many irons allow the user to substitute various shapes and types of tips: everything from large tips for soldering to a metal chassis to needle-point models for heating a hairline printed-circuit trace. Figure 2 shows several commonly available shapes and variations.

How to solder

How do you use those tools to make a *guaranteed* reliable connection—one that will last forever and a day? Figure 3 shows a four-step approach to soldering terminals and printed-circuit boards.

Begin with a wet sponge. Heat the soldering tip, wipe it off on the sponge, and apply solder to the cleaned tip. That is called "tinning" the tip—it inhibits oxidation. For terminal lugs (Fig. 3-*a*) and relatively thick or wide printed-circuit foils (Fig. 3-*b*), place the soldering tip against the foil or against the terminal, and against the component's lead; then apply solder. Apply heat long enough to allow the solder to flow evenly and uniformly over the joint. Then remove the iron and be sure not to move the component until the solder cools. For hairline traces, the latest recommended technique (Fig. 3-*c*) is to place the solder against the component lead and the foil and then squash the iron down on the solder until there is a good flow. (That way there is less chance of overheating causing a hairline trace to lift off the PC-board.)

When soldering conventional components such as resistors and capacitors it's a good idea to bend their leads to keep them from moving when the soldering iron is removed; you'll find that it's well worth the extra time.

If you soldered the joint correctly, it will be smooth and shiny like the joint on the right in Fig. 4. If not, the joint will resemble one of the "cold" solder joints shown in Fig. 5-*a* and Fig. 5-b. Cold

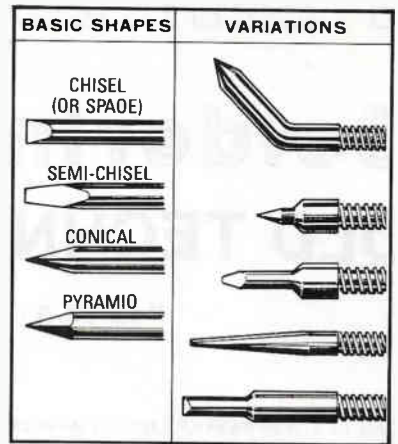


FIG. 2—SOLDERING-IRON TIPS are available in a wide variety of sizes and shapes. They come as complete tips, interchangeable elements, or tips for interchangeable elements.

joints are poor conductors. They are characterized by either a crystalline, grainy texture (Fig. 5-*a*), or by blobs and uneven solder flow (Fig. 5-*b*).

Integrated circuits require extra care when soldering. Typically, they have closely spaced pins on 0.100″ centers, and it's easy to bridge across two (or more) pins if just a bit of excess solder is applied, or if the tip of the soldering iron spans two pins or traces. To avoid the problem, use extra-thin solder (what is usually called "wire gauge"), a small soldering pencil, and great care.

Except for some specialized solders that we'll get to later, one of the principle ways to ensure a good connection is by

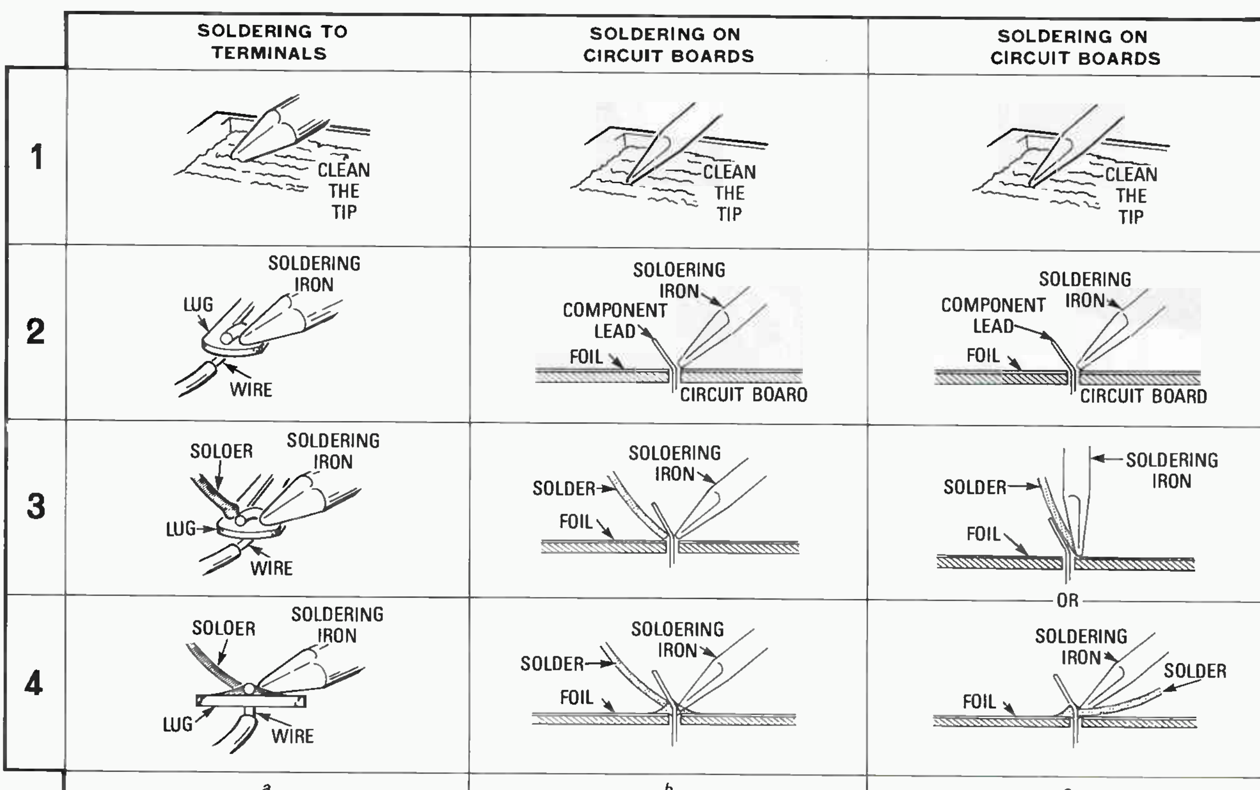


FIG. 3—ALTHOUGH IT'S USUAL to heat the material to which solder will be applied (*a* and *b*), the heat is applied to the solder (*c*) when soldering hairline printed-circuit traces.

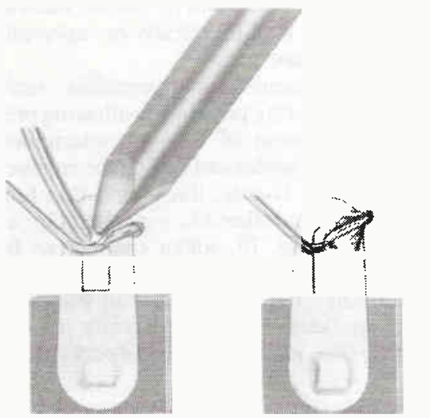


FIG. 4—A PROPERLY-SOLDERED terminal connection looks like this.

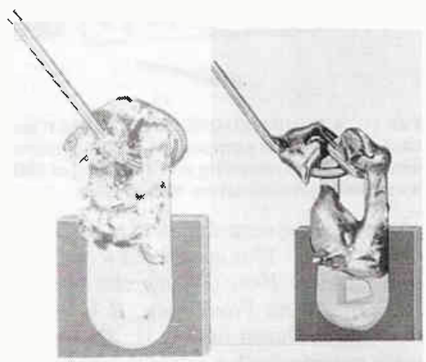


FIG. 5—A COLD SOLDER JOINT may resemble *a* or *b*. One is as bad as the other.

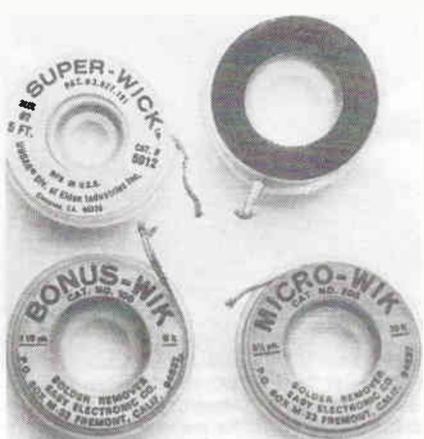


FIG. 6—SOLDER-REMOVAL BRAID is available in several widths to accommodate everything from hairline printed-circuit traces to oldfashioned terminal lugs.

FIG. 7—A SOLDER-SUCKER removes solder from a one-surface component-mounting hole or a plated-through connection.

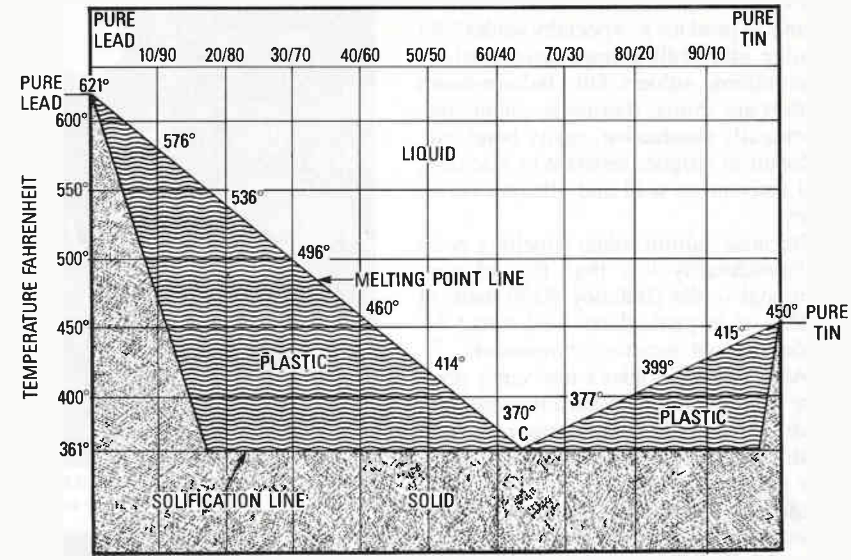


FIG. 8—A SOLDER'S MELTING POINT is determined by its composition. Eutectic solder goes from solid to liquid without passing through a plastic state.

applying a "flux" to the surfaces or wires to be soldered either before or during the application of heat.

Flux is a chemical that is used to remove surface oxides from metal before it is soldered—because oxidation interferes with the adhesion of solder. It is available in powder, paste or liquid form. Many solders contain a core of flux so that the flux is applied continuously.

Occasionally, you will bridge a solder gap or make a cold joint. Usually, it's next to impossible to salvage the connection, or even to avoid further damage, unless the solder is removed first.

Solder removal

There are two ways to remove unwanted solder so that you can start over. You can use a product generically called solder-removal braid—available under several trade names—which is a resin-flux coated braid that absorbs molten solder. As shown in Fig. 6, it comes in different widths tailored for wicking everything from hairline PC-board traces to oldfashioned terminal lugs. Alternately, you can use a "solder sucker" (Fig. 7), a device that uses a vacuum to literally suck solder off a connection.

Conventional solder

As shown in Fig. 8, conventional solder is an alloy of tin and lead that melts at a lower temperature than either tin or lead by itself. The actual temperature at which solder melts it depends on the relative percentages of tin and lead in the solder. Solder with 37% lead and 63% tin yields the lowest melting point, but you will find that most solder is 40% lead and 60% tin.

Incidentally, the term "eutectic" is sometimes used to describe a particular solder alloy. Eutectic simply means the lowest possible melting point of an alloy. For example, the 37/63 solder previously mentioned is eutectic tin-lead solder—no tin-lead solder can melt at a lower temperature.

Plastic solders

Now let's look at plastic solders. Some require heating to make them hard; others, the epoxies, generally do not. They are hardened not by heat, but by adding a catalyst or a hardener—a great advantage when you're working with heat-sensitive semiconductors.

Many epoxies have excellent strength and wettability, even with non-metallic substrates, and they are good conductors of electricity. Emerson and Cumming's Econobond Solder 56C has a resistance of 2 × 10-4 ohms/cm; Aremco-Bond 556 has a resistance of 5 × 10-4 Ohms/cm. The latter yields bonded shear strength of 3,000 to 4,000 psi within a temperature range after curing of −60°C to +200°C (−76°F to +392°F).

TRA-CON, Inc. 55 North St., Medford, MA 02155, produces 56 different kinds of premixed resins and hardeners. Applications range from replacing conventional solder to repair of PC-board delaminations or blistering.

Indium solder

One of the most exciting breakthroughs in soldering technology is the use of indium, a semi-precious, non-ferrous, silvery-white metal having a brilliant luster. It is softer than lead—you can scratch it with your fingernail—and it is extremely malleable and ductile, even at temperatures approaching absolute zero. It retains its shape when bent, and its softness and plasticity make it particularly suitable for gaskets, seals, and solders. In particular, indium's ability to work into the oxide skin of other metals improves their electrical and thermal conductivity while inhibiting corrosion.

Indium is often combined with other metals to produce a "specialty solder" for joining and sealing applications where conventional solders fail. Indium-based solders are strong, thermally conductive, electrically conductive, easily bondable, resistant to fatigue, resistant to leaching, and resistant to acid and alkaline corrosion.

Because indium solder's melting point is considerably less than that of conventional solder (Indalloy #136 melts at 136°F), it is particularly well-suited for soldering heat-sensitive components.

Also, indium solder's low vapor pressure ideally suits it to vacuum-soldering environments where high-vapor-pressure solder could accumulate on, and thereby ruin other components.

Indium solders are non-toxic, and those with gold, or bismuth and tin are good candidates to replace poisonous lead and cadmium solders in toys and cookware.

Epoxy substitute

Because indium solder is easier to remove than epoxy and plastics, it is often substituted when there's a possibility that repairs or design changes might have to be made to joints and fabrications.

When indium is combined in an alloy, it will wet glass, mica, quartz, glazed ceramics and certain metallic oxides; and it will form a sub-oxide layer that increases its adhesion. To avoid interfering with the sub-oxide layer, flux cannot be used with indium solder. If you want to solder a metallic substance to a nonmetallic substance, precoat the former with solder containing flux; then completely remove the flux before soldering the metallic substrate.

Indalloys #1 and #4 have the best wetting qualities on non-metals, while Indalloys #3 and #290 produce stronger connections. However, because of the silver they contain, they have slightly less wettability.

Bond strengths between 300 psi and 700 psi can be attained with non-metallic substances if they are properly prepared for soldering. To solder the non-metallic substrates, clean them thoroughly with a strong alkaline cleaner, rinse with distilled water, and again with an electronic grade acetone or methanol. Heat glass, quartz, or glazed ceramics to 350°C (662°F) and cool. Heat one non-metallic substrate and the solder to 20- to 30°C higher than the solder's melting point, then gently rub the solder into the substrate with a nickel metallic felt, or a similar applicator. Cool the coated substrate, bring it into contact with the second, and apply heat until the solder flows.

Incidentally, you will find that an ultrasonic soldering iron is sometimes effective in wetting some non-metallic surfaces.

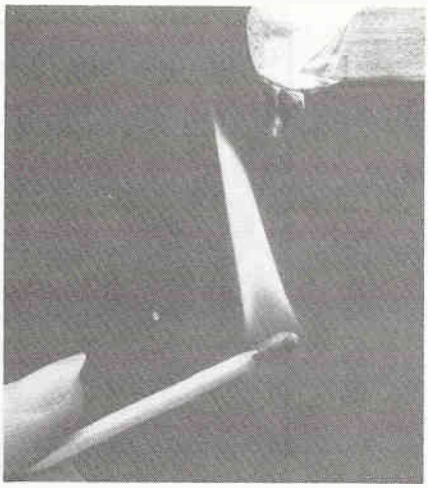


FIG. 9—THE HEAT FROM A MATCH is enough to melt a bar of indium fusible-alloy solder.

FIG 10—INDIUM SOLDER CREAMS, featuring oxide-free spherical powders, are available in various alloys that are specifically packaged for dispensing, screening, and stenciling.

Fusible alloys of indium

A fusible alloy is an alloy of bismuth that contains tin, lead, cadmium, gallium, or indium, and which expands upon solidification. Such alloys have low melting temperatures compared to most indium alloys, but their poor wettability keeps them from being widely used as solders. Normal melting temperatures of fusible alloys range from 40°C to 150°C (104°F to 302°F). This means that you can melt Indalloy fusible alloys, and keep them molten, on an ordinary hotplate. For special applications, you can even get Indalloys that melt as low as 10.7°C (51.3°F). Figure 9 shows an ordinary match melting a bar of Indalloy fusible alloy.

Surface-mounted devices

No discussion of soldering would be complete without mentioning techniques for soldering SMD's (*S*urface-*M*ounted *D*evices). SMD's are not only much smaller than conventional ones—they don't have wire leads. Instead, they have what appears to be a semiconductor substrate with a small metal ridge along the edges. Suface mounted devices are mounted to a PC board by precise vacuum placement, then robotically or vapor-soldered in place.

Solder creams make precision, automated soldering possible by allowing precise placement of tiny, predetermined amounts of solder and flux on the conductors of PC boards, thick- and thin-film circuits, and flexible circuits. Or, as shown in Fig. 10, solder creams can be dispensed manually from a syringe on to a substrate. The intended use of soldering creams determines their viscosity, powder mesh size, metal content, and packaging.

FIG. 11—A COMBINED CREAM DISPENSER and vacuum-operated component-holding device simplifies the positioning and soldering of SMD and other micro-miniature components.

An alternative to the manual dispenser shown in Fig. 10or automated techniques is the Model *1000 DV* manufactured by EFD Inc., East Providence, R.I. 02914; that unit is shown in Fig. 11. The instrument provides both a cream dispenser and a vacuum parts holder. Figure 12 shows how the vacuum holder and cream dispenser are used to install an SMD.

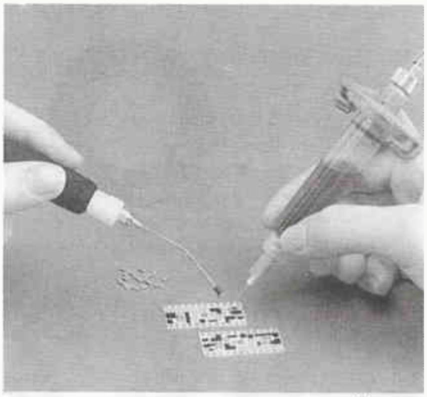
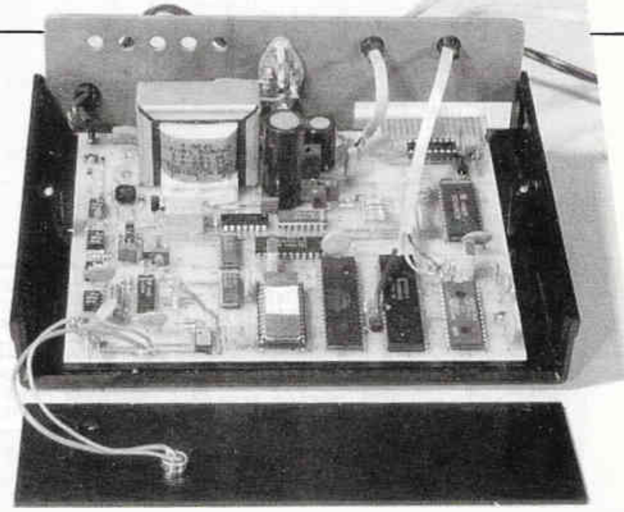


FIG. 12—IT TAKES TWO HANDS to position an SMD device on a PC-board: one for the cream dispenser, the other for the vacuum holder.

Before reflowing solder cream, be sure to cure it to avoid spattering and solder-balling. Substrate type, flux type, the metal content of your solder, and the amount of solder cream deposited on the board will determine the appropriate curing parameters.

Conclusion

Now that you know all the various possibilities available when soldering, your only problem will be figuring out which one is the best to use for a particular application. **R-E**



PHONLINK INTERACTIVE REMOTE CONTROL

Rule the world by telephone!

GENE ROSETH

IF YOU'VE EVER WANTED TO CONTROL AN electronic device, or monitor an electrically measurable quantity from a remote location by telephone, you've probably found that devices to do so are expensive and hard to come by. However, we've got an inexpensive, easy-to-build, yet highly versatile device that both hobbyists and professionals will find useful. It allows you to control as many as eight devices, and it allows you to monitor as many as eight analog or digital quantities, including local temperature. A built-in speech synthesizer reports all values aurally.

A few simple examples will show how useful the controller can be. Suppose you're about to leave work and head home for the day. You pick up the telephone, dial your home, and wait for the controller to respond by saying *activated*. After you enter the access code, the unit gives verbal guidance as you: (1) disable the burglar alarm, (2) turn on the hot tub, (3) enable the garage-door opener, (4) check the house temperature (with the built-in thermometer), (5) turn on the air conditioning, and (6) obtain the state of charge of your solar-energy system. Finally, you activate the built-in microphone for a few seconds to listen for strange sounds.

More technical applications might require transmission of remotely generated analog or digital data using the internal A/D converter. Values are expressed via the built-in speech synthesizer.

How it works

The flowcharts shown in Fig. 1, Fig. 2, and Fig. 3 illustrate the overall function of

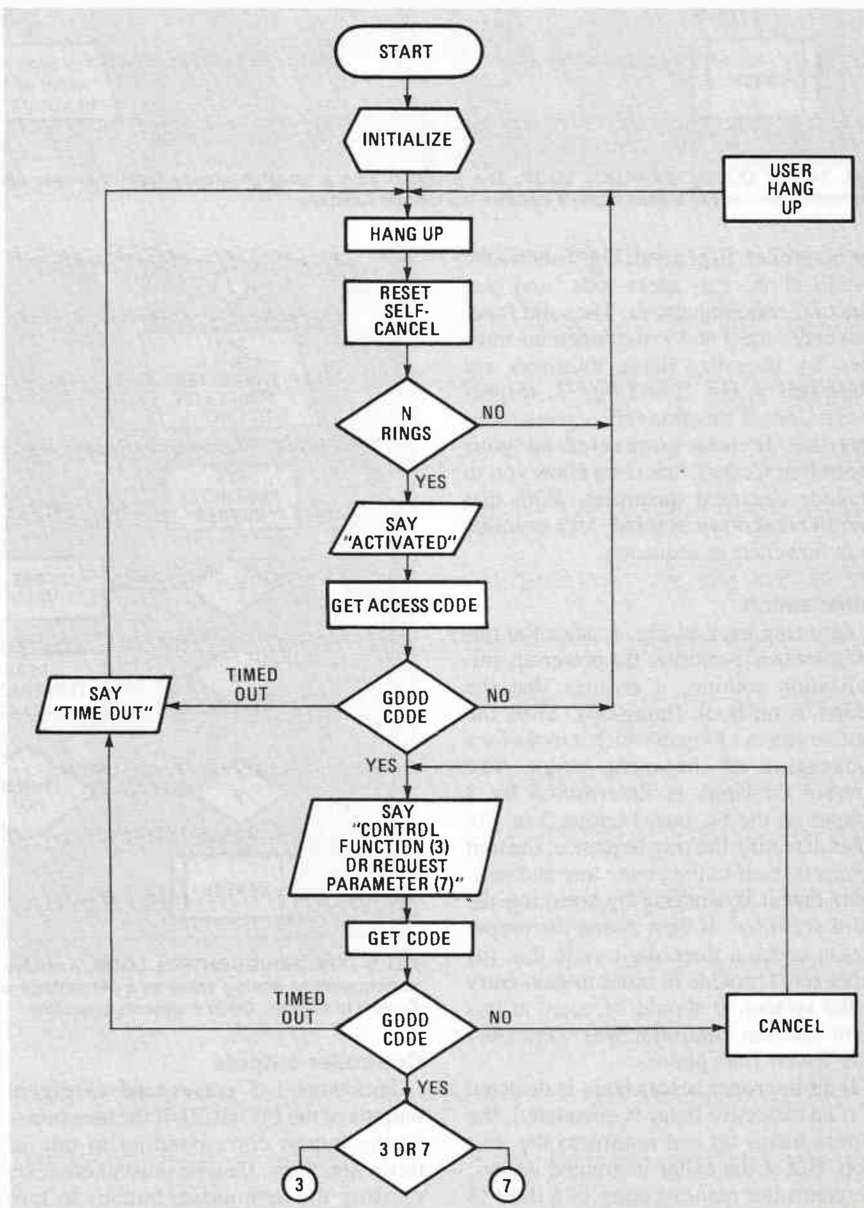


FIG. 1—FLOWCHART OF THE CONTROLLER'S MAIN LOOP: After initialization, the program gets a user-entered code and then transmits data to the user or turns the remote circuits on or off.

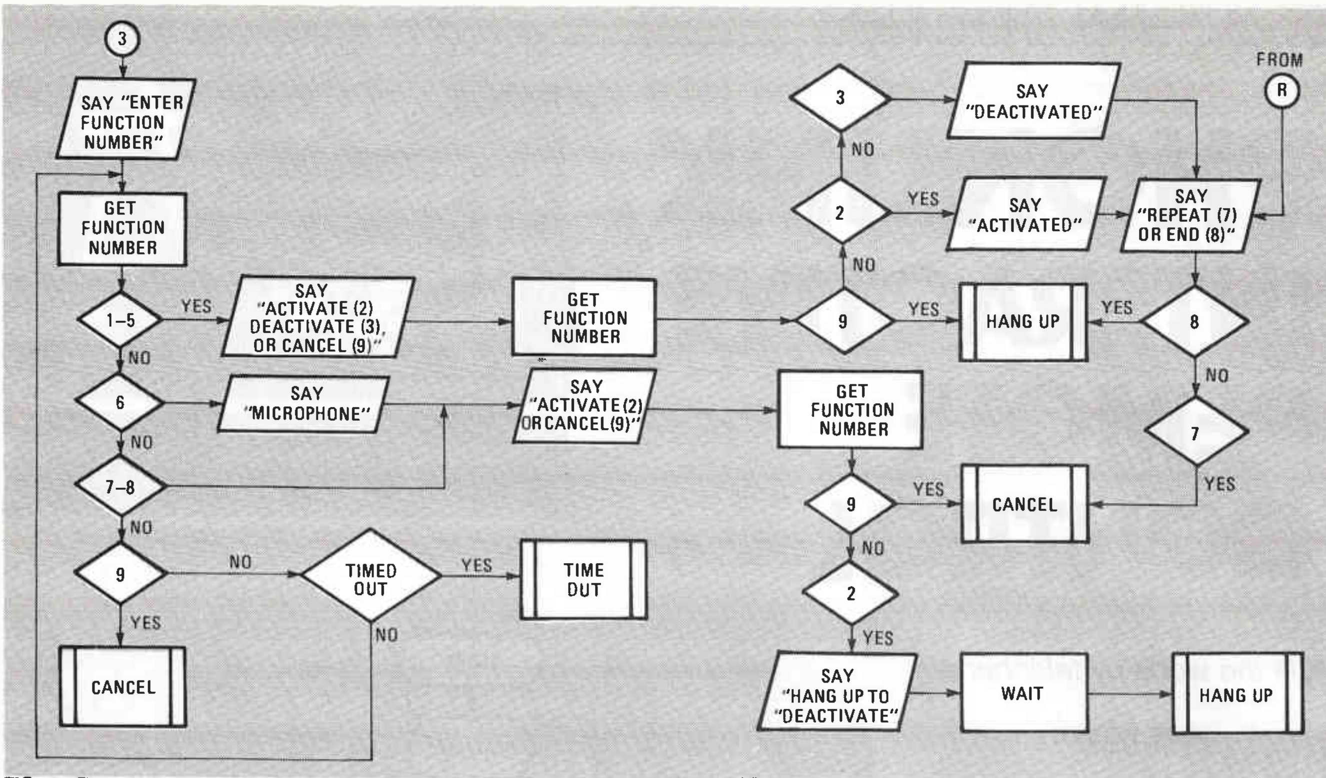


FIG. 2—THE OUTPUT-CONTROL LOOP: The program gets a function choice from the user and performs the desired action. Code 9 initiates the Cancel function.

the controller. In general, Fig. 1 shows the initialization, get-access-code, and get-function-code sequences. The valid function codes are 3 and 7; the functions initiated by pressing those numbers are illustrated in Fig. 2 and Fig. 3, respectively. Code-3 functions allow you to control the devices connected to your controller; Code-7 functions allow you to monitor electrical quantities. With that overall breakdown in mind, let's examine each flowchart in sequence.

Initialization

Referring back to Fig. 1, after the microprocessor performs its power-up initialization routine, it ensures that the phone is on-hook (hung-up). Then the routine enters a loop in which it looks for a succession of incoming rings. The number of rings is determined by a jumper on the PC board (either 3 or 10). After detecting the ring sequence, the unit connects itself to the phone line and indicates that it is working by speaking the word *activated*. It then awaits the proper access code, a three-digit code that the caller must provide in order to gain entry to the system. It should be noted at this point that the controller will work only with *Touch-Tone* phones.

If an improper access code is detected or if an excessive delay is encountered, the system hangs up and returns to the wait loop. But if the caller is granted access, the controller requests entry of a digit (3 or 7). If the user enters a 3, the controller enters the loop outlined in Fig. 2.

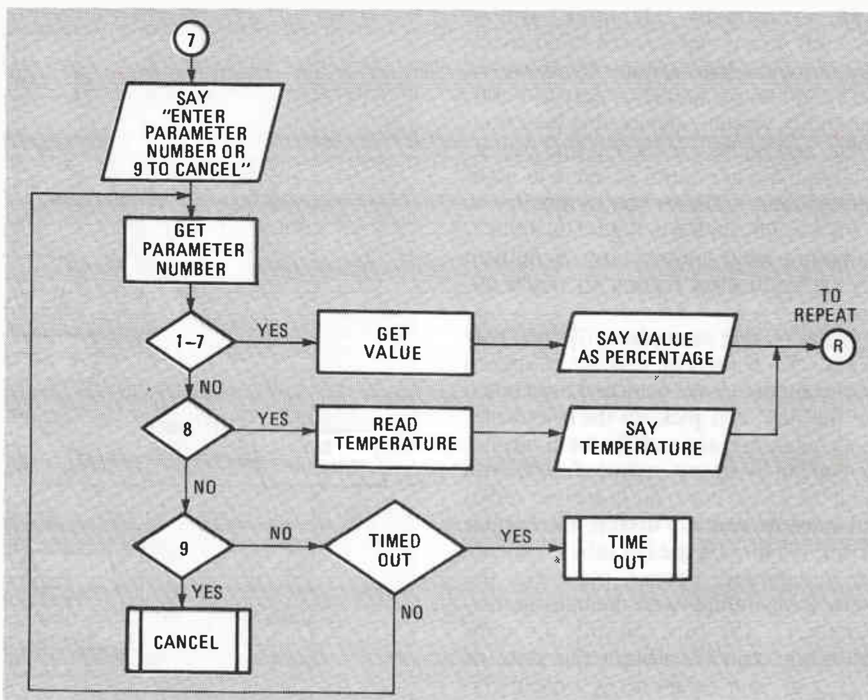


FIG. 3—THE INPUT-CONTROL LOOP: A choice of Code 1–Code 7 causes the program to report the corresponding analog value as a percentage of five volts. Local temperature will be reported when Code 8 is chosen. Code 9 cancels operation.

Controller outputs

Functions 1–5 correspond to digital outputs of the PIO (IC2). If the user presses the button corresponding to one of those functions, then he must choose, by pressing the appropriate button, to turn that function on or off. The controller will respond *activated* or *deactivated* as appropriate. Then the user will be able to repeat the sequence or hang up.

Function 6 corresponds to the built-in microphone, and functions 7 and 8 correspond to two "self-canceling" functions. Each of those functions is activated manually, and de-activated when you hang up or after a period of about five minutes.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—100,000 ohms
R2—250 ohms, 1%
R3—10,000 ohms, 1%
R4, R17, R24, R27, R32, R34, R35—10,000 ohms
R5–R9, R19, R36, R40, R42, R44, R46, R48, R50, R52, R55—33,000 ohms
R10, R15, R38—47,000 ohms
R11, R12, R14—1000 ohms
R13, R20, R21—220,000 ohms
R16, R28, R54—1 megohm
R18, R25—22,000 ohms
R22—330,000 ohms
R23, R30, R31, R33—100,000 ohms
R26—100 ohms
R29—150 ohms, ½-watt, 5%
R37—470 ohms
R39, R41, R43, R45, R47, R49, R51—51,000 ohms
R53—39,000 ohms
R56—150 ohms

Capacitors
C1, C6, C13–C15, C17–C21—0.1 µF, ceramic disc
C2, C8, C10—1 µF, 16 volts, electrolytic
C3, C4—0.022 µF, ceramic disc
C5, C11—10 µF, 16 volts, electrolytic
C7—2.2 µF, 16 volts, electrolytic
C9, C26—33 µF, 16 volts, electrolytic
C12—0.1 µF, 200 volts, disc
C16—4700 µF, 16 volts, electrolytic
C23—470 µF, 16 volts, electrolytic
C24, C25—22 pF, disc

Semiconductors
IC1—TMPZ84COOP, CMOS Z80 (Toshiba)
IC2—8255A, PIO
IC3—SP0256-AL2, speech synthesizer
IC4—74C04, hex CMOS inverter
IC5—74C02, quad CMOS NOR
IC6—27C64, 8K CMOS EPROM
IC7—74C32, quad CMOS OR gate
IC8—ADC0809CCN, A/D converter
IC9—LM234Z, precision current reference
IC10—M-956, DTMF decoder (Teltone)
IC11, IC22—unused
IC12, IC15—TLC271, op-amp
IC13—LM324, quad op-amp
IC14—4066, quad analog switch
IC16–IC19—4N32A, opto-isolator
IC20—LM7805CK, five-volt regulator, TO3 case
IC21—LM7805CT, five-volt regulator, TO220 case
BR1—200 volts, ½ amp
BR2—50 volts, ½ amp
D1, D3–D5—1N914, switching diode
D6–D8—1N5245B, 15-volt, ½-watt Zener diode
Q1—2N2222, NPN small-signal transistor

Other components
F1—125 volts, ½ amp, pigtail leads
MIC1—Electret microphone (Radio Shack 270-092B or equivalent)
RY1—Relay, five volts, 70 mA, (Radio Shack 275-243 or equivalent)
S01—16-pin DIP socket
S02—34-pin edge-card connector
T1—12.6 volts, 0.6 amp (Tria F-158XP)
XTAL1, XTAL2—3.58 MHz

Note: The following items are available from STG Associates, 2705-B Juan Tabo Blvd. N. E., #117, Albuquerque, NM 87112: Complete kit of parts, including cabinet, PC board, and programmed EPROM (KPL-1), $195; etched, drilled, and silk-screened PC board (KPL-2), $36; programmed EPROM (KPL-3), $19; printout of source code (KPL-4), $8. Add 5% for postage and handling. New Mexico residents add appropriate sales tax.

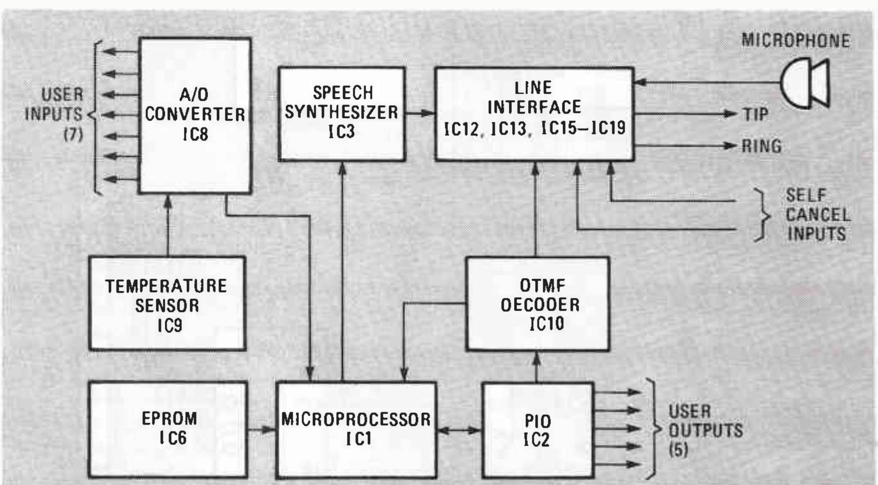


FIG. 4—BLOCK DIAGRAM OF THE CONTROLLER: an analog switch (IC14, not shown) connects the internal microphone, the speech synthesizer, or one of the self-cancel inputs to the phone line.

(Another on-board jumper selects hang-up or time-out.) The automatic hang-up feature would be useful, for example, if you wanted to listen to the sounds picked up by the microphone and just hang up when you were through, without having to explicitly deactivate the function and then hang up. The Hang-up and Cancel routines indicated in Fig. 2 are implemented as jumps to the similarly named routines in Fig. 1.

Controller inputs

If the user had entered a Code 7 from the main loop, he would then enter another code to select the quantity to be reported by the controller. If the user enters Code 1–Code 7, the controller states the value as a percentage of 0–5 volts. Obviously, you'll have to correlate that percentage with the output of your device. If the user enters Code 8, the controller responds with the ambient temperature (in degrees Celsius). Code-9 here (as in the output-function loop) cancels the current operation, returns to the main loop, and allows the user to choose between inputs and outputs (3 or 7).

Circuit overview

A block diagram of the system hardware is shown in Fig. 4. The microprocessor is a CMOS Z80; the program code is stored in an 8K-byte EPROM (a 27C64). The PIO (*P*arallel *I*nput/*O*utput) is an 8255A, which contains three 8-bit ports that interface most of the remaining circuits to the microprocessor. The A/D converter (IC8, an ADC0809) has eight analog inputs. Seven are available for use as desired; the eighth is connected to the built-in temperature-reference, IC9 (an LM334). The speech synthesizer (IC3, an SP0256), the DTMF (*D*ual-*T*one *M*ulti-*F*requency) decoder (IC10, an M-956), and the built-in microphone all interface to the telephone line via an analog switch (IC14, a 4066), several op-amps and opto-isolators.

WARNING

PLEASE NOTE THAT, ALTHOUGH THE CONTROLLER presented here has been designed to meet the interface requirements of the telephone system, it is not FCC type-approved. Connection of such a device to your operating company's line is subject to the regulations of that company. It is *your* responsibility to ascertain the pertinent regulations for your area.

Software

As anyone who has ever designed a microprocessor-based device is all too aware, the majority of work is embodied in the software. The controller's software is written in Z80 assembly language, and, due to space limitations, is not discussed here in detail (there are about 1800 lines of source code). However, both object code (contained in EPROM) and source code are available from the source noted in the Parts List.

That's all the space we have now. Next time, we'll present more complete circuit details. We'll also show you how to build the controller and offer some interfacing tips. Until then, why not use the time to gather parts or to order the kit offered by the supplier? **R-E**

BUILD THIS

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INTER-ACTIVE REMOTE CONTROL

Rule the world by telephone!

GENE ROSETH

Part 2 NOW THAT WE KNOW A little bit about how our telephone controller works, it's time to look at the circuit in greater detail. So let's get to work.

Circuit details

Figure 5 shows the microprocessor section. The EPROM (IC6) is enabled whenever a read is done to the Z80's memory (not I/O) space. Note that there is no RAM in the system; the abundance of Z80 registers and some careful programming have allowed us to dispense with RAM and associated address decoders.

The gates in the lower-left corner of the schematic (IC4-c–IC4-f, IC5-a, IC5-b, IC7-c, IC7-d) decode the I/O space for the speech synthesizer, the PIO, and the ADC. The Z80's clock input is driven via the clock output of the *Touch-Tone* decoder (shown in Fig. 6).

Figure 6 shows the analog interface circuitry. Data to the speech synthesizer and from the ADC is transferred via the data bus; data from the *Touch-Tone* decoder is transferred via the PIO. The control inputs of the analog switch are driven by the PIO and serve to connect the appropriate signal source to the telephone-line interface circuitry via terminal U13.

The speech synthesizer is a complex device that can be viewed as a storehouse of fundamental speech sounds called phonemes. The microprocessor causes the speech synthesizer to ouput individual phonemes along with appropriate delays to form complete words and phrases.

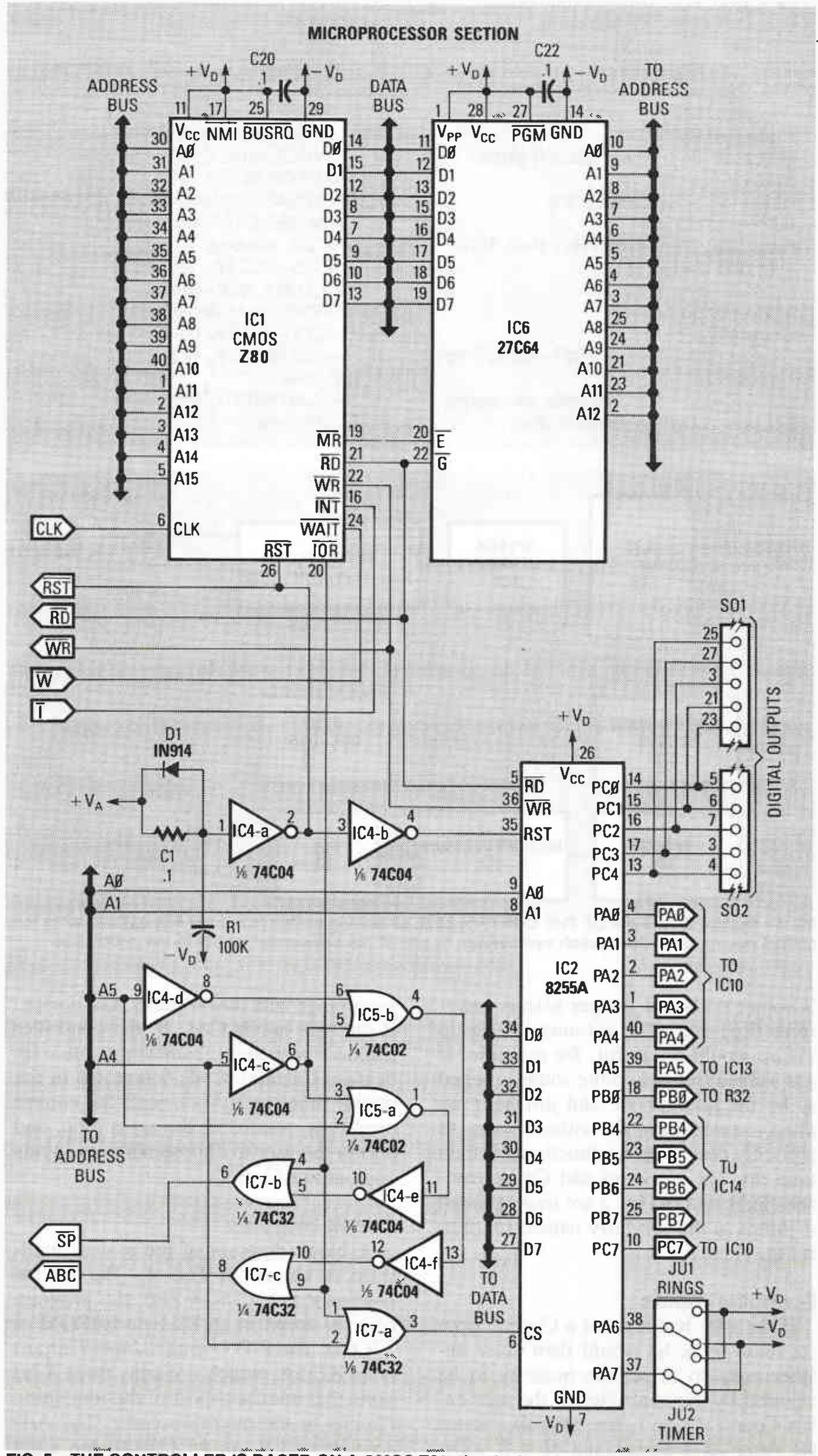


FIG. 5—THE CONTROLLER IS BASED ON A CMOS Z80; the design uses no RAM external to the Z80!

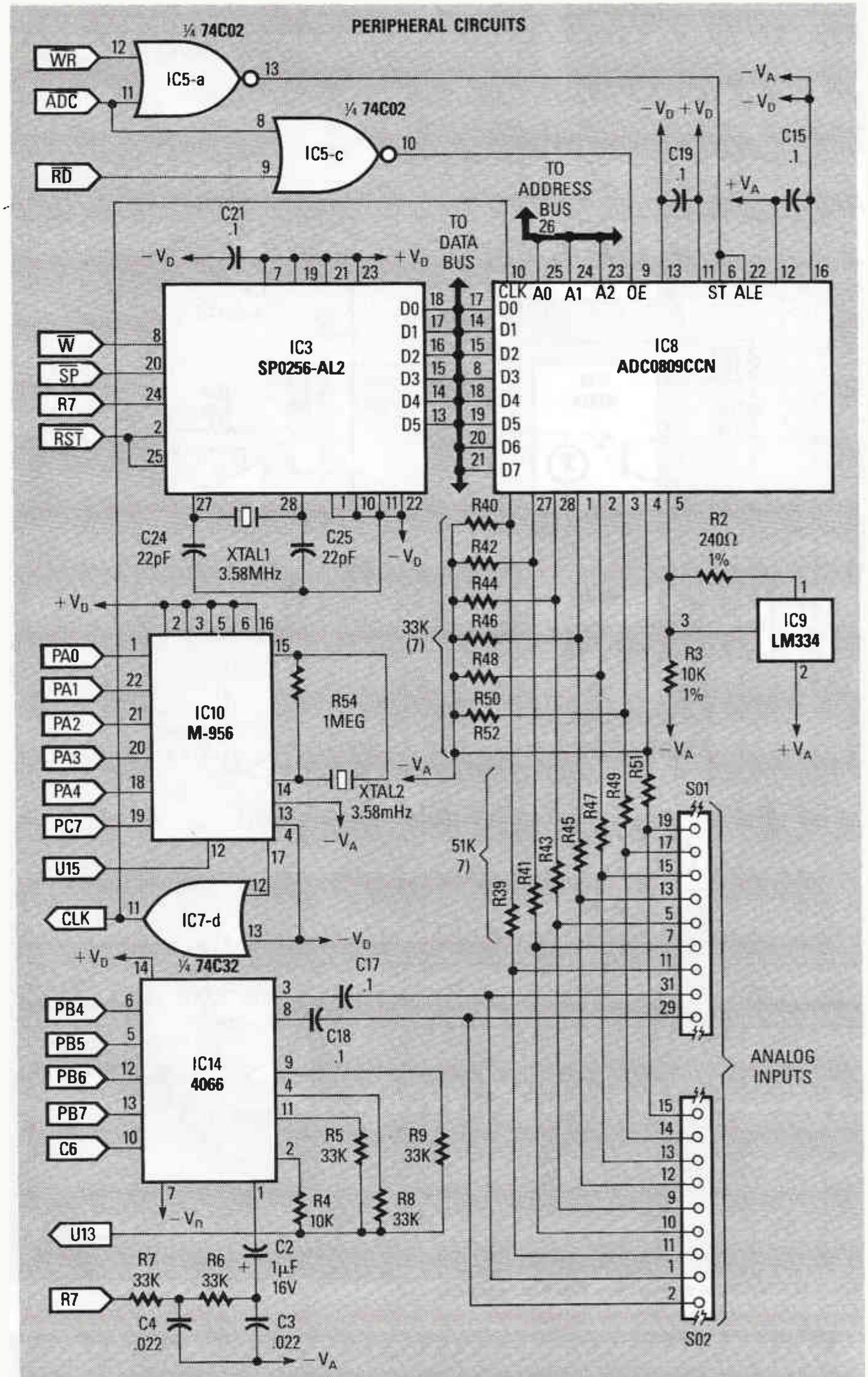


FIG. 6—THE ANALOG-INTERFACE CIRCUITS, including a speech synthesizer (IC3), an A/D converter (IC8), and a DTMF decoder (IC10) are shown here.

The ADC is a successive-approximation type; the resistive voltage divider connected to each of the first seven inputs (pins 1–5 and 26–28) is in the proper ratio to allow the microprocessor to translate a 0–5-volt input to a 0–100 percent output. For other input-voltage ranges, those resistors must be changed accordingly. The eighth input is connected to IC9, a precision current reference that produces a voltage proportional to ambient temperature.

Turning to Fig. 7, note first of all that there are two separate five-volt power supplies, one for the analog and one for the digital circuits. Now you know why the power connections to some IC's in the previous figures are labeled $\pm V_D$ and to others, $\pm V_A$. The analog and digital grounds are connected together, but only at one point; analog and digital ground runs around the board are separate.

The remainder of the circuitry provides the telephone-line interface. Line isolation is achieved through the use of opto-isolators. Opto-isolator IC16 and its associated passive components comprise the ring detector. Each time a ring occurs, a negative-going pulse is generated at pin 5 of IC16; that pulse is applied to pin 2 of IC13-a. The output of that op-amp is then applied to the PIO where it can be detected by the CPU.

Driving the remainder of the interface is BR1, a fullwave bridge rectifier that ensures proper operation of the controller even if the controller is connected to the phone lines backwards. Relay RY1 serves as the hook switch, which is equivalent to the cradle switch on any telephone. The relay is controlled by Q1, which in turn is controlled via the PIO by the Z80.

A closed-loop feedback circuit is composed of IC12, IC17, IC19, IC13-c, and the C9/R16 lowpass filter; that circuit compensates for temperature drift. The data or voice signal is modulated onto the phone line by IC13-c and IC19, but the rest of the feedback loop is needed for stability and to optimize the operating point of IC19. The purpose of IC18 is to detect the disconnect pulse from the tele-

WARNING

PLEASE NOTE THAT, ALTHOUGH THE CONtroller presented here has been designed to meet the interface requirements of the telephone system, it is not FCC type-approved. Connection of such a device to your operating company's line is subject to the regulations of that company. It is *your* responsibility to ascertain the pertinent regulations for your area.

TABLE 1—I/O CONNECTIONS

Function	Pin Number SO1	SO2
Self-cancel function 2	31	1
Self-cancel function 1	29	2
Output 4	27	3
Output 5	25	4
Ouput 1	23	5
Output 2	21	6
Output 3	3	7
Ground	*	8
Input 3	5	9
Input 2	7	10
Input 1	11	11
Input 4	13	12
Input 5	15	13
Input 6	17	14
Input 7	19	15
+5 volts, 200 mA	33	16

*All even numbered pins are grounded.

Note: Pin 1 and pin 9 are not connected.

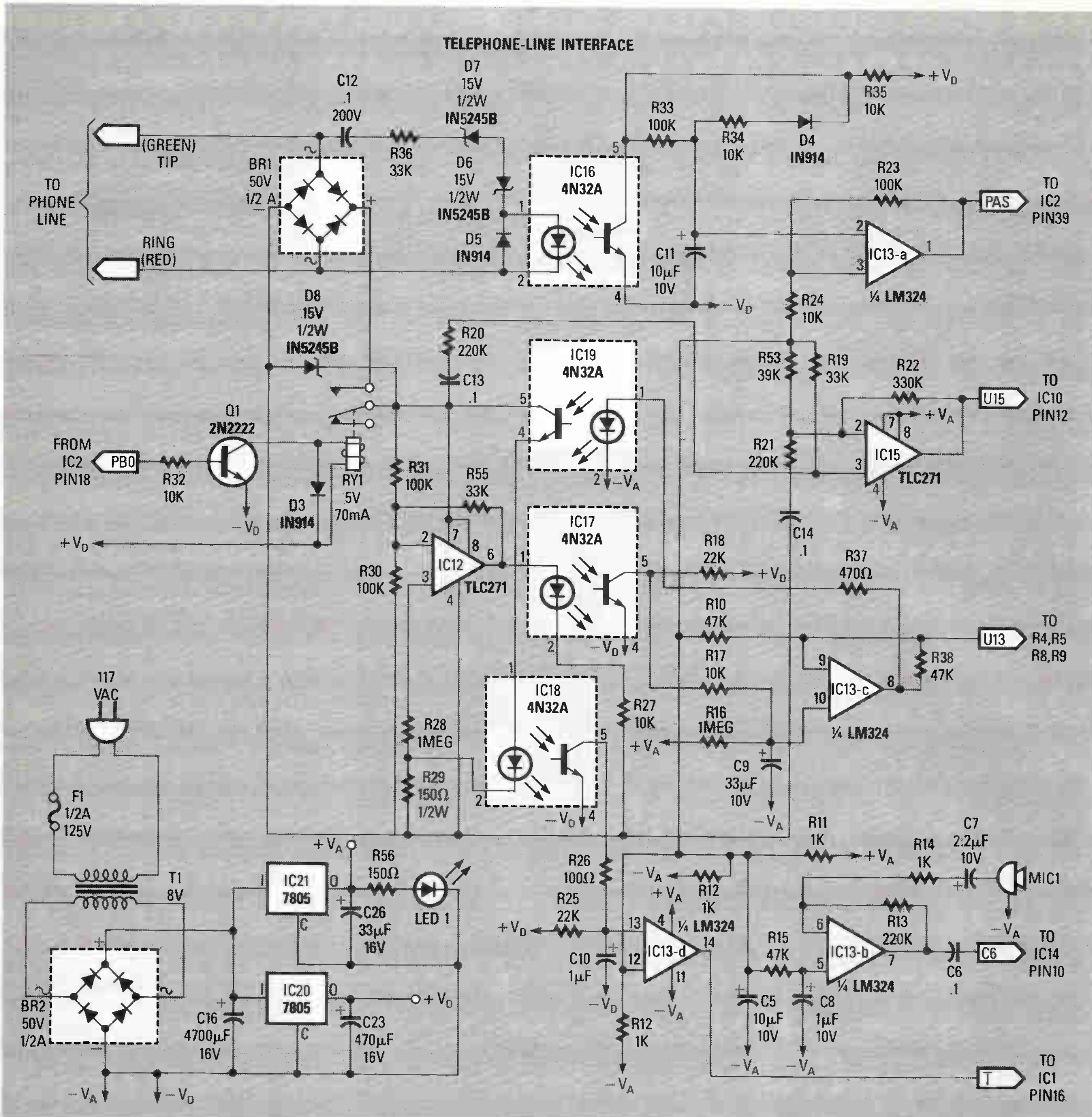


FIG. 7—THE POWER SUPPLY AND TELEPHONE-LINE INTERFACE are shown here. There are separate supplies for the analog and digital circuits.

phone exchange if the caller hangs up. That pulse causes an interrupt to the microprocessor, which then terminates the current session, re-entering the program near the top of the flowchart that was shown in Fig. 1 last time (**Radio-Electronics**, May 1987).

Software

The controller's software is written in Z80 assembly language; it comprises about 1800 lines of code. Due to space limitations, we can't print the listing here, but we have posted it on our BBS. The file is called PHONLINK.AQM, and it has been squeezed, so you'll have to unsqueeze it to use it.

LISTING 1

```
;                    *ENTER8* MODULE
;
ENTER8   LD      A,04H          ;PA5
         OUT     (SPCHPT),A     ;PRE-DELAYS
         OUT     (SPCHPT),A     ;  "     "
         OUT     (SPCHPT),A
         OUT     (SPCHPT),A
         OUT     (SPCHPT),A
         LD      HL,RTRN85
         JP      ENTER          ;"ENTER"
RTRN85   LD      HL,RTRN86
         JP      EIGHT          ;"EIGHT"
RTRN86   LD      HL,RTRN87
         JP      TWO            ;"TO"
RTRN87   LD      HL,RTRN88
```

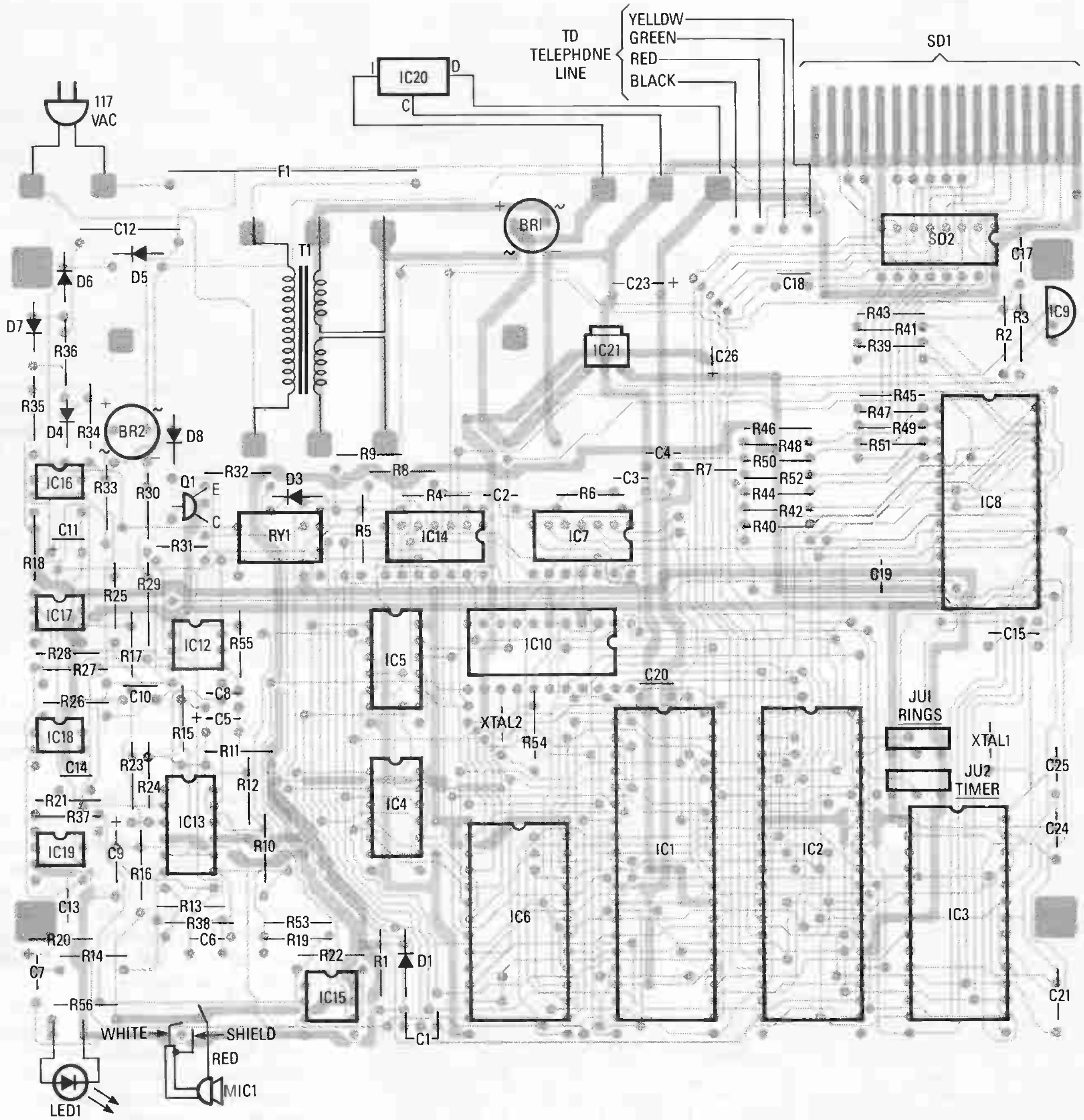


FIG. 8—STUFF THE PC BOARD as shown here. Be sure to mount all electrolytic capacitors, semiconductors, and the power transformer in the correct orientation.

To get an idea of how we use the Z80's registers rather than RAM to store subroutine return addresses, examine the routine in Listing 1.

The routine shown there causes the speech synthesizer to say "Enter eight to end or seven to repeat." After executing several delays (by outputting a 4 to the speech port), the address of the routine that speaks the word *Enter* (RTRN85) is loaded in the HL register. Then the program jumps to the routine that pronounces the word.

That routine returns to the location pointed to by HL—the next line in the routine shown in Listing 1. It in turn calls the routine that speaks the word *eight* and continues in the same manner.

Construction

Use of a PC board is not absolutely necessary, but is strongly recommended, in order to minimize crosstalk and other problems. The commercially available PC board is double-sided, has plated-through holes, and is silk-screened, which greatly simplifies construction. Alternatively, you can etch your own board using the patterns shown in PC Service.

To stuff the board, follow the parts-placement diagram (shown in Fig. 8). Observe all polarity markings and make sure that the transformer is mounted correctly! Mount IC20 (the 7805 regulator that supplies power to the digital circuitry) on the rear panel of your case, or some other heatsink. The power-on indicator (LED1) and the microphone (MIC1) should be inserted through holes in the front panel. Don't forget to solder the two jumpers in the desired positions.

Interfacing

There are two basic approaches to interfacing the controller with external circuitry. The simpler method, which is suitable for small, low-power circuits, is to mount a small piece of perfboard inside the cabinet. The board can be secured to the top half of the cabinet with #4 screws. DIP connector SO2 on the main board allows an easy interface to the user board. The pinouts of SO1 and SO2 are shown in Table 1. The wires connecting the user board to the real-world inputs and outputs

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—100,000 ohms
R2—250 ohms, 1%
R3—10,000 ohms, 1%
R4, R17, R24, R27, R32, R34, R35—10,000 ohms
R5–R9, R19, R36, R40, R42, R44, R46, R48, R50, R52, R55—33,000 ohms
R10, R15, R38—47,000 ohms
R11, R12, R14—1000 ohms
R13, R20, R21—220,000 ohms
R16, R28, R54—1 megohm
R18, R25—22,000 ohms
R22—330,000 ohms
R23, R30, R31, R33—100,000 ohms
R26—100 ohms
R29—150 ohms, ½-watt, 5%
R37—470 ohms
R39, R41, R43, R45, R47, R49, R51—51,000 ohms
R53—39,000 ohms
R56—150 ohms

Capacitors
C1, C6, C13–C15, C17–C22—0.1 µF, ceramic disc
C2, C8, C10—1 µF, 16 volts, electrolytic
C3, C4—0.022 µF, ceramic disc
C5, C11—10 µF, 16 volts, electrolytic
C7—2.2 µF, 16 volts, electrolytic
C9, C26—33 µF, 16 volts, electrolytic
C12—0.1 µF, 200 volts, disc
C16—4700 µF, 16 volts, electrolytic
C23—470 µF, 16 volts, electrolytic
C24, C25—22 pF, disc

Semiconductors
IC1—TMPZ84COOP, CMOS Z80 (Toshiba)
IC2—8255A, PIO
IC3—SP0256-AL2, speech synthesizer
IC4—74C04, hex CMOS inverter
IC5—74C02, quad CMOS NOR
IC6—27C64, 8K CMOS EPROM
IC7—74C32, quad CMOS OR gate
IC8—ADC0809CCN, A/D converter
IC9—LM234Z, precision current reference
IC10—M-956, DTMF decoder (Teltone)
IC11, IC22—unused
IC12, IC15—TLC271, op-amp
IC13—LM324, quad op-amp
IC14—4066, quad analog switch
IC16–IC19—4N32A, opto-isolator
IC20—LM7805CK, five-volt regulator, TO3 case
IC21—LM7805CT, five-volt regulator, TO220 case
BR1—200 volts, ½ amp
BR2—50 volts, ½ amp
D1, D3–D5—1N914, switching diode
D6–D8—1N5245B, 15-volt, ½-watt Zener diode
Q1—2N2222, NPN small-signal transistor

Other components
F1—125 volts, ½ amp, pigtail leads
MIC1—Electret microphone (Radio Shack 270-092B or equivalent)
RY1—Relay, five volts, 70 mA, (Radio Shack 275-243 or equivalent)
S01—16-pin DIP socket
S02—34-pin edge-card connector
T1—12.6 volts, 0.6 amp (Tria F-158XP)
XTAL1, XTAL2—3.58 MHz

Note: The following items are available from STG Associates, 2705-B Juan Tabo Blvd. N. E., #117, Albuquerque, NM 87112: Complete kit of parts, including cabinet, PC board, and programmed EPROM (KPL-1), $195; etched, drilled, and silk-screened PC board (KPL-2), $36; programmed EPROM (KPL-3), $19; printout of source code (KPL-4), $8. Add 5% for postage and handling. New Mexico residents add appropriate sales tax.

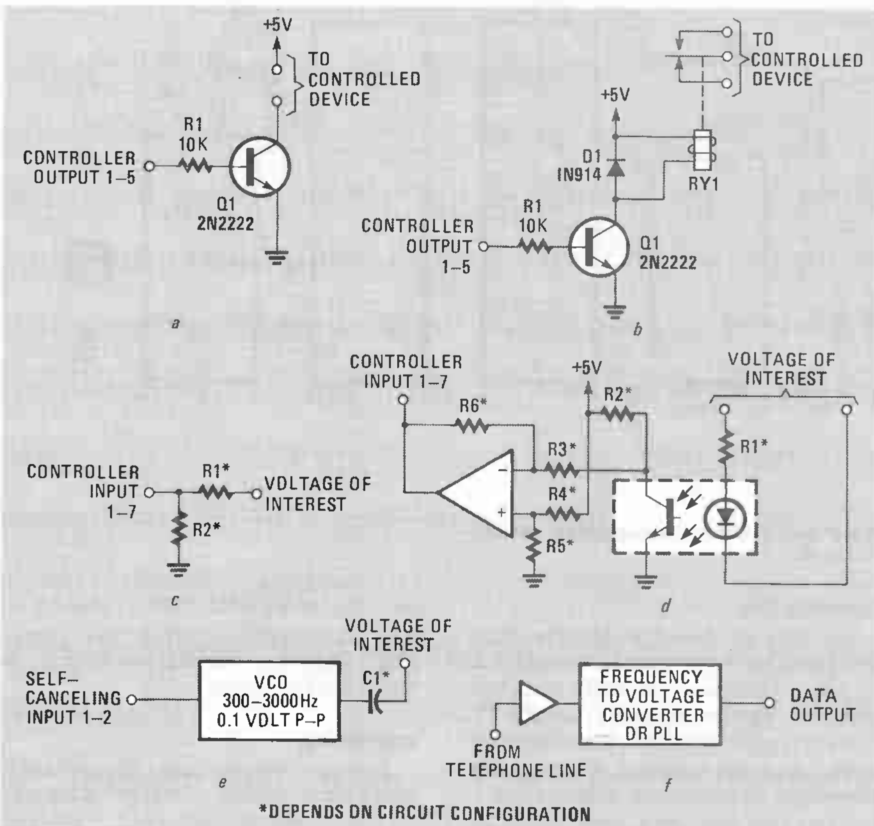


FIG. 9—A VARIETY OF INPUT/OUTPUT CIRCUITS: at *a*, an unisolated digital output; at *b*, an isolated digital output; at *c*, an unisolated analog input, at *d*, an isolated analog input. Shown in *e* and *f* are one means of transmitting digital data over the phone lines.

can be routed out an opening in the rear panel. The internal power supply can provide a maximum of about 200 mA to user circuitry. If that's not enough for your applications, use another method.

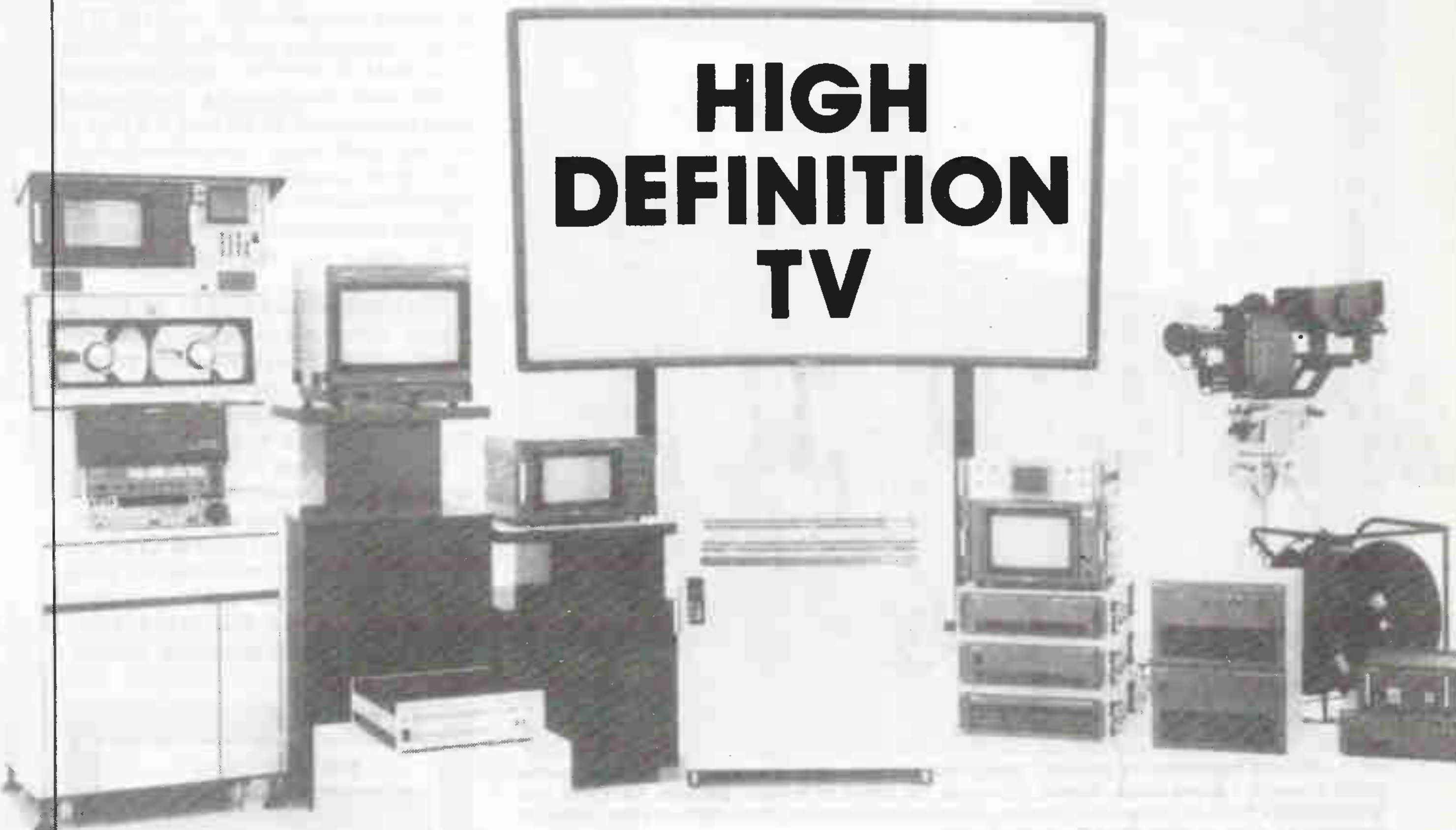
The other method of interfacing is required when the application demands devices that are too big or too power-hungry to be mounted internally. Here a separate box should be built that contains its own internal power supply. The edge-card connector identified as SO1 in the schematics can be used to connect the controller to the interface box.

Construction aside, the type of circuit you'll need will depend on your inputs and outputs. Figure 9 shows ideas for several types of interfaces. Component values are not given for most of the circuits because those values can only be determined based on the voltage levels you'll be dealing with. But the circuits shown provide a good starting place.

Figure 9-*a* and Figure 9-*b* show two simple digital-output circuits. Neither can supply much current; the relay in Fig. 9-*b* should be a low-current type. The Fig. 9-*a* circuit is suitable for applications where isolation is unimportant; otherwise, use the Fig. 9-*b* circuit.

Figure 9-*c* and Figure 9-*d* show two simple analog-input circuits. As with Fig. 9-*a* and Fig. 9-*b*, the Fig. 9-*c* circuit is suitable for applications where isolation is unimportant; otherwise, use the Fig. 9-*d* circuit.

Last are circuits for transmitting digital data over the telephone lines. As shown in Fig. 9-*e*, the remote voltage of interest should be processed by a VCO (*V*oltage-*C*ontrolled *O*scillator) so that a tone suitable for phone-line bandwidth (3000 Hz) will be generated. The signal applied to either of the converter's self-canceling inputs should be in the range of 50–100 mV p-p. As shown in Fig. 9-*f*, the tone can be recovered at the receiving end after suitable isolation and buffering by a voltage-to-frequency converter or a PLL (*P*hase-*L*ocked *L*oop). **R-E**



HIGH DEFINITION TV

The most important change in TV technology since it was invented is just over the horizon.

JOSEF BERNARD

CREATED BY NEON LAMPS AND VIEWED through a spinning spiral of holes in a Nipkow disc, the very first TV images were so crude that they barely allowed the viewer to distinguish light from shadow. Today we are much more fortunate—on-screen resolution of several hundred lines, both horizontally and vertically, permits us to read street signs, subtitles, and movie credits on color CRT's or LCD's.

Even so, we're always aware that we're looking at a television picture, that is, a picture displayed on a screen. And when we can not discern the finer details in an image, no matter how hard we strain, the shortcomings of the current system becomes evident. That is true whether the system in question is the NTSC system used in this country, or the slightly higher-resolution PAL and SECAM systems that have been adopted by most of the rest of the world.

But help is on the way. Dramatic improvements are on the horizon in the form of *H*igh-*D*efinition *TV* (HDTV) systems that will add realism and detail to the images we view for entertainment and information.

HDTV technology exists today; it is used, for example, in Hollywood for special-effects work in TV. By as early as 1990, Japanese broadcaster NHK plans to have an HDTV system in place and operational. And work here, in Europe, and elsewhere is progressing so fast that systems may be in place worldwide shortly thereafter. In this article we'll examine the Japanese HDTV system and others, see how they evolved, and learn about what obstacles remain before they can become adopted for widespread use.

HDTV criteria

One of the goals of HDTV is to create a sense of realism for the viewer that's at least as good as that provided by motion-picture film. How? Tests have shown that, to overcome the "picture-in-a-box" effect of TV viewing, the image must subtend a viewing angle of at least 30°. To obtain such an angle, one could simply sit closer to the screen. However, at a distance of less than 7 times the image height, scan lines become noticeable and give the image a grainy appearance.

Figure 1 compares the geometries provided by viewing both conventional TV and HDTV screens from the distance at which scan lines are rendered invisible. In a conventional system, the viewing angle is only about 10°, but an HDTV system provides the desired 30° viewing angle.

As shown in the figure, if the number of scan lines is increased to 1000 or more, the minimum viewing distance is reduced to about 3 times the image height. At that distance a 30° viewing angle can be achieved. Further, due to the limited resolution of the human eye, the lines will blend together and give the impression of a smooth image.

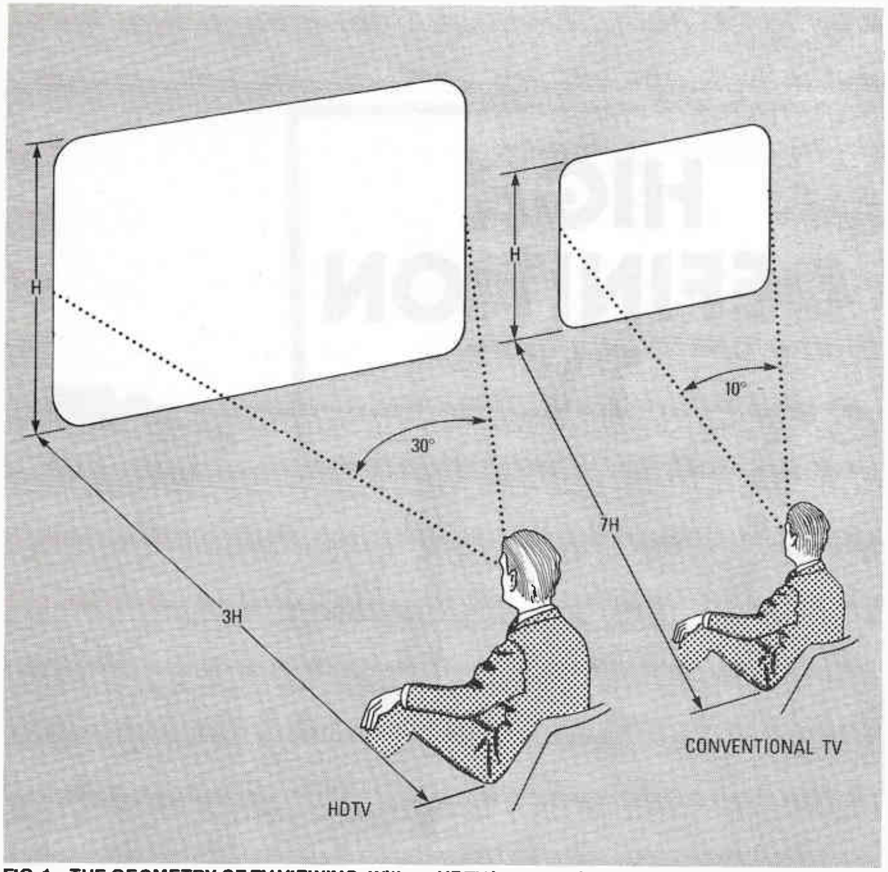


FIG. 1—THE GEOMETRY OF TV VIEWING. With an HDTV image, a viewer can sit closer to the screen to attain a greater viewing angle, thereby improving the sense of realism. Because the signal has approximately twice as many scan lines as a conventional system, those lines are not visible at distances as close as three times the image height.

Another factor adding to the impression of realism offered by HDTV is a change in aspect ratio, the ratio of an image's width to its height. Conventional TV has a 4:3 aspect ratio, which means that the picture is four units wide and three units high. That aspect ratio was adopted originally to conform to what was used at the time for motion-picture photography. These days, most films are shot using the Panavision process, which uses a 1.85:1 (5.55:3) aspect ratio. It is expected that HDTV will use an aspect ratio between the two, with 1.77:1 (16:9) being endorsed by many. See Fig. 2.

The NHK system

As we mentioned earlier, the HDTV system closest to being a practical reality is the one proposed by Japan's NHK. That system uses a signal with 1125 scan lines and a 2:1 interlaced scan rate of 60 fields (30 frames) per second. NHK's HDTV system has already been demonstrated both in Japan and in the U.S.

One problem with all HDTV systems is that they potentially require enormous amounts of bandwidth. For instance, in the system proposed by NHK, a high-definition TV picture contains about five times more luminance (brightness) information that does a conventional one, thus requiring a bandwidth at least five times greater than that specified for the NTSC system used by U.S. broadcasters today. That translates to a bandwidth requirement of 30 MHz, compared to the 6 MHz NTSC standard.

To squeeze all of the information required for a HDTV picture into a more manageable bandwidth, NHK developed a system called MUSE (*MU*ltiple Sub-Nyquist *S*ampling *E*ncoding). MUSE converts a wideband analog studio signal to digital form, compressing it to slightly more than 8 MHz for transmission. At the receiver, the signal is re-expanded to its original form for display. The MUSE specifications call for:

- Processing of luminance and chrominance information by TCI (*T*ime *C*ompressed *I*ntegration).
- Time-compressed line-sequential processing of chrominance information generating R – Y (red minus luminance) and B – Y (blue minus luminance) color-difference signals.
- Time compression of the chrominance signal by a factor of four.
- Bandwidth reduction of the TCI signal through subsampling.
- A PCM digital audio signal to be multiplexed with the video signal.

MUSE is known as a "motion-compensated subsampling" system. The terms *subsampling* and *sub-Nyquist* refer to the fact that when the video information is processed, fewer samples are extracted from it than would be the case if it were to be processed using conventional methods, where sampling occurs at twice the highest frequency (i. e., the *Nyquist frequency*) involved; the lower sampling rate is the reason why that method is called sub-Nyquist.

The principal trick used by the MUSE system is that it sub-samples the video signal over a four-field sequence prior to transmission; the sampling pattern used is shown in Fig. 3. That technique allows for the 4:1 reduction in required bandwidth.

Reconstruction of the MUSE signal requires an HDTV receiver equipped with a memory capable of storing the four fields. For still (non-moving) parts of an image, the picture can be reconstructed using samples from all four fields since there will be no movement from field to field.

But where there is movement, attempt-

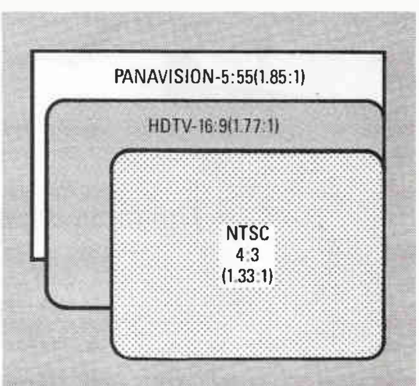


FIG. 2—ASPECT RATIOS. Here, the aspect ratios of conventional-TV, HDTV, and Panavision motion-picture viewing screens are compared.

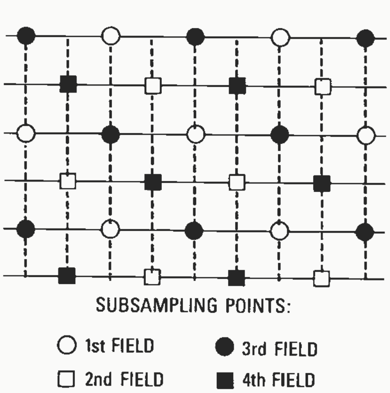


FIG. 3—THE SAMPLING PATTERN used by NHK's MUSE system. Picture information is transmitted over four fields rather than the two of conventional TV.

ing reconstruction using two or more fields will yield a picture with unacceptable blurring. That's because the picture content will be changing from field to field. Therefore, only the information from one field can be used to form the image and a 1:4 loss of resolution occurs.

However, a MUSE receiver also incorporates a motion detector. That stage enables the receiver to integrate the stationary and moving parts of a scene into a single image. (That's where the "motion-compensated" part of the MUSE system comes in.) The result is that stationary parts have maximum resolution while moving parts appear slightly blurred. Such blurring is not considered serious, however, since our perception of sharpness is not reduced by blur in a moving image. We simply accept it as an attribute of the motion.

A special case in the MUSE system occurs when the camera is panned or tilted, causing the entire image to change. When the encoding circuitry detects that type of picture content, a vector representing the motion of a scene is calculated and the information is sent during the vertical-blanking interval. At the receiver, the information is applied to the field memories, causing the position of the sampled picture elements to be shifted as appropriate to the motion. The bottom line is that the moving pictures are processed as if they were stationary ones, with conspicuous blur in uniformly moving regions of the image held to a minimum, subject to the accuracy of the motion vectors. Note however that non-uniform moving regions will unavoidably suffer a loss of resolution. In most instances, however, such loss will be acceptable as a consequence of motion.

Other systems

Although NHK's MUSE system is the one closest to implementation, work on HDTV is also continuing in Europe and the U.S. In this section we will look at some of the more promising systems.

Most of these systems are based on the following standard: 1125 lines, 60 frames per second, 2:1 interlace, 16:9 aspect ratio. The number of lines was chosen as a compromise between the PAL/SECAM and the NTSC camps. It is more than 1000 lines, but not exactly equal to twice either 625 or 525 lines. Also, although 50 frames per second is used in Europe and elsewhere, the NTSC standard of 60 frames per second was accepted because it substantially reduces flicker and allows a higher sampling rate. Interlaced scanning, as opposed to a progressive scanning scheme, is used because of the reduced bandwidth it requires.

Note that those specifications have not been formally accepted as a worldwide standard, however. It was hoped that a standard would be adopted at the International Radio Consultative Committee's 1986 Plenary Assembly. Instead, a decision was postponed until 1990, at the earliest. That postponement has added some confusion to the HDTV world, so there is no guarantee as to what shape, if any, a worldwide specification will take. It is expected, however, that the 1125/60/2:1 standard will become a *de facto* standard in most 60-Hz HDTV studios.

Several of the systems are of the MAC (*M*ultiplexed *A*nalog *C*omponents) type. In a MAC signal, the luminance, color difference, and multiple digital sound signals are compressed in time and multiplexed onto the same signal. In particular, most European HDTV systems are based on some type of MAC system.

For instance, Philips, the Dutch electronics giant, has proposed a European HDTV system called HD-MAC. The system is based on the 625-line, 50-Hz PAL standard. The input signal is 1250 lines, 50 Hz, with 2:1 interlace. Vertical filtering is used to make a wide-bandwidth 625/50/2:1 signal for transmission. The bandwidth is reduced by transmitting only alternating horizontal samples; four fields are required to receive a complete HD-MAC picture. That, once again of course, means that the receiver must have a frame memory to display the 1250/50/2:1 picture.

Other MAC systems are similar, except for the numbers involved. For instance, B-MAC is a MAC system that's compatible with the 1125/60/2:1 proposed worldwide standard.

And things have not been quiet in this country, either. Bell Laboratories has proposed a two-channel transmission system in which one channel contains an NTSC signal that is derived from an HDTV signal of 1050 lines. The second channel contains the high-frequency luminance and color-difference information. According to Bell Labs, a normal NTSC receiver would receive the NTSC channel with only a slight degradation of picture quality. An HDTV receiver would receive both channels and combine them using a frame store. The result is then scan-converted to reproduce the original 1050-line picture.

CBS has proposed another two-channel system. One channel would contain a MAC-like time-multiplexed component signal in a 525-line/60-Hz format. The second channel would contain another time-multiplexed component signal. When the two signals are combined, an HDTV image results. The system does not require a receiver with frame store and would use *D*irect-*B*roadcast *S*atellite (DBS) delivery.

William Glenn of the New York Institute of Technology has proposed a system that makes use of the properties of human vision to reduce the bandwidth of a transmitted HDTV signal. In his proposal, an "improved" NTSC signal is transmitted over a standard NTSC channel. (Those improvements could entail pre-combing to eliminate interference between the luminance and color information, use of progressive rather than interleaved scan, etc. Some improvements may require modified NTSC receiving equipment.) That signal, which already will offer somewhat better resolution than standard NTSC, is accompanied by a 3-MHz wide auxiliary signal that contains high-frequency, low temporal-rate information, as well as information

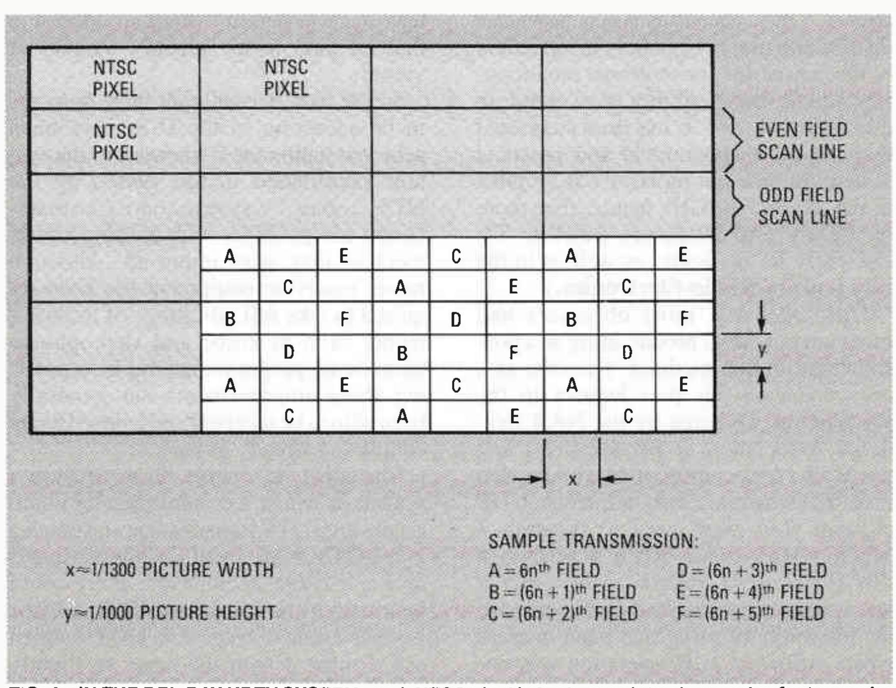


FIG. 4—IN THE DEL RAY HDTV SYSTEM, each NTSC pixel is broken up into six samples for transmission. Picture information is relayed in a sequence of six fields.

required to produce a wide aspect-ratio picture. The two signals would be combined in a frame store to produce an HDTV image.

The Del Ray Group of Marina Del Ray, CA, has proposed a system that uses a single NTSC channel to transmit a 525/60/2:1 HDTV signal. They propose a system in which a single NTSC luminance sample (pixel) is broken up into 6 samples. One sample is transmitted each field until after 6 fields the complete NTSC pixel is sent. The sampling pattern is shown in Fig. 4. At the receiver, a frame store is used to recreate the complete picture. According to the Del Ray Group, such a signal could be displayed on a non-HDTV NTSC receiver with little degradation when compared with a normal NTSC signal.

A wider aspect ratio is achieved in this system by reducing the number of active video lines transmitted by 69. The Del Ray Group contends that due to overscan losses in a typical receiver, the removed lines would not be missed. Further, those 69 lines could then be used to transmit digital sound.

Distribution

After an HDTV specification has been established and agreed upon, the problem remains of how to distribute material produced in that medium to the public waiting for it. So specifications, distribution, and compatibility are HDTV's toughest remaining problems. Let's look at the distribution problem in more detail first; later on we'll delve deeper into compatibility.

As with today's video programming, there are two alternatives: broadcast and pre-recorded material. In the realm of broadcasting, one possibility is, of course, DBS. Satellites could provide a distribution route completely independent of those used for conventional broadcasting, and the compatibility issue could, in a sense, be skirted. It has been suggested that the most economical and practical system for distributing HDTV is by DBS in the 22- and 40-GHz bands. (For more on HDTV and DBS, see Satellite TV elsewhere in this issue, as well as in the July issue of **Radio-Electronics.**)

Until recently, most observers had ruled out terrestrial broadcasting as a possible distribution medium. However in a test conducted this past January in the Washington, DC area by the NAB (*N*ational *A*ssociation of *B*roadcasters) and the MST (Association of *M*aximum *S*ervice *T*elecasters), two adjacent UHF channel slots were used to transmit a MUSE HDTV signal. At the same time, a 13-GHz terrestrial-microwave relay signal was used as a backup, and to demonstrate the feasibility of using that band in areas where sufficient UHF spectrum was unavailable. On the UHF band the broadcast was made using vestigial sideband AM; on 13 GHz, FM was used. In general, the results were satisfactory, although some problems were encountered with the PCM digital audio, which was designed for satellite rather than terrestrial distribution, when the signal was attenuated. That problem will have to be solved to make terrestrial distribution of a MUSE signal practical.

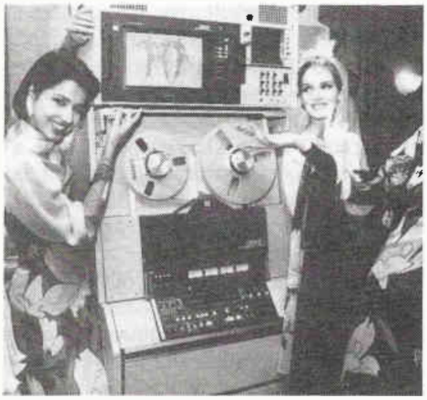


FIG. 5—AN HDTV videotape recorder from Sony was used this past spring to present one designer's spring line in New York.

The other way in which HDTV programming could be provided is in pre-recorded form—on videotape and videodiscs. While the wide bandwidths of HDTV are beyond the capabilities of conventional broadcast and consumer equipment, Sony and other manufacturers have developed systems capable of storing HDTV images. See Fig. 5.

Compatibility

High-definition television is certainly practical. Indeed, it already exists. The problem that concerns many, though, is how to get program material produced in that medium to the greatest number of viewers.

In the past, virtually all improvements in broadcasting in the U.S. have been achieved within the framework of the system established in the 1940's by the NTSC; other TV systems have also maintained compatibility with existing equipment as they were improved. Although newer receiving equipment has been required to take full advantage of improvements such as color and stereophonic broadcasts, program material incorporating those improvements has generally been able to be received and enjoyed using equipment already in use.

The ideal, of course, is to develop a system in which a current receiver could accept an HDTV transmission and display it in HDTV form. In all likelihood, that is an unattainable dream. More likely would be a system in which an NTSC receiver would be able to receive an HDTV signal and display it with the same or slightly worse quality as it displays an NTSC signal. Another possibility would be a system in which an NTSC receiver could be modified, perhaps through an outboard adapter, to receive HDTV signals. Of course, the cost of such a modification must be relativelylow to be practical. If it is too high, most consumers would opt to forgo modification and simply replace their equipment when they decide to upgrade. A final possibility would be that an NTSC receiver simply could not be used to receive and display HDTV signals in any form. In other words, it would be a completely incompatible system.

Of course, compatibility is a desirable goal, but you can not overlook the cost at which it is achieved. At this point in HDTV research, it appears that the higher the compatibility with existing systems, the poorer the high-definition performance. Images will be strikingly better than those provided by a non-HDTV system, but they will not provide maximum possible performance.

On the other hand, the highest performance HDTV system will likely be achieved only if the compatibility problem is completely ignored. In that event, a separate programming distribution system likely will develop that will supply programming to viewers that possess the appropriate equipment.

Ignoring compatibility altogether is not without precedent. When FM radio broadcasting was introduced, that mode was incompatible with the existing AM system. That, however, did not stop people from investing in what then was expensive equipment to take full advantage of the benefits (superior audio quality) offered by that medium.

The newer FM system coexisted with the older AM one, and prospered. Today, it is commonplace to find AM and FM tuners in the same piece of equipment—even small portable receivers. And even now the same program material is sometimes broadcast by a station in both AM and FM, so that those with FM equipment can enjoy the all the benefits of the new technology, and those who are still AM-bound will not be left out.

Similarly, television broadcasters could provide high-quality HDTV programming by satellite or some other means to those equipped to receive it, while performing scan- and media-conversion at their own facilities and simultaneously sending NTSC-format signals containing the same material on their conventional VHF and UHF frequencies for viewers with existing NTSC (or PAL or SECAM) receivers.

Whatever final form politics, policies, and technology dictate for HDTV, it appears that there's no holding that technology back. In just a few short years, Japanese viewers will be enjoying its benefits; it's very likely that shortly thereafter we'll be getting the "big picture" in this country, too! **R-E**

HDTV UPDATE

BRIAN C. FENTON

HDTV—sooner than you think

ACTV

YOU COULD BE WATCHING HIGH-DEFinition television in your home in as little as five years, thanks to a breakthrough from the David Sarnoff Research Center (formally RCA Labs). They announced—in collaboration with NBC and GE/RCA Consumer Electronics—the development of a new high-definition television system called ACTV or *A*dvanced *C*ompatible *T*ele*V*ision. It's the most exciting thing to happen to TV since color.

ACTV is a single-channel, NTSC-compatible, widescreen, extended-definition television system. It has features that set it apart from any of the other high-definition systems proposed to date, including NHK's MUSE, Philips' HD-MAC, or the Del Rey Group's HD-NTSC. (For background information on those HDTV systems, see the August 1987 issue of **Radio-Electronics**.)

The most important feature of ACTV is that the high-definition picture can be delivered within the existing 6-MHz NTSC broadcast channel. And ACTV is completely compatible with today's TV sets. Of course, a standard NTSC receiver can't display a high-definition picture, but it can display an ACTV picture with the same quality as it can display an NTSC one today.

On the other hand, a high-definition ACTV receiver would display a picture with 1050 lines per frame (that's double the 525 we get today). Its aspect ratio—the ratio of the picture's width to its height—is 5:3, which is close to that of motion pictures, and a far cry from NTSC's 4:3 aspect ratio.

How it works

Figure 1 shows how ACTV delivers what no other system has been able to. The process starts with a high-definition signal, which is separated into four components. The four components are processed and recombined into a single NTSC-compatible signal for both standard and ATSC receivers.

The first component of the high-definition signal is the main NTSC signal, which contains the center panel of the widescreen picture. The low-frequency information of the side panels is also contained in the first

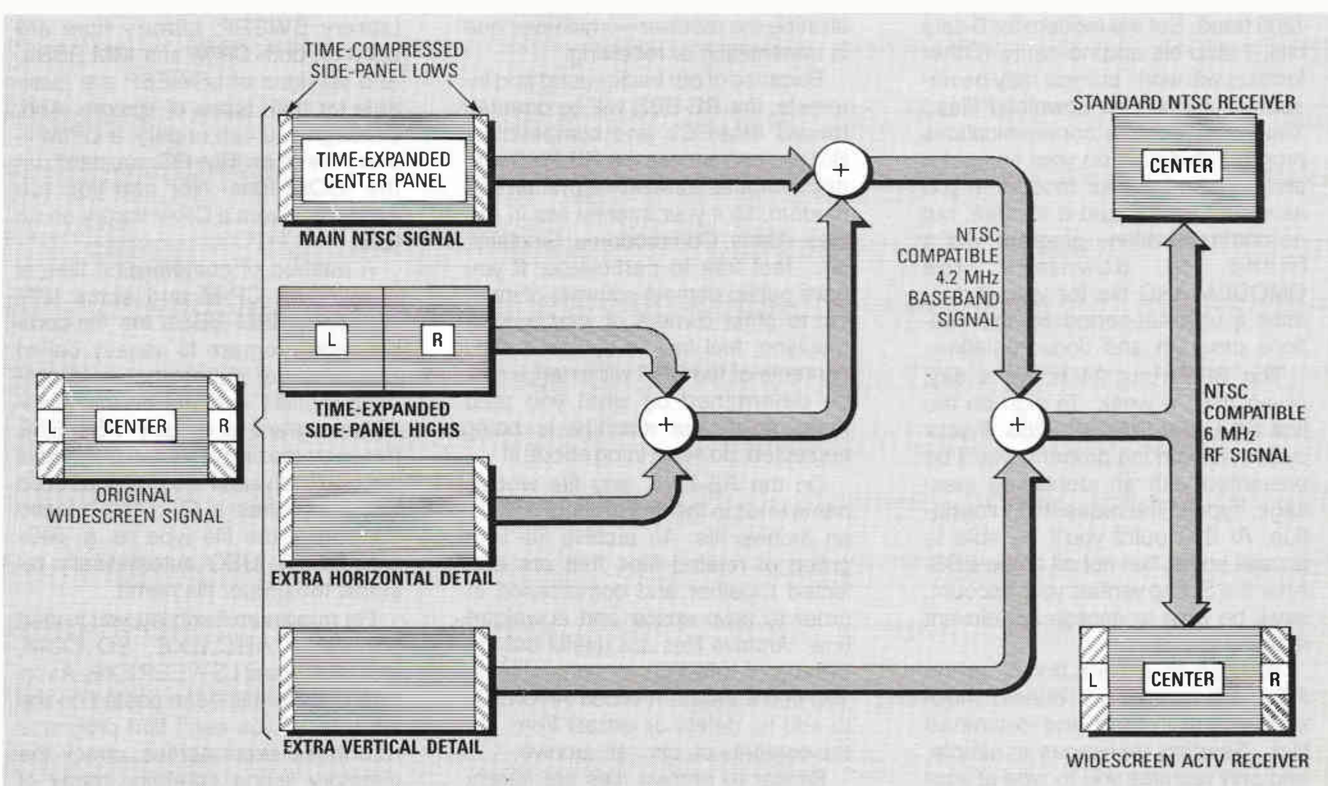


FIG. 1—THE ACTV SIGNAL starts with a widescreen picture that is separated into four components. Those components are digitally processed and combined using quadrature modulation techniques into an NTSC-compatible 6-MHz RF signal.

component, but it is time-compressed and forms a narrow band on each side of the picture (which is hidden by the normal overscan in home receivers.)

The second component of the ACTV signal contains the high-frequency information of the side panels. It is combined with the third component, the extra horizontal detail. Those three are digitally processed and then combined into a single NTSC-compatible baseband signal, which is then combined with the fourth component, the extra vertical detail, on the RF carrier.

NTSC still survives

Today's NTSC standard was developed in the early 1940's by the *N*ational *T*elevision *S*tandards *C*ommittee. Considering that the standard was developed for black-and-white TV, it is truly amazing that the advances in TV technology we've seen since that time—such as color, stereo sound, and teletext—have been developed within its framework.

With the investment in television transmitting and receiving equipment estimated at $100-billion, a compatible system is certainly desirable. But until the Sarnoff/NBC announcement, most had considered that goal to be unachievable.

NTSC compatibility is a tremendous benefit to viewers and broadcasters alike. It gives a consumer the option of keeping his current TV set—with no degradation in picture quality—or of buying a new TV set to receive the improved picture. And each broadcaster can decide when he is ready for the change.

But not all of the players in the HDTV game are concerned with compatibility. The cable-TV industry, for example, does not have the same spectrum-conservation concerns as TV broadcasters. It's possible that they wouldn't mind having an exclusive HDTV system to call their own. In fact, the cable industry is studying a plan to use fiberoptics to distribute programing —perhaps high-definition cable programming. That, in the words of a cable-industry executive, would give cable "enormous advantages over broadcasting."

The Sarnoff research center has spent about $45 million over the last decade developing ACTV and expects that another $30 million is needed to complete development. Because everyone involved in the TV industry has so much to gain from a successful, compatible HDTV system, we would expect them to quickly adopt the new system, and to work on solving any of the problems that arise.

Despite the promise of the new system, it's important to realize that no broadcast field tests of ACTV have taken place. However, ACTV signals have been computer-simulated at Sarnoff's Digital Video Facility and stored on videotape. The system was demonstrated publically for the first time at the HDTV Colloquium in Ottawa in early October, and we hope to have a first-hand report and more technical details of the new system in the near future. If the system lives up to its promise, perhaps compatible 3-D TV isn't too far behind! **R-E**

USING THE RE-BBS

To access the RE-BBS, you need a personal computer and a modem capable of communicating at 300 or 1200 baud. Set the modem for 8 data bits, 1 stop bit, and no parity. (Other formats will work, but you may be unable to upload and download files.) You'll also need a communications program that runs on your computer and can control your modem. If you have an IBM-PC and a modem, but no communications program, get a friend to download the QMODEM.ARC file for you. It contains a user-supported communications program and documentation.

The BBS runs 24 hours a day, seven days a week. To sign on the first time, dial 516-293-2283. If your system is working properly, you'll be presented with an identifying message. Type in the requested information. At that point you'll be able to access some, but not all of the BBS. After the Sysop verifies your account, you'll be able to access all relevant areas of the BBS.

You can do several things on the RE-BBS: send and receive messages, and upload and download files. Sending messages is simple, and only requires you to type at your keyboard. Receiving messages is also simple, but to save messages, your communications program must allow you to set up a capture buffer.

Uploading and downloading files is easy after you get the hang of it; just follow directions, and remember always to start the transmitter before starting the receiver—whichever end is transmitting or receiving.

Because of our background and interests, the RE-BBS will be oriented toward IBM-PC's and compatibles. But you can access the RE-BBS with any computer (or ASCII terminal) and modem, so if your interest lies in Apples, Ataris, Commodores, Sinclairs, etc., feel free to participate. If you have public-domain software of interest to other owners of your type of machine, feel free to upload it. The contents of the BBS will in large part be determined by what you post there, so if your machine is being neglected, do something about it!

On the RE-BBS, any file whose name ends in the three letters ARC is an archive file. An archive file is a group of related files that are collected together and compressed in order to save space and download time. Archive files are useful only to owners of IBM-PC's or compatibles. You use a program called ARC.EXE to add to, delete or extract from, list the contents of, etc., an archive.

Similar to archive files are library files, which have the file type .LBR (e. g., HIDDEN.LBR). Like archive files, libraries are also composed of compressed, inter-related programs and data files, but they are incompatible with .ARC files. So an additional utility is necessary to process library files; one such utility is LSWEEP, for Library SWEEP. Library files are used on both CP/M and IBM BBS's, and versions of LSWEEP are available for both types of system. And, although you can unpack a CP/M library file on an IBM-PC, you can't run the .COM files! Nor can you run .COM files from a CP/M library on an IBM!

A method of compressing files is popular on CP/M and some IBM BBS's. On IBM BBS's the file-compression program is usually called SQ.COM (for squeezing) or something similar, and the de-compression program is usually USQ.EXE (for unsqueezing). *SQ and USQ work only on individual files;* a squeezed file always has a *Q* in the second position of the file type (e. g. RIDDLES.TQT). USQ automatically restores the proper file name.

For maximum flexibility, you'll need copies of ARC.EXE, SQ.COM, USQ.EXE, and LSWEEP.EXE. A version of each has been posted on the RE-BBS. If you can't find programs with those exact names, check the directory listing carefully; many of those programs also contain version numbers in their names (e. g., LSWP103.EXE). **RE-BBS**

ANTIQUE RADIO CLUBS

THE FOLLOWING IS A LIST OF RADIO CLUBS, COURTESY OF *ANTIQUE RADIO CLASSIFIED* (9511 Sunrise Blvd., J-23, Cleveland, OH 44133), for those interested in the history of radio, or in the collecting of antique radio or radio-related equipment. Most of the clubs publish their own bulletins or newsletters, and many sponsor conventions and flea markets in their areas throughout the year. Those clubs are a good way to meet fellow collectors who share your antique-radio interests.

Most clubs invite out-of-state membership. Most clubs have some dues or membership requirments; contact the individual clubs for more information on that. Also, while the information presented here is as accurate as possible, several of the clubs have not provided their current status. When writing to any of the clubs, please mention that you saw its name in **Radio-Electronics**.

Antique Wireless Association, Inc.—C/O Bruce Roloson, Box 212, Penn Yan, NY 14527. Publishes *The Old Timer's Bulletin* on a quarterly basis. Sponsors regional conventions as well as an annual conference in September at Canandaigua, New York.

Antique Radio Club of America, Inc.—C/O William Denk, 81 Steeplechase Rd., Devon, PA 19333. Publishes *The Antique Radio Gazette* on a quarterly basis. Sponsors several regional chapters of A.R.C.A. as well as an annual convention, usually in June, in a different part of the country each year.

Antique Radio Club of Illinois—C/O Randy Renne, 1020 Idlewild Dr., Dixon, IL 61021. Publishes *ARCI News* on a quarterly basis. Sponsors meets throughout the year in addition to the large "Radio-Fest" meet in August of each year.

Antique Radio Club of Schenectady—C/O Jack Nelson, 915 Sherman St., Schenectady, NY 12303.

Arizona Antique Radio Club—C/O Lee Sharpe, 2224 West Desert Cove Rd., No. 205, Phoenix, AZ 85029. Publishes *Radio News* on a quarterly basis.

Arkansas Radio Club—P.O. Box 4403, Little Rock, AR 72214.

British Vintage Wireless Society—C/O Robert Hawes, 63 Manor Rd., Tottenham N17, London OJH, England. Publishes *Vintage Wireless* on a monthly basis.

Buckeye Antique Radio and Phonograph Club—C/O Steve Dando, 627 Deering Dr., Akron, OH 44313. Publishes its *Soundings* newsletter on a quarterly basis. Sponsors several informal meets at collector's homes throughout the year, plus exhibits at area shopping malls.

California Historical Radio Society—CHRS, P.O. Box 1147, Mountain View, CA 94041. Publishes the *CHRS Official Journal* and the *CHRS Newsletter*; both appear four times a year. Sponsors conventions and flea markets.

Houston Vintage Radio Association—C/O Ron Taylor, 12407 Mullins, Houston, TX 77035. Publishes the *Houston Vintage Radio News* and also the *Grid Leak* on a frequent basis. Yearly activities include a Spring show and public auction, swapfests, a picnic, and a banquet.

Indiana Historical Radio Society—C/O E.E. Taylor, 245 N. Oakland Ave., Indianapolis, IN 46201. Publishes the *IHRS Bulletin* on a quarterly basis. Sponsors at least four swap meets per year in various areas of Indiana, including the well-attended Auburn, Indiana meet, held in the Fall.

Long Island Antique Radio Society—160 S. Country Rd., East Patchogue, NY 11772

Michigan Antique Radio Club—C/O Jim Clark, 1006 Pendleton Dr., Lansing, MI 48917. Sponsors two swap meets in the Lansing, Michigan area.

Mid-America Radio Club—C/O Robert Lane, 1444 E. 8th, Kansas City, MO 64106.

Mid-Atlantic Antique Radio Club—C/O Joe Koester, 249 Spring Gap South, Laurel, MD 20707. Publishes a newsletter for members. Sponsors monthly meets.

Niagara Frontier Wireless Association—C/O Larry Babcock, 8095 Centre Lane, E. Amherst, NY 14051. Publishes the *NFWA Chronicle* on a quarterly basis. Conducts swap meets and meetings four times a year in the Buffalo, New York area.

Northwest Vintage Radio Society—Box 02379, Portland, OR 97202

Puget Sound Antique Radio Association—C/O N.S. Braithwaite, 4415 Greenwood Ave. N., Seattle, WA 98103. Publishes the *Horn of Plenty* monthly. Holds swap meets and meetings in the Seattle, Washington area.

Rocky Mountain Wireless Association—16500 W. 12th Dr., Golden, CO 80401.

Sacramento Historical Radio Society—5724 Gibbons Dr., Sacramento, CA 95608.

Southern California Antique Radio Society—C/O Floyd Paul, 1545 Raymond Ave., Glendale, CA 91201. Publishes the *California Antique Radio Gazette* on a quarterly basis. Holds four swap meets and meetings at various locations in Southern California.

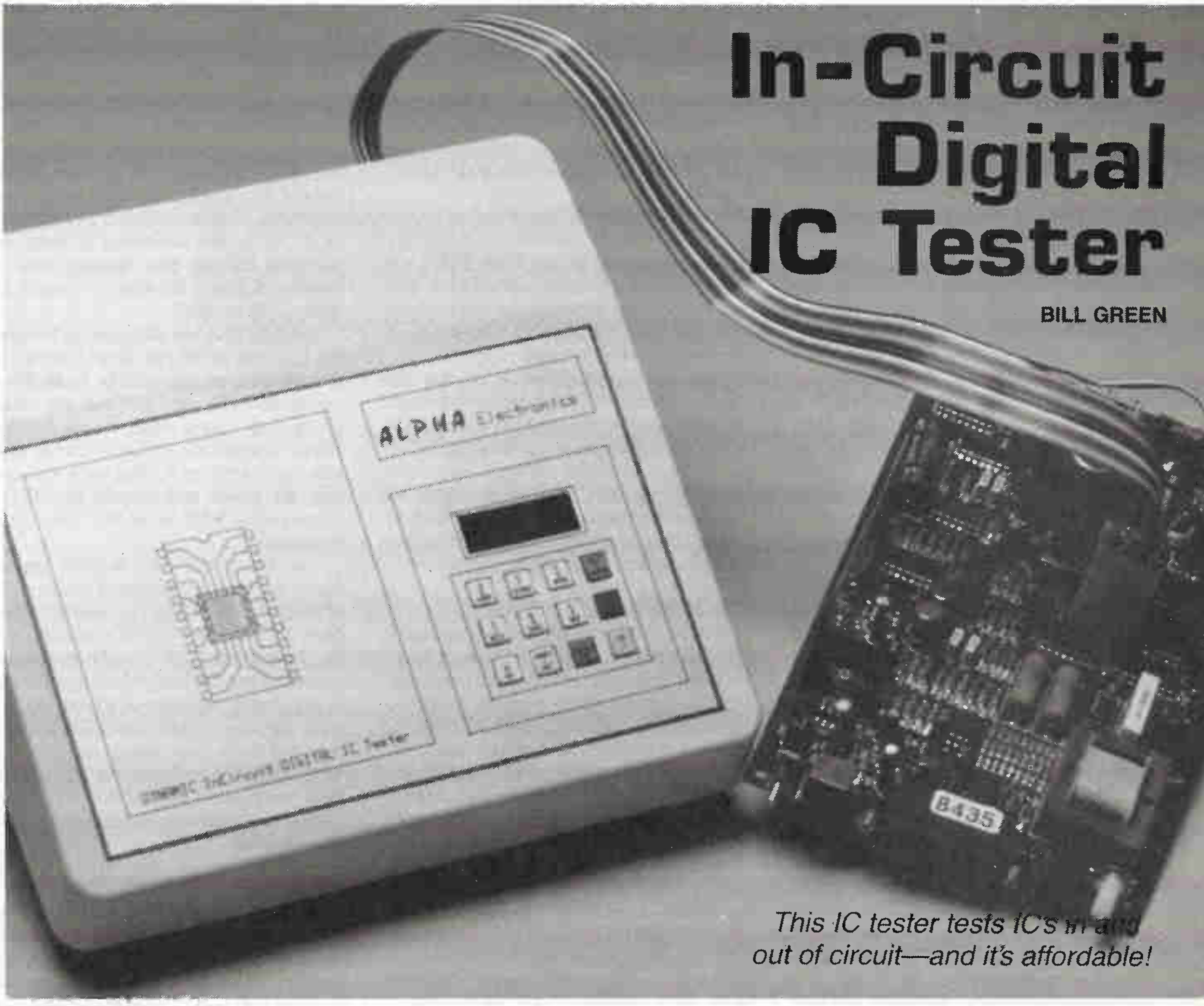
Society of Wireless Pioneers—P.O. Box 530, Santa Rosa, CA 95402. Publishes the *Sparks Journal* on a quarterly basis.

Vintage Radio and Phonograph Society—P.O. Box 165345, Irving, TX 75016. Publishes *The Reproducer* approximately six times a year. Sponsors radio meets in Dallas, Texas area.

Whippany Vintage Radio Club—217 Ridge Wale Ave., Florham Park, NJ 07932. **R-E**

In-Circuit Digital IC Tester

BILL GREEN



This IC tester tests IC's in and out of circuit—and it's affordable!

SERVICING DIGITAL ELECTRONIC EQUIPment is seldom easy; difficulties arise from several sources. For example, microprocessors, RAM, and ROM IC's are usually socketed, but digital "glue" IC's (gates, flip-flops, etc.) are seldom socketed, because the sockets may cost as much as the IC's themselves.

Not using sockets reduces manufacturing costs, but causes nightmares for the serviceperson. Often, an inexpensive assembly can be discarded and replaced for less than it would cost to repair it. But when a board must be fixed, the headaches begin. For example, how do you locate a bad IC when most or all are soldered to the board?

One way is to remove IC's one by one, replacing each until the board starts functioning again. However, if two or more IC's are bad, the difficulty of locating them increases tremendously. Defect isolation using logic probes, logic analyzers, oscilloscopes, and other equipment can be performed, but doing so requires a high degree of technical knowledge, which may not always be available. Clearly, a better method is needed.

The in- and out-of-circuit IC tester presented here is such a method. It is a moderately priced device that can test most parts in most TTL families, as well as TTL-compatible MOS and CMOS devices. You use the device by selecting a test routine, clipping a test probe to the *D*evice *U*nder *T*est (DUT), and examining an LED display.

Other IC testers in its price range ($300 for a complete kit, other configurations available) require a known-good IC of the type to be tested for comparison; ours doesn't. In addition, our tester has enough memory to store 105 different IC test routines, and it has a serial interface to upload and download test routines. Those capabilities allow a field-service technician to load different test set-ups depending on the device he or she will be servicing.

Test routines may be entered by hand on the tester's keyboard or downloaded from any computer with an RS-232 serial port. In addition, routines entered via the tester's keypad may be uploaded and saved for future use. Simple BASIC programs allow you to upload and download test routines. Those programs will appear here, and will be available on the RE-BBS; the routines run (or can be adapted to run) on many computers, including IBM's and clones, Radio Shack *Models III* and *IV*, the *Color Computer*, Commodore and Apple computers, etc.

Basic features

The tester has a 12-key keyboard to allow manual entry and editing of test data and commands, and transfer of test data to and from a personal computer. A four-digit sixteen-segment alphanumeric display prompts the user to enter data and displays pin-by-pin test results (both expected and actual data).

External back-up batteries are unnecessary because data and programs are stored in a special non-volatile 32K-byte CMOS RAM IC.

IC's are tested dynamically: inputs are cycled high and low as many as forty times, according to the test routine. That capability allows thorough testing of difficult-to-test parts, including counters, flip-flops, and registers.

Using the tester

Testing an IC out-of-circuit is straightforward: Simply attach the test clip and run the appropriate test routine, which is selectable by part number. The tester then writes data to the device and reads back the results for comparison. (We'll show you how to generate the test data later.) An out-of-circuit IC is not connected to any other devices, so we needn't worry about input pins of the DUT that might be connected to outputs of the same or another device, or to ground or V_{CC}.

To test IC's in-circuit, the tester allows for inputs that may be connected to outputs, ground, or V_{CC} as follows: The tester's output drivers can be floated (i. e., placed in a high-impedance state); in addition, they have enough current drive (both sourcing and sinking) to pull an input high or low (briefly), even if it is connected to an output. Further, you can specify that the test routine ignore any desired pin or pins.

How it works

All circuitry is contained on two PC boards, which are interconnected by a short length of ribbon cable. One board contains the interface circuitry through which the DUT and the on-board microprocessor communicate. The other contains the microprocessor, the RAM, and the support circuitry, including a 5-volt regulated power supply, an RC reset network, and a 2-MHz crystal-controlled clock. Crystal control is required for precise timing of the serial communications channel. A Z80 microprocessor directs all tester operations.

A major design goal of the tester was the ability to store many test routines, so a large amount of nonvolatile storage is provided by a DS1230 32K byte non-volatile static RAM. The lower 4K of the RAM contains the control program.

The tester's schematic is shown in Fig. 1. It uses several custom CMOS gate arrays for various purposes. Part of IC5 (a 75498) provides the write-enable function. It decodes address lines A12–A14 and disables the processor's write enable signal whenever all three address lines are low, thus preventing corruption of the control program. The remainder of IC5 decodes the input and output strobes for the driver board and the display.

Another custom IC (IC6, a 75500) is the input/output port for the keyboard and the display. That IC latches the appropriate keyboard row signals and reads the column signals of the keyboard, and it latches the digit address lines for the display.

The third custom IC (IC4, a 75499), is used in the RS-232 I/O channel. The IC decodes the port strobes and latches the serial input and output data and "busy" signals.

The RS-232 driver/receiver is a MAX-233, which provides the necessary level conversions to and from TTL (+5 volts) and RS-232 (±10 volts) levels. The MAX 233 has an internal charge pump that generates the RS-232 voltages from the single-ended five-volt supply.

The keyboard and display provide the human interface. Twelve tactile-feedback keyswitches are arranged in two columns of six rows; they are scanned by the 75500 (IC6). In order to provide legible operator prompts, we use a DL1414 intelligent alphanumeric display. It contains built-in storage, decoders, and drivers for its four red 16-segment LED digits.

The driver board

The IC tester provides for a maximum of 24 test pins. Each test pin may serve as an input or output; as an output, each pin may be forced either high or low. So, functionally, speaking, each test pin is connected to three IC's in the tester: an input latch, a pull-down driver, and a pull-up driver. The outputs, of course, can be three-stated so that the input can be read.

As shown in Fig. 2, that DUT interface circuit is implemented with nine IC's (IC7–IC15) on the driver board, including three each of the NE590, the NE591, and the 74LS373. The 74LS373's are 8-bit data input latches; the NE590's and NE591's are 8-bit addressable latches with open-collector and open-emitter Darlington output transistors, respectively. The NE590's outputs pull to ground and the NE591's pull to V_{CC}. Each of the NE590/1 IC's has three address inputs and one data input. The data present at the latter is routed to the internal latch/output circuit decoded by the former when $\overline{CS}$ and $\overline{CE}$ are low.

We connect those drivers to the pins of the DUT through P3 by way of a test cable and a DIP header clip. There are 24 test connections, plus power and ground, for a total of 26 pins. You can wire up different test cables for IC's with different sizes and shapes.

An additional ground wire in the test cable is terminated with a miniature clip, which should be connected to ground on the circuit board being tested. The V_{CC} pin may be terminated in the same manner to supply power to an IC for out-of-circuit testing. The tester's power supply will not supply much current for external circuitry, so the system being tested must have its own power supply.

Buffer space

Now let's talk about how test data is stored in the tester's non-volatile RAM. First, each test routine takes 256 bytes of memory. In addition to the stored routines, a separate 256-byte buffer is used to store input data.

Next, corresponding to the 24 test pins are 24 "slots" in memory. Each slot consists of five groups; each group contains two bytes. That accounts for 240 bytes (24 × 5 × 2). An additional 16 bytes are reserved for the part number and the number of pins. That makes a total of 256 bytes (240 + 16).

The first byte in each group determines the function of the pin: input, output, indeterminate, or ignore. The second byte constitutes test data for that pin. Each group may have a different pin function (input, output, etc.). That is useful when you are testing an IC that uses the same pins for inputs and outputs at different times (a 74LS245 octal bus transciever, for example.)

One bit of test data is used per test cycle. Each cycle consists of sending a bit of data to each of eight drivers in each of three NE590's and NE591's, starting with the lowest pin. The drivers latch those signals. Then the level on each pin is read in and stored, one byte at a time, starting with the lower eight pins. The cycle is repeated seven more times, for each byte in a group; the procedure is repeated for each group, for a total of 40 (5 × 8) test cycles. We'll present several practical examples later.

Assembly

Start assembly by procuring or making the printed-circuit boards. We will present foil patterns in "PC Service next month." Etch the boards and carefully drill the 700 holes. Several hundred connections are made through the board (via plated-through holes), so you will have to make these connections with short pieces of bare wire soldered on both sides.

As shown in Fig. 3, the display may be mounted in one of two positions, depending on whether the boards are mounted in a case or are allowed to "float." If you are using a case, mount it on the foil side of the PC board in the area outlined with dashed lines in the diagram. Otherwise, mount the display on the component side of the board in the area that is outlined with solid lines.

Similarly, if you use a case, the pushbuttons must also mount on the foil side of the board. In that case, the key legends must be reversed left to right.

If you use a case, install the keyswitches first. Lay the board on a flat surface, foil side up. Orient each switch so that the flat sides on each is toward the Z80. The keyswitches are colored differently: the 0–8 switches are white; the ENTER switch, green; the SHIFT key ('),

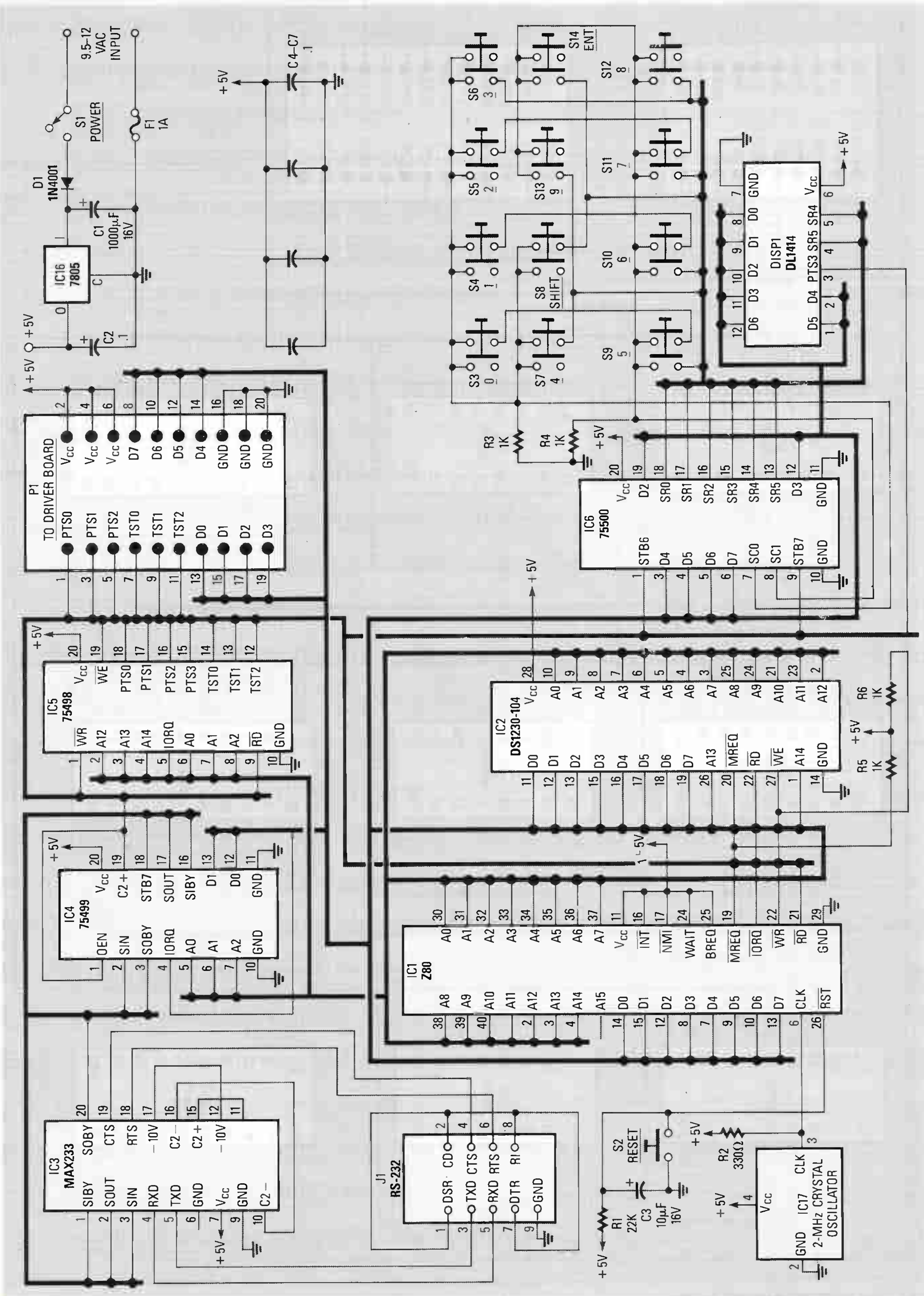


FIG. 1—THE IC TESTER'S MAIN BOARD is built around a Z80 microprocessor running at 2 MHz.

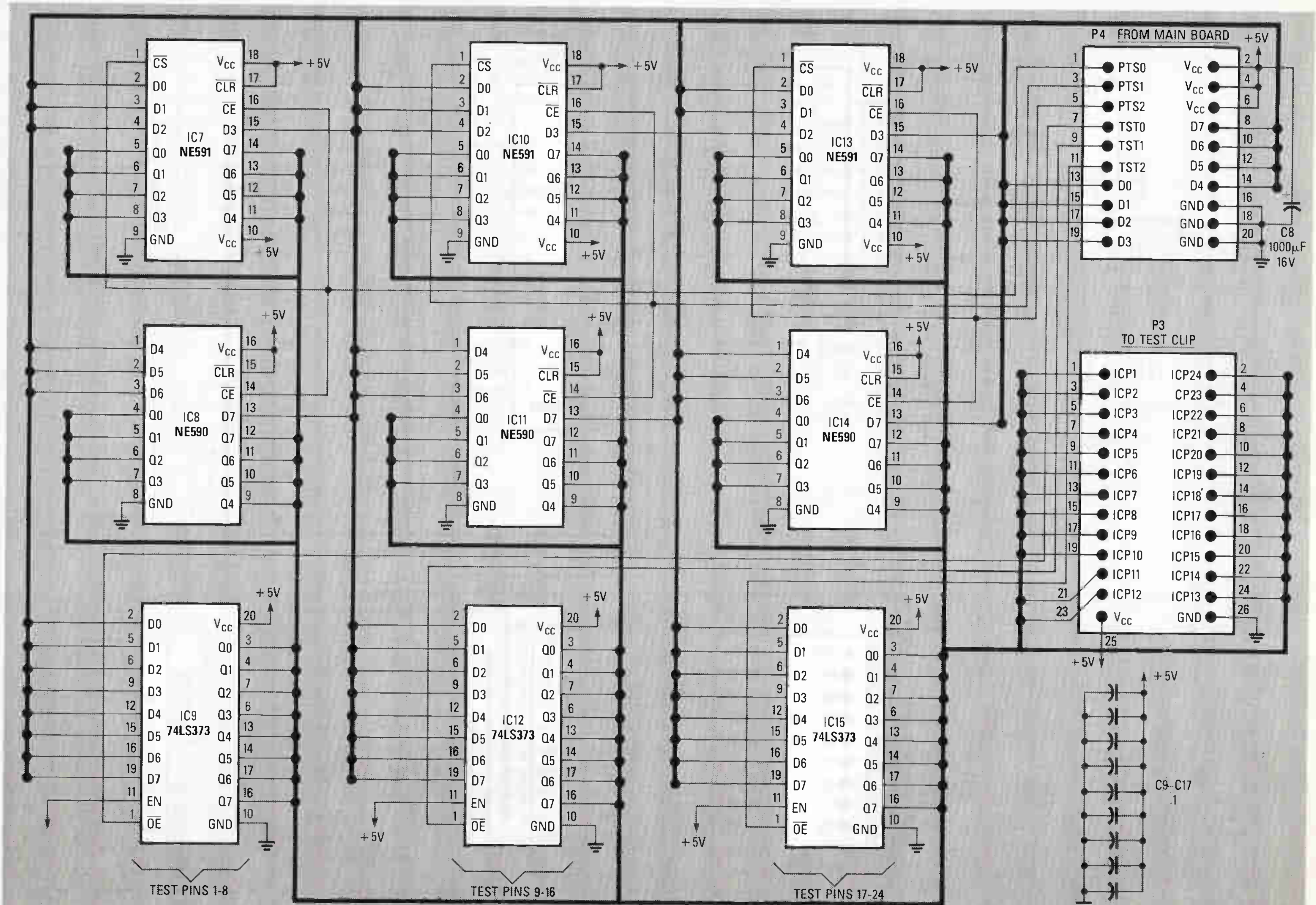


FIG. 2—THE IC TESTER'S DRIVER BOARD provides separate inputs, sourcing outputs, and sinking outputs for each of 24 test pins.

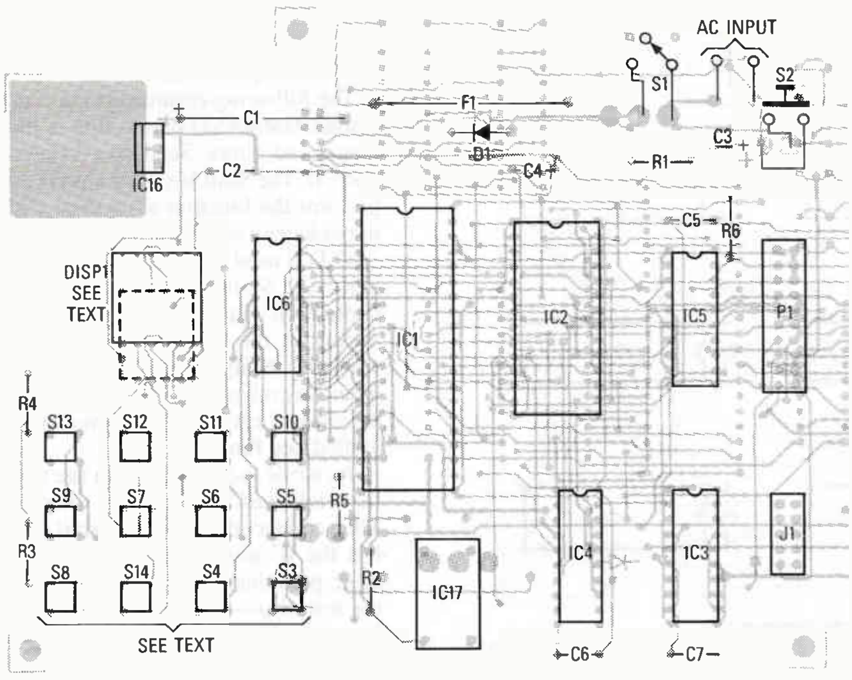


FIG. 3—STUFF THE MAIN BOARD as shown here. Mount the display and switches S3–S14 on the foil side if you will install the tester in a case. Note that the display is oriented differently depending on whether or not the tester is installed in a case.

yellow; the 5 key, red, and the 9 key, blue. Select the proper color and install and solder one pin of each switch from the solder side of the board. Then turn the board over and solder the remaining three pins of each switch from the component side. Mounting the keyswitches that way lifts them off the board enough to protrude through the panel of the case. Now install the 12-pin display socket made from a 24-pin IC socket that has been cut in half.

When not using a case, the keyswitches are installed on the component side of the board and are not spaced away from the board. To mount the power and reset switches on the board, you'll have to enlarge the holes indicated in the parts-placement diagram.

The remainder of the instructions apply to both case and case-less installation. Install the IC the sockets on the component side of both boards next, followed by the remaining components, starting with the low-profile devices.

Be sure to orient the electrolytic capacitors, the diode, the clock module and the voltage regulator (IC16) correctly. It is installed so that its metal tab will contact the foil area of the PC board. To provide extra heatsink capacity, you want to slip a clip-on heatsink on the regulator.

Next mount the male header strips on both boards. (See Fig. 4.) Connect the power and reset switches to the board with 10-inch insulated wires (or directly to the board if you're not using a case). Connect the leads of a 9–12-volt AC, 1-amp wall-mount power transformer to the board. **Do not install any IC's yet.** Connect the driver board to the main board with an 8-inch, twenty-conductor ribbon cable terminated on each end with a twenty-pin female header.

CAUTION! At this point it is possible to erase the control program in the CMOS RAM. For example, if there is a solder short on the board in the right place, the write-protect function of the 75498 will be defeated. Or the write enable pin on the RAM may be shorted to ground, allowing just about anything to be written to the IC. To prevent that from happening, use an ohmmeter or continuity tester to ensure that there are no connections between the following pins and ground, V_{CC}, or any nearby traces on the board: IC5, pins 1, 2, 3, 4, and 19; IC2, pins 20, 27, and all of the address lines, and IC1 pins 20, 21, and 22. Fix any shorts before proceeding.

Measure the output of the regulator; it should be +5 volts, ±0.25 volt. Assuming it's correct, insert the clock module, and check pin 3 for a 2-Mhz squarewave. Now remove power from the board and allow a minute for the filter capacitors to discharge. Being careful to observe proper procedures to avoid static damage to the MOS (Z80) and CMOS (RAM, MAX233, 75498, 75499 and 75500) IC's, install all IC's in their sockets properly oriented. A square foil pad on the board indicates pin 1 of all IC's. Pin one of the display is marked with a small triangle.

When you're certain that all parts are installed correctly, in the correct place, with no pins bent under any of the IC's, and so on, apply power again. The word *COMMAND?* should scroll across the display repeatedly. If it does, you are ready for final assembly. Turn power off and unplug the transformer.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—22,000 ohms
R2—330 ohms
R3–R6—1000 ohms

Capacitors

C1, C8—1000 µF, 16 volts, electrolytic
C2, C4–C7, C9–C17—0.1 µF, 10 volts, ceramic disc
C3—10 µF, 16 volts, electrolytic

Semiconductors

IC1—Z80 microprocessor
IC2—DS1230-104 32K nonvolatile RAM
IC3—MAX233 RS-232 interface
IC4—75499 custom decoder
IC5—75498 custom decoder
IC6—75500 custom decoder
IC7, IC10, IC13—NE591 open-emitter octal driver
IC8, IC11, IC14—NE590 open-collector octal driver
IC9, IC12, IC15—74LS373 octal latch
IC16—7805 5-volt regulator
IC17—2-Mhz crystal oscillator
D1—1N4001 rectifier
DISP1—DL1414 16-segment decoder/driver/display

Other components

F1—1-amp pigtail fuse
J1—9-pin D connector
P1, P2—right-angle double-row 20-pin male header strips
P3—right-angle double-row 26-pin male header strips
S1—minature SPDT toggle switch
S2—momentary SPST pushbutton
S3–S14—momentary SPST keyboard switches
T1—Transformer, 9.5–12-volts, 1-amp, wall-mount

Miscellaneous: One 10-pin, two 20-pin and one 26-pin double-row female IDC header connectors. Two 12-pin single-row female IDC header connectors. Flat ribbon cable. 16-pin, 20-pin and 24-pin DIP test clips, others as desired.

Note: The following are available from: ALPHA Electronics Corporation, P.O. Box 541005, Merritt Island, Florida 32954-10005, (407) 453-3534: Kit of parts for $299.000 + $6.00 P&H. Includes all parts, punched and screened panel, case, and labeled keys. Test cable and clips not included. Partial kit, including all IC's except IC16 and IC17, display, and PC boards for $199.00 + $5.00 P&H. Three custom IC's (75498, 75499 and 75500) for $60.00 + $4.00 P&H. Flordia customers please add 5% State sales tax. Canadian customers please add $3.00 additional postage to all orders. All foreign orders add appropriate postage for Air shippng and insurance.

Final assembly

Using the keyboard layout (shown in Fig. 5) as a guide, label the keyswitches. If you plan to use the board without a case, the arrangement of the keys must be reversed from left to right. If you are installing the tester in a case, you will need

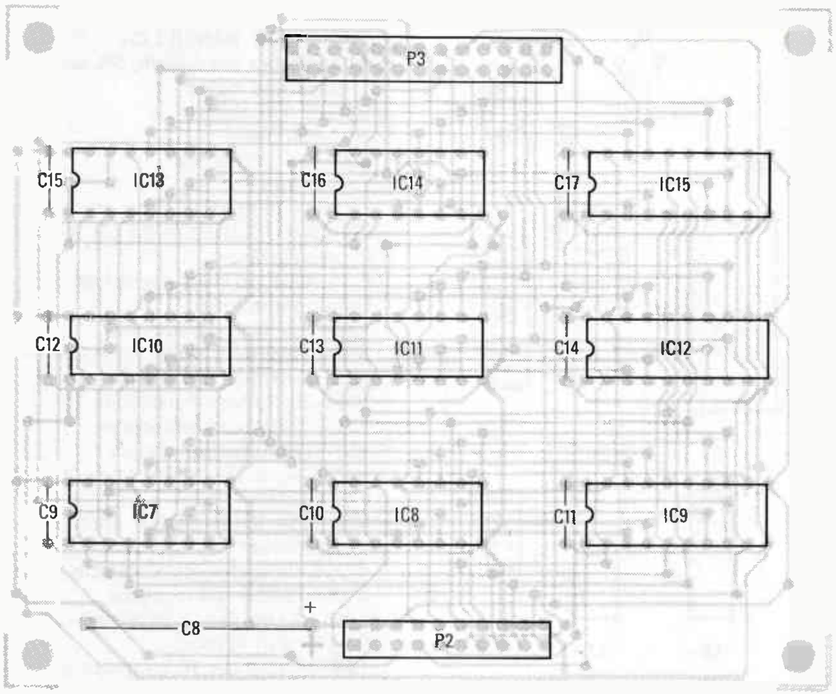


FIG. 4—STUFF THE DRIVER BOARD as shown here. Mount all parts on the component side of the board.

to prepare a front panel for the display and switches; Fig. 6 shows a suitable layout. To protect the display and enhance contrast, install a thin (0.040") plastic bezel inside the panel opening. Then mount the two PC boards to the case.

Using a maximum of three feet of 26-conductor flat ribbon cable, make a test cable. Terminate one end with a 26 pin female header connector. On the other end of the cable separate the 25th and 26th wires. Terminate the 25th wire (+ 5 volts) with a red test clip, and the 26th wire (ground) with a black test clip. Terminate the remaining 24 wires with two 12-pin single-row female header connectors.

Depending on your needs, you'll want to obtain several IC test clips with different numbers of pins; 16-, 20-, and 24-pin clips will allow you test 14- and 16-, 18- and 20-, and 24-pin IC's easily. When attaching the test clip to the cable, orient the clip so that the connnector on the end of the cable connects to the side of the test clip with pin 1 on it. When using a clip with less than twenty-four pins, align the connectors so that the pins on the right end of the clip—the end furthest from pin 1—are even with the right end of the connectors."

If you are going to use the serial port to send and receive files, connect a 10-pin female header connector to one end of a 10-conductor ribbon cable, and a DB9 chassis-mount connector to the other. Mount the DB9 connector on the rear of the case. Also mount the power and reset switches on the back of the case. Wire an interface cable to connect the IC tester's port to that of your computer. RS-232 ports come in many configurations, so you will have to determine which pins are

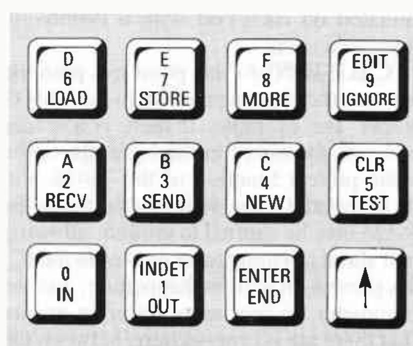


FIG. 5—LABEL THE KEYS as shown here for installation in a case. Otherwise, reverse labels from left to right.

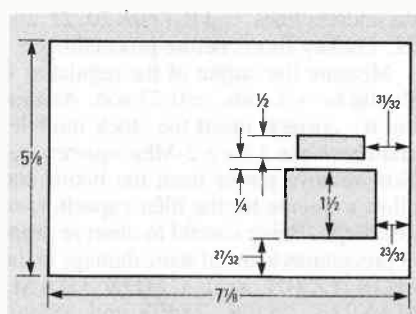


FIG. 6—BASIC DIMENSIONS for the front panel.

needed for your computer. The tester sends and receives serial data at 1200 baud, no parity, 8 data bits, and 2 stop bits. Pin 4 (CTS) is the transmit busy signal, and pin 6 (RTS) is the receive busy signal. The tester requires no other signals to work, but your computer's serial port might. On PC-compatibles, try connecting DSR, CD, DTR and RI together.

Finally, put the case together, plug in the test clip cable and the power transformer, and turn the power switch on.

Basic test procedure

The following commands are available when *COMMAND* is scrolling in the display: Load, Store, Send, Recv, New, Test, and Clr. The Shift key (') is always used to perform the function associated with the upper legend on each key. For example, '6 is a "D," used to enter hexadecimal numbers. The Shift key is a toggle. The first depression causes the shift symbol (') to appear in the display; it will disappear when the Shift key is pressed again, or when any other key is pressed. Shift must be pressed each time you want to use a shifted key function.

As a rule, you should turn the tester on first, followed by the circuit to be tested. Then connect the tester's ground clip, and last the IC test clip. If the test clip has more pins than the IC, "bottom justify" the test clip—when testing a 14-pin IC, for example, connect pin 8 of the clip to pin 7 of the DUT.

Here's how to enter a new test routine. With *COMMAND?* scrolling, press New. The input buffer is cleared of any previous test data. (That also occurs at power up and when the reset button is pressed.) *ENTER PART NO.?* will scroll now. You may enter between one and eight numbers or letters, followed by Enter. *ENTER NO. OF PINS?* appears now. You may enter any even number between 4 and 24 inclusive. Press Enter. *TYPE? PN01* appears. Enter the function of pin 1 by pressing In, Out, Indet, or Ignore, and then the test byte in two hex digits. (We'll show you how to create the test byte later.) For example, I55, OAA, X (no data necessary), or D98.

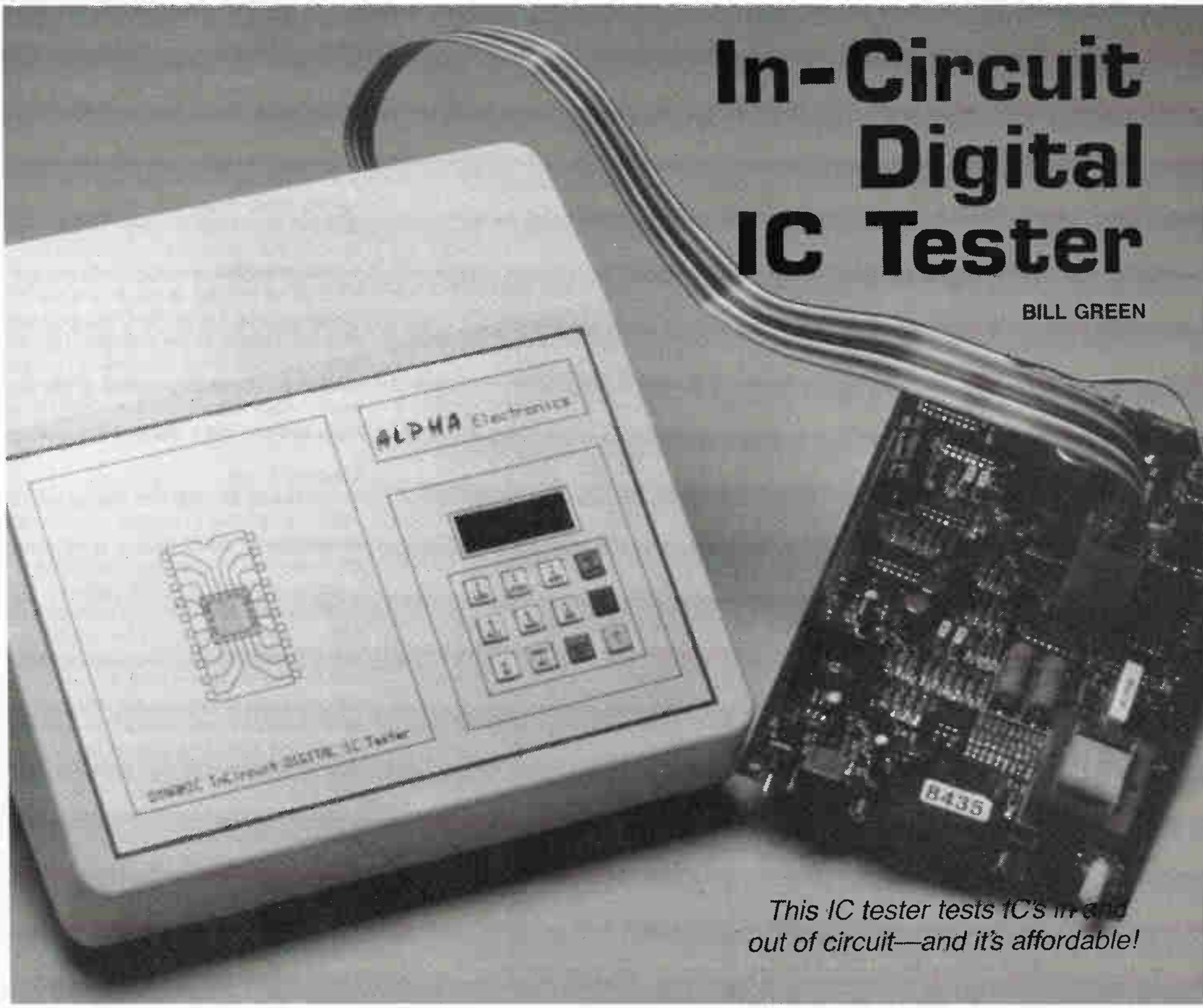
After entering data for all pins (or all pins you want to enter data for) press End. The display will ask *MORE OR END?*. Unless you wish to enter data for another test group (remember, there are five possible), press End again to indicate you are finished entering data.

The Edit key allows you to back up one pin if you make an error after entering the three (or one if a pin is set for IGNORE) of the test data characters. Each time you press Edit, you back up one pin. The Clear key works any time the tester is expecting a keyboard entry, and pressing that key is functionally the same as pressing the reset button.

Press the Test key after all data has been entered. The IC will then be tested. If it is good, the display will read *IC TESTS GOOD*. Otherwise, *ERROR PN?? GRP? EXP/RD ????* will scroll across the display for each pin in error, showing the pin number, the group, and the expected and read data. Each question mark in the preceding message will be replaced by a numeral. For example, *ERROR PN01 GRP 01 EXP/RD 0100* would indicate a problem with pin 1 in test group 1; a "0" was read where a "1" was expected. **R-E**

In-Circuit Digital IC Tester

BILL GREEN



This IC tester tests IC's in and out of circuit—and it's affordable!

Part 2 LAST MONTH WE BUILT the tester and discussed basic test methodology. Now we'll go on and provide specific examples showing how to set up your own test routines on paper and by computer, and how to send those files to and from your desktop computer.

7404 test data

Here is how to generate test data. This procedure applies whether data is entered via external computer using the data-entry routine discussed later, or is entered via the tester's keyboard.

Our first example illustrates the process for a 7404 hex inverter. First, obtain the pin numbers for inputs, outputs, V_{CC}, and ground, and the functional description (or truth table) from the device's data sheet.

To ease the process of generating the test data, make a copy of the template shown in Fig. 7; then fill in the blanks for the part number, number of pins, and group number. You must make a template for each test group if you need more than one. You may also sketch the part's logic diagram in the box on the template.

Next fill in the data blanks, leaving room to write eight binary digits at each pin that must be tested. If we put a 1 into an inverter, we should get a 0 out of it. So put a 1 in the blank for pin 1, and a 0 by pin 2. Repeat the procedure with the remaining five inverters. Then put an X at pins 7 and 14 to indicate that they will be ignored. Now we have all data for the first test cycle.

There is a total of eight test cycles, so now place a 0 at each input and a 1 at each output. (The X's should remain by pins 7 and 14.) That accounts for two of the eight bits in this test group's byte, so duplicate the bit pairs four times. Then convert the eight-bit data, four bits at a time, to two hexadecimal digits using the binary/hexadecimal chart at the bottom of the template. The completed test form is shown in Fig. 8.

The test information, along with the part number and the number of pins, is then stored in the tester's memory using the procedure outlined last time. There is no need for more than one test group to test a 7404 completely.

In-circuit example

The data for an in-circuit IC depends on how the IC is connected. For example, input pins may be tied to V_{CC} or to ground, so we tell the tester to ignore those pins. Or, if the IC's input is connected to one of its outputs, ignore the input, because its data will be supplied by the output it's connected to. A sample chart is shown in Fig. 9.

TEST ROUTINE TEMPLATE

PART NUMBER (8 Alphanumeric Digits Maximum: ____________________
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): ____________
GROUP NUMBER (1 to 5): ________
REMARKS: ____

Binary Data		Hex	Funct	Pin#		Pin#	Binary Data		Hex	Funct
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___
______	=	___	___	___		___	______	=	___	___

BINARY TO HEXADECIMAL CONVERSION TABLE

BINARY	HEX	BINARY	HEX
0000	0	1000	8
0001	1	1001	9
0010	2	1010	A
0011	3	1011	B
0100	4	1100	C
0101	5	1101	D
0110	6	1110	E
0111	7	1111	F

FIG. 7—COPY THIS TEMPLATE to simplify generating your own test routines.

Multiple test groups

IC's with pins that can function as both inputs and outputs can be tested as follows. We'll use a 74LS245 octal bus transceiver for illustration. That IC is commonly used to buffer data into and out of a microprocessor; direction of data flow is controlled by a single DIR input (pin 1).

The data for testing the IC in send mode is shown in Fig 10; the data for testing it in receive mode is shown in Fig. 11. Notice that the data in both cases is identical except for the setting of the direction line.

The enable line of a registered (latched) IC must be toggled to ensure that the IC responds when it is enabled, and does not respond when it is not enabled. Fig. 12 shows the test pattern for a 74LS373 octal data latch. The outputs should follow the inputs when the enable line (pin 11) is high, and shouldn't change otherwise.

Clocked logic

A clocked IC that has no means of setting or clearing its outputs will have an indeterminate state before it is clocked. Therefore, all outputs must be listed as indeterminate (D). The first state of a pin defined as indeterminate will be cleared to zero. (Only outputs can be indeterminate.) The remaining 7 states of the group will be processed normally. If more than one test group is needed, the first state of each additional group will not be indeterminate and should be defined as Output. Note in the test data that the clock line goes high in the odd-number cycles (1, 3, 5, and 7). The outputs will only change on those cycles, because the 74LS374 changes state during the leading clock edge. Test data is shown in Fig. 13.

Multiple-output-state devices

An IC with many inputs or outputs may require more than one test group. (Remember that there is a maximum of five test groups per part number). For exam-

PART NUMBER (8 Alphanumeric Digits Maximum: 7404
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 14
GROUP NUMBER (1 to 5): 1
REMARKS: HEX INVERTER

Binary Data	Hex	Funct	Pin#		Pin#	Binary Data	Hex	Funct
0101 0101	55	I	1		14			X
1010 1010	AA	O	2		13	0101 0101	55	I
0101 0101	55	I	3		[illegible]	1010 1010	AA	O
1010 0101	AA	O	4		[illegible]	0101 0101	55	I
0101 0101	55	I	5		10	1010 1010	AA	O
1010 1010	AA	O	6		9	0101 0101	55	I
		X	7		8	1010 1010	AA	O

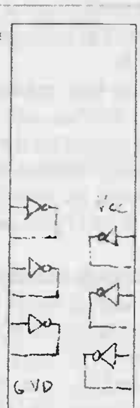


FIG. 8—TEST DATA FOR A 7404 hex inverter. All states are redundantly checked four times.

PART NUMBER (8 Alphanumeric Digits Maximum: 7404
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 14
GROUP NUMBER (1 to 5): 1
REMARKS: IN-CIRCUIT

Binary Data	Hex	Funct	Pin#	Pin#	Binary Data	Hex	Funct
0101 0101	55	I	1	14			X
1010 1010	AA	O	2	13			X
		X	3	12	0000 0000	00	O
0101 0101	55	O	4	11	0101 0101	55	I
		X	5	10	1010 1010	AA	O
1010 1010	AA	O	6	9	0101 0101	55	I
		X	7	8	1010 1010	AA	O

FIG. 9—TEST DATA FOR AN IN-CIRCUIT 7404. Input pins 3, 5, and 13 are marked X, for "ignore." Those pins might be hard-wired to ground, V_{CC}, or elsewhere in an actual circuit.

LISTING 1

```
000 'PROGRAM (RECVTEST.BAS)
001 'TO RECEIVE TEST FILES FROM A COMPUTER
002 'ALPHA Electronics Corporation,
003 'PO Box 541005, Merritt Island, FL 32954
100 INPUT"ENTER NAME OF TEST FILE TO RECEIVE ";TF$
200 PRINT"RECEIVING ";TF$;" FROM COM1"
300 OPEN TF$+".FIL" AS 1 LEN=1
400 FIELD 1, 1 AS B$
500 OPEN "COM1:1200,N,8,1,CS3000,BIN" AS 2 LEN=1
600 FIELD 2, 1 AS C$
700 FOR X=1 TO 512
800 GET 2,1
900 LSET B$=C$
1000 PUT 1,X
1100 NEXT X
1200 CLOSE
```

These three listings are available on the Radio-Electronics Bulletin Board System (RE-BBS). Call: 516-293-2283 at 1200 or 300 baud.

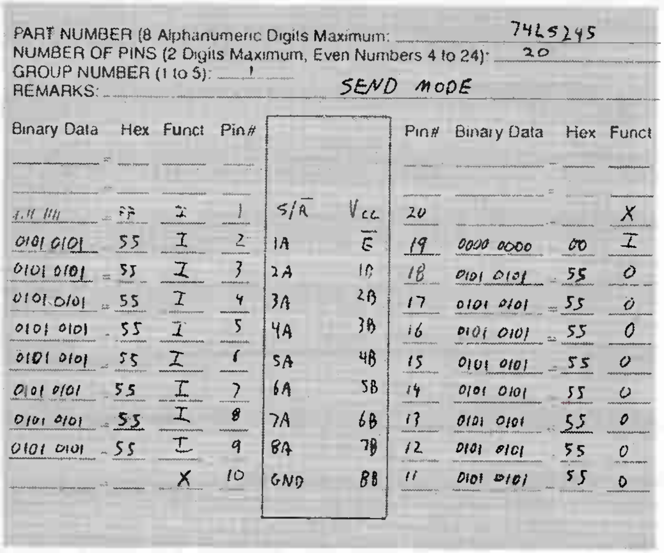
LISTING 2

```
000 'PROGRAM (SENDTEST.BAS)
001 'TO SEND TEST FILES TO A COMPUTER
002 'ALPHA Electronics Corporation,
003 'PO Box 541005, Merritt Island, FL 32954
100 INPUT"ENTER NAME OF TEST FILE TO SEND ";TF$
200 PRINT"SENDING ";TF$;" TO COM1"
300 OPEN TF$+".FIL" AS 1 LEN=1
400 FIELD 1, 1 AS B$
500 OPEN "COM1:1200,N,8,2,CS3000,BIN" AS 2 LEN=1
600 FIELD 2, 1 AS C$
700 FOR X=1 TO 512
800 GET 1,X
900 LSET C$=B$
1000 PUT 2,1
1100 NEXT X
1200 CLOSE
```

For more detailed information about how to use the Radio-Electronics Bulletin Board System, see page 72.

LISTING 3

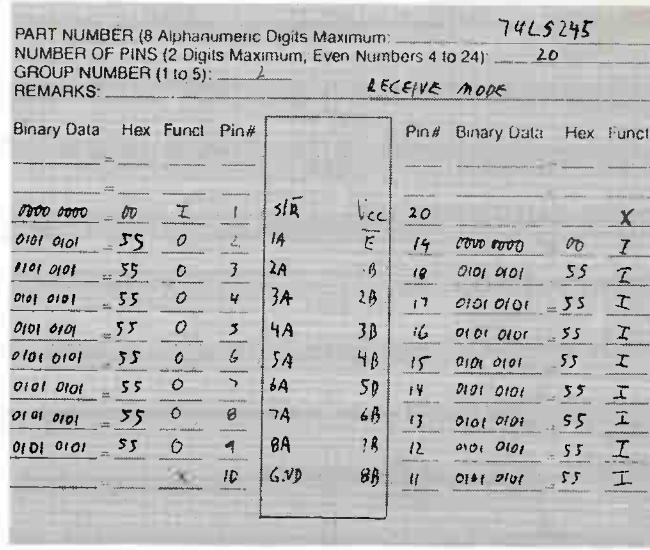
```
000 'PROGRAM (ENTERTST.BAS)
001 'TO GENERATE TEST FILES ON A COMPUTER
002 'FOR TRANSFER TO THE IC TESTER
003 'ALPHA Electronics Corporation,
004 'PO Box 541005, Merritt Island, FL 32954
100 DIM A$(512):DIM PART$(9):GRP=1:TF$="" 'TF$=Testfile name
110 FOR X=1 TO 512:A$(X)="0":NEXT 'Clear the array
120 PRINT"ENTER PART NUMBER ? ";
130 FOR Y=1 TO 8 'Up to eight digits
140 IN$=INKEY$:IF IN$="" GOTO 140
150 PRINT IN$;:IF IN$=CHR$(13) GOTO 180
160 PART$(Y)=IN$:TF$=TF$+IN$:NEXT:PRINT
180 INPUT"ENTER NUMBER OF PINS ";NP$
190 IF LEN(NP$)<2 THEN NP$="0"+NP$ 'Stretch to 2 digits
200 NP=VAL(NP$):OFFSET=(24-NP)/2
210 X=(OFFSET*2)+1 'Offset adjusts for less than 24 pins
220 PRINT"ENTERING DATA FOR GROUP ";GRP:PN=1
230 PRINT"ENTER FUNCTION OF PIN  ";PN;:INPUT;PF$:PRINT
240 X=X+1
250 IF PF$="I" THEN A$(X)="2":GOTO 290 'In, Out, inDet, ignore
260 IF PF$="O" THEN A$(X)="1":GOTO 290
270 IF PF$="D" THEN A$(X)="3":GOTO 290
280 IF PF$="X" THEN X=X-1:A$(X)="F0":X=X+2:PD$="00":GOTO 310
290 X=X+1
300 PRINT"ENTER HEX DATA FOR PIN ";PN;:INPUT;PD$:PRINT
310 A$(X+46)=LEFT$(PD$,1):A$(X+47)=RIGHT$(PD$,1)
320 PN=PN+1:IF PN<NP+1 GOTO 230
330 GRP=GRP+1:IF GRP=6 THEN 370
340 CLS:INPUT"DO YOU WISH TO ENTER ANOTHER GROUP (Y OR N) ";Q$
350 IF Q$="N" THEN 370
360 X=((OFFSET*2)+1)+((GRP-1)*96):GOTO 220 'Groups are 96 bytes apart
370 X=496:Y=Y-1
390 A$(X)=PART$(Y) 'Assemble part number for storage
400 X=X-2:Y=Y-1:IF Y<>0 GOTO 390
420 X=498:A$(X)=LEFT$(NP$,1):A$(X+2)=RIGHT$(NP$,1)
430 OPEN TF$+".FIL" AS 1 LEN=1
440 FIELD 1, 1 AS B$
450 FOR X=1 TO 512 'File must have exactly 512 bytes
460 LSET B$=A$(X)
470 PUT 1,X
480 NEXT
490 CLOSE
```



PART NUMBER (8 Alphanumeric Digits Maximum: 74LS245
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 20
GROUP NUMBER (1 to 5): 1
REMARKS: SEND MODE

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
1111 1111	FF	I	1	S/$\overline{R}$	Vcc	20			X
0101 0101	55	I	2	1A	$\overline{E}$	19	0000 0000	00	I
0101 0101	55	I	3	2A	1B	18	0101 0101	55	O
0101 0101	55	I	4	3A	2B	17	0101 0101	55	O
0101 0101	55	I	5	4A	3B	16	0101 0101	55	O
0101 0101	55	I	6	5A	4B	15	0101 0101	55	O
0101 0101	55	I	7	6A	5B	14	0101 0101	55	O
0101 0101	55	I	8	7A	6B	13	0101 0101	55	O
0101 0101	55	I	9	8A	7B	12	0101 0101	55	O
		X	10	GND	8B	11	0101 0101	55	O

FIG. 10—TEST SETUP FOR A 74LS245 octal bus transceiver in send mode.



PART NUMBER (8 Alphanumeric Digits Maximum: 74LS245
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 20
GROUP NUMBER (1 to 5): 2
REMARKS: RECEIVE MODE

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
0000 0000	00	I	1	S/$\overline{R}$	Vcc	20			X
0101 0101	55	O	2	1A	$\overline{E}$	19	0000 0000	00	I
0101 0101	55	O	3	2A	1B	18	0101 0101	55	I
0101 0101	55	O	4	3A	2B	17	0101 0101	55	I
0101 0101	55	O	5	4A	3B	16	0101 0101	55	I
0101 0101	55	O	6	5A	4B	15	0101 0101	55	I
0101 0101	55	O	7	6A	5B	14	0101 0101	55	I
0101 0101	55	O	8	7A	6B	13	0101 0101	55	I
0101 0101	55	O	9	8A	7B	12	0101 0101	55	I
		X	10	GND	8B	11	0101 0101	55	I

FIG. 11—TEST SETUP FOR A 74LS245 octal bus transceiver in receive mode.

ple, the 74154 4-to-16 line decoder has four address inputs (pins 20–23), two active-low gate inputs (pins 18 and 19), and 16 outputs, one of which goes low when both gate inputs are low, depending on the state of the four address inputs. Figures 14, 15, and 16 show the data required to test the IC completely.

Advanced commands

After generating test data you'll probably want to store it in your desktop computer. The tester provides storage for as many as 105 test routines, which you may upload to and download from the tester's internal memory.

After entering test data, if you wish to store it, press the Store key, and the data will be stored in memory for future use under the part number that is entered with the data.

To load a test routine from the tester's local memory, press Load and then enter the part number. If a corresponding routine is in memory, *CLEAR OR ENTER?* will appear on the display. Press Clr to erase the entry from memory, or press Enter to leave the data in the test buffer for testing or transfer to the external computer. To upload the data, press Send. To download it, press Recv. If you wish to retain a received file, press Store. Use the BASIC programs shown in Listings 1 and 2 to send and receive programs.

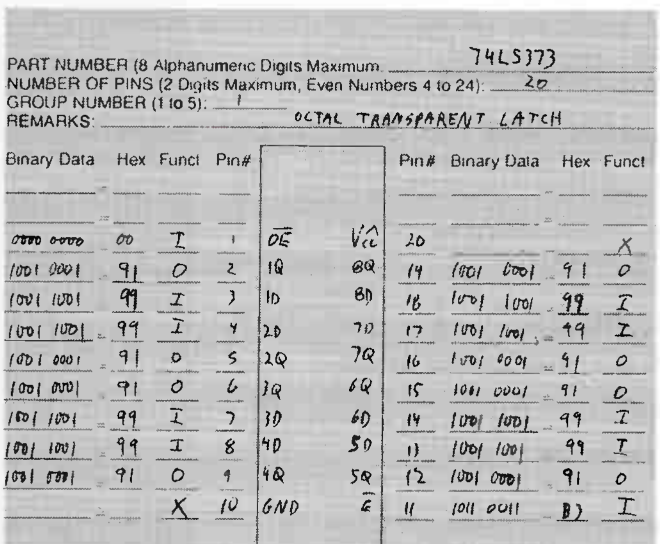
Remote data generation

The BASIC program shown in listing 3 can be used to create test patterns somewhat more conveniently than on the tester itself. It is important to note that when using the program to generate test files, only hex characters (0–9, A–F) may be used in the part number (TF$) if the file is to be stored in the Tester's memory. The reason for this is that the Tester's keyboard has no other characters to access the test routine in its memory. Therefore you would not be able to load or delete the test routine. For example, a part entered as 74LS138 would be inaccessible because there is no L or S on the Tester's keyboard.

Usage hints

First a few words of caution. Never connect the test clip to an IC that has power on it unless the tester is on and *COMMAND?* is scrolling in the display. Conversely, never shut the tester off when the clip is connected to a powered IC. And always make sure when testing in-circuit IC's that the tester and the DUT (*D*evice *U*nder *T*est) share a common ground. Connect the black test hook clip to a ground on the board near the IC's to be tested.

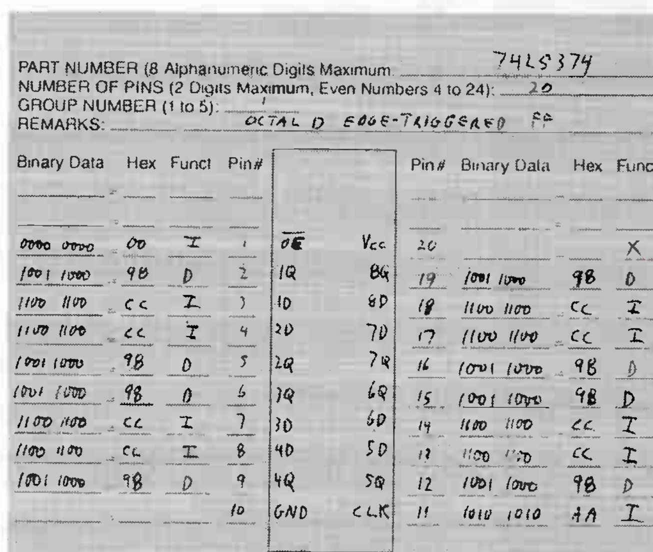
The test drivers (IC7–IC15) are rated at 7 volts maximum, so be careful what you connect the test clip to. A powered RS-232 driver might have ±12 volts, or even more, and voltages at those levels



PART NUMBER (8 Alphanumeric Digits Maximum. 74LS373
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 20
GROUP NUMBER (1 to 5): 1
REMARKS: OCTAL TRANSPARENT LATCH

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
0000 0000	00	I	1	$\overline{OE}$	Vcc	20			X
1001 0001	91	O	2	1Q	8Q	19	1001 0001	91	O
1001 1001	99	I	3	1D	8D	18	1001 1001	99	I
1001 1001	99	I	4	2D	7D	17	1001 1001	99	I
1001 0001	91	O	5	2Q	7Q	16	1001 0001	91	O
1001 0001	91	O	6	3Q	6Q	15	1001 0001	91	O
1001 1001	99	I	7	3D	6D	14	1001 1001	99	I
1001 1001	99	I	8	4D	5D	13	1001 1001	99	I
1001 0001	91	O	9	4Q	5Q	12	1001 0001	91	O
		X	10	GND	$\overline{E}$	11	1011 0011	B3	I

FIG. 12—TEST SETUP FOR A 74LS373 octal transparent data latch. Whenever the enable line (pin 11) is high, each output follows the corresponding input.



PART NUMBER (8 Alphanumeric Digits Maximum. 74LS374
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 20
GROUP NUMBER (1 to 5): 1
REMARKS: OCTAL D EDGE-TRIGGERED FF

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
0000 0000	00	I	1	$\overline{OE}$	Vcc	20			X
1001 1000	98	D	2	1Q	8Q	19	1001 1000	98	D
1100 1100	CC	I	3	1D	8D	18	1100 1100	CC	I
1100 1100	CC	I	4	2D	7D	17	1100 1100	CC	I
1001 1000	98	D	5	2Q	7Q	16	1001 1000	98	D
1001 1000	98	D	6	3Q	6Q	15	1001 1000	98	D
1100 1100	CC	I	7	3D	6D	14	1100 1100	CC	I
1100 1100	CC	I	8	4D	5D	13	1100 1100	CC	I
1001 1000	98	D	9	4Q	5Q	12	1001 1000	98	D
			10	GND	CLK	11	1010 1010	AA	I

FIG. 13—TEST SETUP FOR A 74LS374 octal D flip-flop. Data on each input is clocked into the corresponding output on the leading edge of each clock pulse. Clock pulses are applied to pin 11.

PART NUMBER (8 Alphanumeric Digits Maximum: 74154
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 24
GROUP NUMBER (1 to 5): 1
REMARKS: 4-TO-16 LINE DECODER

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
1111 0111	F7	0	1	Q0	Vcc	24			X
1110 1111	EF	0	2	Q1	A	23	0101 0111	57	I
1101 1111	DF	0	3	Q2	B	22	0110 0111	67	I
1011 1111	BF	0	4	Q3	C	21	1000 0111	87	I
0111 1111	7F	0	5	Q4	D	20	0000 0111	07	I
1111 1111	FF	0	6	Q5	$\overline{G2}$	19	0000 0011	03	I
1111 1111	FF	0	7	Q6	$\overline{G1}$	18	0000 1001	05	I
1111 1111	FF	0	8	Q7	Q15	17	1111 1111	FF	0
1111 1111	FF	0	9	Q8	Q14	16	1111 1111	FF	0
1111 1111	FF	0	10	Q9	Q13	15	1111 1111	FF	0
1111 1111	FF	0	11	Q10	Q12	14	1111 1111	FF	0
		X	12	GND	Q11	13	1111 1111	FF	0

FIG. 14—A 74154 demultiplexer has six inputs and 16 outputs, so it requires three test groups to test all combinations. Group 1 is shown here.

PART NUMBER (8 Alphanumeric Digits Maximum: 74154
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 24
GROUP NUMBER (1 to 5): 2
REMARKS: 4-TO-16 LINE DECODER

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
1111 1111	FF	0	1	Q0	Vcc	24			X
1111 1111	FF	0	2	Q1	A	23	0101 0101	55	I
1111 1111	FF	0	3	Q2	B	22	0110 0110	66	I
1111 1111	FF	0	4	Q3	C	21	1000 0111	87	I
1111 1111	FF	0	5	Q4	D	20	1111 1000	F8	I
1111 1110	FE	0	6	Q5	$\overline{G2}$	19	0000 0000	00	I
1111 1101	FD	0	7	Q6	$\overline{G1}$	18	0000 0000	00	I
1111 1011	FB	0	8	Q7	Q15	17	1111 1111	FF	0
1111 0111	F7	0	9	Q8	Q14	16	1111 1111	FF	0
1110 1111	EF	0	10	Q9	Q13	15	1111 1111	FF	0
1101 1111	DF	0	11	Q10	Q12	14	0111 1111	7F	0
		X	12	GND	Q11	13	1011 1111	BF	0

FIG. 15—GROUP TWO OF THE 74154 TEST set is shown here.

PART NUMBER (8 Alphanumeric Digits Maximum: 74154
NUMBER OF PINS (2 Digits Maximum, Even Numbers 4 to 24): 24
GROUP NUMBER (1 to 5): 3
REMARKS: 4-TO-16 LINE DECODER

Binary Data	Hex	Funct	Pin#			Pin#	Binary Data	Hex	Funct
1111 1111	FF	0	1	Q0	Vcc	24			
1111 1111	FF	0	2	Q1	A	23	1111 1101	FD	I
1111 1111	FF	0	3	Q2	B	22	1111 1110	FE	I
1111 1111	FF	0	4	Q3	C	21	1111 1111	FF	I
1111 1111	FF	0	5	Q4	D	20	1111 1111	FF	I
1111 1111	FF	0	6	Q5	$\overline{G2}$	19	1111 1000	F8	I
1111 1111	FF	0	7	Q6	$\overline{G1}$	18	1111 1000	F8	I
1111 1111	FF	0	8	Q7	Q15	17	1111 1011	FB	0
1111 1111	FF	0	9	Q8	Q14	16	1111 1101	FD	0
1111 1111	FF	0	10	Q9	Q13	15	1111 1110	FE	0
1111 1111	FF	0	11	Q10	Q12	14	1111 1111	FE	0
1111 1111	FF	X	12	GND	Q11	13	1111 1111	FE	0

FIG. 16—GROUP THREE OF THE 74154 TEST set is shown here.

could damage the drivers easily. The display will probably dim if you inadvertently connect the test clip to an IC incorrectly, or if you have entered test data incorrectly. If the display does become dim, disconnect the test clip and remove power immediately.

In addition to testing IC's both in and out of circuit, the tester can also be used as a simple logic analyzer to test as many as twenty four points in a digital circuit. Simply replace the DIP clip with individual test-hook clips. Some lines would be used as outputs to stimulate the circuit, and others would be used as inputs to read the results. **R-E**

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.

R1—22,000 ohms
R2—330 ohms
R3–R6—1000 ohms

Capacitors

C1, C8—1000 µF, 16 volts, electrolytic
C2, C4–C7, C9–C17—0.1 µF, 10 volts, ceramic disc
C3—10 µF, 16 volts, electrolytic

Semiconductors

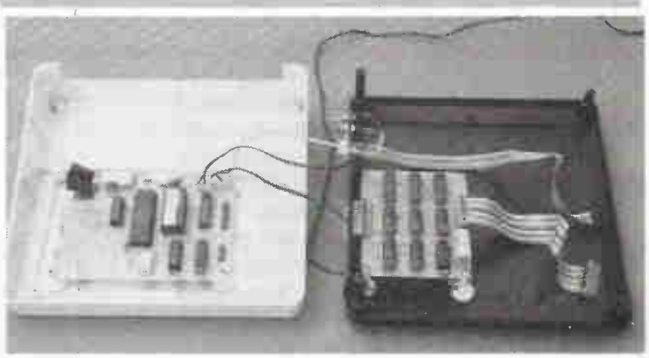
IC1—Z80 microprocessor
IC2—DS1230-104 32K nonvolatile RAM
IC3—MAX233 RS-232 interface
IC4—75499 custom decoder
IC5—75498 custom decoder
IC6—75500 custom decoder
IC7, IC10, IC13—NE591 open-emitter octal driver
IC8, IC11, IC14—NE590 open-collector octal driver
IC9, IC12, IC15—74LS373 octal latch
IC16—7805 5-volt regulator
IC17—2-Mhz crystal oscillator
D1—1N4001 rectifier
DISP1—DL1414 16-segment decoder/driver/display

Other components

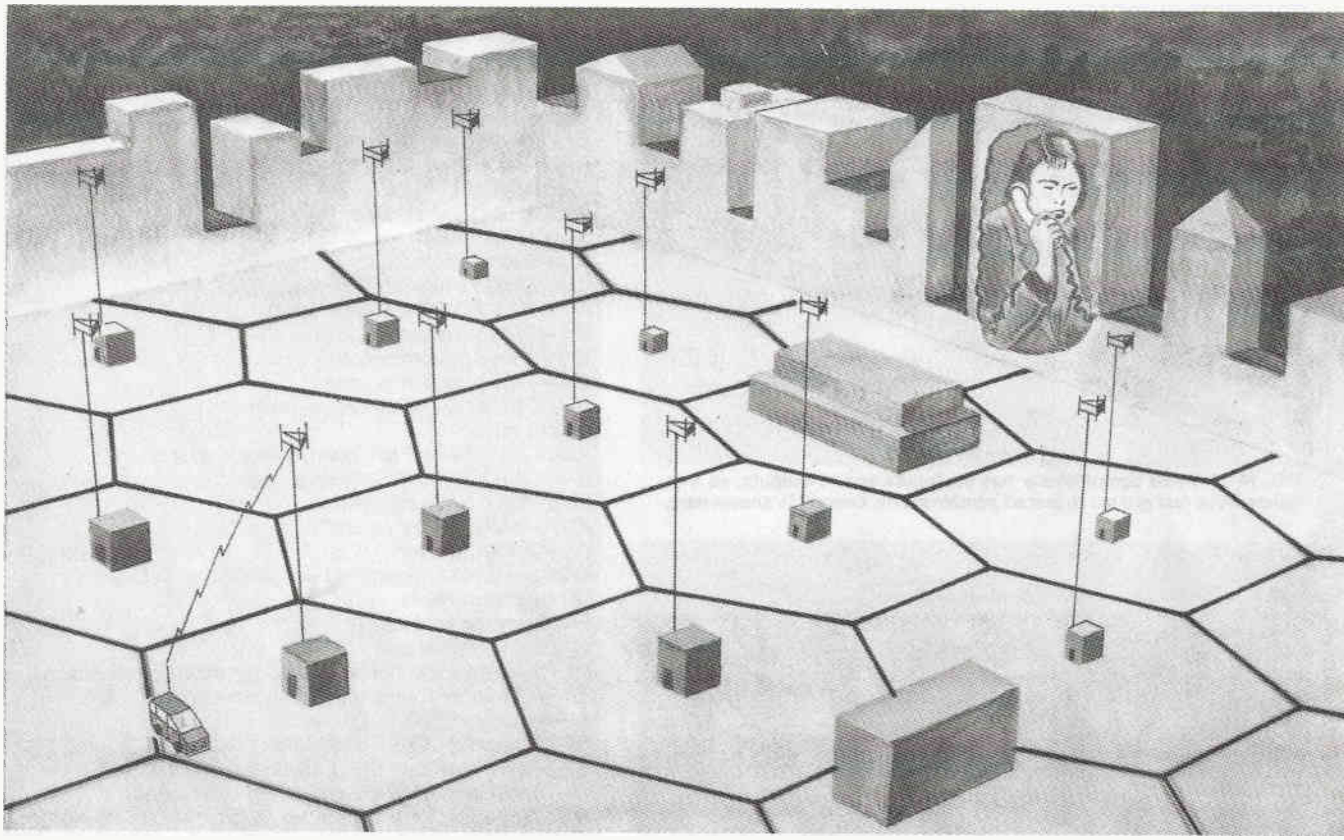
F1—1-amp pigtail fuse
J1—9-pin D connector
P1, P2—right-angle double-row 20-pin male header strips
P3—right-angle double-row 26-pin male header strips
S1—minature SPDT toggle switch
S2—momentary SPST pushbutton
S3–S14—momentary SPST keyboard switches
T1—Transformer, 9.5–12-volts, 1-amp, wall-mount

Miscellaneous: One 10-pin, two 20-pin and one 26-pin double-row female IDC header connectors. Two 12-pin single-row female IDC header connectors. Flat ribbon cable and test clips.

Note: The following are available from: ALPHA Electronics Corporation, P.O. Box 541005, Merritt Island, Florida 32954-1005, (407) 453-3534: Kit of parts for $299.99 + $6.00 P&H. Includes all parts, punched and screened panel, case, and labeled keys. Test cable and clips not inlcuded. Partial kit, including all IC's (except IC16 and IC17), display, and PC boards for $199.00 + $5.00 P&H. Three custom IC's (75498, 75499 and 75500) for $60.00 + $4.00 P&H. Florida customers please add 5% State sales tax. Canadian customers please add $3.00 additional postage to all orders. All foreign orders add appropriate postage for Air shipping and insurance.



INSIDE THE IC TESTER. Last time we showed you how to build the project; this month we show you how to use it.



INSIDE CELLULAR TELEPHONE

A look inside cellular telephone, and the fascinating technology that has revolutionized mobile communications.

JOSEF BERNARD

NOT SO LONG AGO, WHEN ONE THOUGHT of a telephone, the image conjured up would be of a jet-black, rotary-dial, electromechanical device. Now, conventional telephones come in a rainbow of colors, sport sleek lines, and feature pushbutton dialing. But even more impressive are the features that are packed inside them. Thanks to microprocessors and memories, phones are capable of storing a telephone-book's worth of most-often-called numbers to be dialed at the push of a button. And that's only the beginning.

But if you think that the phone on your desk or in your kitchen is "smart," then you would have to place cellular mobile phones in the "genius" class. Those phones have to perform a number of sophisticated tasks, including monitoring signal levels and frequency switching, in such a way that the user is not aware of them. Because of that, many people who use cellular phones daily aren't aware of the high level of technology built into their equipment. That's unfortunate, because the technology inside the phones is, for the most part, much more interesting than the conversations that they transmit.

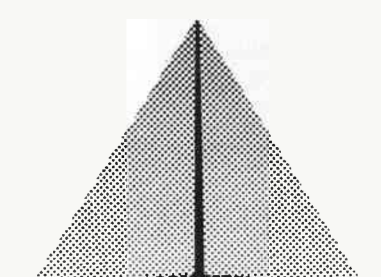


FIG. 1—EARLY, NON-CELLULAR, MOBILE-phone systems used a centrally located high-power transmitter. Only a few communications channels could be accommodated within a service region.

Cellular principles

Prior to the development of the cellular system, mobile telephone systems relied on centrally located transmitting and switching equipment to communicate with vehicles subscribing to their services. See Fig. 1. Cellular systems, on the other hand, divide their region of coverage into many small areas, each encompassing only a few square miles. See Fig. 2. It is that territorial subdivision that allows the mobile units to use low-powered transmitters (no more than three watts), and to use and reuse the same frequencies in the same area to increase the number of communications channels available.

There are 999 two-way communica-

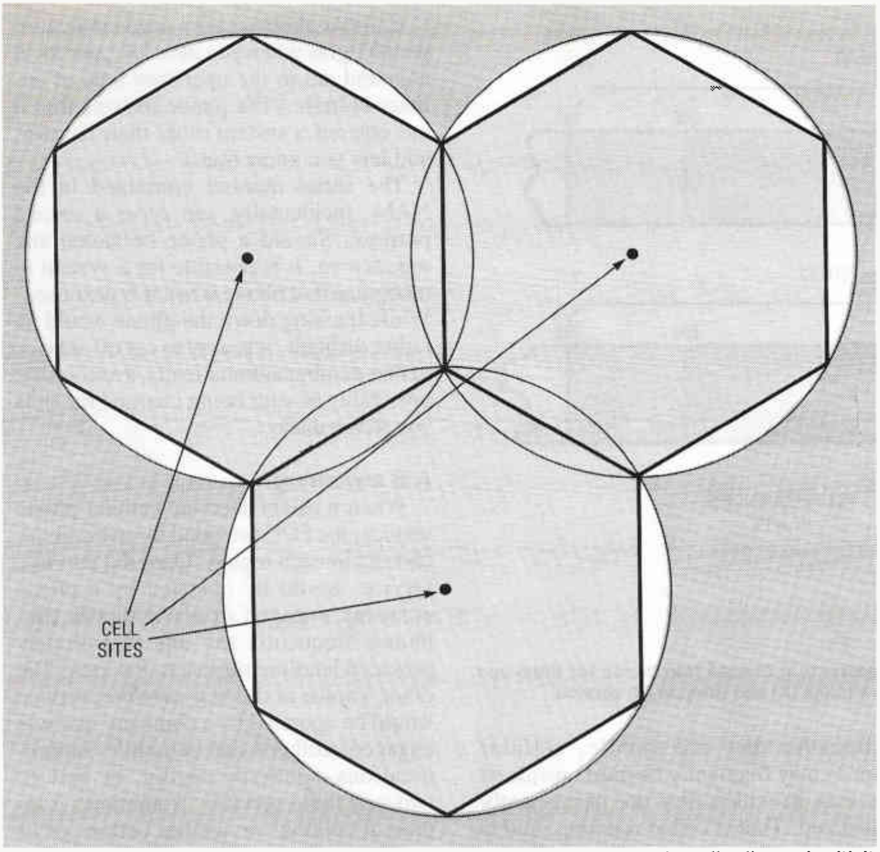


FIG. 2—A CELLULAR SYSTEM DIVIDES its region of service into a number of small cells, each with its own cell site containing a low-power transmitter and receiving equipment. As a vehicle passes between cells, the signal is analyzed and any further communications are handed off to the cell best able to handle them.

tions channels allocated for cellular service, although the phones currently available can use only 666 of them. (The other 333 frequencies were allocated in 1986 and equipment manufacturers, as of this writing, have not yet caught up with the FCC.) Of those channels, 42 are devoted to carrying control signals between cellular phones and the cell sites, where the transmitting and receiving equipment for each cell are located. It is over those channels—which you never hear, and rarely hear about—that a cellular system coordinates its activities.

All kinds of information flows on those channels, including that for coordinating frequency changes, identifying phones, and even adjusting power levels.

Handing off

When a mobile unit leaves the region of coverage of one cell site and enters that of the adjoining one, it is said to be *handed off* from one cell to the other. There is a lot of behind-the-scenes activity connected with that transfer of responsibility, and the intelligence built into cellular phones handles a lot of it.

As a vehicle equipped with a cellular phone traverses a particular cell, it eventually reaches a point where its signal is no longer strong enough for reliable communications. Fortunately, by the time it has reached that point, it is well within the region of coverage of an adjacent cell. The handing-off process of transferring the responsibility for a call-in-progress from one cell site to another requires a lot of "intelligence" on the part of both the cell site and the mobile unit.

The first thing that has to be done is to sense when a signal is approaching the point where it is about to become too weak to be usable. That's easy—all you need is what amounts, more or less, to a signal-strength detector. More complicated is the task of determining which new cell site is to receive the hand-off. The cell sites in the system have to "confer" to see which of them is receiving the signal in question the best, and make arrangements for transferring the call without interruption. That's not too difficult, either. The next part of the process, however, is quite complex.

Because adjacent cell sites cannot use the same frequencies, even though others in the same system can, a new set of frequencies must be used after the hand-off. And, since the new cell site will be using different frequencies, so must the mobile phone. That is where the control channels, and the intelligence built into a cellular phone, come into play. The new cell site knows which of its frequencies are in use and which are free, and makes a decision to allocate one of its frequency pairs (one channel) to the new conversation entering its district. It then transmits, over the control channel, instructions for the cellular phone carrying the conversation to switch to those new frequencies. The phone adjusts the voltages of its frequency synthesizer accordingly, and the conversation continues in the new cell site, on the new frequencies—all of that with only an unnoticeable interruption of a millisecond or two.

Power levels

A cellular system can use the same frequencies for different conversations at the same time, provided, of course, that the signals of one cell site do not interfere with those of another. That non-interference is accomplished in several ways.

The first is simple coordination of frequencies. While several cells in the same system may use the same frequencies, no two adjacent cells do. That puts cells using the same frequency far enough away from one another that the signal from one to a vehicle in its area, and vice versa, will override another signal from farther away. That is further ensured by the *capture effect*, which is a characteristic of FM, the transmission mode used by cellular phones. If there are two signals on the same frequency, one stronger than the other, the capture effect guarantees that a receiver will lock onto the stronger one, and ignore the weaker. Unless the two signals are nearly identical in strength, the stronger one will completely capture the receiver, and no trace at all of the weaker one will be heard.

All that is the consequence of good planning, and of the nature of FM equipment. Inside a cellular phone is circuitry that adds another level of interference protection. There is a constant dialogue going on between a cellular mobile unit and the cell site it is using. One "topic of conversation" is signal strength. Cellular equipment is low powered. Cell-site transmitters have an output of only 25–35 watts (compared to about 250 watts in older systems using central transmitters), and the mobile equipment a maximum output of three watts—and as low as 600 milliwatts for handie-talkie-size units.

One of the rules of cellular telephony is "use only as much power as you need." Consequently, a cell site monitors the strength of the signal it receives from a mobile unit. If the strength increases to a predetermined level, the cell site sends instructions over the command channel for the low-powered phone to reduce its power to an even lower level. Conversely, if the received signal strength drops, a mobile phone can be instructed to increase its power. Cellular phones are capable of between 3 and 8 discrete output levels. Keeping output power to the minimum required for good communications

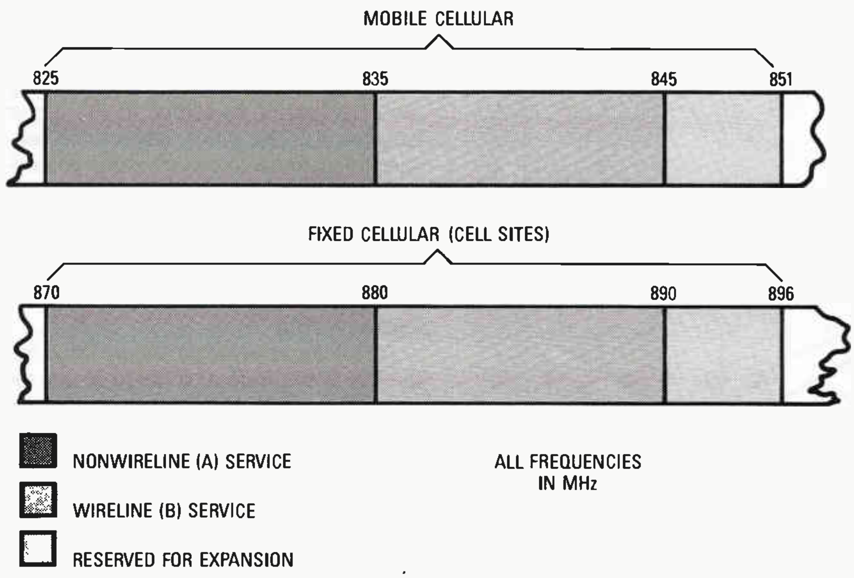


FIG. 3—THE 666-CHANNEL CELLULAR PHONE RF spectrum is divided into bands for fixed and mobile equipment (cell sites and phones), and for non-wireline (A) and wireline (B) service.

also reduces the risk of interfering with communications in a nearby cell.

NAM's

Every cellular phone contains an "identification" PROM or EPROM. In cellular terminology, this is called a NAM (*N*umeric *A*ssignment *M*odule). A phone's NAM is programmed at the time the phone is purchased; it contains such information as:

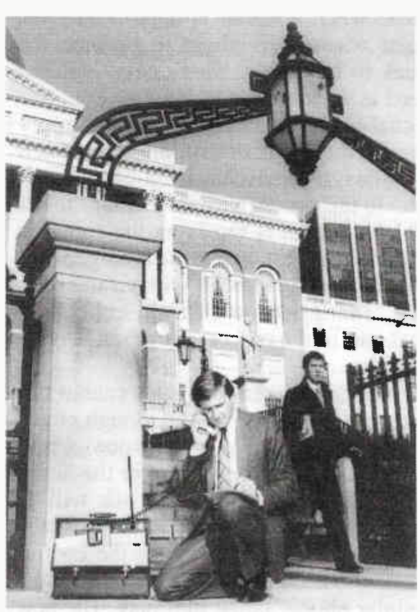
- The telephone number, or ESN (*E*lectronic *S*ervice *N*umber), assigned to the phone.
- The serial number given to the phone at the time of its manufacture.
- Personal codes that can be used to lock and unlock the phone electronically, to prevent its unauthorized use.

NAM information is more useful than you might at first imagine. For one thing, it is the job of the NAM to identify the phone containing it to the cellular systems it uses. When a cellular phone is turned on, it makes an announcement over a control channel that says, "Here I am." The cell site responds, "And exactly who *are* you?" The reply from the phone consists of information contained in its NAM.

That information tells the cellular system several things. First, of course, is that that particular phone is now on the air and is ready to receive calls placed to its number. The cell site is connected to a computer at the MTSO (*M*obile *T*elephone *S*witching *O*ffice), which is the link between the cellular system and the conventional landline phone system, and which recognizes all the cellular phones registered in the calling area it is responsible for. If the phone is a local one, the process is more or less complete at the point of recognition.

Because they are mobile, cellular phones may frequently be used outside of the area in which they are permanently registered. That is called *roaming*, and is one of the outstanding features of cellular telephony. You can take your cellular phone almost anywhere in the country where there is service, turn it on, and use it to call anywhere in the world.

In some areas you can roam and use a foreign system without advance notification. Other cellular systems require that you let them know ahead of time that you are coming. In either case, the NAM information transmitted to the system allows you to log on to it, and tells that system what to do about your billing.



NOT JUST FOR CARS, cellular phones come in portable models, like this one from GE, that keep you constantly in touch.

Cellular phones have a ROAM indicator, which lights when you have left your local area and are in the operating area of another system. (The phone realizes that it has entered a system other than its own, and lets you know that.)

The serial number contained in the NAM, incidentally, can serve a second purpose. Should a phone be stolen and reported so, it is possible for a system to recognize that phone when it is next used. While tracking down the phone would be rather difficult, it is easy to cut off service to that number automatically, avoiding the possibility of your being charged for calls you never made.

A/B switching

When it established the cellular phone service, the FCC provided for two cellular carriers in each region. One, the *wireline* service, would be operated by a phone company engaged in conventional telephony, frequently the one that already provided landline service to the area. The other, known as the *non-wireline*, service would be operated by a company that was engaged in other forms of mobile communications—perhaps paging, or private two-way radio services. Sometimes a region of cellular service has both types of carriers, and sometimes only one, at least when service is inaugurated. Each service is assigned a separate set of frequencies. See Fig. 3.

Regardless of where in the country you are, the non-wireline service is referred to as the *A service*, and the wireline one as the *B service*. Normally you subscribe to only one service or the other (provided your area offers you a choice), but you may at times have occasion to use the other type—when you are roaming, for example.

To provide for that, cellular phones have A/B switches to allow you to go from one type of service (band of frequencies) to the other. Those switches are generally not mechanical devices, but are programmable from a phone's keypad. Some of the switches are more flexible in their capabilities than are others, and the more sophisticated of them offer at least the following modes of operation:

- A (or B) service only—the other is locked out.
- Give priority to one type of service over the other.
- Automatic selection of the one active service in an area.

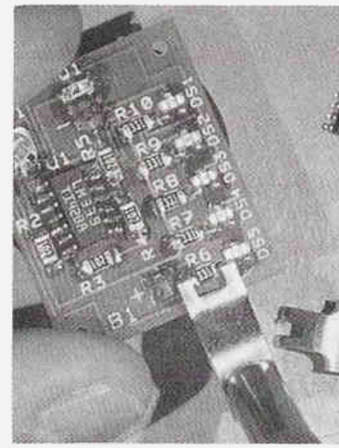
Again, it is the intelligence a phone applies to the information coming in over its control channel that makes it possible for it to select the appropriate A or B setting.

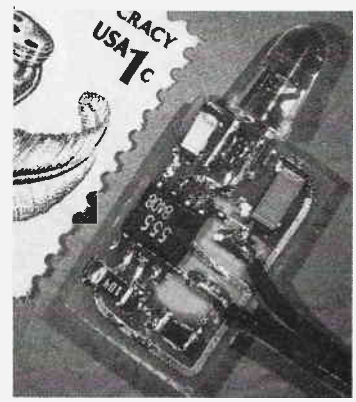
When you are roaming, the phone lets you know you are outside of your normal area of use by illuminating its ROAM indicator. Some phones can apply their

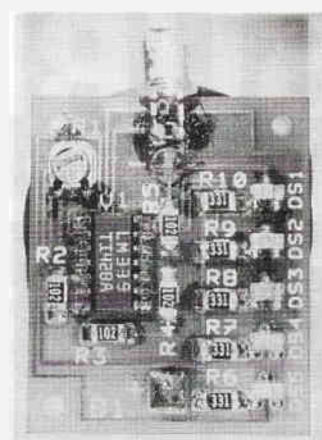
continued on page 163

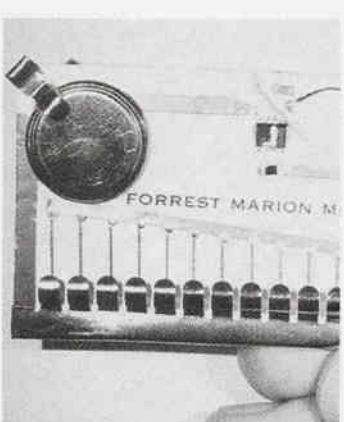

Radio-
Electronics
SURFACE-MOUNT
TECHNOLOGY
AN
INTRODUCTION
TO THE
PACKAGING REVOLUTION

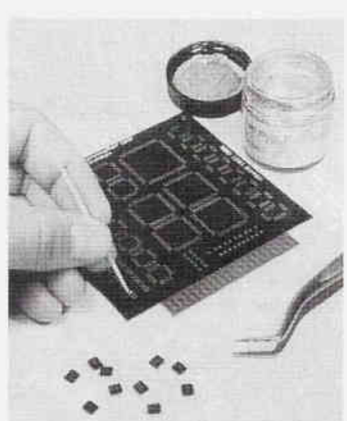
SURFACE MOUNT TECHNOLOGY

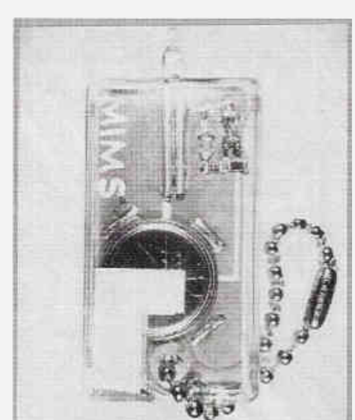


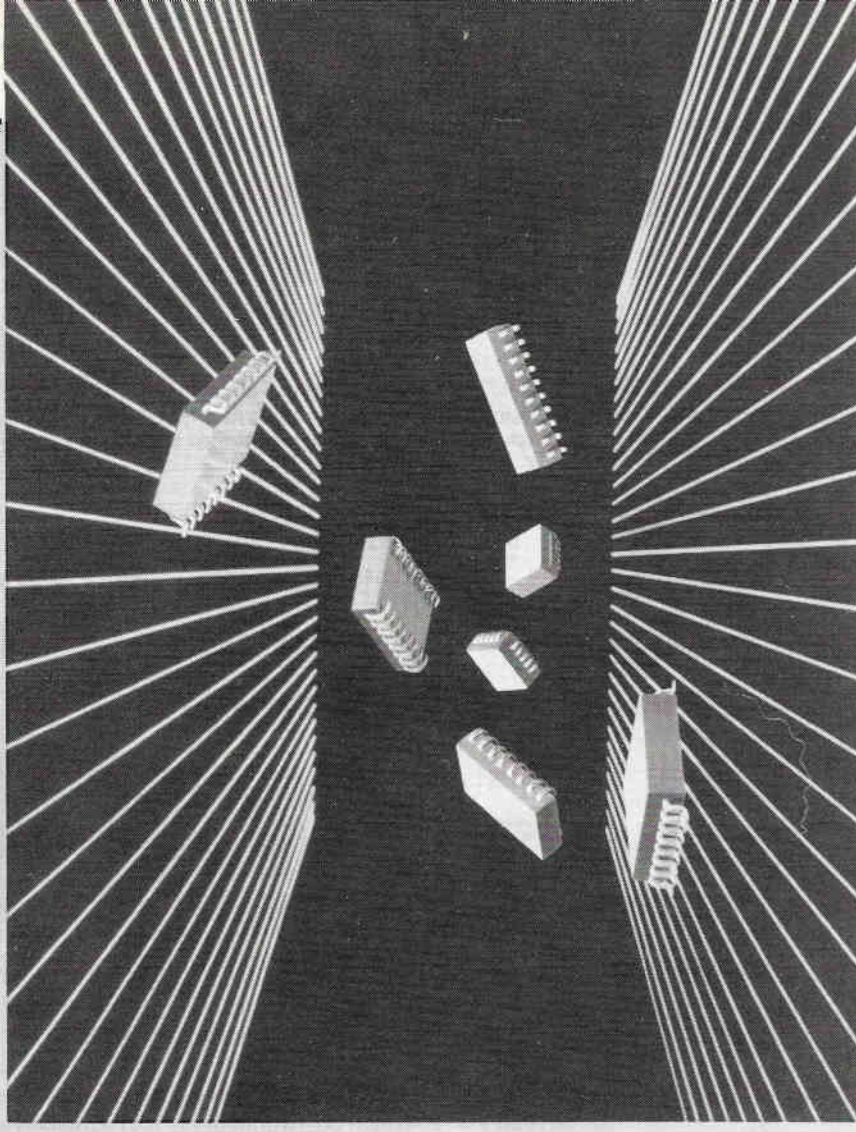












Surface-Mount Technology

Surface-mount technology is literally changing the shape of electronics manufacturing and packaging.

Introduction to SMT

FORREST M. MIMS, III

THE COMPACT SIZE OF MICROCASSETTE RECORDERS, CAMcorders, and credit-card size calculators and radios is not a result of radically new solid-state developments. Rather, those amazingly tiny personal electronic devices are made possible by a clever electronic component packaging and assembly means known as *surface mount technology.*

In *S*urface *M*ount *T*echnology, or SMT, both components and conductive traces are installed on the same side of a substrate or surface. Many kinds of substrates can be used, including ceramic, paper, plastic, and both rigid and flexible printed-circuit boards.

Though components used for conventional through-hole circuit board assembly can be modified for SMT, the vast majority of SMT components, like those shown in Fig. 1, are considerably smaller than their conventional through-hole counterparts. That means that a circuit assembled with SMT components is much more compact than an identical circuit assembled with conventional components.

Surprising as it may seem, SMT is not a new technology. Its roots can be traced to the development of miniature circuit assemblies in the United States during World War II. Similar techniques were applied to the assembly of circuit boards for hearing aids. Many of the components and techniques used in the well established field of hybrid microcircuits are used in SMT.

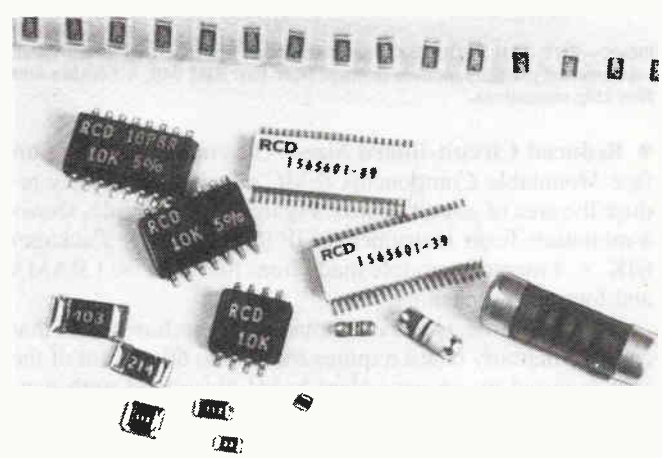


FIG. 1—SURFACE-MOUNTABLE COMPONENTS are supplied in a wide range of miniature package types.

Though SMT has a history at least 30 years long, only in the past decade has it made major inroads in consumer electronics. In coming years SMT will impact virtually everyone whose career or avocation is electronics. Those who choose not to become familiar with SMT do so at their own peril, for SMT will inevitably replace most conventional circuit assembly methods during the 1990's.

Of course, none of that is news to the electronics technicians who service the personal electronic products mentioned above as well as electronically-controlled 35-mm cameras, pocket and laptop computers, and a host of other products. They have learned, sometimes the hard way, that troubleshooting and repairing SMT circuitry requires different techniques and tools than those used with conventional through-hole circuits.

Engineers, product managers, and entrepreneurs have found that surface-mount technology offers a vitally important means for competing with off-shore electronics manufacturers. Moreover, the economics of SMT are such that circuits can often be produced on-shore using automated production equipment for less money than having them built off-shore.

Finally, SMT provides electronics experimenters and inventors with unprecedented miniaturization capabilities. The proverbial "garage inventor" can now produce functional prototype circuits every bit as tiny as the personal-electronic products popularized by the Japanese; and he can produce an SMT circuit in the same time required to produce a conventional circuit.

Advantages of SMT

The advantages of SMT that we've outlined so far are only some of the reasons the electronics industry is moving so rapidly to SMT. Here is a brief discussion of each of the advantages of SMT:

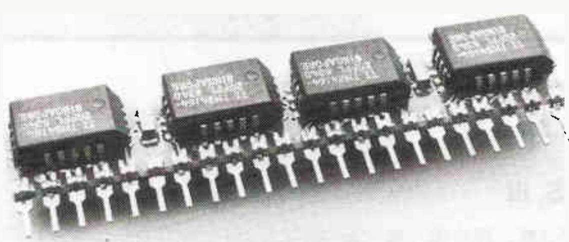


FIG. 2—SMT CAN REDUCE the area of circuit boards. This small Texas Instruments' memory module is made from four SMT 64K × 1 RAM's and four chip capacitors.

• **Reduced Circuit-Board Size**—The compact size of *S*urface-*M*ountable *C*omponents (SMC's) can substantially reduce the area of circuit boards. Figure 2, for example, shows a miniature Texas Instruments SIP (*S*ingle *I*n-line *P*ackage) 64K × 4 memory module made from four 64K × 1 RAM's and four chip capacitors.

Texas Instruments and other manufacturers have found that an SMT memory board requires from 30 to 60 percent of the area required by an equivalent board assembled with conventional through-hole DIP (*D*ual *I*n-line *P*ackage) integrated circuits. A surface-mountable SOT-23 transistor occupies only a tenth of the board space of a conventional TO-92 transistor package. A 44-pin surface-mountable PCC (*P*lastic *C*hip *C*arrier) integrated-circuit package occupies only 27.5 percent of the board space required by a standard 40-pin DIP.

A few years ago, TI engineers made an SMT memory board that had been previously assembled with standard

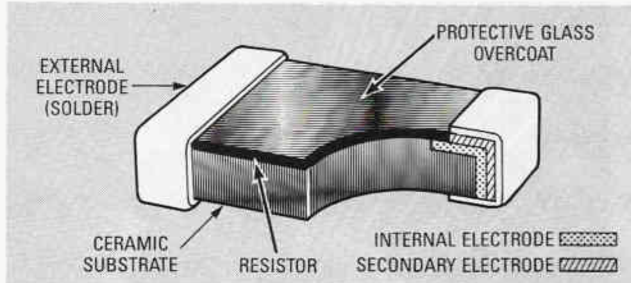


FIG. 3—INSIDE A LEADLESS CHIP RESISTOR. The construction is identical to a that of a thick-film resistor deposited directly onto a ceramic substrate.

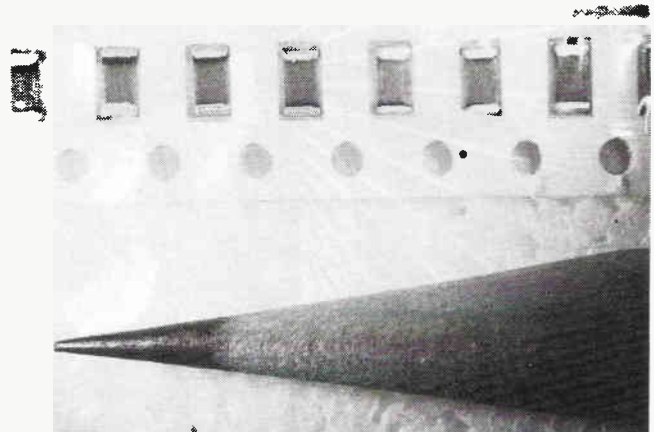


FIG. 4—A STRIP OF CHIP RESISTORS supplied on tape. The pencil point in the photograph is shown for scale.

DIP's. The area of the original board was 152.5 square inches while the area of the SMT version was 62.4 square inches, or only 41 percent of the area of the original board. Ray Prasad, the SMT Program Manager at Intel Corporation, has observed that a 4- × 4-inch board containing half a megabyte of 256K DRAM memory DIP's can contain a full megabyte of surface-mountable DRAM's. If both sides of the board are used, the board can hold 2 megabytes.

SMC's are considerably lighter than their through-hole counterparts. For example, the 8-pin DIP version of National Semiconductor's popular LM308M operational amplifier weighs 600 milligrams. The SO (*S*mall *O*utline) version of the same IC weighs only 60 milligrams. The low weight of SMC's and the smaller circuit boards they require combine to give typical SMT boards a 5-to-1 weight advantage over conventional boards. Furthermore, the very low profile of SMC's keeps SMT boards very thin and gives them as much as an 8-to-1 volume advantage over conventional boards.

SMT boards are not necessarily used only in highly miniaturized products. Consider, for example, the coming generation of small footprint desktop computers. Those machines will be made possible by 3.5-inch disk drives and SMT. As for add-on peripheral cards, two or more SMT cards will fit in the same space required by a conventional board.

• **Double-Sided Circuit Boards**—Conventional circuits are often installed on boards that have printed or etched wiring on both sides. Plated-through holes provide interconnections between the two sides of the board.

SMT can also make use of double-sided boards but with a new twist. Components can be installed on *both* sides of an SMT board, thereby greatly increasing the savings in space over boards assembled with conventional components. Since many SMC's have a much lower profile than conventional components, an SMT board having components on *both*

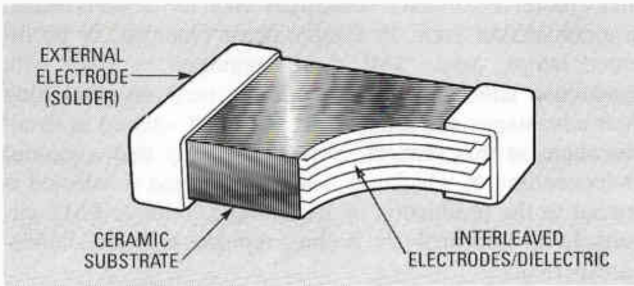


FIG. 5—INSIDE A CERAMIC CHIP CAPACITOR. The device is a sandwich of interleaved metal film and dielectric layers.

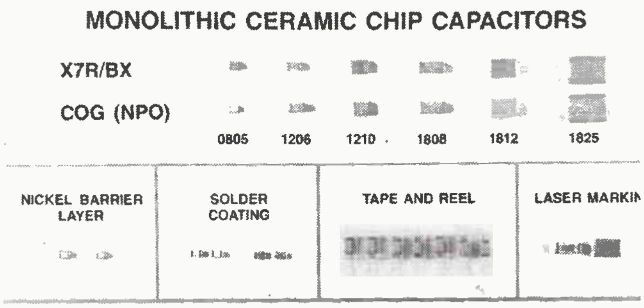


FIG. 6—CHIP CAPACITORS, like these from American Precision Industries, come in a variety of sizes and values.

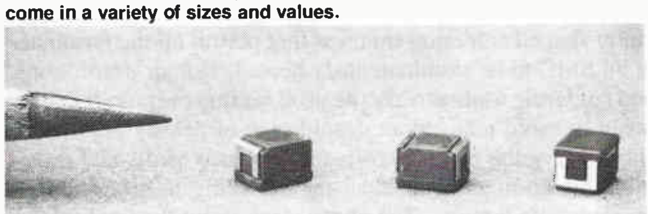


FIG. 7—SMT INDUCTORS are available in values that range from a few tens of nanohenries to one millihenry.

sides can be thinner than a board assembled with conventional components.

- **Subminiature Circuits**—SMT is a spinoff of hybrid microcircuit technology, and some SMT circuits are nearly as tiny as their hybrid cousins. Moreover, subminiature SMT circuits are considerably cheaper than hybrid circuits and prototypes can be assembled in as little as a day using inexpensive assembly tools. Now engineers, technicians, and experimenters can assemble tiny circuits on a low budget and without special facilities.
- **Automated Assembly**—Conventional through-hole components can be installed on circuit boards by means of automated assembly machines. SMT, however, is much more compatible with automated assembly equipment. Unless the board includes plated-through holes, the time-consuming chore of drilling holes in the circuit board is eliminated. SMC's have no wire leads to cut, bend, and insert. For those and other reasons, SMT boards can be automatically assembled much more quickly than conventional boards using through-hole components.

Although automated pick-and-place SMT assembly equipment is expensive, it's also very fast. At the low end are machines that pick and place up to several thousand SMC's per hour. Faster machines can pick and place from 15,000 to 20,000 SMC's per hour. Sophisticated multihead pick-and-place machines can operate at rates exceeding 500,000 SMC's per hour. Automated assembly, the chief driving force behind the rapid acceptance of SMT, will be covered in more detail in the next article.

- **Lower Cost**—The cost of individual SMC's has fallen rapidly in recent years, but SMC's generally cost more than their through-hole counterparts. Nevertheless, SMT can reduce overall board cost for a variety of reasons. According to National Semiconductor, for instance, a savings of up to 40 percent results from the elimination of drilled holes required for conventional-component leads and pins and the reduction of plated-through holes and conductive trace layers in multilayer boards.
- **Other Advantages**—Some advantages of SMT are less obvious than those listed above. For instance, the compact size of SMT boards can significantly improve a waveform's rise and fall times, and reduce crosstalk in high-performance logic systems. Those advantages are a result of shorter current paths and reduced pin-to-pin capacitance and mutual inductance. Finally, there is the undeniable advantage that SMT is the wave of the future. Those firms that adopt SMT today will be better prepared to compete tomorrow.

Disadvantages of SMT

Since SMT will eventually become the dominant circuit-assembly technology, it's important to fully understand its limitations and drawbacks. They include:

- **The SMT Learning Curve**—*Before* the advantages of SMT can be realized, the new SMT user, whether a large corporation or a home experimenter, *must* fully understand the many pitfalls that can trap the unwary. Some companies have learned about the pitfalls of SMT the hard way. They committed to manufacturing a new product using SMT *before* fully understanding the potential problems. Whether through overconfidence or ignorance, the end result in several such cases has been a very costly disaster. It's important to keep the principle of the SMT learning curve foremost in mind as you review the rest of the drawbacks.
- **SMC Standardization**—As recently as 1983, only around 300 specific SMC's were available in the United States. According to Bourns, Inc., by the end of 1986 some 15,000 specific SMC's were available. While that increase has helped spur the rapid growth of SMT, it has been accompanied by standardization problems. Supposedly identical components, especially semiconductors, made by different manufacturers may have slightly different dimensions. In view of the close tolerances required for SMT circuit-board design, dimensional compatibility is an essential requirement. Even when identically configured components are available from two or more manufacturers, each company may package its SMC's for different automated assembly formats. The SMT industry recognizes the standardization problem and is working toward solutions. Meanwhile, engineers and parts buyers for companies entering SMT for the first time are often surprised by the lack of standardization that currently exists.
- **SMC Availability**—While some 15,000 components may be available as SMC's, not all of them may be available when needed. The author's experience has been that ordering SMC's from major electronics distributors can be trying. It's particularly frustrating to order an assortment of subminiature SO integrated circuits and receive a package of monster DIP's having the same part numbers. It is extremely important that before committing to an SMT product, manufacturers find one or more reliable sources for the components. And care must be taken to be sure that the supplied components will be identically packaged and both functionally and dimensionally equivalent.
- **High Start-Up Expense**—The start-up cost of SMT for

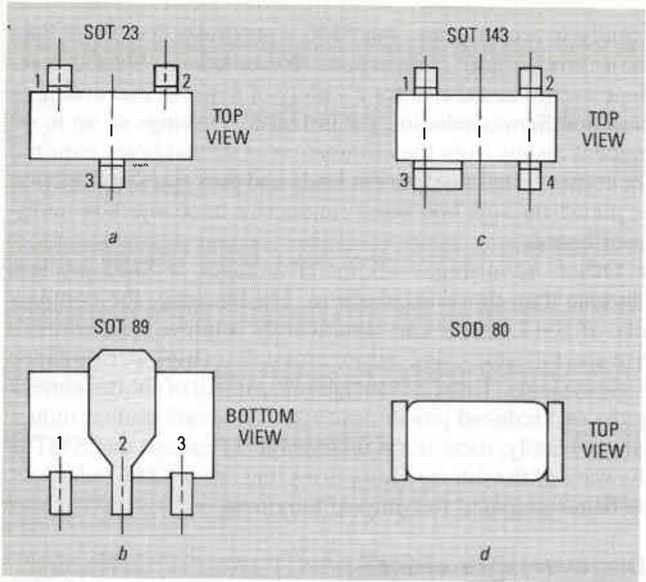


FIG. 8—FOUR MAJOR SO package outlines.

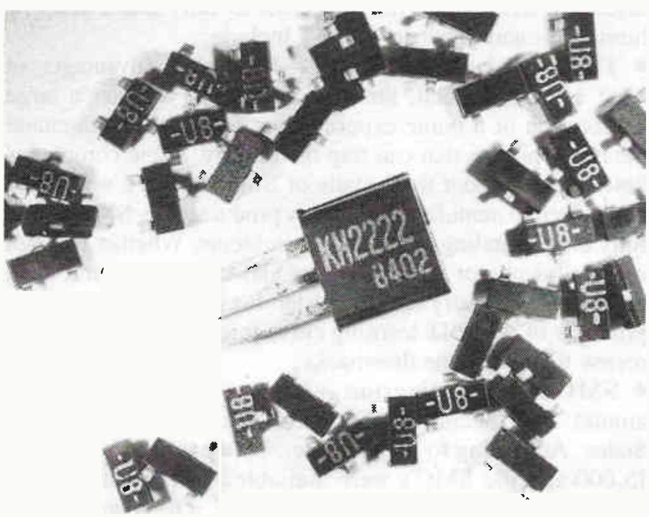


FIG. 9—A TO-92 TRANSISTOR dwarfs its SOT-23 counterparts.

both manufacturers and individual experimenters can be high. For manufacturers, automated production equipment is by far the most expensive investment. Experimenters face the problem of acquiring new assembly tools and a stock of surface-mountable resistors, capacitors, LED's, diodes, transistors, and integrated circuits. While the cost of an individual SMT project may be only slightly higher than the same project assembled with through-hole components, acquiring a sufficient stock of SMT components can easily cost a few hundred dollars or more. That situation will change when retail and mail-order electronics dealers begin offering kits of SMC's.

• **Soldering**—The components of virtually all manufactured through-hole circuit boards are wave soldered. A variety of soldering options, each with various advantages and disadvantages, is available to the SMT user. They include single- and double-wave soldering, and reflow soldering. Wave soldering requires that the SMC's be attached to the circuit board with a droplet of non-conductive adhesive. Reflow soldering involves the use of solder paste or cream. The paste is screened over the SMC footprints or pads, or applied directly to the pads with either an automated or a hand operated syringe. The terminals of the SMC's, which adhere to the sticky paste, are soldered to the pads when the board is heated in a convection oven, in a vapor-phase chamber, or by infrared lamps. Some SMC's are connected in place with conductive adhesives. SMT soldering methods, including their advantages and drawbacks, will be discussed in detail elsewhere in this section. Suffice it to say that a careful understanding of whichever soldering method is selected is crucial to the production of functioning, reliable SMT circuits. In the final analysis, nothing replaces practical, hands-on experience.

• **Troubleshooting and Repair**—The best way to fully appreciate the differences between conventional and SMT circuitry is to take a peek inside a handheld video camcorder. The optics, focusing motor, gears, and image sensor of the typical camcorder are virtually surrounded by thin circuit boards that are peppered with hundreds of tiny SMC's. The sight of those boards will provide convincing proof that servicing SMT circuits requires a completely different set of tools and skills than those that are required to service conventional through-hole circuits.

Since most SMC's are very closely spaced and do not have leads, conventional test instrument probes may not be suitable. Fortunately several companies now make a variety of probes and clips specifically intended for connection to SMC's. Desoldering and resoldering SMC's requires specially shaped soldering iron tips that permit all the terminals of an SMC to be simultaneously heated. Hot air desoldering and soldering tools can also be used for that purpose if care is taken to avoid inadvertent desoldering of nearby SMC's. In short, servicing SMT circuits requires new skills and much more attention to detail than the servicing of conventional through-hole circuits. The observation about the vital role of practical, hands-on experience given in the discussion of soldering surface-mountable components applies equally well to servicing SMT circuits.

• **Other Drawbacks**—Some of the pitfalls awaiting new SMT designers are less obvious than those discussed so far. Thermal overload is a good example. Since surface-mountable semiconductors are so small, they dissipate less heat than their conventional counterparts. That, and the fact many such devices can be densely packed together on a compact circuit board, can lead to unanticipated thermal-overload problems in your designs.

Another drawback is that SMT boards require tighter dimensional tolerances than conventional through-hole boards. In addition, board designers and draftsmen must become acquainted with the configuration of the many different kinds of SMC's. Computer-aided drafting software may have to be updated or even replaced if it doesn't include an SMT capability.

Surface-mountable components

Many, but not all, through-hole components have a surface-mountable counterpart. Physical limitations often prevent a conventional component from being manufactured as an SMC. For example, high-capacity capacitors and power transformers are simply too large. And the pinouts and chip dimensions of some IC's don't readily lend themselves to standard surface-mount packages. Nevertheless, most circuits can be assembled using SMT, even if some conventional through-hole components are required.

It's important for SMT circuit designers, draftsmen, and service technicians to be aware of the general physical configurations and operating parameters of the various families of

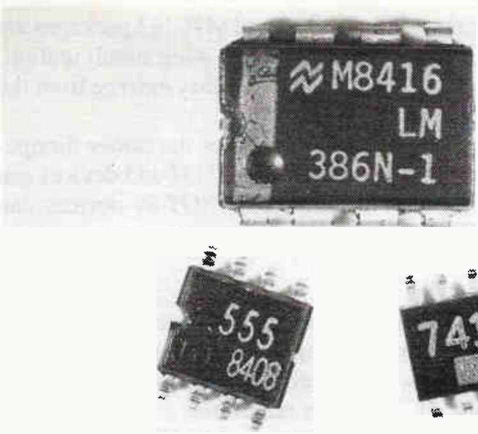


FIG. 10—TWO SO INTEGRATED CIRCUITS and a conventional 8-pin mini-DIP.

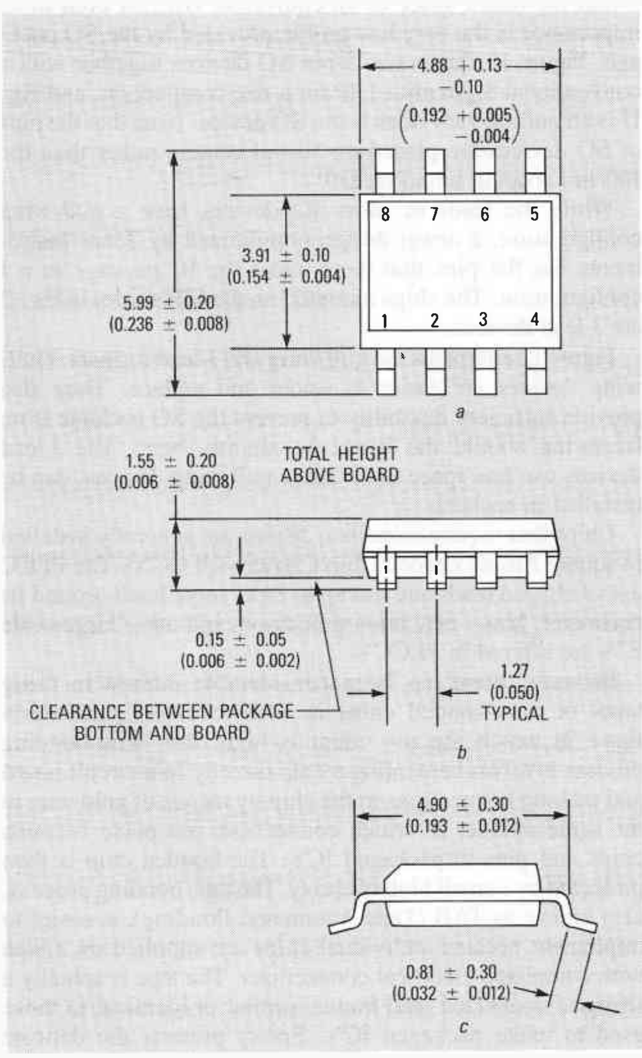


FIG. 11—TOP VIEW (*a*), side view (*b*), and front view (*c*) of a Texas Instruments 8-pin SO integrated circuit.

SMC's. What follows is a quick tour of the most important families of SMC's. All SMC's in those families are available individually or in quantity. SMC's intended for automated assembly are supplied in reels of paper or embossed plastic tape, or in magazines. Some automatic assembly equipment is equipped with vibratory feeders that can be loaded with non-packaged leadless chip components, such as resistors and capacitors.

Chip resistors

Chip resistors are the most widely produced of all SMC's. Originally developed for use in hybrid microcircuits, chip-resistor technology was well established when SMT was adopted for consumer and industrial products.

Figure 3 shows the cross section of a typical leadless chip resistor. The construction of the device is identical to that of a thick-film resistor deposited directly on the ceramic substrate of a hybrid microcircuit. The nickel barrier between the inner electrode and the solder coating prevents the electrode from leaching during soldering. Without the nickel barrier, leaching may impair the connection between the chip resistor and the external circuit.

Figure 4 shows the very small size of chip resistors. The taped resistors in the photo are classified as 1206, a type designation indicating a physical size of 1.6 × 3.2 millimeters. Other types are the 0805 (1.4 × 2.0 mm) and 1210 (2.6 × 3.2 mm). The resistance range of most chip resistors is 10 ohms to 2.2 megohms. Some companies offer values up to 10 megohms and even higher.

Trimmers and potentiometers

Both single- and multi-turn trimming potentiometers are available in surface-mountable configurations. They are made from ceramic or high-temperature plastics to protect them from the heat of immersion soldering. The smallest single-turn trimmers measure less than 4 × 4 millimeters. Multi-turn trimmers, which closely resemble their through-hole counterparts, measure 6.35 × 6.35 mm (0.25 inch) or 8.9 × 8.9 mm (0.35 inch).

Although surface-mountable trimmers are adjustable, it's important to realize that most of those devices are not designed for repeated adjustments. A typical trimmer, for example, might be rated for no more than 10 adjustment cycles. Another consideration is the adjustment mechanism itself. Most trimmers are designed to be adjusted by means of a miniature screwdriver or special tool. The required slot or slots may not be compatible with all kinds of automated pick-and-place equipment. Also, trimmers that require a special adjustment tool can pose a major problem when only a screwdriver is available.

Chip capacitors

Like chip resistors, leadless chip capacitors were developed originally for use in hybrid microcircuits. There are three principle categories of surface-mountable chip capacitors: multilayer ceramic, electrolytic, and tantalum. Four out of five chip capacitors are ceramic multilayer devices. As shown in Fig. 5, a ceramic chip capacitor is a sandwich of interleaved layers of metal film and ceramic dielectric. At opposite ends of the chip, every other metal layer is interconnected by an external metal electrode. Often a nickel layer is added to prevent leaching of the internal metal layers.

Ceramic chip capacitors, like the ones in Fig. 6, are rugged, very stable, and highly reliable. Capacitance values ranging from 1 pF to 1 μF are available. Package styles identical to those of chip resistors described above (0805 and 1206) are available, as are larger packages. Unlike chip resistors, the size of a chip capacitor is directly related to its value.

For high capacity, electrolytic and tantalum chip capacitors are available. Tantalums are available in values from 0.1 to 100 μF. Aluminum electrolytics, which are larger than tantalums, are available in values from around 1.5 to 47 μF.

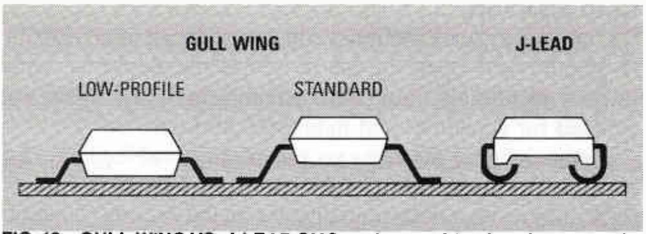


FIG. 12—GULL-WING VS. J-LEAD SMC packages. J-lead packages can be mounted using sockets

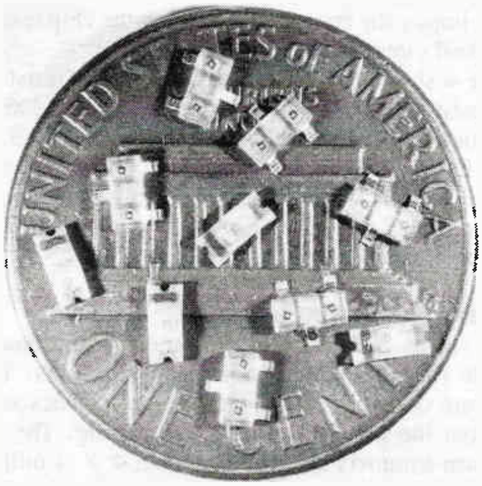


FIG. 13—SOT-23 DUAL-CHIP red LED's and single-chip green LED's are dwarfed by a penny.

FIG. 14—COMPONENTS SUCH AS CRYSTAL FILTERS, relays, switches, and crystals are available as SMC's. An SMC crystal is shown here.

Those capacitance ranges continue to be expanded as new products are added.

Inductors

Many kinds of surface-mountable leadless and formed-lead inductors, and even toroidal transformers, are available. Inductance values range from a few tens of nanohenries to one millihenry. Figure 7 shows several surface-mountable inductors.

Discrete semiconductors

Many diodes, transistors, and other discrete semiconductors are available in miniature surface-mountable packages. Figure 8 shows the outlines of the four major package styles SOT-23 (Fig. 8-*a*), SOT-89 (Fig. 8-*b*), SOT-143 (Fig. 8-*c*), and SOD-80 (Fig. 8-*d*). The SOD (*S*mall *O*utline *D*iode) package is a leadless cylinder used for diodes. The SOT (*S*mall *O*utline *T*ransistor) packages are used for transistors, diodes (1 or 2 chips), and various optoelectronic components. Figure 9 compares the SOT-23 transistor with its conventional through-hole counterpart.

Referring back to Fig. 8, note the configuration of the leads of the SOT packages. The SOT-23 and SOT-143 packages are equipped with formed leads in a gull-wing configuration. The SOT-89 leads are not formed since they emerge from the lower side of the package.

The package configuration determines the power dissipation of any semiconductor. SOT-23 and SOT-143 devices can dissipate from 200 to 400 milliwatts. SOT-89 devices can dissipate from 500 to 1000 mW.

Integrated circuits

Surface-mountable integrated circuits have been available since Texas Instruments developed the gold-plated flat pack IC in the early 1960's. Today more than a dozen families of surface-mountable IC packages are in use.

The most popular surface-mountable IC package, the *S*mall-*O*utline (SO) configuration developed by Philips, resembles a miniature DIP. An SO device occupies around a fourth the board space of an equivalent DIP. Of even more importance is the very low profile provided by the SO package. Figure 10 shows two 8-pin SO devices together with a conventional 8-pin mini-DIP for a size comparison, and Fig. 11 is an outline view of an 8-pin SO device. Note that the pins of SO devices are placed on 50-mil centers rather than the 100-mil spacing found on DIP's.

While the leads of most SO devices have a gull-wing configuration, a newer design popularized by Texas Instruments has flat pins that bend under the IC package in a J configuration. The chips mounted on the SIP shown in Fig. 2 are J-lead devices.

Figure 12 compares the gull wing and J-lead formats. Gull-wing devices are easier to solder and replace. They also provide sufficient flexibility to prevent the SO package from fracturing should the board be slightly bent. The J-lead devices use less space and, unlike gull wing devices, can be installed in sockets.

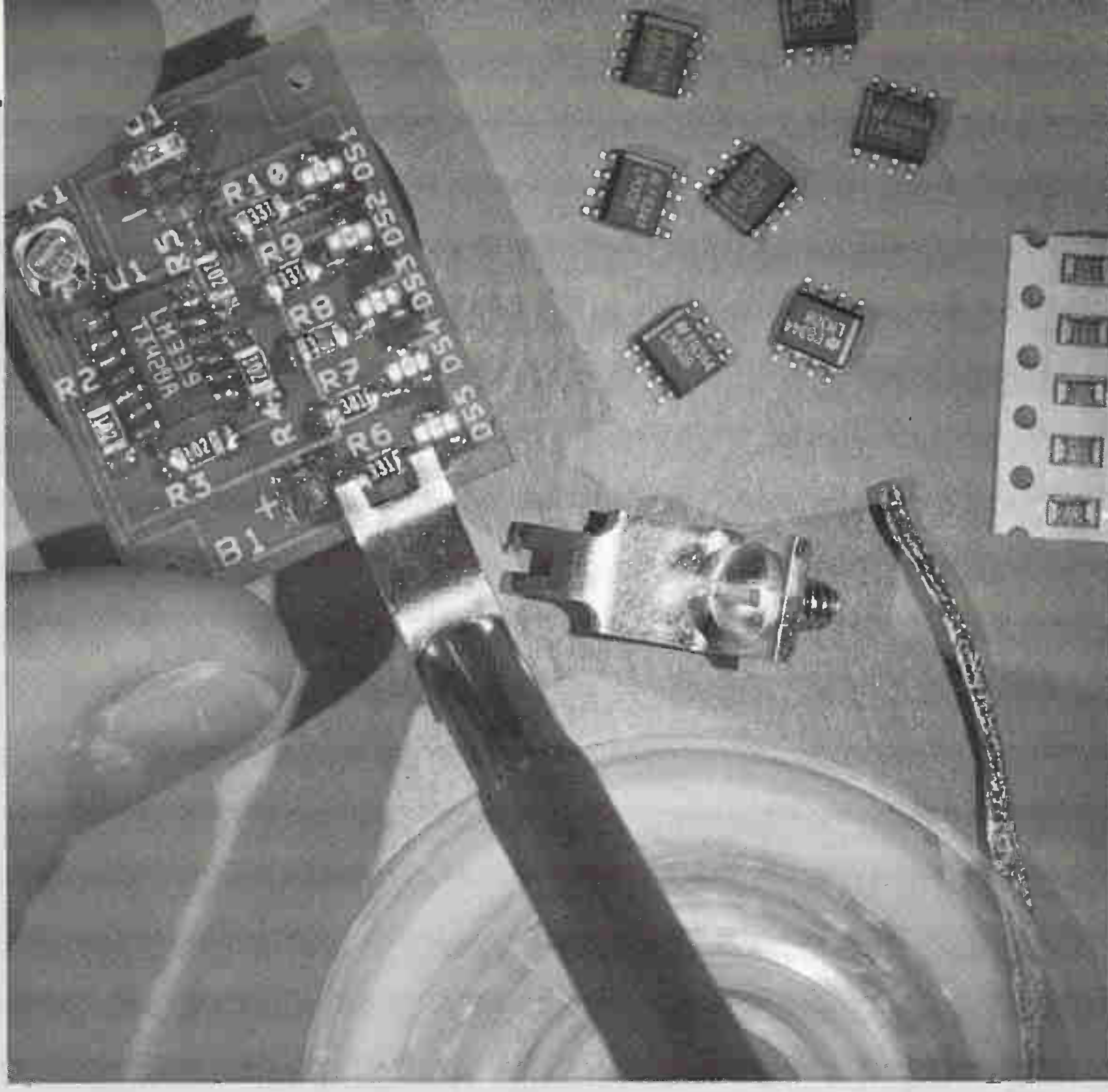
Chips that require more than 28 pins are generally installed in square *P*lastic *L*eaded *C*hip *C*arriers (PLCC's). The PLCC uses J-shaped leads and has up to 84 or more leads around its perimeter. Many new microprocessors and other large-scale IC's are offered in PLCC's.

Recently, there has been considerable interest in using tape- or wire-bonded chips in SMT circuits, particularly those in which the pin count is high. The wire-bonding process involves cementing a chip directly to a circuit board and making connections to the chip by means of gold wire in the same manner in which connections are made between chips and pins in packaged IC's. The bonded chip is then protected by a small blob of epoxy. The tape bonding process, also known as TAB (*T*ape *A*utomated *B*onding), is easier to implement because individual chips are supplied on a tape with completed electrical connections. The tape is actually a string of connected lead frames similar or identical to those used to make packaged IC's. Epoxy protects the delicate chips and connection leads from damage. TAB chips can be used in automated assembly.

Other Surface Mountable Components

In addition to the component families discussed above, there are many other surface-mountable devices. For example, many optoelectronic components are available, including phototransistors, optoisolators and many kinds of one- and two-chip infrared and visible LED's (see Fig. 13). Also available are ceramic filters, relays, switches and crystals (see Fig. 14). **R-E**

Surface-Mount Technology



Hand-Soldering SMC's

Once you master the techniques, soldering SMC's is easy, and fast.

FORREST M. MIMS, III

THE EASIEST WAY TO HAND-SOLDER SMC'S TO A CIRCUIT board is to use soldering tools and materials, such as soldering tweezers and hot-air soldering/desoldering systems, which are designed specifically for that task. Unfortunately, specialized SMC soldering tools can be expensive and difficult to locate. However, it is safe to assume that such items will become more economical and widely available in coming years. In the meantime, SMC's can be installed using only the common tools shown in Fig. 1. Those tools include an ordinary soldering pencil and a soldering iron equipped with a slotted tips designed for SMC's.

There are two chief differences between hand-soldering conventional through-hole components and SMC's. First, SMC's are installed and soldered on the foil side of a circuit board. Second, the absence of wire leads and pins inserted through holes means that the SMC's must be secured in place during soldering.

In industry, small droplets of adhesive are used to secure SMC's in place for wave soldering. While wave soldering may be impractical for hobbyist applications, the same technique for securing SMC's in place is used when hand-soldering circuits. For reflow soldering, SMC's are held in place by sticky dabs of solder paste or cream that are placed over each footprint before the SMC's are placed on the board. Reflow soldering can also be used by hobbyists.

Let's now examine some hand- and reflow-soldering techniques.

Conventional soldering

It's surprisingly easy to solder or "tack" SMC's in place using only a handheld iron and small-diameter wire solder. Solder 25 mils (0.025 inch) in diameter works best, but 30-mil solder, which is more readily available, can also be used. The only special requirement is that the SMC must be held in place until at least one terminal or pin is soldered.

It's possible to use various kinds of adhesives to cement an SMC in place for hand soldering. That, however, can unnecessarily complicate what is essentially a very simple procedure. The adhesive must not be allowed to flow over the SMC's footprints, must be non-corrosive, and must be allowed to set before the SMC's can be soldered. For those reasons, we have experimented with two simpler and faster methods.

One method is to secure one side or corner of an SMC in

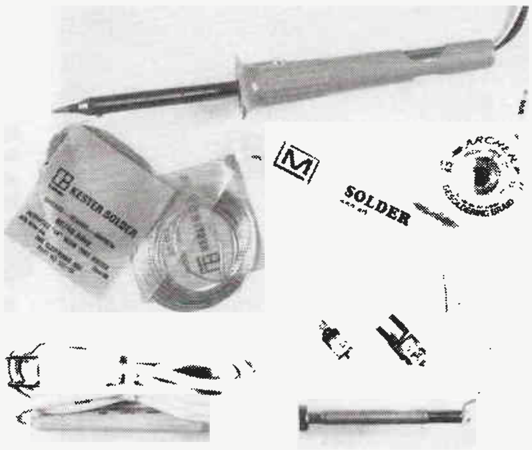


FIG. 1—SMC's CAN BE HAND SOLDERED using only the common tools and materials shown here.

place with masking tape as shown in Fig. 2. An exposed terminal or corner pin can then be soldered. The tape is then removed and the remaining terminals or pins can be soldered.

Another method is to place a tiny bead of reusable adhesive between the terminals on the bottom side of the SMC. Suitable reusable adhesives include *Plasti-Tak, Fun-Tak*, and *Stikki-Wax*. Those and similar adhesives are widely available at department stores.

Use a toothpick, a sharply pointed probe, or pointed tweezers to apply the adhesive. Then grasp the SMC with pointed tweezers, place it on its footprints, and press it in place. It is important that the SMC be pressed flat against the board. Too much adhesive will keep the SMC suspended slightly above the board and may even cause adhesive to creep between a terminal and its footprint.

After an SMC is attached to the board with tape, cement, or reusable adhesive, carefully touch the tip of a soldering pencil to the junction of a terminal and its footprint. After a

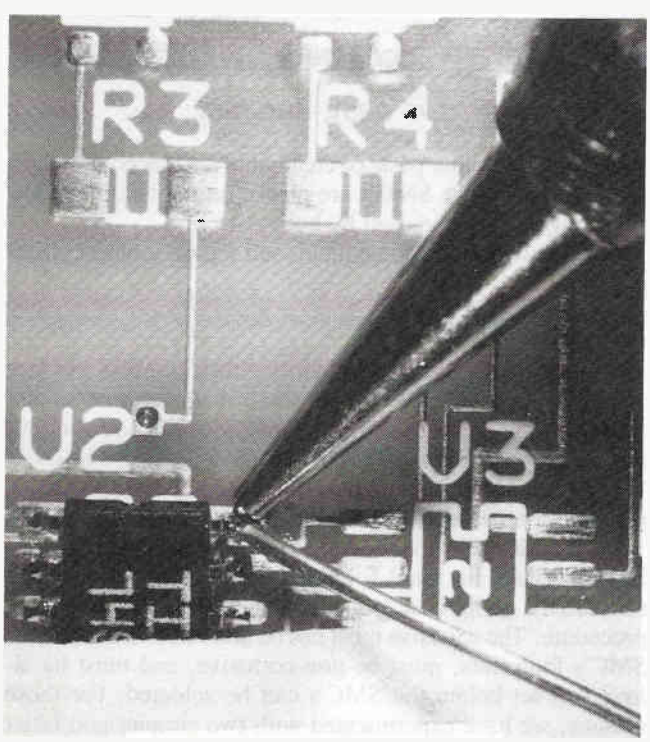


FIG. 2—ONE SIMPLE METHOD of securing an SMC in place is to tape down one side with masking tape.

second or so, lightly touch the end of a length of solder to the junction and immediately remove both the iron and the solder. A shiny solder fillet should neatly bond the terminal to the footprint.

Until you gain some hands-on SMC soldering experience, *always* inspect the completed junction with a magnifying lens before moving to the next terminal or SMC. If you use too much solder or form a solder bridge, use desoldering braid to carefully remove the excess solder. Place an unused section of desoldering braid over a footprint and press it in place with a soldering iron tip. Within a second or so, capillary action will wick the excess solder on the footprint into the braid. Remove the iron and braid and go on to the next footprint as needed. Be sure to use a fresh section of braid at each footprint. Clip off used sections of braid as necessary. If necessary, reapply a small amount of solder.

Reflow soldering

The most straightforward approach to mounting SMC's is reflow soldering. The SMC is held in place with tweezers while a soldering iron presses one end terminal or corner pin against a pretinned footprint. The tinned layer then melts and reflows around the terminal or pin and the footprint. Since no additional solder is used, the tinned layer must include enough solder to provide a good joint.

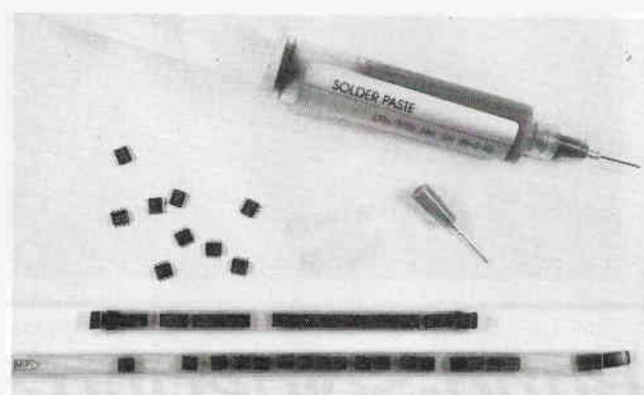


FIG. 3—SOLDER PASTE OR CREAM is available in a syringe. That makes dispensing the paste or cream convenient, once you get the hang of how it's done!

Reflow soldering works best with SMC soldering tools that simultaneously heat all the pins or terminals of the chip being soldered. When a standard soldering iron is used, only one pin or terminal at a time can be heated. That can lead to problems when working with chip SMC's. If the tinned layer is too thick, only the terminal being reflow soldered will be pushed through the molten solder against the footprint; the remaining terminal will remain atop the tinned layer over its footprint. Also, the SMC will be badly tilted when the second terminal is soldered. On the other hand, if the tinned layer is too thin, there will be insufficient solder to form the bond. Therefore, consider other soldering techniques when working with chip components.

Reflow soldering with solder paste or cream is particularly interesting since all the SMC's are soldered in place in a single operation without a soldering iron. Instead, the entire board is heated in a convection oven or on a hot plate. Unfortunately, solder pastes and creams are not always readily available, have a limited shelf life, and have instructions that must be strictly followed. Nevertheless, the method is so efficient that it warrants discussion here.

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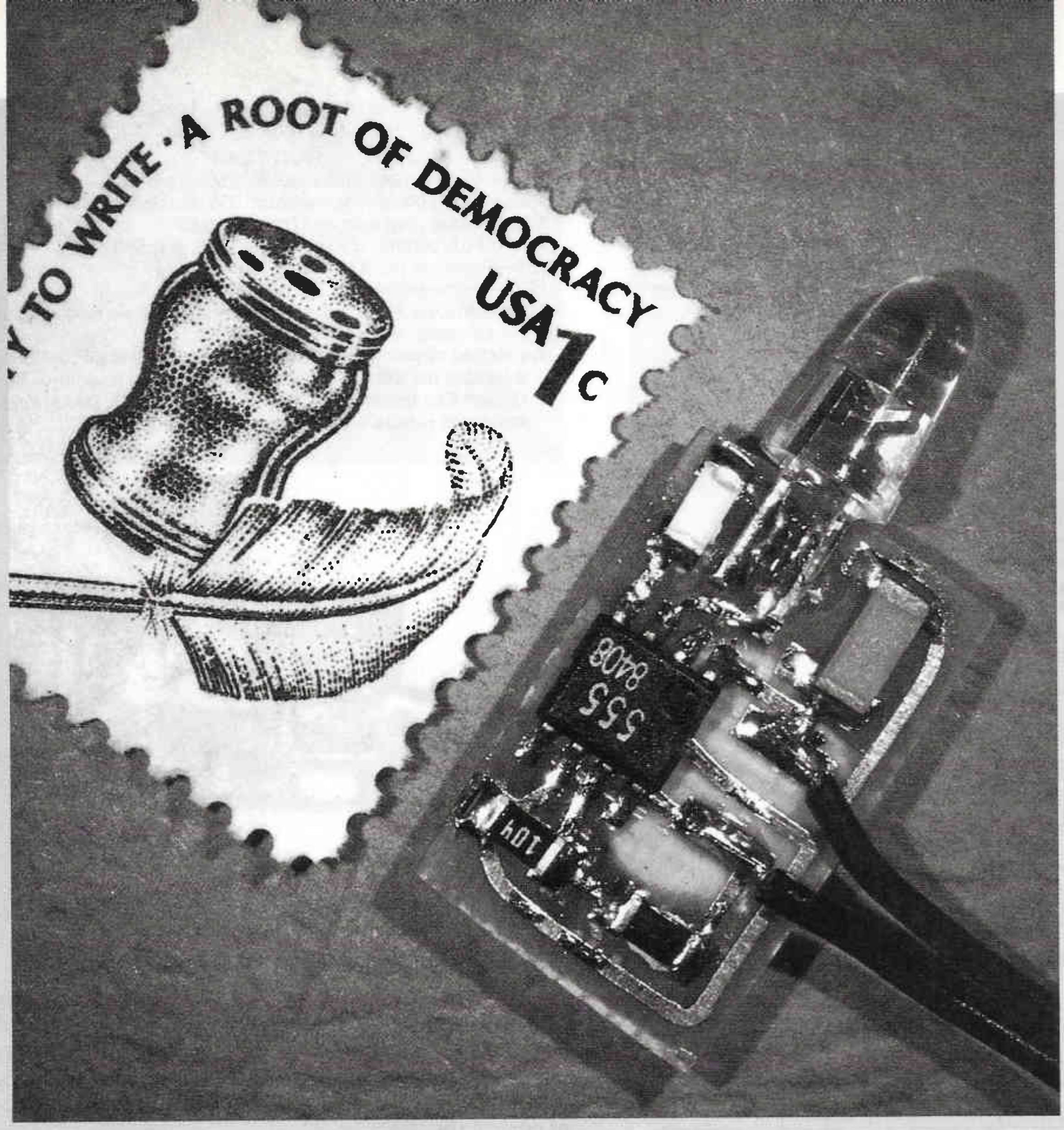

SMT PROJECT: *LED FLASHER*

Use surface-mountable components to build this subminiature LED flasher.

FORREST M. MIMS, III

A GOOD WAY TO APPRECIATE THE MINIATURIZATION POTENTial of *S*urface-*M*ountable *C*omponents (SMC's) is to assemble the subminiature LED flasher described in this article. Besides teaching you the basics of how to assemble a simple circuit using SMC's, the flasher has many practical uses. It can, for example, function as a warning flasher, indicator, a tracking beacon for night-launched model rockets or in a number of other applications.

A flasher made with conventional through-hole components can be assembled on a circuit board of about the same size. But while the conventional circuit is more than 0.4-inch thick, the surface-mount version is less than 0.1-inch thin. That means that the surface-mountable circuit can be easily slipped inside a slim slot or a space that might never be used or be usable otherwise.

How it works

Figure 1 is the circuit for the flasher. In operation, the 555 is connected as an astable multivibrator whose frequency of oscillation is given by 1.44/(R1 + 2R2)C1. With the values shown in Fig. 1, LED1 will flash once each second. The rate can be speeded up by reducing the value of R1 or C1. Resistor R3 is a current limiter.

For best results, the LED should be an AlGaAs super-bright unit. At night the flashes from such an LED can be clearly seen from more than several hundred feet away. Keep in mind that the light level from the LED is directly proportional to the supply voltage. Although Fig. 1 specifies a 9-volt supply, the circuit can be powered by from 3 to 12 volts. Figure 2 shows the relative power output of the LED over that range of supply voltages.

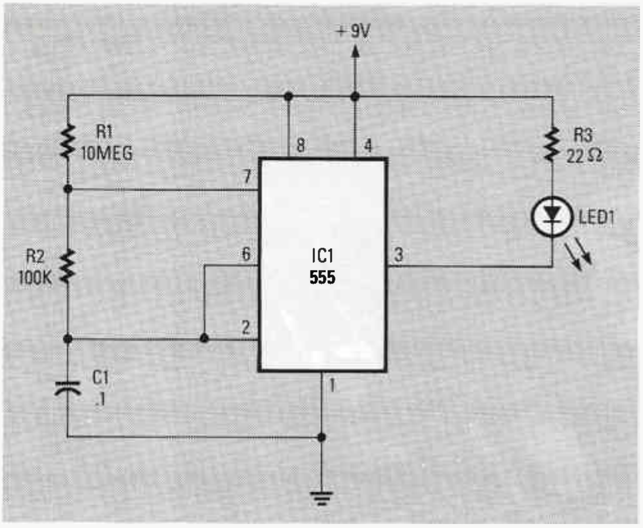

FIG. 1—WHEN THIS LED FLASHER is assembled using SMC's, the assembly is about 0.1-inch thick.

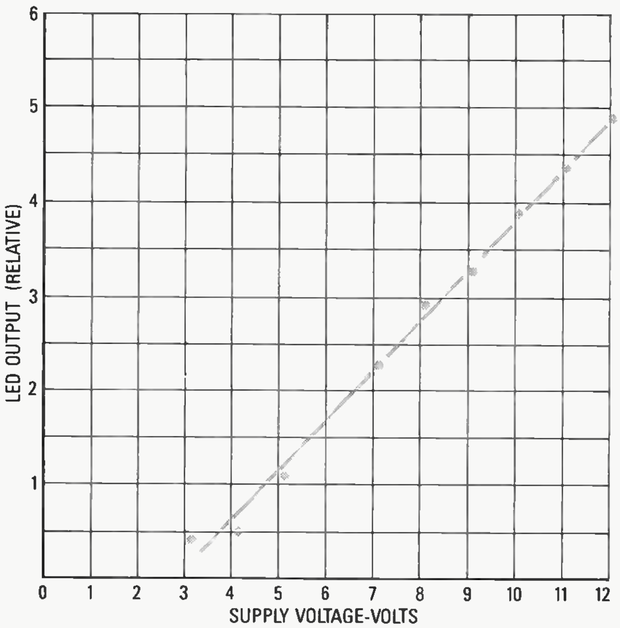

FIG. 2—RELATIVE OUTPUT of a super-bright LED is a function of its supply voltage.

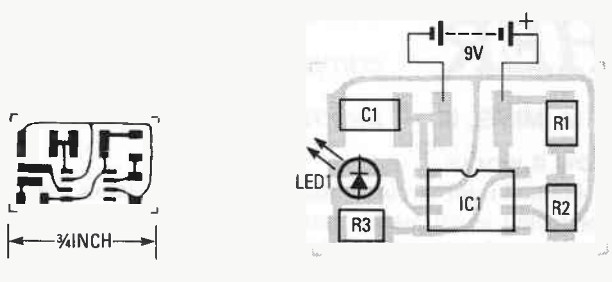

FIG. 3—USE THE PC PATTERN shown in *a* to etch the board. The parts layout is shown in *b*.

Preparing the board

The circuit should be assembled on a thin PC board. A pre-etched board and all necessary components are available from the source given in the Parts List. You can also make your own board using the pattern shown in Fig. 3-*a*. However or wherever you obtain your board, the component layout is shown in Fig. 3-*b*.

PARTS LIST

R1—10 megohms, chip resistor, 1206 size SMC
R2—100,000 ohms, chip resistor, 1206 size SMC
R3–22 ohms, chip resistor, 1206 size SMC
C1—0.1 µF, ceramic chip capacitor, 1206 size SMC
IC1—555 timer, SO-8 package
LED1—super-bright red LED, see text
Miscellaneous: PC board, 9-volt battery clip, 30-mil solder, reusable adhesive, etc.
An etched circuit board, super-bright LED, and all SMC's are available for $10.00, including postage and handling, from Gilbert Electronics, P.O. Box 95, Leesville, TX 78122. Texas residents please add appropriate sales tax.

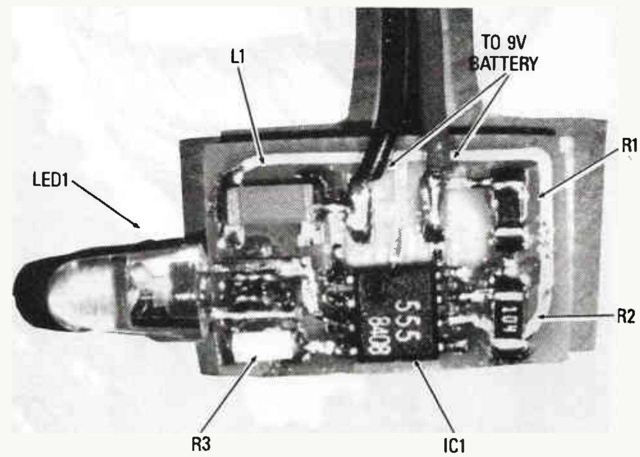

FIG. 4—THE COMPLETED CIRCUIT BOARD. The light from the super-bright LED can be seen for several hundred feet.

The circuit can be assembled in less time than an equivalent conventional circuit since no holes need be drilled in the circuit board. Although an experienced technician can install the components with a 30-watt soldering iron having a wedge tip, for best results use a 15-watt pencil iron having a pointed or conical tip.

Begin assembly by tinning the component footprints on the board. First, use an abrasive cleanser or steel wool to polish the copper traces. Wash and dry the board. Then use masking tape to attach a corner of the board to a flat, movable surface placed on your workbench.

Tinning the board takes just a few minutes. Just touch the soldering iron tip to a footprint for a second or so and then touch the end of a length of 30-mil rosin-core solder to the footprint. When the solder flows over the footprint, immediately remove the iron and solder and proceed to the next footprint. Be sure to rotate the board for best access to each footprint.

After the footprints on the board are tinned, remove any excess solder from the footprints with desoldering braid. That procedure will also remove any solder bridges.

After the board is tinned and the excess solder is removed, remove any solder balls or splashes from the traces and the substrate. Then use a defluxing agent to remove the flux residue from the board.

Installing the SMC's

Begin assembly of the LED flasher by first attaching the 555 to the board. Use the methods described in the article on SMC soldering, which can be found elsewhere in this sec-

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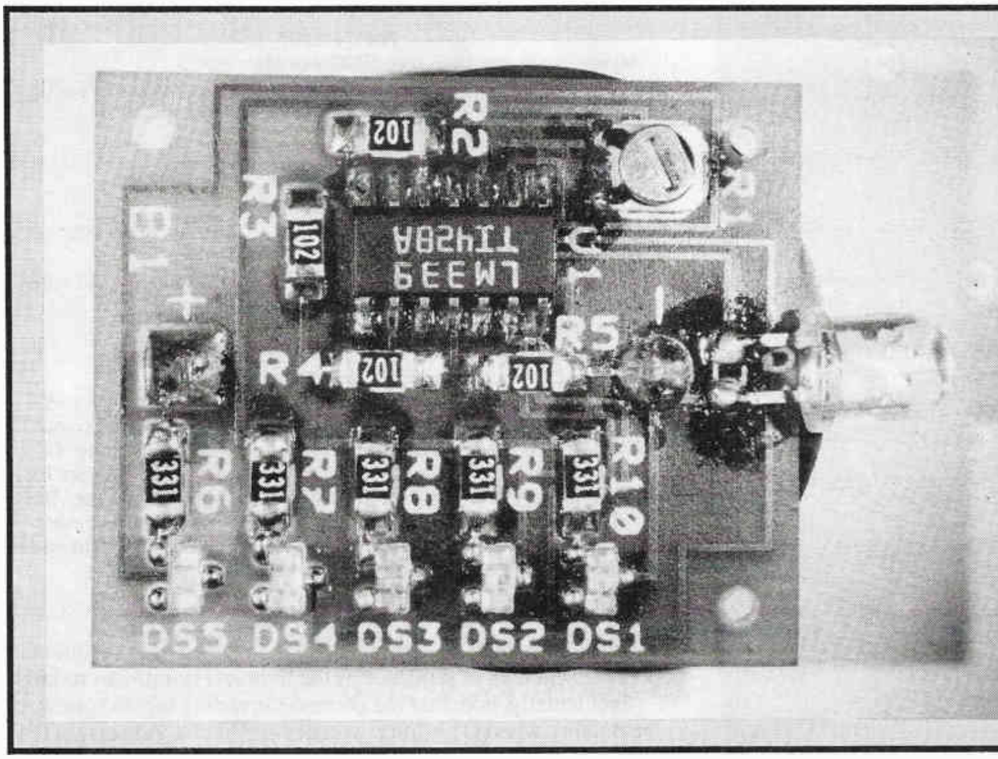

SMT PROJECT: *LIGHT METER*

Here's a simple "dark meter" that you can build using SMC's.

FORREST M. MIMS, III

IN THIS ARTICLE WE WILL SHOW YOU A SIMPLE LIGHT METER with a built-in four-element LED bargraph readout that combines the advantages of analog and digital displays. Since the number of illuminated elements in the bargraph increases as the light reaching a phototransistor decreases, the circuit can be considered a "dark meter." A bonus feature of the circuit is that it can also be used as a four-step timer or as a simple resistance indicator.

The circuit shown in Fig. 1 can be assembled on a tiny circuit board having an area of only about 1.25 square inches, a size made possible by the use of surface-mountable components. Consequently, the circuit is much more compact than an equivalent circuit assembled from conventional through-hole components.

Though the circuit is configured as an inverse light meter or "dark meter," it can be revised so that the number of glowing elements increases with the light level. It can also be used as a timer or resistance indicator by omitting phototransistor Q1. Even if none of the applications for the circuit are of interest, you might want to assemble it anyway since it provides an excellent hands-on introduction to surface-mount technology.

How it works

There is nothing new about the design of the circuit in Fig. 1, which is often called a parallel or "flash" analog-to-digital converter. To understand how the circuit works, it's necessary to review the operation of the basic inverting comparator shown in Fig. 2. In that circuit, a reference voltage is applied to the non-inverting input of an operational amplifier operated without a feedback resistor. That provides a two-state (off-on) output voltage instead of the linear output that characterizes an op-amp operated with a feedback resistor.

A voltage input is applied to the inverting input of the op-amp. When that input exceeds the reference voltage, the output of the op-amp is low; as far as the LED is concerned, the output is ground. Therefore, the LED switches on. Series resistor R1 limits current to the LED, thereby protecting both the LED and the output-driver stage of the op-amp. When the input voltage is below the reference voltage, the output from the op-amp swings to near the supply voltage (output high). The output LED, which no longer receives sufficient forward bias, then switches off.

The circuit is called a "comparator" since it compares the voltages at its two inputs and switches *on* when one exceeds the other. The circuit shown in Fig. 2 can be changed from an inverting comparator to a non-inverting comparator simply by switching the connections to the inputs. Then the output will swing from low to high when the input voltage exceeds the reference voltage.

Referring back to Fig. 1, IC1 is a quad comparator in a 14-pin SO package. Resistors R1 through R5 form a 4-stage voltage divider with taps connected to the non-inverting inputs of each comparator. The reference voltage delivered to each comparator is determined by the setting of trimmer R1.

Each comparator in Fig. 1 functions exactly like the model comparator in Fig. 2. Therefore, the outputs from the comparators will swing, in sequence, from high to low as the input voltage rises above the reference voltage applied to each comparator. The output LED's will then switch *on* in sequence as the voltage rises.

When the circuit is configured as a light meter, the inverting inputs of the comparators are connected in common to the

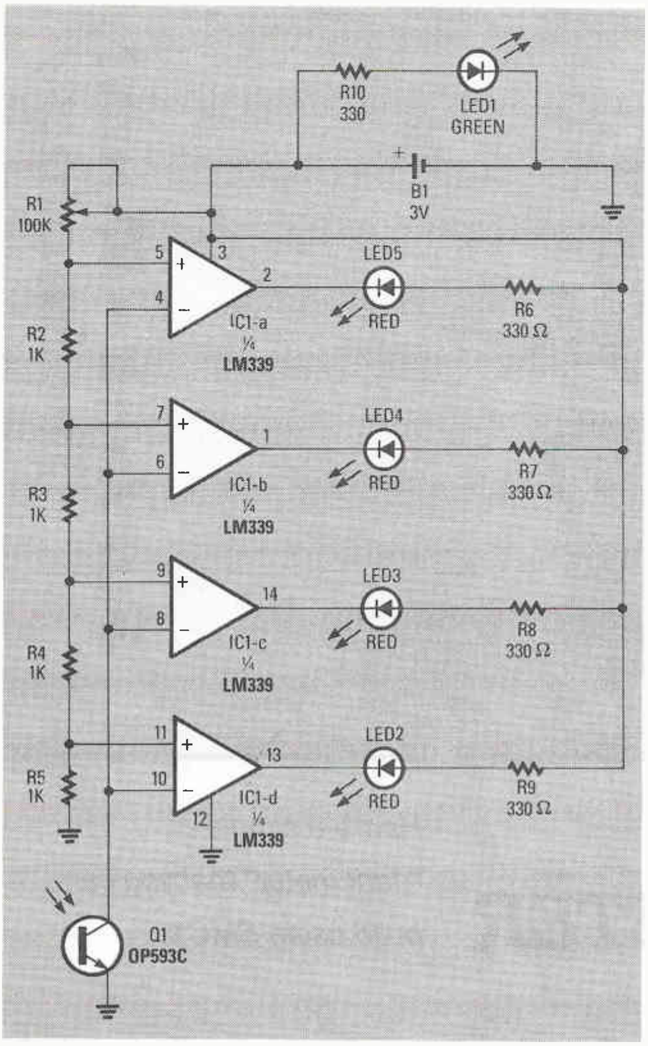

FIG. 1—USING SURFACE-MOUNT COMPONENTS this bargraph "dark meter" can be assembled on a circuit board with an area of just 1.25 inches.

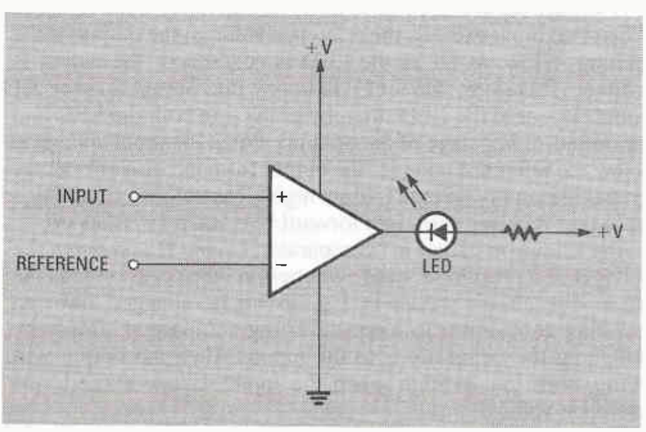

FIG. 2—IN AN INVERTING COMPARATOR, the output is low when the input voltage exceeds the reference voltage; the output is high when the input is lower than the reference voltage.

collector of phototransistor Q1. When Q1 is illuminated, its collector-emitter junction conducts, thereby placing all the inverting inputs within a few millivolts of ground. For most settings of R1, each of the four reference voltages exceeds that value. Therefore, when Q1 is illuminated, the output from each comparator is high and its respective indicator LED is off. As the light level at Q1 is gradually decreased, the voltage at the inverting inputs rises until it exceeds the first comparator's reference voltage (pin 10). The output from that comparator (pin 13) then

PARTS LIST

All resistors are 1206 size SMC's unless noted

R1—100,000 ohms, trimmer potentiometer, Micro-Ohm RV43B-CV or equivalent
R2–R5—1000 ohms
R6–R10—330 ohms

Semiconductors

IC1—LM339 quad comparator, SO-14 package
LED1—Green LED, SOT-23 package, ROHM SLM-13M or equivalent
LED2–LED5—Red LED, SOT-23 package, ROHM SLM-13V or equivalent
Q1—OP593C NPN phototransistor (TRW), or equivalent

Other components

B1—CR2320 or similar 3-volt lithium coin cell

Miscellaneous: Lithium coin cell holder (Keystone P/N 107), PC board, Reusable adhesive or masking tape, 25 or 30 mil solder

A complete kit including a drilled, etched, and plated PC board, Q1, all SMC's, battery, battery holder and solder is available from the Heath Company, Benton Harbor, MI 49022 for $19.95 plus postage and handling; for credit-card orders, call 800-253-0570. Michigan residents must add appropriate sales tax. Specify catalog number SMD-1.

swings from high to low and LED1 switches on. Additional LED's switch on in sequence as the light level continues to fall.

Incidentally, note that the common inverting inputs appear to be floating when Q1 is fully switched off (dark). Actually, a few tenths of a volt appear between those inputs when Q1 is dark. The inputs can be connected to the positive supply through a pull-up resistor, but leaving them "floating" makes the applications discussed at the end of this article possible.

Preparing the circuit board

Figure 3-a shows a suggested layout for the circuit board; the board itself is shown in Fig. 3-b. Also, an etched, silk-screened,

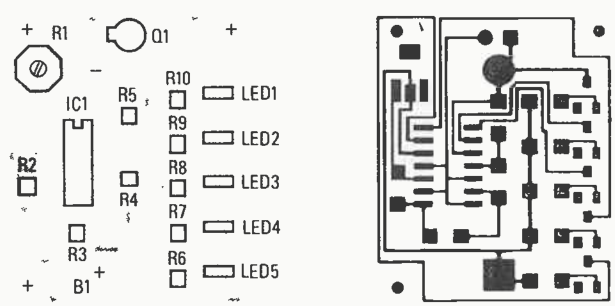

FIG. 3—USE THIS LAYOUT *a* when building the circuit. The PC board is shown in *b*.

and pre-tinned board is available as part of a kit that includes all necessary components; see the Parts List for more information. Note that the board in the kit also includes a solder-mask coating that both simplifies soldering and greatly reduces solder-bridge problems. The board also includes drilled mounting holes for a Keystone 107, or equivalent, lithium coin-cell holder.

If you build your own board, follow the tinning procedure given in the LED-flasher project described elsewhere in this special section. Also review the SMC soldering procedures given elsewhere in this special section before soldering SMC's to the circuit board.

Begin construction by installing the LM339. Be sure to solder a corner pin first. If the device stays aligned over the remaining pads, then continue soldering.

Next, install the chip resistors one at a time. If you use the tape method to hold the chip resistors in place, you can solder one terminal of each resistor; then you solder the remaining terminals. You can use the same approach when installing the LED's. No matter which method you use, until you become an experi-

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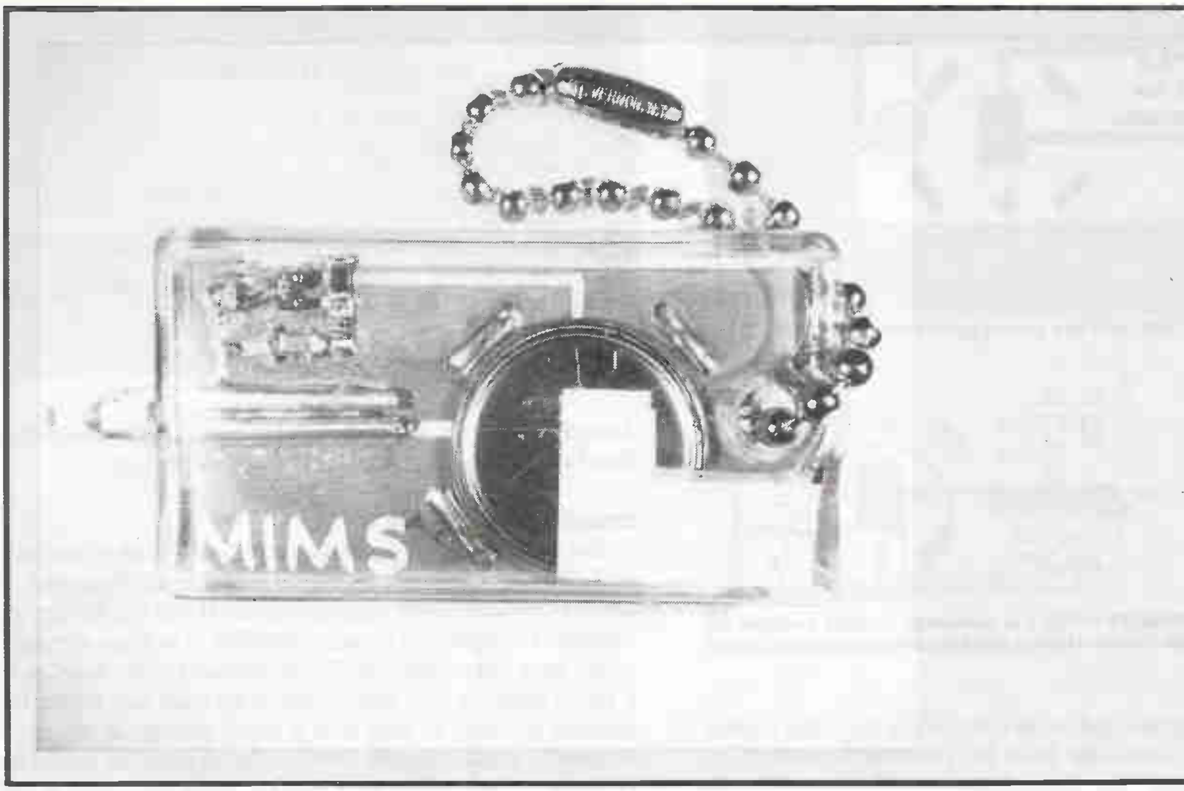

SMT PROJECT: I-R REMOTE ON A KEYCHAIN

Use surface-mount technology to build an infrared transmitter small enough to fit on your keychain.

FORREST M. MIMS, III

ONE OF THE MAJOR CAPABILITIES OF SURFACE-MOUNT TECHNOLOGY is that experimenters and prototypers can assemble ultraminiature, fully functioning circuits only a few millimeters thin. For example, you can make an optoelectronic remote-control transmitter that is so small that it can be slipped inside a plastic identification-tag holder, yet it's powerful enough to activate a receiver located more than 10 feet away.

The transmitter, shown in Fig. 1, projects a pulse-modulated red or near-infrared beam. Although a 555 timer is often used as an LED driver in this kind of application, the simple two-transistor driver shown is a better choice because it can drive an LED with greater current. Moreover, it can be powered by a supply of less than one volt.

How it works

Referring to Fig. 1, assume that Q1 and Q2 are initially off when power switch S1 is closed. Capacitor C1 then begins charging through resistors R1 and R2, and LED1. Eventually the charge on C1 becomes high enough to switch Q1 on, which then switches Q2 on.

When Q2 is on, LED1 is connected directly across battery B1 through Q2's emitter-collector junction. Meanwhile, C1 discharges to ground through Q1's base-emitter junction. Eventually the charge on C1 falls below that necessary to keep Q1 on. Transistor Q1 then switches off and, in turn, switches Q2 off. The LED is then switched off. The charge/discharge cycle is then repeated at a frequency that is determined by C1's value. The circuit drives the LED with 725 pulses per second using the values given in the Parts List.

Preparing the circuit board

An ultra-thin circuit board is required if the project is to fit inside the thin label space of a plastic ID-tag holder. A

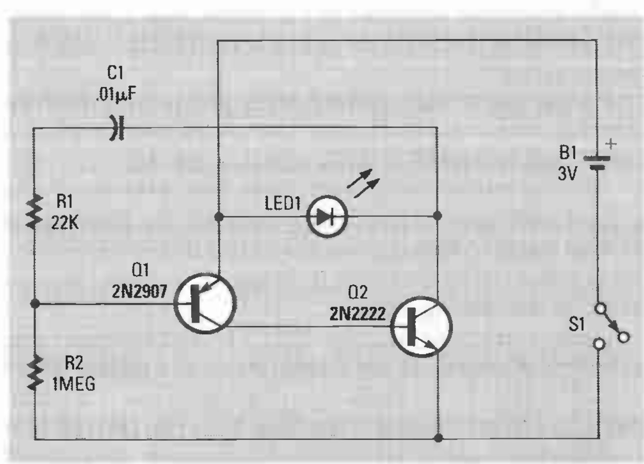

Fig. 1—THE KEY-CHAIN TRANSMITTER uses two transistors to generate a red or near-infrared beam that pulsates at approximately 725 Hz.

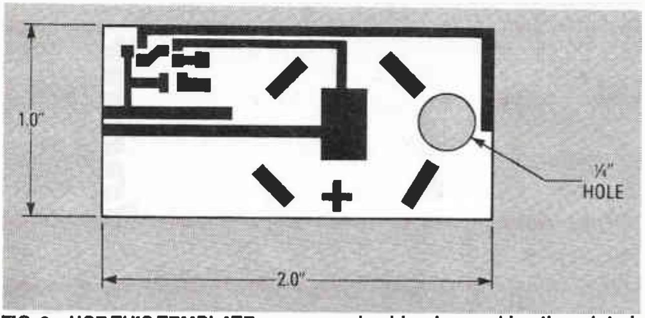

FIG. 2—USE THIS TEMPLATE as a general guide when making the printed-circuit board.

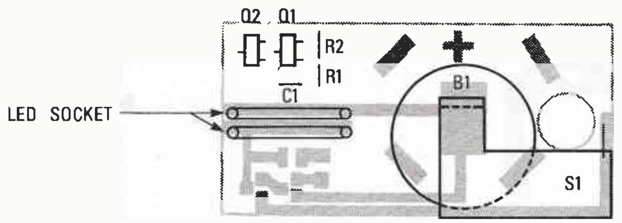

Fig. 3—THE COMPONENT LAYOUT is somewhat unusual because the LED's socket is made from thin tubing, while the battery is secured by four bumps of solder.

double-sided copper-clad board only 7-mils thick that is ideal for the project is available from the Edmund Scientific Co. (101 E. Gloucester Pike, Barrington, NJ 08007). A 12 × 18 inch sheet of the board, catalog number E35,652, sells for only $2.50.

Although the transmitter is assembled on only one side of the board, keep in mind that SMC's can be mounted on both sides of a double-sided circuit board. The foil pattern for the board is shown in Fig. 2; use it as a general guide and apply the resist by hand using a small brush, which is a somewhat faster way to make a small board compared to using the photo-resist technique.

Hand-made board

Use a pair of scissors to cut the board to size, then polish the foil with fine steel wool. Use a ¼-inch hole punch to create the hole for the keychain, then place the various components including B1, a 2016 lithium coin cell, on the board in the approximate locations shown in Fig. 3. Mark their terminal or pin locations on the board with a pencil. Then remove the parts and pencil in the required terminal footprints and interconnection traces. Be sure to include four marks around the perimeter of the lithium cell. Later, solder bumps will be placed on the marks to keep the coin cell in its proper place.

Finally, use a sharp-pointed resist pen to trace over the penciled traces and footprints. Use a straightedge for best results and be careful to avoid smearing the ink.

After the resist dries, cover the back side of the board with a protective layer of tape. Then immerse the board in an etchant solution. Etching time can be speeded up by agitating the solution. After the board is etched, thoroughly rinse the board under running water.

Unless you plan to attach the SMC's to their footprints with conductive adhesive, the footprints of the etched board should be plated with a thin layer of solder or tin. A dip-and-dunk tin-plating solution is available from The DATAK Corporation (Guttenberg, NJ 07093). Alternatively, you can melt a thin layer of standard rosin-core solder over each footprint. For best results, the solder layer should be thin and flat.

PARTS LIST–TRANSMITTER

R1—22,000 ohms, SMT size 1206
R2—1 Megohm, SMT size 1206
C1—0.1 µF, SMT size 1206
Q1—2N2907, PNP transistor, SOT-23 package
Q2—2N2222, NPN transistor, SOT-23 package
LED1—Light-emitting diode, near-infrared or super-bright red
B1—3-volt lithium coin cell, type 2016
Miscellaneous: circuit-board material, plastic keychain ID-tag holder, solder, masking tape, wire, etc.

Therefore, after all the footprints are coated, use desoldering braid to remove excess solder and solder bridges.

Installing the SMC's

The SMC's can be attached to the board with either conductive adhesive or solder. Both methods are described in detail elsewhere in this special section. If you use solder, the method of temporarily securing the SMC's in place with tape works best. Attach the SMC being soldered to the board with a bit of masking tape across one of its ends and solder the exposed terminal or pins with a small amount of solder. If necessary, make sure the SMC is flat against the board by pressing it down with a pencil eraser while the solder is still molten. Then remove the tape and solder the remaining terminal or pins.

After the SMC's are soldered in place, prepare a socket for the LED by cutting two 0.5- to 0.65-inch lengths of 62.5 mil (1/16 inch) O.D. brass tubing purchased from a hobby shop. Prepare the tubes for soldering by burnishing them with steel wool or fine sandpaper. Insert the wire from a bent paper clip in one end of one tube and melt a line of solder along its entire length. Repeat the procedure for the second tube. Then use the paper clip to hold one of the tubes in place over its footprint and remelt the solder on both the tube and the footprint until the tube is bonded in place. If necessary, apply some additional solder to the side of the tube away from the second tube's location. Repeat the procedure for the second tube. Be sure to keep solder from entering the open ends of

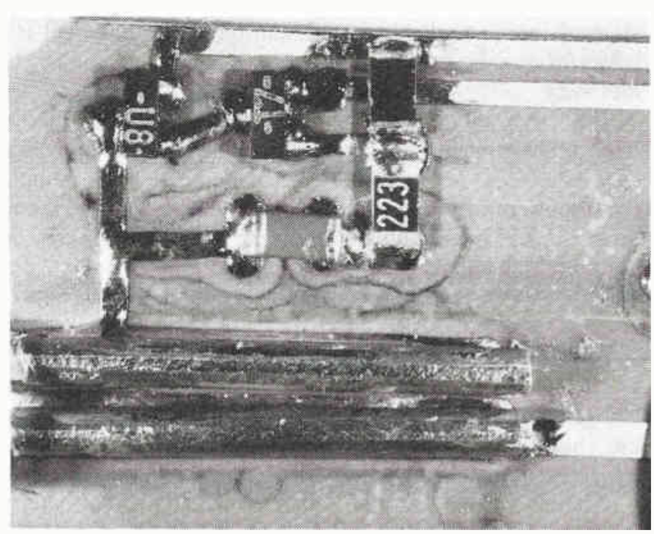

Fig. 4—THIS CLOSE-UP SHOWS how really small the components are. The transistor, labeled U8, is actually smaller than the resistor and capacitor chips. The two "giant" horizontal tubes near the bottom are the LED socket.

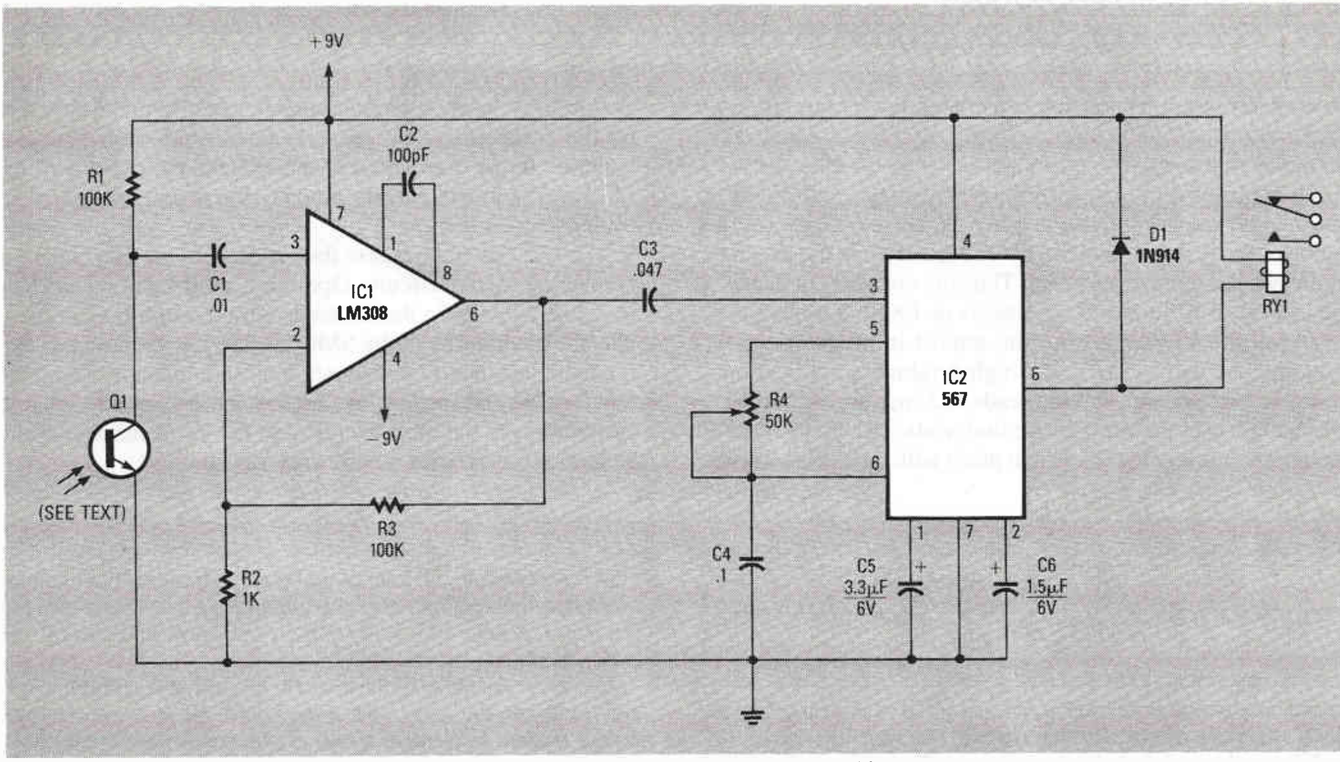

Fig. 5—IF YOU NEED A RED-LIGHT RECEIVER, try building this circuit. Most of what's needed is probably lying somewhere around your shop. Relay RY1 can be any low-current relay rated from 5 to 9-volts DC; such relay's are called "sensitive relays."

the tube, especially the end closest to the edge of the circuit board. Fig. 4 shows the tubes, and the Q1/Q2 circuit soldered to the board.

Switch SI is a *squeeze switch* made from an L-shaped piece of circuit board, as shown in Fig. 3. The exact shape of the switch is unimportant so long as it fits the allowed space. Solder a short length of wire-wrap wire to the lower side of the base of the L. With the exception of a narrow strip of exposed copper along the end of the lower side of the L (the dashed line in Fig. 3), cover both sides of the L with a clear tape. Solder the exposed end of the wrapping wire to the adjacent positive circuit-board foil. Then attach the copper L to the board with a hinge made from a strip of clear tape.

Testing the circuit

Test the circuit before installing it in an ID-tag holder. First, insert the leads of a red AlGaAs super-bright LED into the LED socket (be sure to observe polarity). Then place B1 on the board (positive side down) and press the squeeze switch. The LED should glow. When the LED is pointed toward a phototransistor or solar cell connected to the input of an audio amplifier, a 725-Hz tone should be heard from the amplifier's speaker.

If the circuit is working properly, remove the LED and slip the circuit inside the ID-tag holder. You might want to first place a self-adhesive label on the back side of the board. You can leave the label blank or record the circuit's operating parameters on it. At least two kinds of plastic keychain ID-tag holders are available from office supply companies. The one used for this project, which has a retail cost of approximately 70 cents, has a 2-mm high slot at one end, opposite the hole for the keychain.

After the circuit is inside the holder, insert the LED into its holder through the 2-mm slot. The slot also simplifies removal of the circuit board: Simply push the board out with a small screwdriver or a flat implement passed through the slot. Adjusting the squeeze switch can be tricky. If the LED stays on when the board is slipped inside the tag holder, bend the exposed copper end of the L slightly upward. If excessive pressure is required to close the switch, expose additional copper by removing a narrow strip of the tape with a knife.

Suitable remote-control receivers

The keychain transmitter can be used to trigger various kinds of optoelectronic receivers. The circuit for a suitable receiver is shown in Fig. 5. The circuit uses a 567 tone decoder to help prevent triggering by any unauthorized transmitters.

In operation, pulsed infrared or visible light is received by Ql and transformed into a pulsed voltage. Any NPN phototransistor can be used for Ql. The signal from Ql is amplified 1,000 times by ICl, an LM308 high-input impedance operational amplifier, and is passed to IC2, a 567 tone decoder. Resistor R4 and capacitor C4 determine IC3's center frequency. Resistor R4 is a potentiometer rather that a fixed resistor to permit the receiver to be tuned. IC3's output drives RY1, a low- current relay.

The receiver can be assembled on a printed-circuit board using either conventional or surface-mountable components. Both IC1 and IC2 are available in small outline packages.

Test the receiver by pointing the transmitter at Ql while carefully adjusting the receiver's R4. With R4's wiper set near its midpoint, the relay should pull in when Ql is receiving the transmitter's signal. For best results, bright ambient light must not be allowed to strike Ql; otherwise, Ql may become saturated and fail to respond fully, or at all, to incoming pulses from the transmitter. If ambient light proves to be a problem, place one or two pieces of developed color film in front of Ql to serve as a near-infrared filter, and insert a near-infrared LED into the transmitter. **R-E**

LED FLASHER

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tion. Refer to the component placement diagram in Fig. 3 to make sure the 555 is oriented properly. Then solder each terminal in place.

Continue assembly by installing the resistors and C1 one at a time and soldering them in place as we've described. The value of the resistors is given by a code in which the last digit indicates the number of zeros. Thus the code 104 indicates a resistance of 10 followed by 4 zeros or 100,000 ohms.

Install the LED next. For the utmost in miniaturization, you can use a chip LED. For high-brightness applications, use a leaded device. Cut the leads 0.2 inch from the LED, place them over their respective footprints (be sure to observe polarity), and secure the LED in place with tape. Then solder the leads in place. Repeat that procedure for the leads from a 9-volt battery clip. Figure 4 shows the completed board.

Testing the Circuit

Carefully inspect the completed circuit to make sure that all the components are properly positioned. Pay particular attention to the orientation of the 555 and the polarity of the LED and battery clip leads. And be sure to remove any solder bridges and balls.

The LED should begin to flash as soon as a 9-volt battery is connected to the circuit. Operation of the circuit will be identical to that of a flasher made with through-hole components. The thinness of the SMC flasher, however, means that it can be installed in previously unusable locations. And the relative ease and speed with which it can be assembled should convince even the most skeptical builder that surface-mount technology is an idea whose time has come. **R-E**

LIGHT METER

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enced hand-solderer of SMC's, it is essential to carefully inspect each and every junction with a magnifying lens.

Next, solder trimmer R1 to the board. Since cementing R1 to the board might interfere with its rotor if you are not careful, it's best to use a bit of masking tape to secure R1 in place for soldering.

If you want to use the circuit as a light meter, solder Q1 in place next. However, if you want to use the circuit for one of the specialized applications that we'll describe later on in this article, you should omit Q1 and, instead, solder a pair of stranded, insulated hookup wires to its two mounting holes.

Note that Q1 is a conventional through-hole component. The prototype used a tiny surface-mount phototransistor (Stettner Electronics CR10TE1). However, that meant that the phototransistor was aligned in the same direction as the readout. The result was that someone viewing the readout could cast a shadow over Q1, affecting accuracy.

To overcome that, the surface-mountable version of Q1 was replaced with a leaded phototransistor that can be installed facing away from the person viewing the readout.

The leads of the phototransistor are installed in two holes drilled in the circuit board adjacent to the negative battery holder terminal. The emitter of Q1, which is indicated by a small protruding tab (see Fig. 4-*a*), must be installed in the hole connected to the negative battery-holder terminal. Therefore, bend Q1's leads as shown in Fig. 4-*b* and insert both leads through the bottom side of the circuit board so that Q1 points away from the circuit board as shown in Fig. 4-*c*. When the

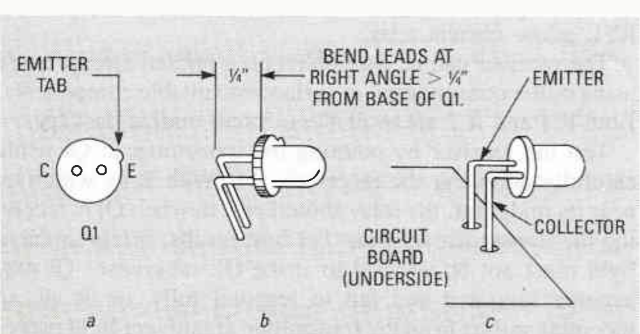


FIG. 4—THE PHOTOTRANSISTOR'S EMITTER is indicated by the tab (*a*). When installing the device, bend the leads (*b*) and mount it so that it is pointing away from the circuit board (*c*).

circuit is complete, Q1's leads will emerge from the board under the battery-holder. Therefore, be sure to keep those leads close to the board. Solder Q1's leads to their footprints and clip off the excess lead lengths.

Complete assembly of the board by installing the lithium coin-cell holder on the underside of the board. Be sure to orient the holder so that its positive terminal (the uppermost battery contact) is inserted in the hole marked +. Solder the terminals in place and clip off the protruding pins. Use caution; the clipped terminals may fly away from your clippers with considerable force.

Testing the circuit

If you have installed Q1, the circuit will function as a light meter when lithium cell B1 is installed in its holder. LED1 will glow to indicate the power is on. Use a jeweler's screwdriver to adjust trimmer R1 for the desired sensitivity. For best results, perform the adjustment with the circuit in subdued light. Generally, LED2–LED5 will switch off when Q1 is brightly illuminated. Those LED's will then glow in sequence as the light reaching Q1 is progressively reduced.

You can switch the circuit off by removing B1. Or, you can slip a small piece of paper or thin plastic under, or a short length of heat-shrinkable tubing over, the uppermost battery-holder electrode.

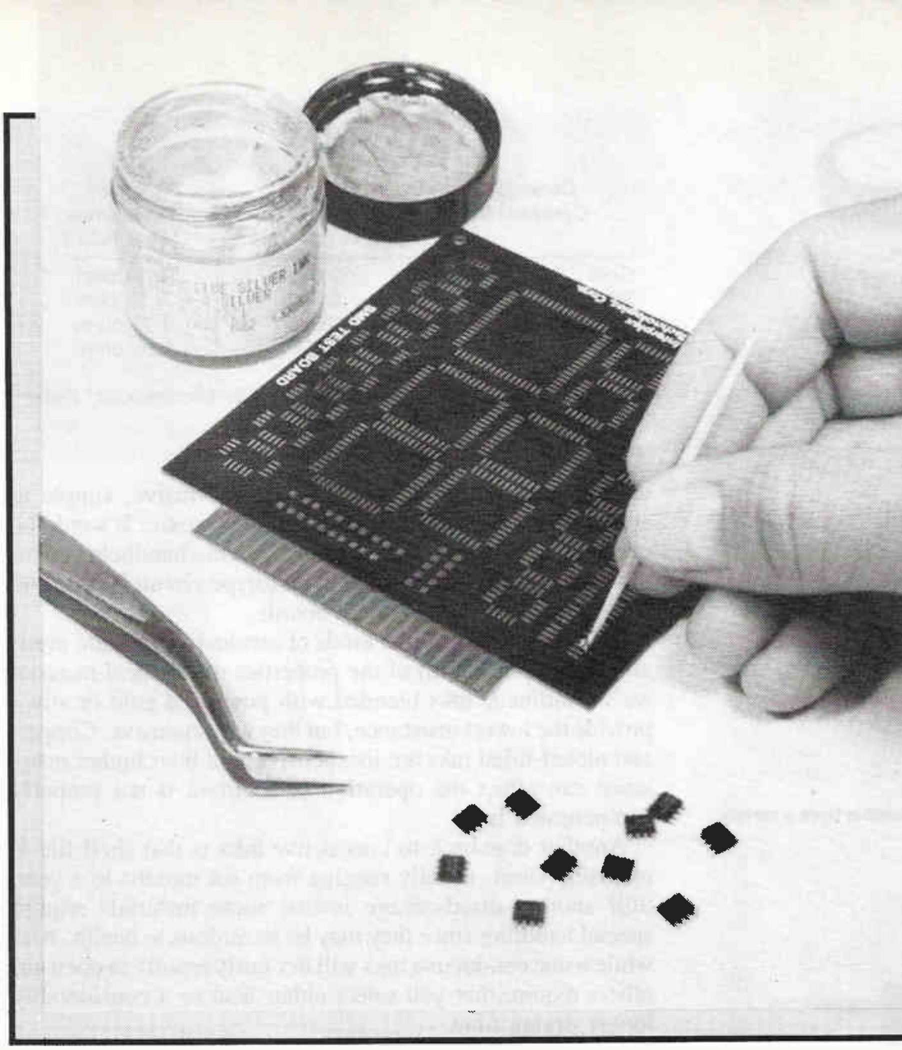
Going further

As noted previously, when Q1 is omitted the circuit can be used for other applications. For example, when a discharged capacitor is connected in the circuit in place of Q1, LED2–LED5 will glow in sequence as the capacitor is charged by the small voltage appearing at the common non-inverting inputs. One application for that configuration is as a timer whose period is determined both by the size of the capacitor and the setting of resistor R1.

The timing intervals can be increased by increasing the value of the capacitor. A new timing cycle can be started at any time by momentarily shorting the capacitor.

Another interesting application is to use the circuit to indicate resistance. When the input leads are open, all the LED's will glow. If a variable resistance is connected to the circuit in place of Q1, LED2–LED5 will glow in sequence as the resistance is lowered. We're sure that you have often wished for a visual continuity checker.

Finally, keep in mind that the circuit as presented here functions as a parallel array of inverting comparators. It can be revised to function as a parallel array of non-inverting comparators simply by reversing the connections to the inputs of the four comparators. **R-E**



Who needs copper foil and solder when you can use these conductive inks and adhesives?

Conductive Inks and Adhesives

FORREST M. MIMS, III

FOR MANY YEARS, THE HYBRID MICROELECTRONICS INDUSTRY has used electrically-conductive inks and adhesives to interconnect components, and to bond them both mechanically and electrically to a substrate. Those same inks and adhesives can also be used with all sorts of surface-mountable components.

While conductive inks and adhesives are usually used with standard circuit boards or ceramic substrates, they also make possible some very unusual and even novel circuit-assembly methods. For example, they permit surface-mountable components and even complete circuits to be installed on paper, plastic, glass, wood, painted surfaces, and many other substrates. Do-it-yourself examples of such circuits are presented elsewhere in this special section.

Figure 1 shows an assortment of conductive inks and adhesives. Whether or not you decide to experiment with conductive inks and adhesives now, chances are you will encounter those versatile counterparts of copper foil and solder sometime in the future. Therefore, let's take a close look at both conductive inks and adhesives.

Conductive inks

Electrically conductive liquids and pastes that can be applied to a substrate to form a network of interconnections are collectively known as *conductive inks*. Those materials are usually much more viscous than drawing ink, and often resemble paints. Indeed, conductive paints and coatings are available that will add RF shielding to enclosures.

Conductive inks are often used to repair broken traces and to form new traces on etched circuit boards. For decades, however, their chief application has been to form conductive traces on hybrid microelectronics substrates. Generally, a conductive-ink pattern is screen or stencil printed on a ceramic substrate that is then fired in an oven. The result is a very tough and permanent conductive network. Additional conductive layers can be added if previously-applied conductive layers are first coated with a dielectric paste.

Figure 2 shows a very simple hybrid microcircuit, a microswitch Hall-effect sensor assembled on a thin ceramic substrate. The Hall sensor is installed behind the oval protrusion. The three shaded rectangles are thick-film resistors that have been screened onto the substrate. Upon close examination, two of them show the thin slice marks that result from laser trimming, a method used for tuning a low-tolerance thick-film resistor to a precise value. The Hall sensor, the resistors, and the three terminals are interconnected by a solderable conductive ink that has been screened onto the substrate and then fired.

The conductive property of an ink is provided by powdered gold, silver, and other metals. Gold, while expensive, provides very low resistance and long-term stability. Silver is cheaper than gold but has several times its resistance. Further-

FIG. 1—CONDUCTIVE INKS AND ADHESIVES are available from a variety of manufacturers.

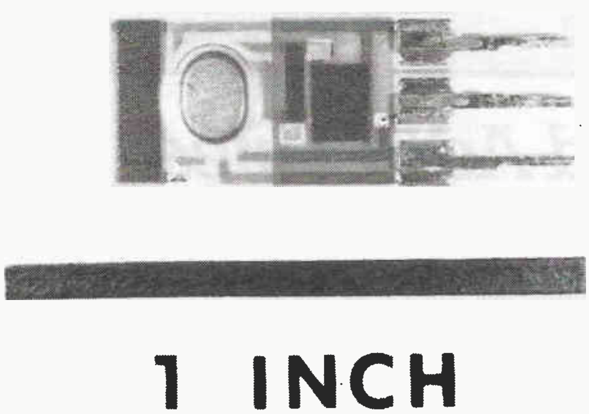


FIG. 2—THIS MINIATURE THICK-FILM hybrid microcircuit uses conductive ink for its interconnections.

more, silver may migrate from the fired ink over time. Alloys of platinum and gold or silver are used when it is necessary to solder to the fired ink. Copper and nickel are used as inexpensive substitutes for gold and silver. Both, however, have higher resistance and other less-desirable characteristics.

The resistance of conductive inks is often specified in terms of sheet resistivity. Sheet resisivity, which is given in terms of ohms-per-square centemeter, is the electrical resistance across opposite sides of a square pattern of conductive material. Resistance of conductive inks can also be given in terms of a line of material having specified dimensions. The resistances of several common inks used in the hybrid-microelectronics industry are shown in Table 1.

Ink properties

The ideal conductive ink would be an inexpensive material having zero sheet resistivity, a short curing time, and an unlimited shelf life. It would be non-corrosive, simple to apply, odorless, non-flammable, and non-toxic. It would be available in bulk for screen printing, and in a handheld pen for the instant preparation of SMC-prototype circuit boards and for the repair of conventional boards.

TABLE 1

Conductor Composition	Sheet Resistivity (ohms/square cm)	Line Resistance (1" × 0.02")
Gold	0.003	0.15 ohm
Silver	0.020	1.00 ohm
Palladium Silver	0.035	1.75 ohms
Platinum Gold	0.100	5.00 ohms

Source: "Designers Handbook on Thick Film Microcircuits," Paine Instruments, Inc.

Though many different kinds of conductive inks are available, none possess all of the properties of the ideal material we've outlined. Inks blended with powdered gold or silver provide the lowest resistance, but they are expensive. Copper- and nickel-filled inks are inexpensive, but their higher resistance can affect the operation of a circuit if not properly compensated for.

Another drawback to conductive inks is that shelf life is relatively short, usually ranging from six months to a year. Still another disadvantage is that some materials require special handling since they may be hazardous to health. And while some conductive inks will dry fairly rapidly in open air, others require that you select either heat or a considerably longer drying time.

Applying inks

In an industrial setting, conductive inks are usually applied by screening or stenciling. Those methods require considerable preparation time and often are impractical when only a few boards are needed.

Fortunately there are several ways to apply conductive inks by hand to make relatively simple circuit boards. It's even possible to make multiple-layer boards by interspersing conductive layers with a layer of insulating material.

Before going on, a few caveats are in order. The best conductive inks can be very expensive. Also, the physical properties of various inks, both when liquid and after hardening, can be very different. The metal particles in a conductive ink generally do not remain in suspension. Instead, they sink to the bottom of their container under a layer of syrupy carrier fluid. Therefore, for lowest resistance it is essential that the particles be thoroughly mixed with the carrier before the ink is applied. Shaking alone may not be adequate; stirring may be required. Finally, the carriers of most conductive inks are volatile and may be flammable, hazardous to health, or both. Therefore, it is essential to use conductive inks in a well ventilated area and to follow the safety instructions provided with a specific product.

The ideal way to apply conductive ink by hand would be with a drawing pen. However, the author has been unable to find a pen intended for that application. It is possible to load conventional drawing pens with conductive ink. But, the viscous nature of most conductive inks means that they must first be thinned with a suitable solvent or carrier. The drawback to that procedure, aside from it being rather messy, is that thinning increases the resistance of the ink. Furthermore,

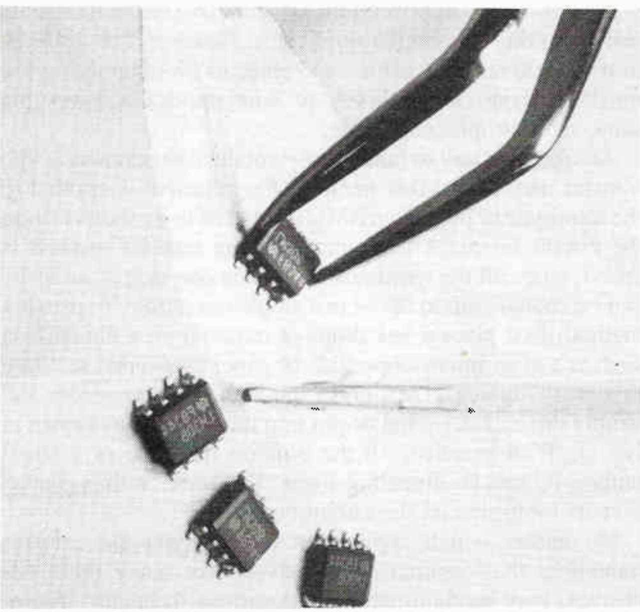


FIG. 3—USING THE TRANSFER METHOD to apply conductive adhesive to the pins of an SO device.

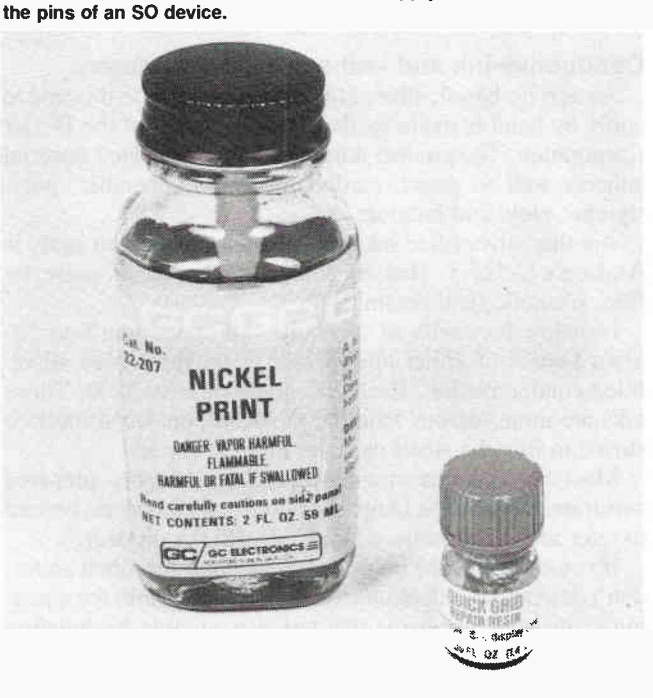


FIG. 4—THESE TWO CONDUCTIVE INKS are low priced, readily available, and suitable for hand application.

considerable experimentation may be needed to arrive at the best combination of pen-orifice size, ink, and thinner.

A simpler method is to apply the ink dot-matrix style; that is, a droplet at a time, by means of a small wire dipped into the material. Generally, dipping the wire into the ink will pick up enough fluid for several dots. The dots should be placed close together so they form a continuous line. That is best done by a quickly tapping the end of the wire against the substrate while moving it in the desired direction. With practice, you can form closely-spaced component footprints and both curved and straight lines. While that low-tech method is both slow and tedious, it works quite well with simple circuits. In fact, a complete interconnection pattern for a circuit consisting of an IC and half a dozen outboard components can be produced in 10 minutes or so.

Another method is to use a hand-held automatic dispensing syringe to form lines consisting of precisely metered dots of material. The necessary equipment, however, is expensive. A conventional syringe with a hand-depressed plunger can be used but only after some experience has been gained to avoid dispensing too much material.

It's best to experiment before selecting a method for hand applying a conductive ink. Then, before beginning work, plan each step carefully. For best results, use a pencil to draw the outline of the circuit on the substrate. If you use a transparent substrate such as Mylar, you can draw the circuit outline on a sheet of white paper that is then placed under the substrate, allowing you to trace several circuits from a single pattern.

Using inks as adhesives

The composition of some conductive inks and adhesives is very similar. And there are some inks that can provide a relatively strong bond to an SMC terminal or pin. Therefore, it follows that some conductive inks can double as conductive adhesives.

The surface-mount circuit builder can exploit the adhesive property of some conductive inks to speed up the assembly of simple prototypes. For example, the author has assembled a number of miniature circuits using only a lacquer-based conductive ink. First, the footprints for a component are formed with the material. The SMC is then placed on the footprint. Additional component footprints are made and their SMC's are positioned in place. Interconnections between the footprints are made as the circuit is assembled. Any remaining interconnections are formed after all the SMC's are in place. Though the lacquer-based ink hasn't the strength of a conductive adhesive, circuits assembled in that fashion have survived being dropped on the floor from a distance of as much as a few feet.

Conductive adhesives

Heretofore, the principle application of adhesives in surface-mounting technology has been to use non-conductive materials to bond SMC's to a circuit board in preparation for wave soldering. Although considerable literature and many application notes on the use of non-conductive adhesives for that purpose have been published, comparatively few publications about surface-mount technology even discuss conductive adhesives. That is surprising, particularly since conductive adhesives provide a fast and reliable method of attaching SMC's to a circuit board without using solder. Moreover, conductive adhesives are well suited for use with heat-sensitive components, and they can be used to make quick circuit repairs and modifications when soldering equipment is either unavailable or impractical.

The ideal conductive adhesive would be an inexpensive, single-part material having zero electrical resistance, a short curing time, and an infinite shelf life. It would be non-corrosive, simple to apply, provide a strong bond, and be easily reworked. Finally, it would be odorless, non-flammable, and non-toxic.

While the perfect conductive adhesive has yet to be formulated, a surprising number of products possess many of those properties. Adhesives blended with powdered gold or silver provide the lowest resistance, but they are expensive. Copper- and nickel-filled adhesives provide reasonably low resistance for less cost.

Some conductive adhesives have novel properties. For instance, some can actually be soldered-to using conventional tin-lead solder. And some conductive adhesives are thermoplastics that can be reworked merely by reheating the existing adhesive. In other words, a connection can be heated until the adhesive softens enough for the SMC to be removed. A replacement SMC can then be bonded in place with fresh adhesive or, with some materials, by heating the joint once again.

Unfortunately, the typical shelf-life of conductive adhesives ranges from two months to a year, with six months being fairly typical. Another drawback is that some materials require special handling since they may be hazardous to health. While those drawbacks are certainly undesirable, they are not unique to conductive adhesives. Indeed, most adhesives, conductive or otherwise, have limited shelf lives and some require special handling.

Conductive-adhesive types

Regardless of their conductive filler, conductive adhesives can be divided into several major classes. The two most important are:

- Thermosetting adhesives.—Those adhesives have proven their reliability during many years of use in the electronics industry. Thermosetting adhesives provide a very strong, inflexible bond. They are cured by means of a chemical reaction that is initiated by a chemical catalyst, heat, or ultraviolet radiation. The resulting bond is permanent, and cannot be reworked unless the adhesive is first shattered or dissolved with a solvent. Examples of thermosetting adhesives include 1- and 2-part epoxies, acrylics, and also, the polyesters.
- Thermoplastic adhesives.—Those adhesives do not undergo a chemical change when a bond is formed. Therefore, they can be reworked simply by applying heat until the material softens enough to remove the bonded component. A second application of heat permits a replacement component to be attached. Though thermoplastic adhesives provide a weaker bond than thermosetting adhesives, the fact they can be reworked makes them well-suited for many applications in which they will be subjected to only mild mechanical stresses. Examples of thermoplastic adhesives include nylon, polyimide siloxane, and various proprietary materials. Very flexible thermoplastic adhesives can be formulated by mixing synthetic or natural polymers (e.g. neoprene or rubber) in a solvent or other suitable carrier.

Applying conductive adhesives

In an industrial setting, dots of conductive adhesive are applied to each SMC footprint by screening, an array of pins, or an automatic syringe dispenser. The SMC's are then placed over the footprints and the adhesive or ink is allowed to cure or dry.

There are several ways to apply conductive adhesives by hand. A hand-held automatic dispensing syringe will place a precisely metered quantity of material over each footprint. The necessary equipment, however, is expensive. Fortunately, there are some very simple alternatives.

The simplest method is to dip a toothpick or wire into the adhesive to pick up a small droplet of material. The droplet is then touched to the desired footprint. If the material is slow drying, the conductive material can be applied to all the footprints before the SMC's are installed. If the material is fast drying, only the material required for an individual SMC should be applied.

It's possible to apply conductive adhesive to the footprints using a syringe or similar applicator. However, that application method requires some experience to avoid applying too much material. A toothpick or wire applicator gives the same-sized droplet each time.

An alternate way to hand-apply conductive adhesive is the transfer method. In that method, the adhesive is applied to the terminals or pins of an SMC instead of to its footprints on the circuit board. An advantage of the transfer method is speed, since all the terminals or pins on one side of an SMC can be coated with material in a single operation. To use that method, first place a few drops of material on a flat surface such as a glass microscope slide or paper card taped securely to a work surface. Then grasp the SMC with tweezers and simply dip each terminal or pin into the material as shown in Fig. 3. With practice, all the pins on one side of a small outline IC can be dipped at once. The SMC is then placed over its footprints on the circuit board.

No matter which application method you use, always remember that conductive adhesives, like many other adhesives, may be flammable or hazardous to health. Therefore, always work in a well-ventilated area and be sure to follow the safety precautions provided with the product.

Conductive-ink and -adhesive manufacturers

An acrylic-based, silver-filled ink that is easy to mix and to apply by hand is made by the Hysol Division of the Dexter Corporation. The product number is *140-18-Q*. That material adheres well to paper, cardboard, wood, phenolic, polystyrene, vinyl and butyrate.

Another silver-filled ink that is easy to mix and to apply is Amicon's *C-225-3*. That ink adheres well to paper, polyester film, phenolic, and ceramic.

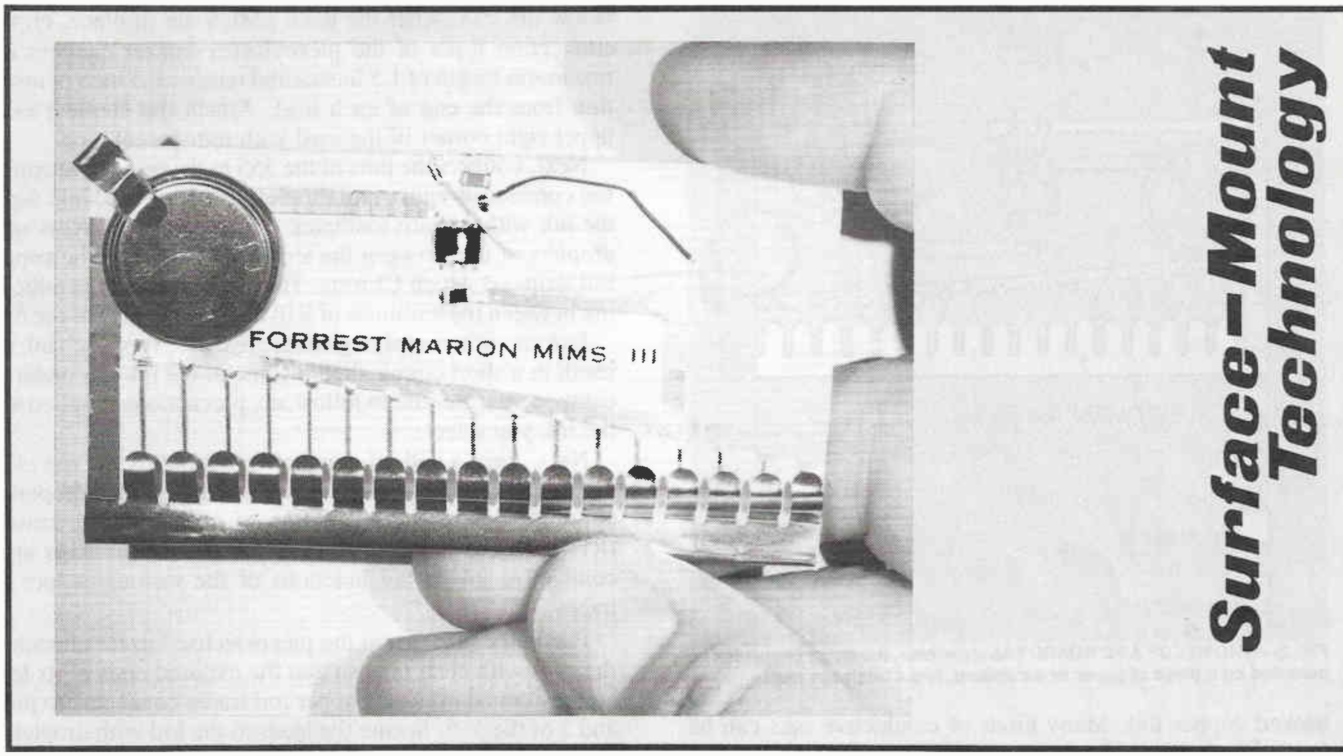
Dynaloy, Inc. sells an evaluation kit containing four 50-gram bottles of either epoxy-base or polyester-base silver-filled conductive ink. Each 200-gram kit costs $100. Those inks are more viscous than the preceding ones and must be stirred to mix the silver particles and the carrier.

Most inks can be cured by placing a freshly prepared substrate under a desk lamp. For best results, however, be sure to refer to the instructions supplied with the product.

If you can't find the industrial-grade inks described above, don't despair. GC Electronics sells conductive inks for repairing etched circuit boards that are also suitable for bonding SMC's to a circuit board. Their highly conductive *Silver Print* (Cat. No. 22-201) is $21.62 for half a troy ounce (price subject to change with the price of silver). GC's *Nickel Print* (Cat. No. 22-207), has a higher resistance than *Silver Print*, but the two-ounce bottle shown in Fig. 4 costs only $3.83. Both of those products can be ordered from GC Electronics or purchased at many electronics dealers.

If those GC products aren't readily available, you can obtain satisfactory results with a silver-filled conductive lacquer available from some automotive parts stores that sell NAPA parts. The product, which is dyed to resemble copper, is Loctite Quick Grid Window-Defogger Repair Kit. The kit, which sells for around $7.25, includes a small bottle containing 0.05 fluid ounces of silver-filled lacquer. It is also shown in Fig. 4.

Dynaloy, Inc. sells various one-part conductive-epoxy pastes that are well-suited for conductive bonds. An evaluation kit containing 50 grams each of one pure-silver and two silver-alloy adhesives costs $100. Conductive adhesives are also available from Amicon. R-E



SMT PROJECT: *A BUSINESS-CARD TONE GENERATOR*

Who needs a PC board?

FORREST M. MIMS, III

SURFACE MOUNT TECHNOLOGY OFFERS CIRCUIT BUILDERS entirely new methods of assembling solid-state circuits. For example, the circuit shown in Fig. 1 can be installed without solder on an ordinary paper business card. The prototype version of the circuit was built in around 90 minutes.

The primary value of this particular circuit-on-paper is that it vividly illustrates some of the unique capabilities provided by surface-mount technology. Among the more interesting techniques it will show you is how to form resistors simply by drawing them in place with a graphite pencil.

How it works

Referring to Fig. 1, the circuit for the tone generator consists of a 555 timer connected as an astable oscillator. The circuit's frequency of oscillation is controlled by resistors R1–R17 and C1. The output from the 555 drives a piezoelectric-buzzer element. Note that Fig. 1 specifies a power supply voltage of 6. Keep in mind that selected 555's and low power 555's can be powered by 3 volts.

Circuit assembly

Figure 2 shows both the conductor traces and the component layout for the assembled circuit. For the circuit to fit on a business card, two specialized components are required. The piezoelectric-buzzer element is a miniature 0.7-inch diameter unit made by Murata Erie North America, Inc. (2200 Lake Park Drive, Smyrna, GA 30080). The keyboard is a section of clip-on cylindrical-radius contacts made by Tech-Etch, Inc. (45 Aldrin Road, Plymouth, MA 02360). One finger from a contact section is used for the battery clip. An 18-finger section, which we'll call the switch strip, is used for the keyboard.

The circuit also requires conductive ink and adhesive-

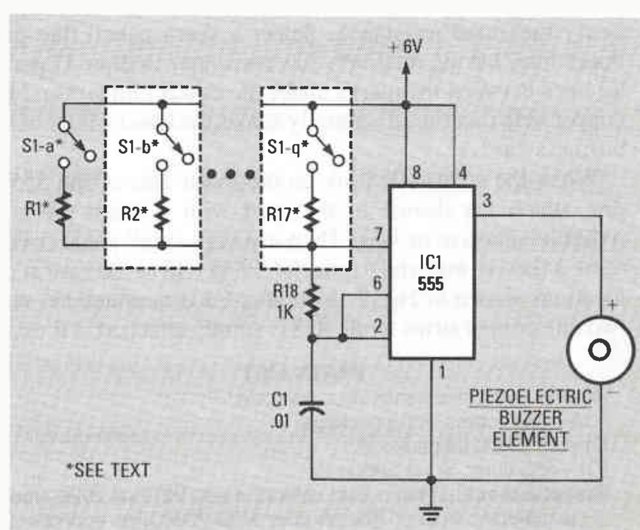


FIG. 1—A SIMPLE TONE-GENERATOR. Resistors R1–R17 consist of nothing more than lines drawn with a graphite pencil.

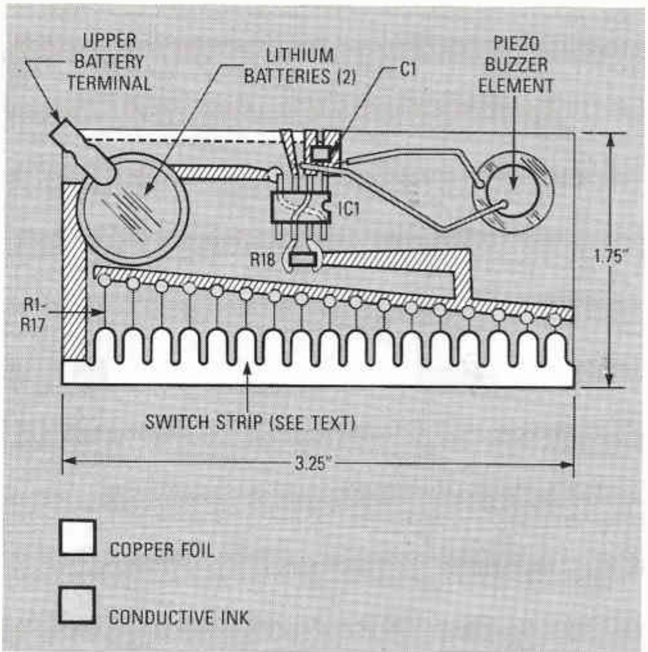


FIG. 2—WHO NEEDS A PC BOARD? As show here, the entire circuit can be mounted on a piece of paper or cardboard, like a business card.

backed copper foil. Many kinds of conductive inks can be used. Silver-filled inks, however, will work best. Adhesive-backed copper foil is available from The Datak Corporation (3117 Patterson Plank Road, North Bergen, NJ 07047).

Begin assembly of the circuit by using conductive ink and a suitable applicator (a wire or a sharp toothpick) to interconnect pins 4 and 8 on the back side of the 555. Set the 555 aside to allow the ink to dry.

Next, follow the layout in Fig. 2 and apply adhesive-backed copper strips to a business card. Note that a single strip is placed along the upper left side of the back of the card.

Cut an 18-finger section from a length of the cylindrical-radius contacts to form the switch strip. Clip off the left-most flexible finger from the switch strip and slip the strip over the lower side of the card. Use a pencil to make a small mark directly below each contact finger, and then remove the switch strip.

Use a multimeter to measure the resistance of lines drawn on paper with various kinds of pencils. While some pencils produce non-conductive lines, others produce lines having an easily measured resistance. Select a sharp pencil that produces lines having relatively low resistance to draw 17 parallel lines between the marks under the contact fingers and the copper strip that runs diagonally across the lower center of the business card.

When the silver-filled ink on the lower side of the 555 is dry, attach the device to the card with a small piece of reusable adhesive or wax. Then use very small pieces of the same adhesive material to attach C1 and R18 to the card at the locations shown in Fig. 2. Note that C1 is mounted between two thin copper strips while R18 is simply attached to the card

PARTS LIST

R1–R17—graphite pencil lines, see text
R18—1000 ohms, 1206 package
C1—.01 μF, 1206 package
IC1—555 timer, SO-8 package
Miscellaneous: Lithium coin cells (2 each, 2016 or 2020 type), piezoelectric buzzer (Murata-Erie MSJ-70383, or equivalent), switch strip (see text), battery terminal (see text), adhesive-backed copper foil, conductive ink, graphite pencil, business card, etc.

below the 555. After the three SMC's are in place, clip the connection leads of the piezoelectric-buzzer element to a maximum length of 1.5 inches and remove 0.1 inch of insulation from the end of each lead. Attach the element to the upper right corner of the card with transparent tape.

Next, connect the pins of the 555 to the respective copper-foil conductors with small droplets of silver-filled ink. Apply the ink with a sharp toothpick or piece of wire. Also apply droplets of ink between the terminals of C1 and the copper-foil strips on which C1 rests. Then form traces of conductive ink between the terminals of R18 and pins 6 and 7 of the 555.

Use care when applying conductive ink. Too much ink will result in a short circuit should some of the ink run under the components. Be sure to follow any precautions supplied with the ink you select.

Next, form a path of conductive ink across the top of the 555 to interconnect pins 2 and 6. Then apply small droplets of conductive ink at the junction of each graphite resistor (R1–R17) and the diagonal copper conductor. Also apply conductive ink at the junctions of the various copper foil traces.

Fasten the leads from the piezoelectric-buzzer element to the card with clear tape so that the exposed ends of its leads are positioned over the copper foil traces connected to pins 1 and 3 of the 555. Secure the leads to the foil with droplets of conductive ink.

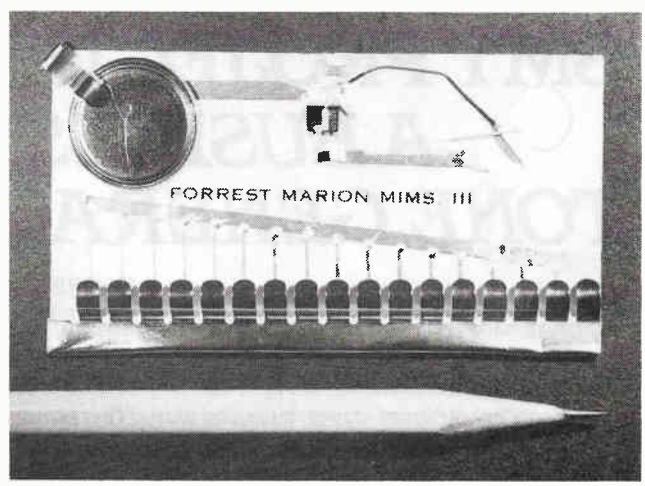


FIG. 3—THE AUTHOR'S PROTOTYPE. Pressing different contacts will cause different pitched tones to be produced.

After the conductive ink has dried, slip the switch strip over the bottom side of the card as shown in Fig. 2. Crimp the ends of the strip slightly to secure the switch strip in place. Crimping will also insure that the switch strip makes good electrical contact with the copper trace applied to the left border of the card.

Cut a single finger from a length of cylindrical-radius contacts to form the upper battery terminal. Place a layer of tape under all but the end of the flexible-finger portion of the terminal. The tape is necessary to prevent a possible short should the edge of one or both coin cells make contact with the terminal. Crimp the clip-on portion of that terminal to the upper-left corner of the card as shown in Fig. 2.

Figure 3 is a photograph of the completed circuit. Figure 4 is a highly magnified view of a droplet of conductive ink over the junction of one of the graphite resistors and the diagonal copper strip. Figure 5 is a highly magnified view of C1. Note that Fig. 5 also shows a droplet of conductive ink bonding one

BUSINESS-CARD TONE GENERATOR

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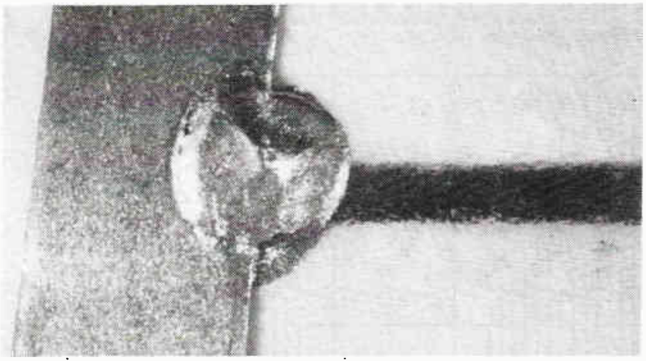


FIG. 4—A DROPLET OF CONDUCTIVE INK connects a graphite resistor to the copper strip.

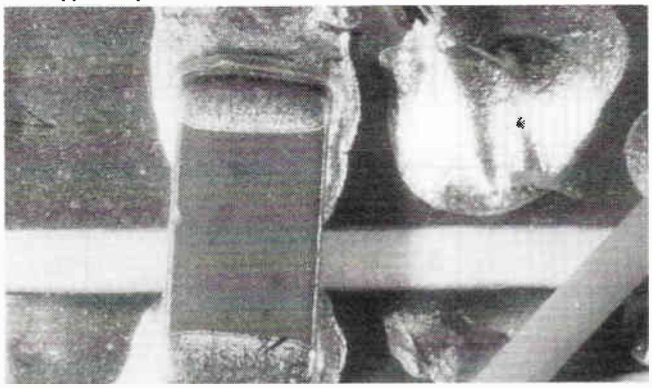


FIG. 5—A CLOSE-UP OF C1. To its right, a droplet of conductive ink bonds one lead from the buzzer to a foil strip.

of the wires from the piezoelectric-buzzer element to its respective copper strip.

Testing the circuit

Carefully inspect the circuit to make sure no errors have been made. Then insert a stack of two lithium coin cells under the upper battery terminal (positive sides down). A tone should be heard when one of the switch-strip fingers (keys) is pressed against its respective graphite line on the surface of the card.

Caution: Use care to avoid shorting the terminals of one or both coin cells. Lithium cells may explode when shorted.

When the circuit works properly, try pressing each of the keys in turn. That test will illustrate the difficulty of drawing graphite lines having uniform resistance per unit length. The prototype circuit yielded a rather irregular sequence of tones as each key was pressed in ascending order.

The circuit has no power switch. When the circuit is not being used, insert a slip of paper between the lithium coin cells and the upper battery terminal or remove the coin cells.

Going further

Whether or not you choose to build this circuit, I hope the construction details presented here have given you some new ideas about the unique possibilities offered by combining surface-mountable components and conductive inks. While you might not wish to build miniature circuits on paper business cards, you can build such circuits on glass, plastic, wood, painted metal and many other substrates. In short, a circuit can be built on virtually any available surface. For example, the author has used silver-filled ink and SMC's to build LED transmitter circuits directly on the battery holders that power the circuits. **R-E**

HAND-SOLDERING SMC's

continued from page 98

Solder paste or cream is offered in convenient syringe applicators by Alpha Metals and Multicore Solders. Figure 3 shows a syringe of solder paste that contains 1.5 ounces of 63%-tin/37%-lead solder paste. Note that when a paste or cream is supplied in that manner, it's generally necessary to mix the material before use by rolling the barrel of the syringe against a hard surface. After the needle is attached and the plunger is installed, a small quantity of material can be applied directly to each SMC footprint as shown in the opening of this article.

It's best to practice applying the paste on a piece of paper first. That will allow you to learn how to cope with unforeseen situations such as how to deal with paste that continues to emerge from the needle after you have coated a footprint. (Hint: Keep some paper towels handy.)

If the syringe method proves too tricky, you can apply the solder paste or cream directly to the terminals and pins of the SMC's themselves using what is called the transfer method. First, place some paste or cream on a clean, flat surface; a glass microscope slide works well. Next, use tweezers to pick up an SMC and then dip its terminals or pins into the paste. When all the terminals or pins are coated with a thin layer of the material, place the SMC on its footprints on the circuit board. The sticky flux will hold the SMC in place while you repeat that procedure for any remaining devices.

After all the components are in place, inspect the board to make sure each SMC terminal or pin is properly positioned. You must then cure the board by preheating it long enough to drive off the volatile solvents from the paste or cream. The curing procedure is very important because it precludes the formation of unwanted solder balls and reduces the thermal shock that that the board and its SMC's are subjected to during reflow soldering.

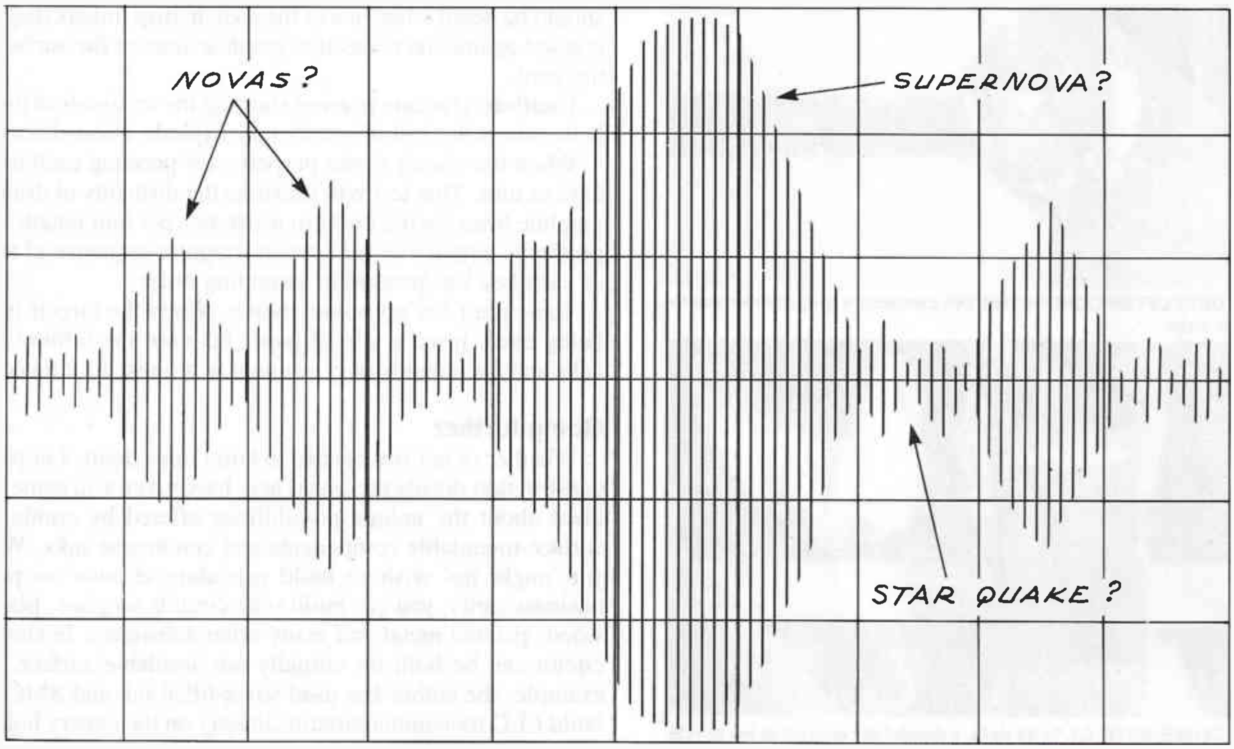
IMPORTANT: Various solder pastes and creams may require different curing times and temperatures. They may also require different reflow soldering times and temperatures. Therefore, it is essential to refer to the manufacturer's literature about a specific product to avoid unreliable solder connections.

With that *caveat* in mind, a typical curing procedure is to heat the board in a convection oven for from 10 to 30 minutes at 85° C. After the paste is cured, the board is removed and the oven temperature is increased to the melting temperature of the solder. The board is then placed back in the oven until the solder melts and then quickly removed. Alternatively, if the board can withstand the temperature, it can be reflow soldered by placing it on a hot plate. Another alternative is to use a desktop vapor-phase system such as Multicore Solders' *Vaporette*.

Once again, it is essential to carefully follow the instructions for a particular solder paste or cream. Also, it's very important to avoid overheating the SMC's. Most, but not all, SMC's can withstand the temperature of molten solder for 10 seconds. **R-E**

ALL ABOUT

Gravitational Impulses



New data shows repeatable and predictable gravity detected from the center of the milky-way galaxy. Build a simple gravity detector and observe that phenomena for yourself.

GREGORY HODOWANEC

THE MAIN PROBLEM TODAY IN ATTEMPTING to observe gravity signals has been the insistence by astrophysicists that only the quadrupole radiated gravity signals predicted by Albert Einstein are permissible in the universe; even though quadrupole-type gravity signals have eluded detection. On the other hand, monopole-type gravity signals that exist profusely in the universe are produced by Newtonian gravity gradients, which are easily detected with a simple device developed by the author.

New scalar definition

A field in physics may be defined as a region in space which is under the influence of some "effect": typically an electric, magnetic, or gravitational effect. Vector type fields must be described in terms of both magnitude and direction. Less understood is the theory of fields that are scalar in nature and described in terms of magnitude alone. A common example of a scalar field is temperature; even though the gradient of such a field will be vectorial. Less well-known are the scalar aspects of gravitational, electric, and magnetic fields.

The author uses the term *scalar* in a unique way. When all the vectors of a force are directed *parallel* to each other, the force can be fully specified by a magnitude only. Therefore, any two forces whose vector fields run *parallel* to each other will interact (as scalars) in a simple algebraic superposition with no need to use vector analysis.

A scalar electric field is realized by the application of a voltage between two parallel plates, where all the electric lines of force are *parallel* to each other. A scalar magnetic field is realized in the H-fields that emanate from the end of a bar magnet into the space just beyond the magnet. Such a "curl-free" magnetic field is scalar for only a short distance because that is the region where the magnetic flux lines are all *parallel*. Similarly, the earth's gravitational-field is also a scalar field because the gravity flux is *parallel* and directed downward only.

It is the author's presumption that scalar gravitational, electric, and magnetic fields may interact with each other only when the fields run exactly *parallel*. Taking that theory a step farther means that energy can be transferred from one scalar field to an other.

> The author has developed a device to detect gravity waves, and explains its operation with a new scalar field theory. We are publishing the results of some of his experiments in the hope it will foster experimentation in gravity detection. By confirming the author's data, new ideas and concepts might emerge to form the basis of a new technology.

Capacitor charging

Traditionalists recognize the polarization "effect" in a dielectric that is placed between the parallel plates of a capacitor. If a DC voltage is applied to the plates of a capacitor, an electric field will develop between the plates . A traditionalist would see the electric field as a vector force directed from the negative plate to the positive plate. The magnitude would depend upon the intensity of the electric field generated by the movement of electrons from one plate to the other. But few traditionalists recognize the scalar nature of such parallel electric fields, and their possible interaction with other similarly directed (scalar) fields; primarily, Earth's ever-present gravity field. The presence of a scalar gravity field on the plates of a capacitor will cause the molecules to polarize just as though an external DC voltage were being applied.

In Fig. 1, the dielectric in the capacitor is shown polarized by the Gravity-fields; that results in a potential difference across the capacitor that drives a current. Because the gravity-fields are modulated by various universe and terrestrial processes, the energy components are both DC and AC in nature. Therefore, as long as the vectors of the gravitational and electric fields run parallel to each other, then both fields can be considered scalar fields, which means energy from one field can be transferred to the other. The gravity field may be visualized as squeezing the plates, however minutely.

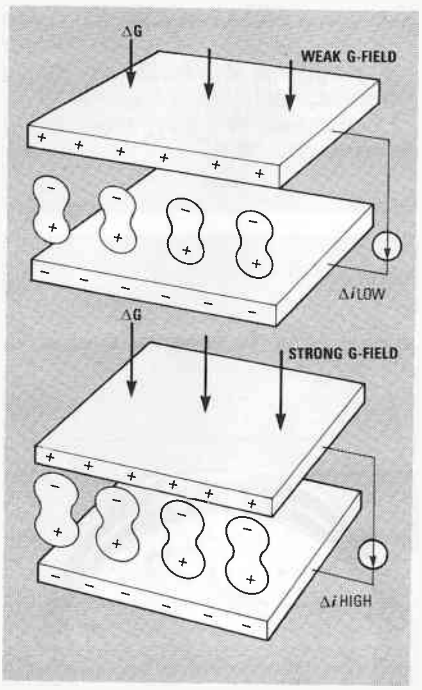


FIG. 1—POLARIZATION EFFECT IN A CAPACITOR is due to the actions of a gravity field. The change in current flow, Δi, through the capacitor is proportional to the gravity field, ΔG.

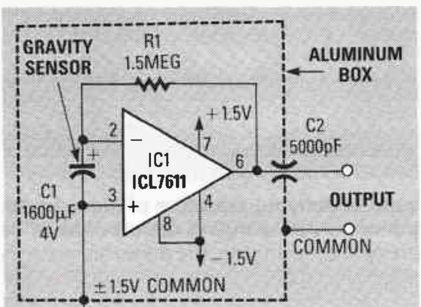


FIG. 2—THE BASIC GRAVITY DETECTOR is a current-to-voltage converter. The current through capacitor C1 is proportional to changes in the strength of the gravity field. IC1 amplifies the signal generated across capacitor C1 to drive a chart recorder or digital multimeter.

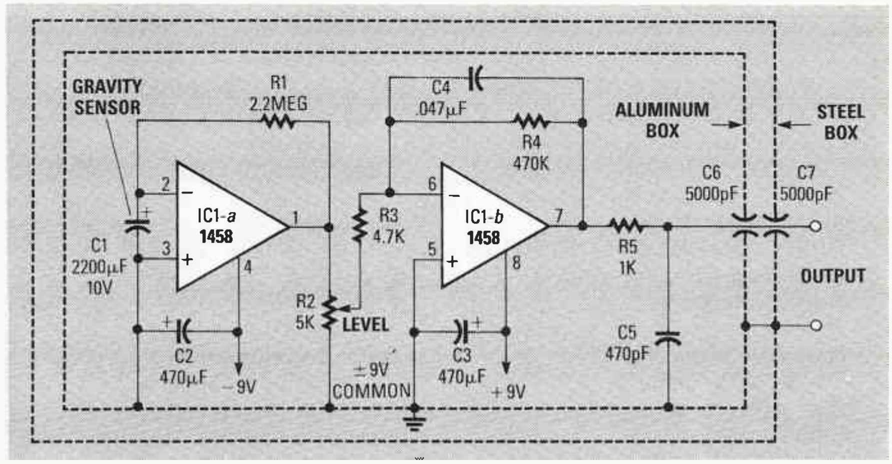
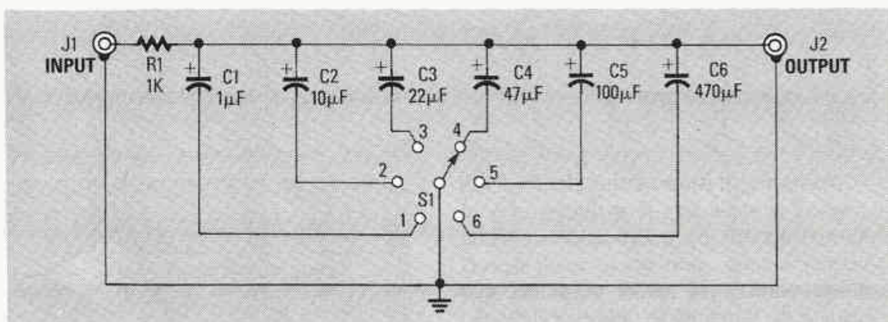


FIG. 3—A BUFFERED GRAVITY DETECTOR increases the detector's sensitivity to gravity fields, and also adds frequency stability to the detector. The aluminum box, the outer steel enclosure, and feedthrough filter capacitors C6 and C7, isolate the detector from electromagnetic interference (EMI).



S1 POSITION	FILTER CUT-OFF	S1 POSITION	FILTER CUT-OFF
1	1KHz	4	21Hz
2	100Hz	5	10Hz
3	45Hz	6	1Hz

FIG. 4—GRAVITY DETECTOR OUTPUT FILTERING will limit the detectors response to certain astronomical distances. The lower cut-off frequencies of 21 Hz to 1 Hz are best for gravity sensing within our own galaxy. Most of the author's chart recordings were done using a 10 Hz filter. The filter should be placed in a RFI shielded enclosure.

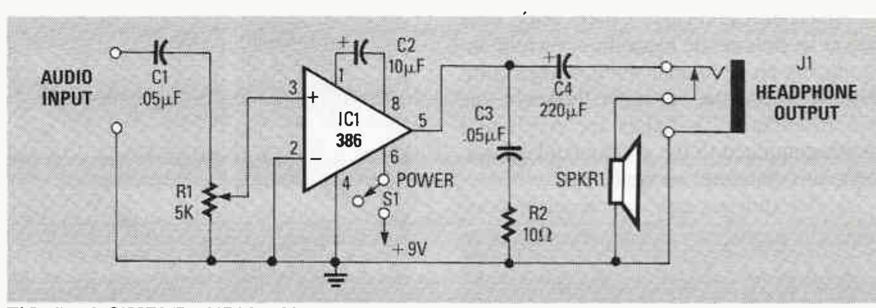


FIG. 5—A SIMPLE AUDIO AMPLIFIER can be used to listen to gravity signals that sometimes contain a musical rhythm.

Thermal tests were conducted at an independent laboratory. Heating the electrolytic capacitor in a shielded hot oil bath (75°C), and cooling in a shielded ice bath (0°C) had no discernible effect on signal output. However, chilling in a shielded dry-ice bath (−79°C) resulted in a steady decrease in amplitude, frequency, and burst rate until the only signal remaining was the 1.5 volt DC. The question was raised: Shouldn't the burst rate have remained constant if caused by gravity waves. The laboratory found that the total effective capacitance decreases rapidly at temperatures less than −30°C. A 300 to 400 fold decrease was observed at −79°C, so that 1600μF at −79°C would have an actual capacitance of only 4μF; effectively, there was very little capacitance in the detector at that temperature, which would account for the diminished burst rate.

PARTS LIST

BASIC GRAVITY DETECTOR
R1—1.5 Megohms, ¼-watt
C1—1600 μF, 4 volts, electrolytic
C2—5000 pF, Feedthrough type
IC1—ICL7611 (Intersil) op-amp
Aluminum Enclosure

BUFFERED GRAVITY DETECTOR
All resistors are ¼-watt, 5%
R1—2.2 Megohms
R2—5000 ohms, potentiometer
R3—4700 ohms
R4—470,000 ohms
R5—1000 ohms
Capacitors
C1—2200 μF, 4 volts, electrolytic
C2–C3—470 μF, 10 volts, electrolytic
C4—.047 μF, ceramic disc
C5—470 pF, ceramic disc
C6–C7—5000 pF, feedthrough type
Semiconductors
IC1—LM1458 (National) op-amp
Miscellaneous: Aluminum enclosure, Steel box.

LOW PASS FILTER
All resistors are ¼-watt, 5%
R1—1000 ohms
Capacitors, 10 volts, electrolytic
C1—1 μF
C2—10 μF
C3—22 μF
C4—47 μF
C5—100 μF
C6—470 μF
Other components
J1–J2—coaxial connector
S1—SPGT rotary switch
Miscellaneous: Aluminum enclsoure RF shiled.

AUDIO AMPLIFIER
All resistors are ¼-watt, 5%
R1—5,000 ohms, potentiometer
R2—10 ohms
Capacitors
C1, C3—.05 μF, ceramic disc
C2—10 μF, 10 volts, electrolytic
C4—220 μF, 15 volts, electrolytic
Semiconductors
IC1—LM386 (National) linear audio amplifier
Other components
J1—Phone jack, 2-circuit type, with one circuit normally closed
SPKR1—8–16 ohms miniature speaker

OTHER GRAVITY DETECTOR
All resistors are ¼-watt, 5%
R1—200 ohms, potentiometer
R2—2 Megohms, potentiometer
Semiconductors
IC1—LM741 (National) op-amp
Miscellaneous: Aluminum enclosure RF shield.

REFERENCES

Hodowanec, Gregory. *All About Gravitational Waves,* **Radio Electronics,** April, 1986, pages 53–56.
Hodowanec, Gregory. *Rhysmonic Cosmology,* 1985.

Browian agitation of the electron-ion structure in capacitors is attributed only to thermal actions by traditionalists. While thermal actions contribute to some aspects of white-noise, the author concludes that much of the white-noise, and especially the low-frequency 1/*f* type impulse noise, is very much independent of the thermal environment. Indeed, the energy causing noise of those types is directly attributable to gravitational fields. The 1/*f* noise is simply the mathematical expression for the rate of occurrence of gravity field events. It is termed 1/*f* noise because the stronger impulses are generated less frequently than the more moderate impulses, and the moderate impulses are seen less frequently than the weaker impulses.

An electrochemical or battery effect does occur in electrolytic capacitors, thereby introducing an additional small voltage component across the capacitor; however, the electrochemical voltages are very small when compared to the gravity field effects, and can, therefore, be neglected.

A flat (planar) type of capacitor positioned so that the flat side is up, is more effective as a gravity detecting element than a tubular-type of capacitor. Different capacitor types (electrolytic, mylar, polystyrene, paper, ceramic disc, etc.) will give the same response to the gravity field provided the effective capacitances are equal.

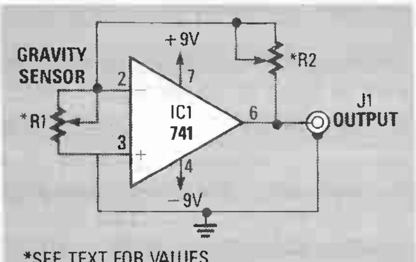


FIG. 6—A GRAVITY DETECTOR THAT USES a resistor sensor to detect gravity signals. Like the capacitor sensor, the resistor sensor is a 1/*f* noise detector. Shield the detector unit from possible RFI interference.

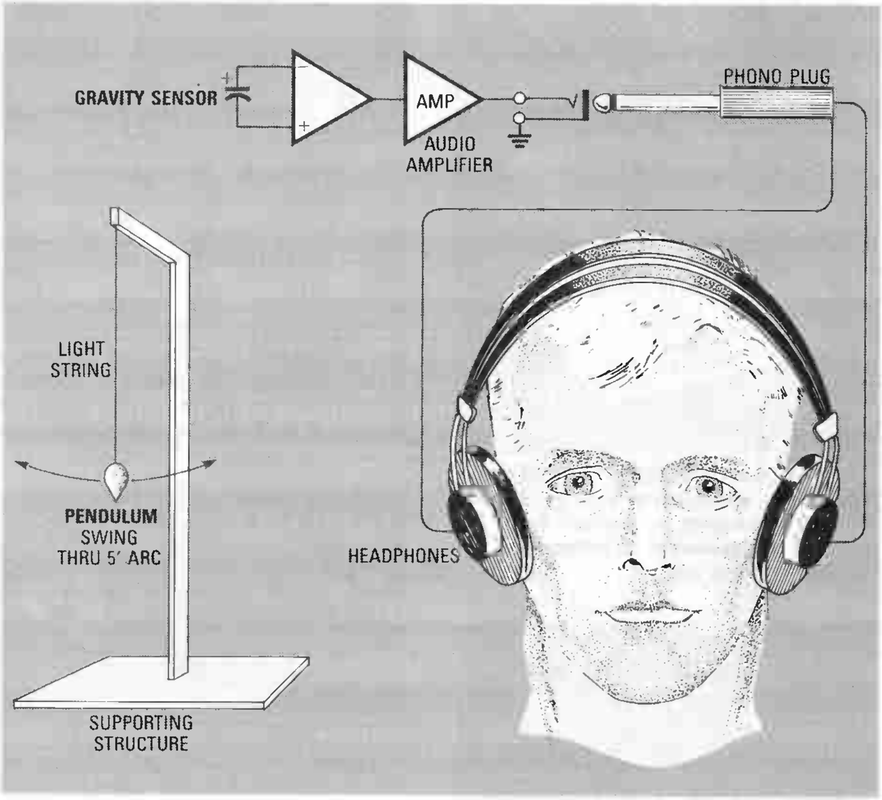


FIG. 7—A PENDULUM IN MOTION will disturb the underlying structure of the universe. Adjust the detector's volume for a good response to the swinging disturbance of the vacuum. Even though the pendulum will eventually stop swinging, the disturbance in the universe continues to remain!

Gravity detectors

A scalar gravity-signal detector is shown in Fig. 2. The small gravity-impulse current generated across capacitor C1 is coupled to the input of IC1 for amplification. IC1 functions as a current-to-voltage converter. The capacitance, C1, and the feedback resis-

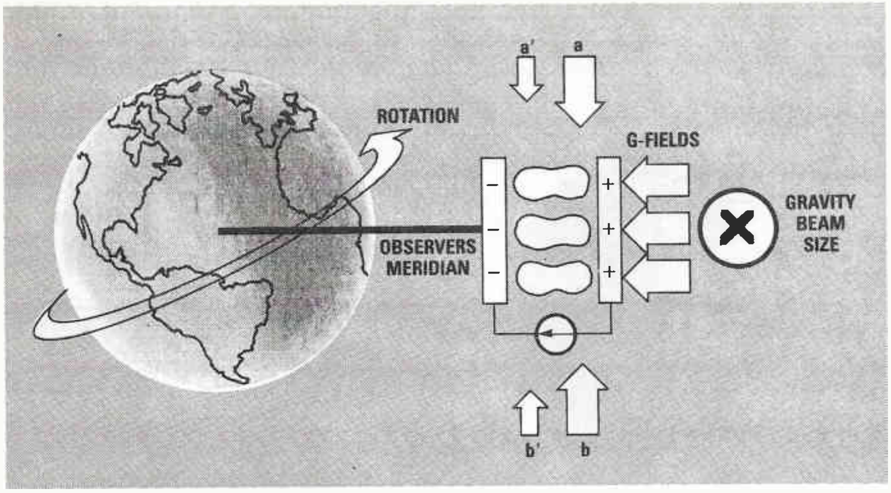


FIG. 8—THE POLARIZATION EFFECTS on a capacitor are caused by the g-fields, *X*, perpendicular to the flat capacitor plates. As the Earth spins, the capacitor sensor sweeps across the cosmos in a beam like fashion. G-field components, *a* and *b* that are tangential to the flat capacitor plates do not affect the capacitor.

tance, R1, are chosen sufficiently high in value so that input circuit "resonances" are very much less than 1 Hz.

Varying C1's value will have an affect on the response time to gravity-field fluxuations; that is because the op-amp's output is a harmonic type oscillation, where the polarization "stress" induced in the capacitor's dielectric by gravity flux is also "restored" by the reverse electric potential developed by the feedback resistance in that circuit. Therefore, the "oscillations" are a function of both the sensing capacitance and the feedback relationship, and will, thus, have different frequencies for different capacitor and feedback resistor values.

The use of CMOS op-amp ICL7611 enables efficient operation with a ± 1.5 volt battery supply. The unit is assembled in a small aluminum box with the batteries enclosed within the box, and the output is brought out with a feedthrough capacitor in order to eliminate any possible response to ambient RF-type signals.

An improved gravity sensor is shown in Fig. 3. The extra op-amp, IC1-b, will add additional gain and frequency stability. Op-amp output off-set components may be included, however, the author found nulling the op-amp to be unnecessary. The gravity detector is enclosed within an aluminum box which is also within another heavy steel box in order to shield the detector from any electromagnetic interference (EMI). A highly permeable magnetic mu-shield was also used to guard the detector against the Earth's magnetic field, and stray magnetic fields generated by the power company's AC line voltage. However, the author found mu-shielding unnecessary. Tests showed no apparent difference in data when using a mu-shield, or when the aluminum box was used alone.

Most gravity detection will require additional output filtering, as shown in Fig. 4. The cut-off frequencies of the filter will limit the detectors response to certain astronomical distance ranges. For example, if the output shunt-capacitance is about 470μF, then the response appears to be largely limited to our own immediate group of galaxies. With lower values of output shunt-capacitance, i.e., a higher filter cut-off frequency, the response will include gravitational effects from deeper in space.

Scalar fields of the gravitational type are generated profusely in the universe. The individual impulses of gravity gradients will be heard as a "noise spectrum" through an audio amplifier, or seen as "grass" on an

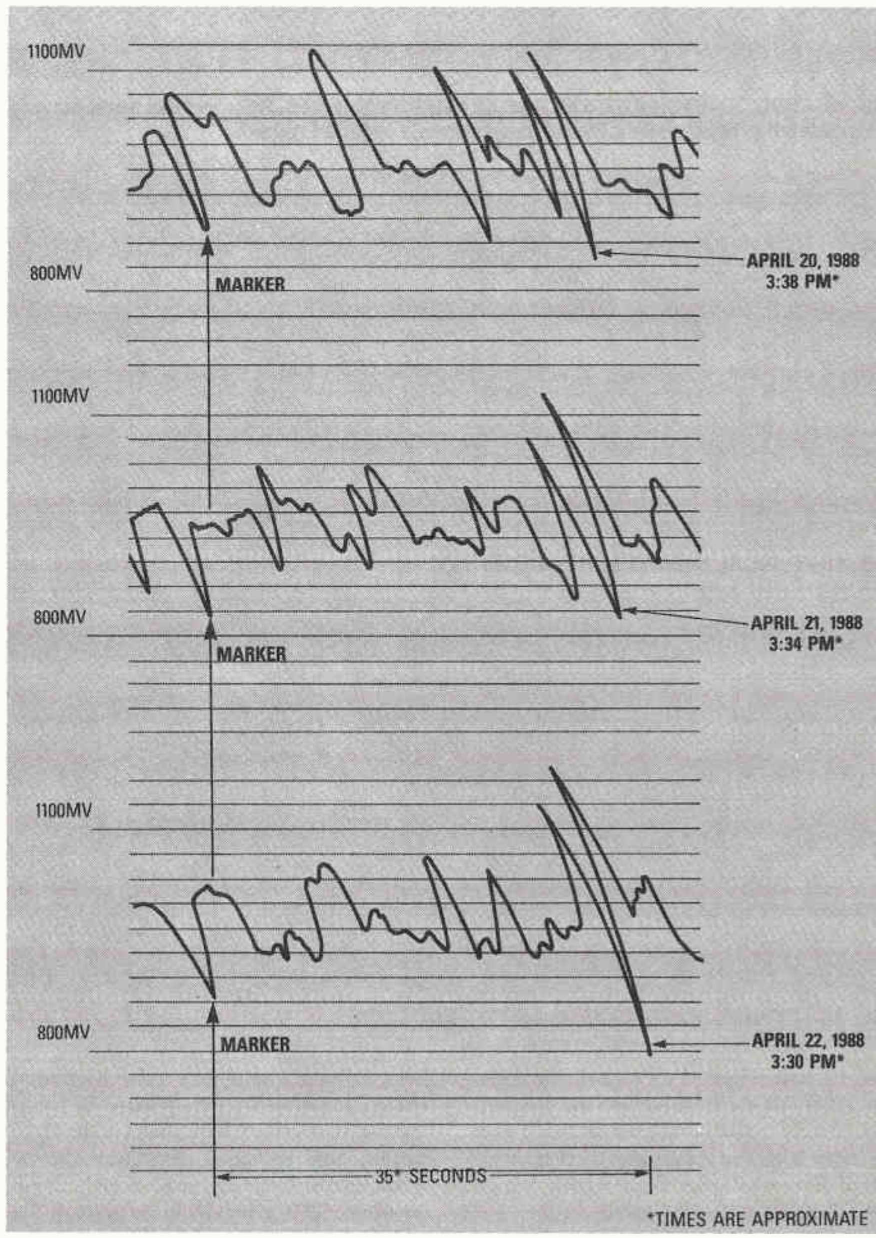


FIG. 9—DATA SHOWS REPEATABLE AND PREDICTABLE gravity impulses detected from the center of the Milky-Way galaxy. A sidereal day is about 23 hours and 56 minutes. If measurements of astronomical events are timed from an Earth's position, then the event should be seen about 4 minutes earlier each day by civil (24 hour) time. That fact is shown by the author's data, where the galaxy center appears four minutes earlier on three successive days.

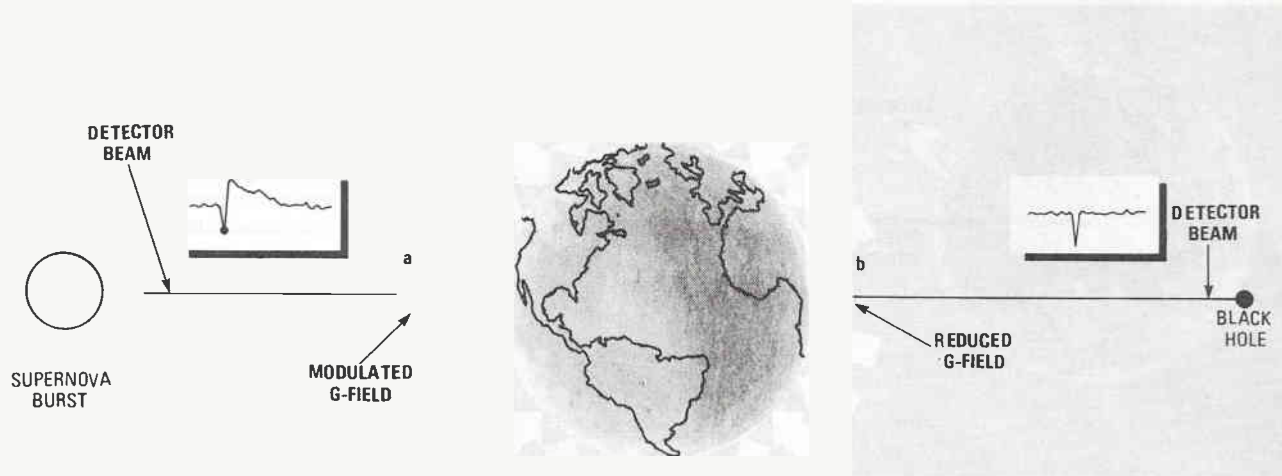


FIG. 10—TWO COMMON ASTRONOMICAL GRAVITY EVENTS. A Supernova burst causes a modulated g-field, while a Black Hole causes a reduced g-field.

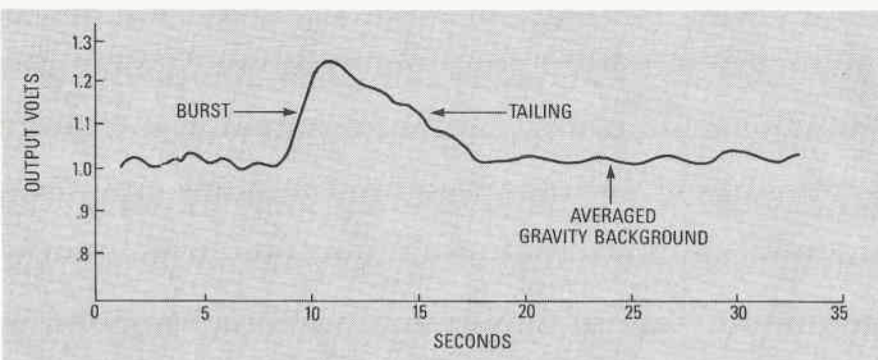


FIG. 11—TYPICAL NOVA GRAVITY RESPONSE.

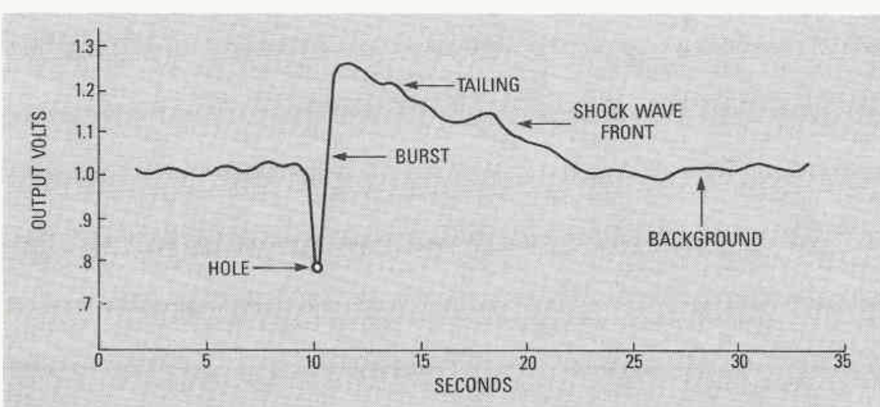


FIG. 12—TYPICAL SUPERNOVA GRAVITY RESPONSE.

oscilloscope. Figure 5 shows a simple audio amplifier that can be used with the detector. The readily available LM386 IC has a gain of about 200. The author also used an audio amplifier available from Radio Shack (#277-1008) with good results.

Another simple gravity detector shown in Fig. 6 uses a low-cost LM741 op-amp. Here, the *l/f* noise is generated in a carbon composition resistive element rather than in a capacitive element. The current impulses developed in the resistor by gravity signals are also highly amplified and converted to voltage impulses by the op-amp. To facilitate the more critical adjustment of the Fig.6 circuit, both the input resistance and the feedback resistance are made variable. Input resistance R1 is generally in the order of 100 to 200 ohms for most of the IC's tested. For optimum results, the feedback resistance R2 is generally in the order of 1000 to 10,000 times R1's value. The experimenter should first adjust the input resistance to about 150 ohms, and then adjust the feedback resistance for maximum *l/f* noise response. Then, re-adjust the input resistance for optimum results.

The output voltage from the gravity detector can be used to drive either a chart recorder, or fed to a DMM (*D*igital *M*ulti*M*eter) and plotted by hand. The detector's output voltage varies quite slowly, with most observations taking several seconds or minutes to record.

Gravity Communication

Present-day communication systems largely make use of the interaction of electric and magnetic flux fields in a vector type radiation field, ie., electromagnetic waves, to convey information between distant points at the speed of light. Such systems range over the entire electromagnetic spectrum, from the very low frequencies (VLF) to the super high frequencies (SHF), reaching past the microwave frequencies and well into the optical range of frequencies. Such vector-type radiation fields have been extensively developed over the years and are in common use today. However, according to the author's theories, scalar-type radiation fields, such as the gravitational field, might eventually be useful to convey information "instantly"

Scientists recognize the physical universe in basic terms such as mass, energy, fields, etc., and all else is but an integration of such factors. The author theorizes that gravitation has 'infinite' wavelengths and are thus not wave-like. Moreover, gravitational impulses travel at Plank's time interval of about 5.4×10^{-44} seconds, and do not propagate at the speed of light—a slow speed when compared to Plank's time constant. The gravity impulse is a monopole and appears to travel almost instantaneously everywhere in the universe.

Listening to the sounds of scalar gravity signals with the audio amplifier can be quite

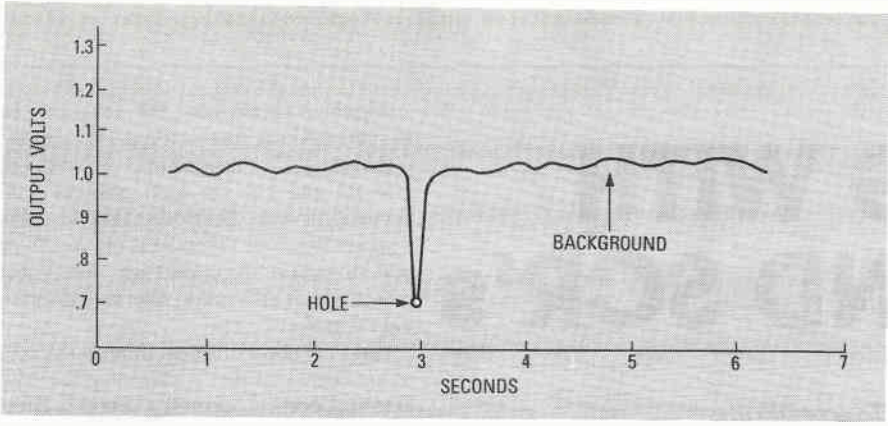


FIG. 13—ANCIENT BLACK HOLE GRAVITY RESPONSE.

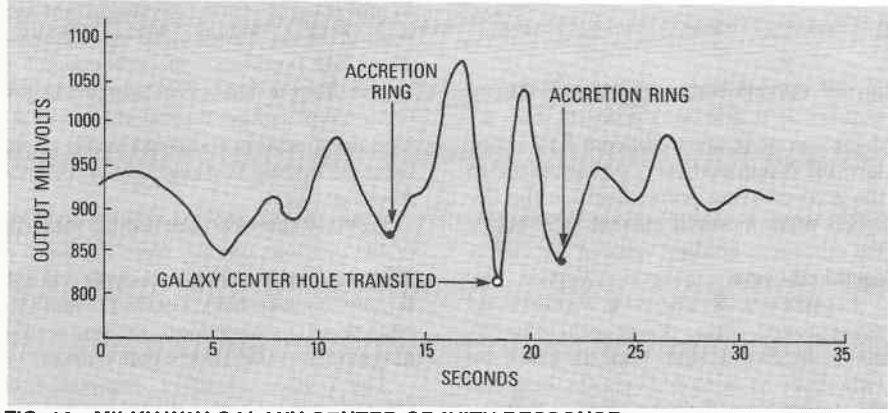


FIG. 14—MILKY-WAY GALAXY CENTER GRAVITY RESPONSE.

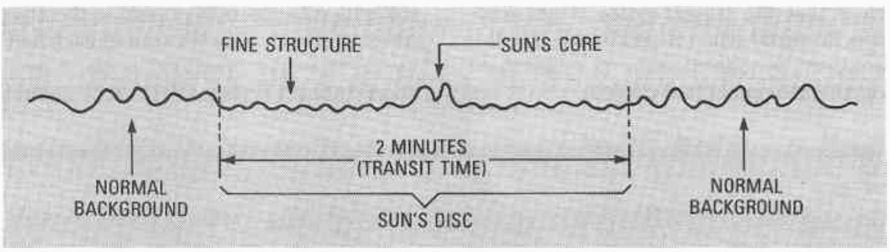


FIG. 15—OUR SUN'S CORE GRAVITY RESPONSE.

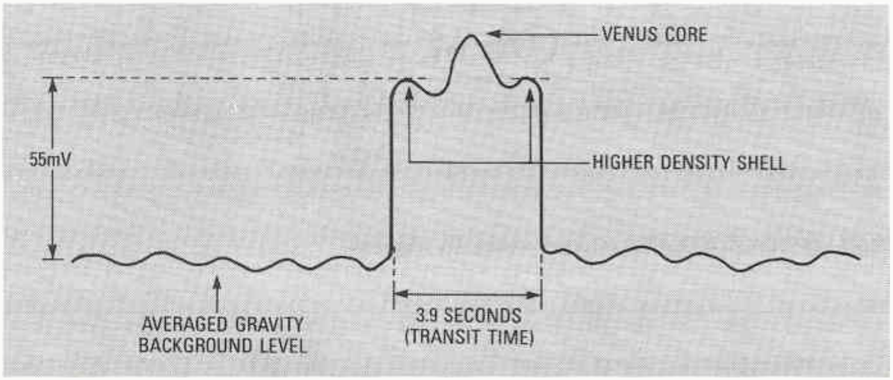


FIG. 16—VENUS PLANETARY GRAVITY RESPONSE.

impressive. Adjust the amplifier's sound level for best response to the particular sound being studied. Of particular interest may be some of the coherent "musical" sounds which appear to come from the same direction of space on a daily basis. At the author's location of 42° N. Latitude, those sounds appear to originate from the Perseus and Auriga regions of our Galaxy when those regions appear in the author's zenith.

Perhaps *some* of those signals might be extraterrestrial intelligence signals, and experimenters' interested in SETI (Search for Extra-Terrestrial Intelligence) might want to investigate that aspect of the detection process. Since gravity impulses travel everywhere almost instantaneously, communication between different galactic cultures would not be limited by the long time intervals required by speed-of-light communication by radio-wave.

Man-made scalar flux signals are largely due to oscillating or rotating masses. A *translation* of mass will generate signals that are due to the perturbations of an apparent standing-wave pattern in the universe's background radiation. That those modulations are truly due to mass in motion can be seen by oscillating a pendulum, or rolling a mass, which will disturb the gravitational background. The author has detected the oscillation of a pendulum 150 feet away that appeared to have the same response in detected intensity as when the pendulum was only 5 feet away. A local translation of mass will appear as a strong rushing sound in the detector's audio output.

As shown in Fig. 7, an interesting pendulum experiment can be performed with a two pound weight that is suspended by a light-weight string from a height of six feet. Set the pendulum in motion with about a five foot arc length. Adjust the detector volume for a good response to the swinging disturbance of the vacuum, ie., the universe. Even though the pendulum will eventually stop swinging, the disturbance in the universe continues to remain! That effect appears to be typical of gravitational perturbations in the universe. Apparently, once the gravity disturbance is generated, the gravity impulses tend to propagate continually until dissipated or over-ridden in some way. It appears that gravitational communications will probably require some sort of modulation that can defeat the continuing propagation characteristics of the vacuum.

Gravity astronomy

Astronomy, in recent years, has undergone a revolution in both theoretical considerations and observational methods. The revolution has not only opened new observational techniques at electromagnetic frequencies other than visible light, but has also given evidence that our universe, in its furthest reaches, also obeys the same scientific principles as those observed here on Earth. Among the new observational methods were attempts to detect gravitational signals. Such signals would be a new window into the universe, and would disclose many aspects not observable with the present-day electromagnetic techniques.

The astronomical gravity signal detection units are special modifications of the basic gravity detector. The modifications are: the input resonance frequency is normally kept much less than one hertz per second, additional amplification is used, and the output is passed through a low pass filter.

The effectiveness of the capacitor element as a detector in gravity-signal astronomy is shown in Fig. 8. The earth's gravity field is in parallel with the polarized electric field in the planar capacitor dielectric. Furthermore, it can be shown that any gravity com-

continued on page 129

WORKING WITH TRIACS AND SCR's

Twenty-eight practical SCR and Triac circuits.

RAY MARSTON

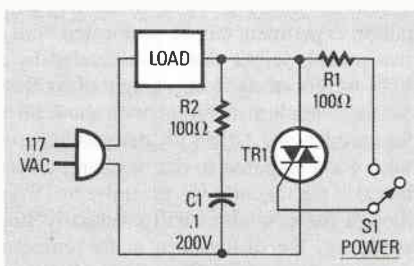


FIG 1—AC POWER SWITCH, AC triggered.

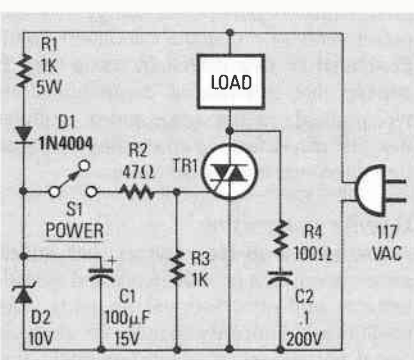


FIG 2—AC POWER SWITCH, DC triggered.

LAST TIME WE DISCUSSED BASIC SCR AND Triac theory, paying particular attention to the principles of synchronous and asynchronous triggering. (See **Radio-Electronics**, September 1987.) This time we'll present a number of practical circuits for which the user need only select an SCR or Triac having suitable voltage and current ratings. Let's start off by looking at several Triac circuits that can be used to control some line-voltage-powered devices.

Asynchronous designs

As explained last time, a Triac may be triggered (turned on) either synchronously or asynchronously. A synchronous circuit always turns on at the same point in each half-cycle, usually just after the zero-crossing point, in order to minimize RFI. An asynchronous circuit does not turn on at a fixed point, and the initial current surge generated during turn-on at a non-zero point of the AC cycle can generate significant RFI. Triac turn-off is automatically synchronized to the zero-crossing point, because the device's main-terminal current falls below the minimum-holding value at the end of each half-cycle.

Figures 1–8 show a variety of asynchronous Triac power-switching circuits. In Fig. 1, the Triac is gated on (whenever S1 is closed) via the load and R1 shortly after the start of each half-cycle; the Triac remains off when S1 is open. Note that the trigger point is not line-synchronized when S1 is closed initially; however, synchronization is maintained on all subsequent half-cycles.

Figure 2 shows how the Triac can be triggered via a line-derived DC supply. Capacitor C1 is charged to +10-volts DC (via R1 and D1) on each positive half-cycle of the line. The charge on C1 is what triggers the Triac when S1 is closed. Note that all parts of the circuit are "live," and that makes it difficult to interface to external control circuitry.

Figure 3 shows how to modify the previous circuit so that it can interface with external control circuitry. Switch S1 is simply replaced by transistor Q2, which in turn is driven from the photo-transistor portion of an inexpensive optocoupler. The LED portion of the optocoupler is driven from a 5-volt DC source via R4. Opto-couplers have typical insulation potentials of several thousand volts, so the external circuit is always fully isolated from the line.

Figure 4 shows an interesting variation of the previous circuit. Here the Triac is AC-triggered on each half-cycle via C1, R1, and back-to-back Zeners D5 and D6. Note that C1's impedance determines the magnitude of the Triac's gate current.

The bridge rectifier composed of D1–D4 is wired across the D5/D6/R2 network and is loaded by Q1. When Q1 is off, the bridge is effectively open, so the Triac turns on shortly after the start of each half-cycle. However, when Q2 is on, a near-short appears across D5/D6/R2, thereby

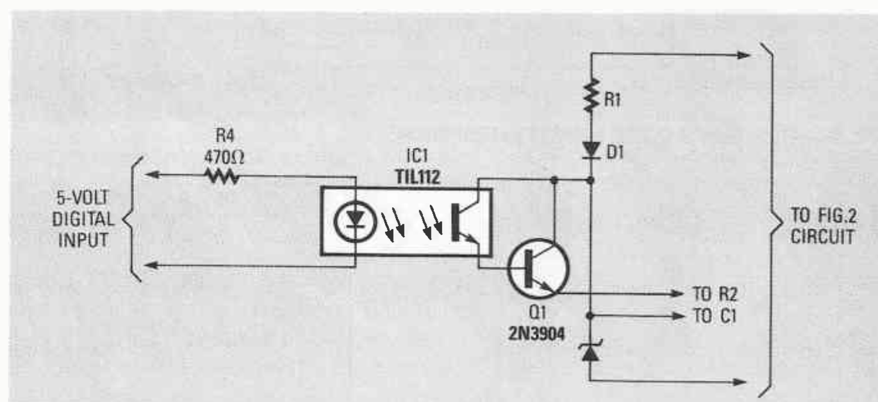


FIG 3—OPTICALLY ISOLATED AC power switch, DC triggered.

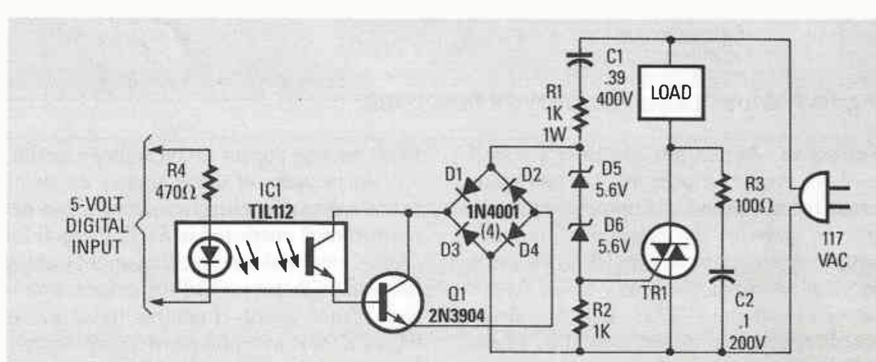


FIG 4—OPTICALLY ISOLATED AC power switch, AC triggered.

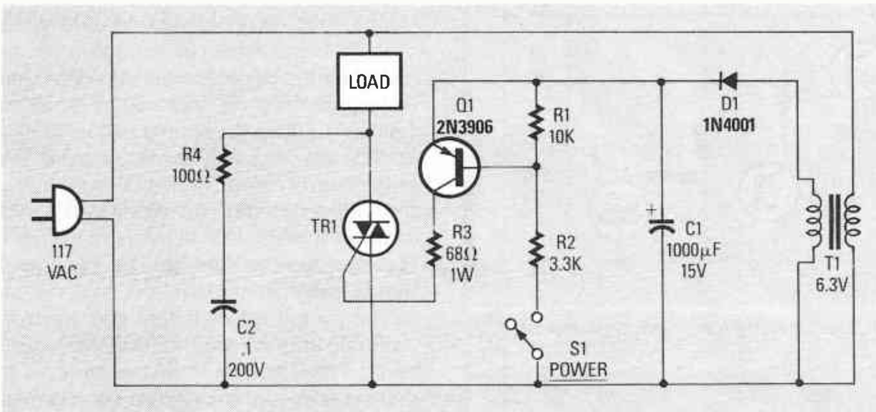


FIG 5—AC POWER SWITCH with transistor- aided DC triggering.

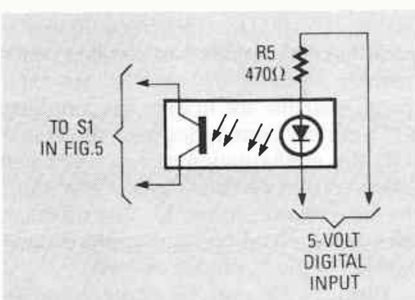


FIG 6—TRIGGER THE PREVIOUS CIRCUIT with an optocoupler.

inhibiting the Triac's gate circuit, so it remains off.

Figures 5 and 6 show several ways of triggering the Triac via a transformer-derived DC supply and a transistor-aided switch. In the Fig. 5 circuit, Q1 and the Triac are both turned on when S1 is closed, and off when it is open. In practice, of course, S1 could be replaced by an electronic switch, enabling the Triac to be operated by heat, light, sound, time, etc. Note, however, that the whole of the Fig. 5 circuit is "live." Figure 6 shows how to modify the circuit so that is is suitable for use with an optocoupler.

To complete this section, Figures 7 and 8 show several ways of triggering a Triac from a fully isolated external circuit. In both circuits, triggering is obtained from an oscillator built around unijunction transistor Q1. The UJT operates at a frequency of several kHz and feeds its output pulses to the Triac's gate via pulse transformer T1, which provides the desired isolation. Also in both circuits, S1 can easily be replaced by an electronic switch.

In the Fig. 7 circuit, Q2 is wired in series with the UJT's main timing resistor, so the UJT and the Triac will turn on only when S1 is *closed*. In the Fig. 8 circuit, Q2 is wired in parallel with the UJT's main timing capacitor, so the UJT and the Triac turn on only when S1 is *open*.

Synchronous designs

Figures 9–18 show a number of power-switching circuits that use synchronous triggering.

Figure 9 shows the circuit of a synchronous line switch that is triggered near the zero-voltage crossover points. The Triac's gate-trigger current is obtained from a 10-volt DC supply that is derived from the network composed of R1, D1, D2, and C1. That supply is delivered to the gate via Q1, which in turn is controlled by S1 and the zero-crossing detector composed of Q2, Q3, and Q4.

Transistor Q5 can only conduct gate current when S1 is closed and Q4 is off. The action of the zero-crossing detector is such that either Q2 or Q3 turns on whenever the instantaneous line voltage is positive or negative by more than a few volts, depending on the setting of R8. In either case, Q4 turns on via R3 and thereby inhibits Q5. The circuit thus produces minimal RFI.

Figure 10 shows how to modify the previous circuit so that the Triac can only turn on when S1 is open. In both circuits note that, because only a narrow pulse of gate current is sent to the Triac, average consumption of DC current is very low (one milliampere or so). Also note that S1 can be replaced by an electronic switch, to give automatic operation via heat, light, time, etc., or by an optocoupler, to provide full isolation.

A number of special-purpose synchronous zero-crossover Triac-gating IC's are available, the best-know examples being the CA3059 and the TDA1024. Both devices incorporate line-derived DC power-supply circuitry, a zero-crossing detector, Triac gate-drive circuitry, and a high-gain differential amplifier/gating network.

Figure 11 shows the internal circuitry of the CA3059, together with its minimal external connections. AC line power is applied to pin 5 via a limiting resistor

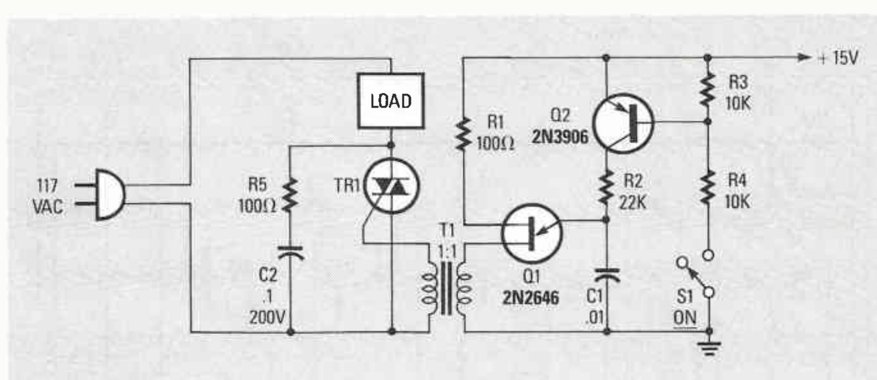


FIG 7—TRANSFORMER-COUPLED AC power switch. The Triac turns on when S1 is closed.

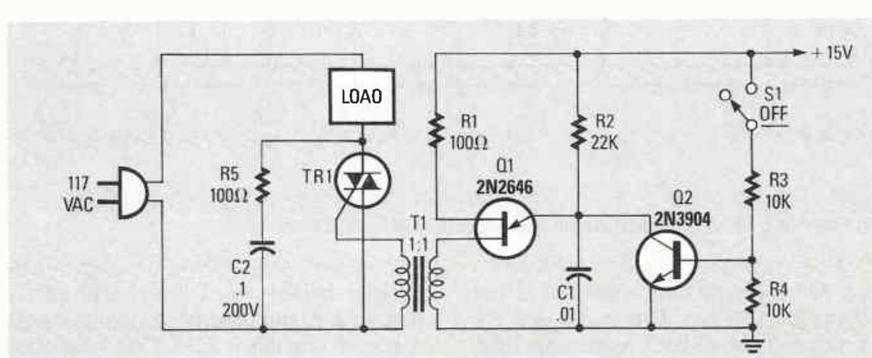


FIG 8—ISOLATED-INPUT AC power switch. The Triac turns on when S1 is open.

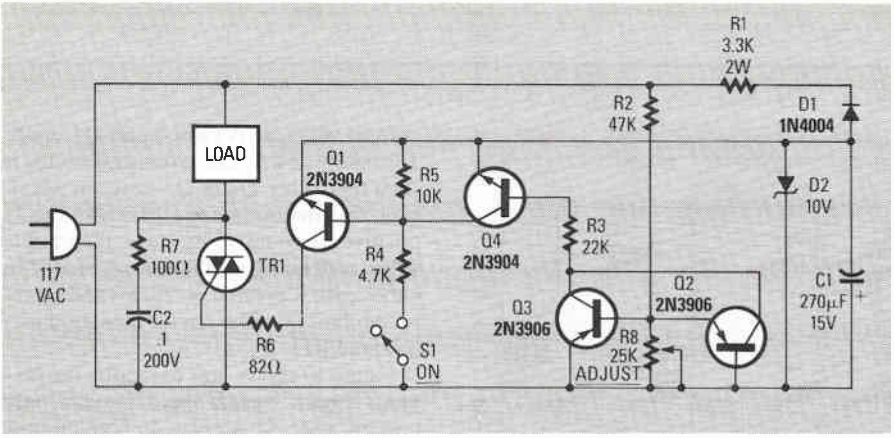


FIG 9—ZERO-CROSSING synchronous line switch. The Triac turns on when S1 is closed.

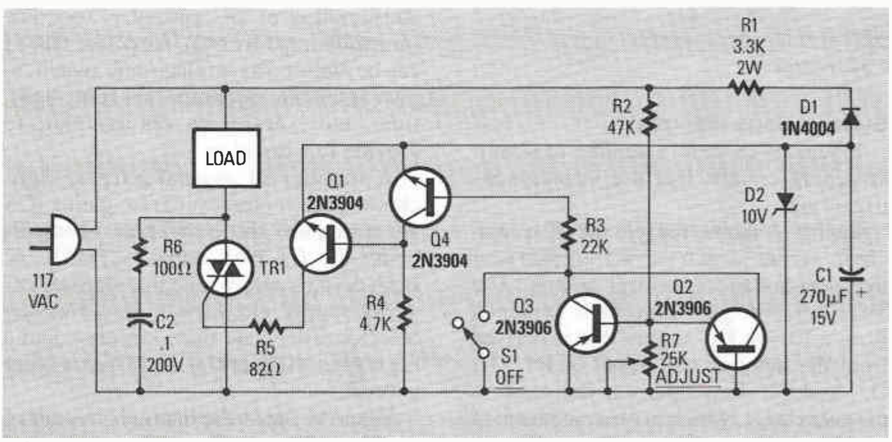


FIG 10—ALTERNATE synchronous line switch. The Triac turns on when S1 is open.

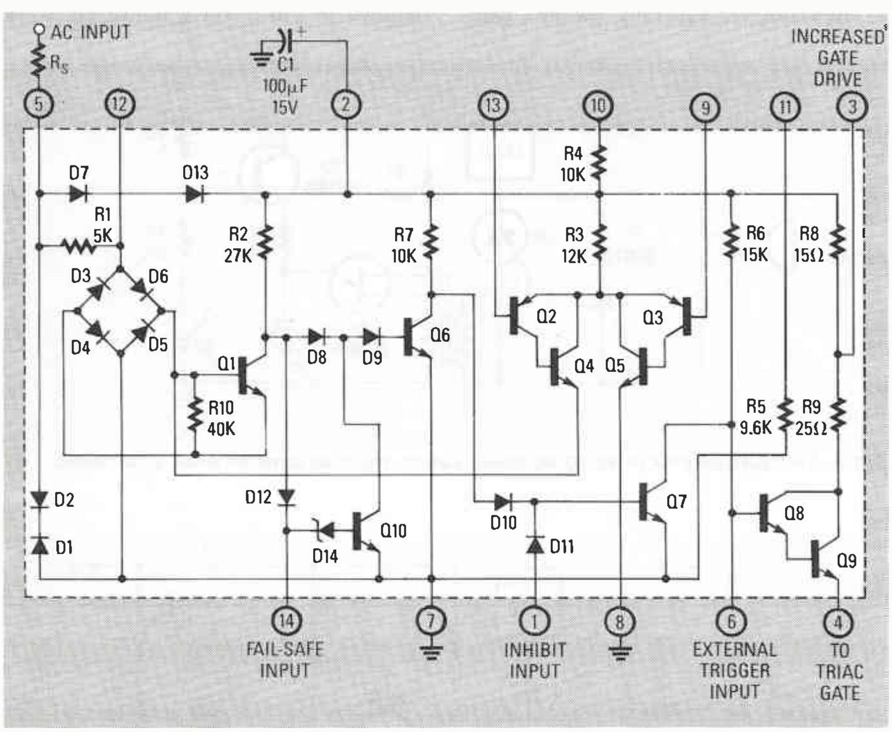


FIG 11—THE CA3059'S internal circuit and necessary external components.

(R_S), which should have a value of 12K at 5W for 117-volt use. Diodes D1 and D2 function as back-to-back zeners that limit the potential on pin 5 to ±8 volts. On positive half-cycles, D7 and D13 rectify that voltage and generate 6.5 volts across external capacitor C1. That capacitor stores enough energy to drive all internal circuitry. It also provides adequate drive to the gate of the Triac, and a few mA of current are available for powering external circuitry.

Bridge rectifier D3–D6 and transistor Q1 function as a zero-crossing detector, with Q1 being driven to saturation whenever the pin-5 voltage exceeds –3V. Gate drive to an external Triac can be provided (via pin 4) from the emitter of the Q8/Q9 Darlington pair; that current is available only when Q7 is off. When Q1 is on (i. e., the voltage at pin 5 exceeds –3V), Q6 turns off through lack of base drive, so Q7 is driven to saturation via R7, so no current is available at pin 4.

The overall effect is that gate drive is available only when pin 5 is close to zero volts. When gate drive is available, it is delivered as a narrow pulse centered on the crossover point; the gate-drive current is supplied via C1.

The CA3059 incorporates several transistors (Q2–Q5) that may be configured as a differential amplifier or a voltage comparator. Resistors R4 and R5 are externally available for biasing the amplifier. Q4's emitter current flows via the base of Q1; the configuration is such that gate drive can be disabled by making pin 9 positive relative to pin 13. The drive can also be disabled by connecting external signals to pin 1, pin 14, or both.

Figures 12 and 13 show how the CA3059 can provide manually-controlled zero-voltage on/off Triac switching. Each circuit uses a switch (S1) to enable and disable the Triac's gate drive via the IC's differential amplifier. In the Fig. 12 circuit, pin 9 is biased at $V_{CC}/2$ and pin 13 is biased via R2, R3, and S1. The Triac turns on only when S1 is closed.

In Fig. 13, pin 13 is biased at $V_{CC}/2$ and pin 9 is biased via R2, R3, and S1. Again, the Triac turns on only when S1 is closed. In both circuits, S1 handles maximums of 6 volts and 1 mA. In both circuits C2 is used to apply a slight phase delay to pin 5 (the zero-voltage detecting terminal); that delay causes gate pulses to be delivered after the zero-voltage point, rather than straddling it.

Note that, in the Fig. 13 circuit, the Triac can be turned on by pulling R3 low, and that it can be turned off by letting that resistor float. The circuits shown in Fig. 14 and Fig. 15 illustrate how that ability can increase the versatility of the basic circuit. In Fig. 14, the Triac can be turned on and off by transistor Q1, which in turn can be activated by any low-voltage circuit, even CMOS devices. And Fig. 15 shows how to use the circuit with an optocoupler.

Figure 16 shows how the Signetics TDA1024 can be used in a similar circuit to provide optically coupled zero-voltage Triac control.

To complete this section, Fig. 17 and Fig. 18 show several ways of using the

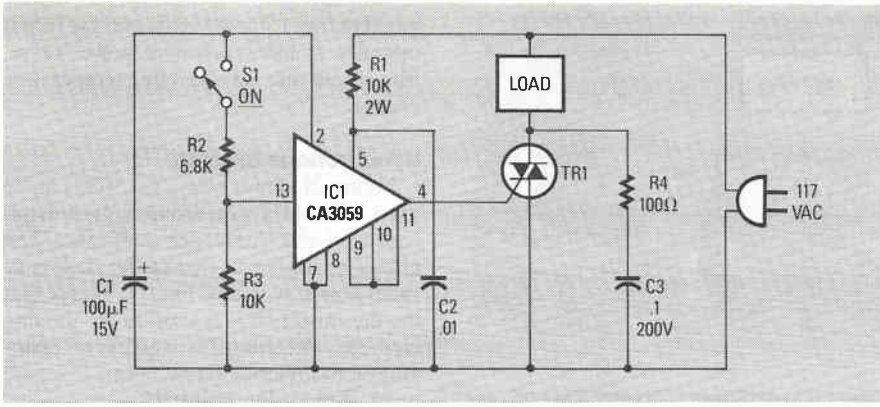


FIG 12—ZERO-VOLTAGE line switch built from the CA3059.

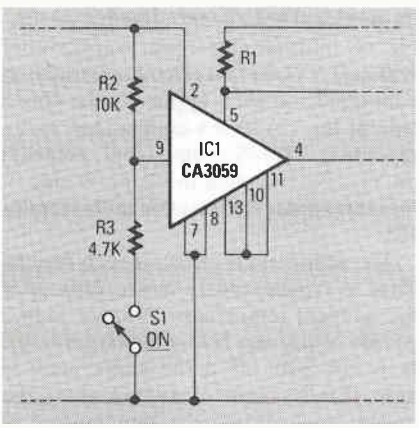


FIG 13—ALTERNATE CA3059 zero-voltage switch.

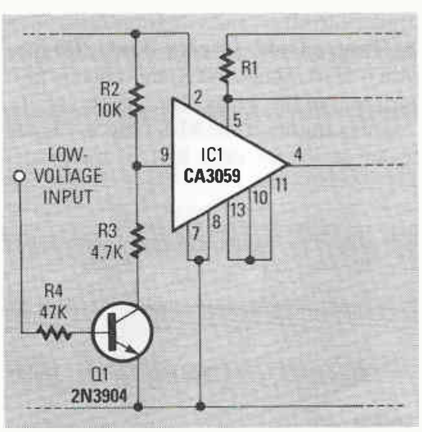


FIG 14—TRANSISTOR-CONTROLLED CA3059 switch.

CA3059 so that the Triac operates as a light-sensitive dark-operated power switch. In both designs the IC's built-in differential amplifier is used as a precision voltage comparator that turns the Triac on or off when one of the comparator input voltages goes above or below the other comparator input voltage.

Figure 17 is the circuit of a simple dark-activated power switch. Here, pin 9 is tied to $V_{CC}/2$ and pin 13 is controlled via the R2–R5 resistive string. In bright light, photocell R4 has low resistance, so the voltage at pin 9 exceeds that at pin 13, and the Triac is disabled. In darkness, the photocell has a high resistance, so the pin 13 voltage exceeds that at pin 9, and the Triac is enabled. The circuit's switching point is set with R3.

Figure 18 shows how a degree of hysteresis or "backlash" can be added to the previous circuit. Doing so prevents the Triac from switching in response to small changes (passing shadows, etc.) in ambient light level.

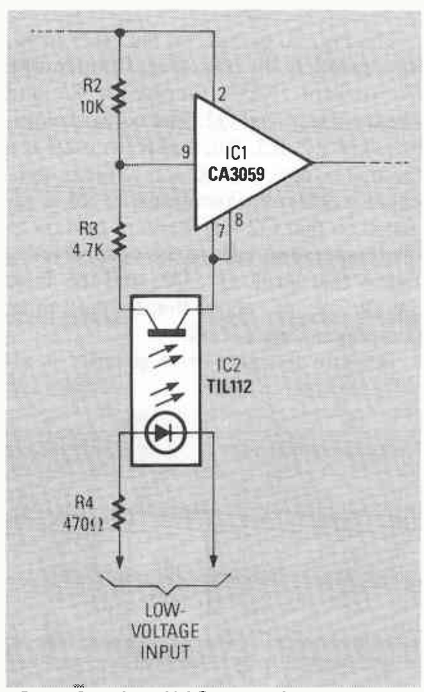


FIG 15—OPTICALLY COUPLED CA3059 switch.

Electric-heater controllers.

A Triac can easily be used to provide automatic room-temperature control by using an electric heater as the Triac's load, and either thermostats or thermistors as the thermal feedback elements. Two

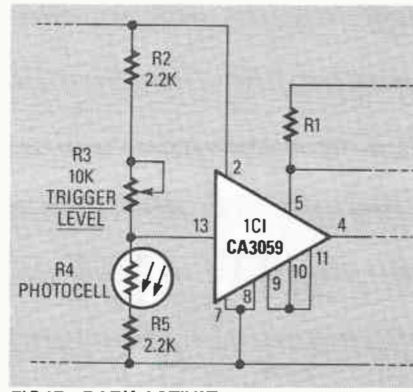


FIG 17—DARK-ACTIVATED zero-voltage switch.

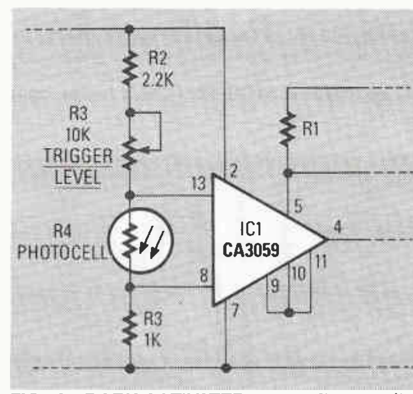


FIG 18—DARK-ACTIVATED zero-voltage switch with hysteresis.

methods of heater control can be used: automatic on/off power switching, or fully automatic proportional power control. In the former case, the heater turns fully on when room temperature falls below a preset level, and it turns fully off when the temperature rises above that level.

In proportional power control, the average power delivered to the heater is automatically adjusted so that, when room temperature is at the preset level, the heater's output power self-adjusts to precisely balance the thermal losses of the room.

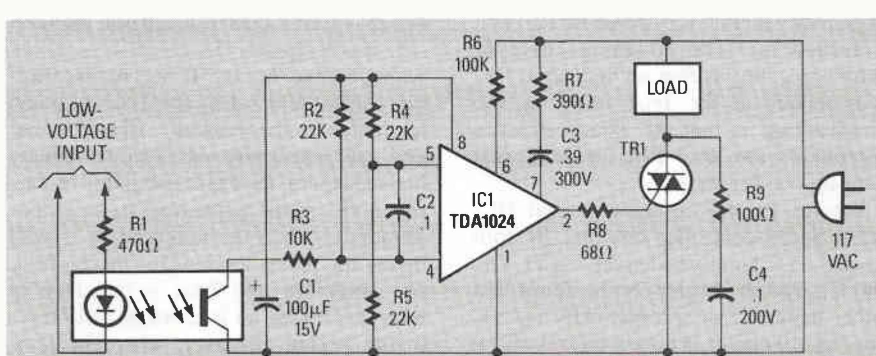


FIG 16—OPTICALLY COUPLED TDA1024-based zero-voltage switch.

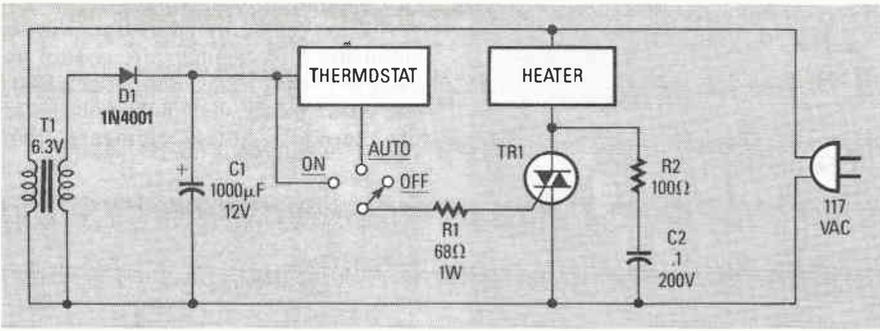


FIG 19—THERMOSTAT-SWITCHED heater controller.

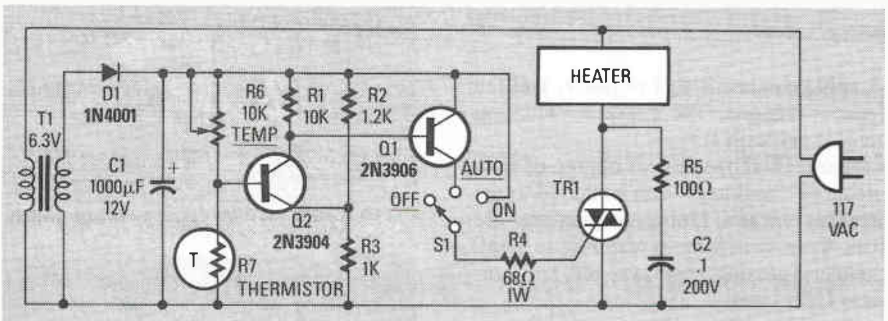


FIG 20—THERMISTOR-SWITCHED heater controller.

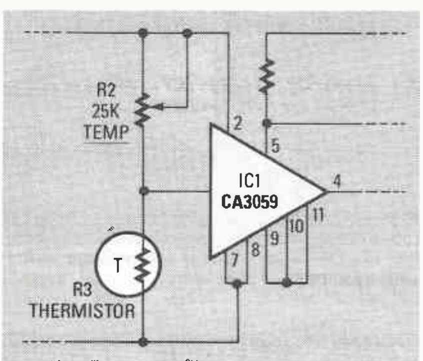


FIG 21—HEATER CONTROLLER with thermistor-regulated zero-voltage switching.

Because of the high power requirements of an electric heater, the circuit must be carefully designed to minimize RFI generation. The designer's two main options are to use either continuous DC gating or synchronous pulsed gating. The advantage of DC gating is that, in basic on/off switching applications, the Triac generates zero RFI under normal running conditions; the disadvantage is that the Triac may generate very powerful RFI as it is turned on. The advantage of synchronous gating is that no high-level RFI is generated as the Triac turns on; the disadvantage is that the Triac generates continuous low-level RFI under normal running conditions.

Figures 19 and 20 show several DC-gated heater-controller circuits. In both cases the DC supply is derived via T1, D1, and C1, and the heater can be controlled either manually or automatically via S1. The Fig. 19 circuit is turned on and off by the thermostat, depending on its temperature.

The Fig. 20 circuit, on the other hand, is controlled by *N*egative *T*emperature *C*oefficeint (NTC) thermistor R7 and transistors Q1 and Q2. The network composed of R2, R3, R6, and R7 is used as a thermal bridge, and Q2 acts as the bridge-balance detector. Potentiometer R6 is adjusted so that Q2 just starts to turn on as the temperature falls to the desired level. Below that level, Q2, Q3, and the Triac are all fully on; above that level all three components are cut off.

Because the gate-drive polarity is always positive, but the Triac's main-terminal current alternates, the Triac is gated alternately in the +I and +III quadrants, and gate sensitivity varies tremendously between them. (See our discussion of gate sensitivity in the September issue.) Consequently, when the temperature is well below the preset level, Q1 is driven fully on. Therefore, the Triac is gated on in both quadrants, so it provides full power to the heater. However, when the temperature is very close to the preset value, Q1 is driven on "gently," so the Triac is gated in the +I mode only, and the heater operates at half maximum power drive. The circuit thus provides fine temperature control.

Synchronous circuits

Figure 21 shows how a CA3059 can be used to build a synchronous thermistor-regulated electric-heater controller. The circuit is similar to that of the dark-activated power switch of Fig. 17, except that the thermistor (R3) is used as the sensing element. The circuit is capable of maintaining room temperature within a degree or so of the value set by R2.

To complete our discussion of heater controllers, Fig. 22 shows the circuit of a proportional heater controller that is capable of maintaining room temperature within 0.5°C. In that circuit a thermistor-controlled voltage is applied to the pin-13 side of the CA3059's comparator, and a repetitive 300-mS ramp signal, centered on $V_{CC}/2$, is applied to the pin-9 side of the comparator from astable multivibrator IC1.

The action of the circuit is such that the Triac is synchronously turned fully on if the ambient temperature is more than a couple of degrees below the preset level, or is cut fully off if the temperature is more than a couple of degrees above the preset level. When the temperature is within a couple of degrees of the preset value, however, the ramp waveform comes into effect and synchronously turns the Triac on and off once every 300 mS, with a *M*ark/*S*pace (M/S) ratio that is proportional to the temperature differential.

For example, if the M/S ratio is 1:1, the heater generates only half of maximum

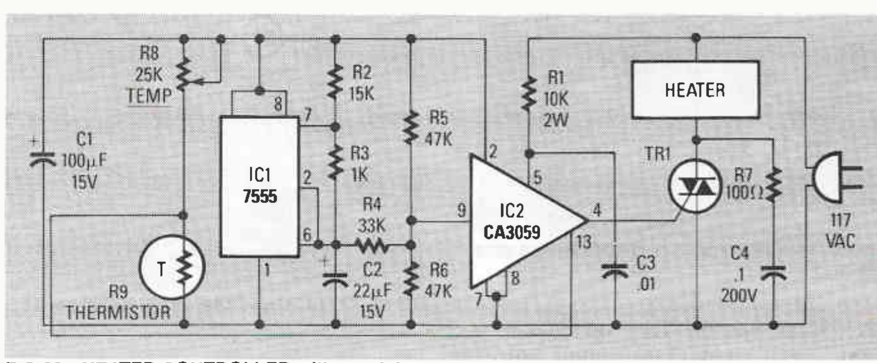


FIG 22—HEATER CONTROLLER with precision temperature regulation.

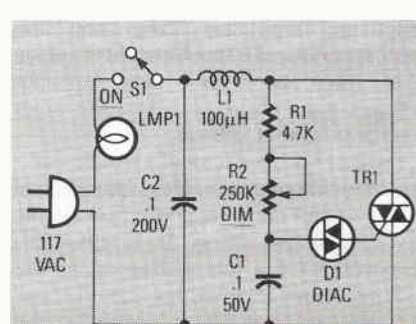


FIG 23—SIMPLE LAMP DIMMER.

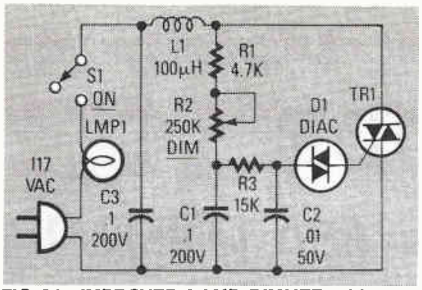


FIG 24—IMPROVED LAMP DIMMER with gate slaving.

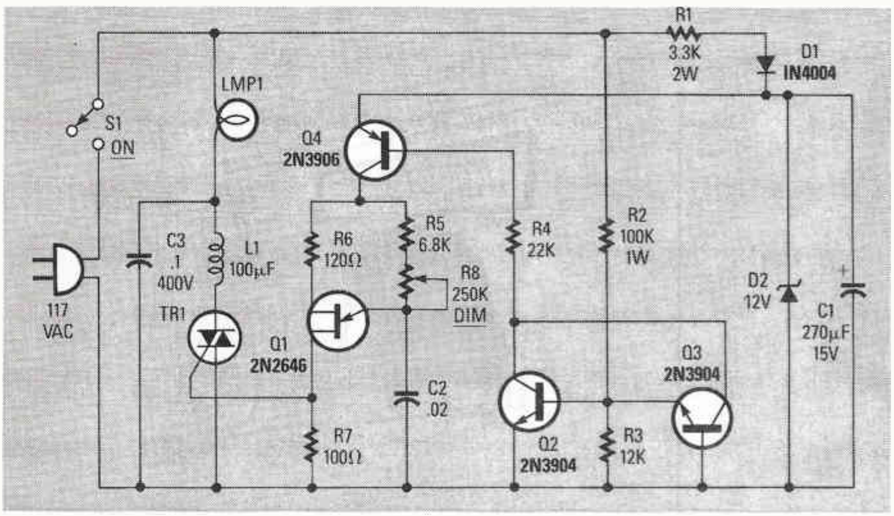


FIG 25—UJT-TRIGGERED zero-backlash lamp dimmer.

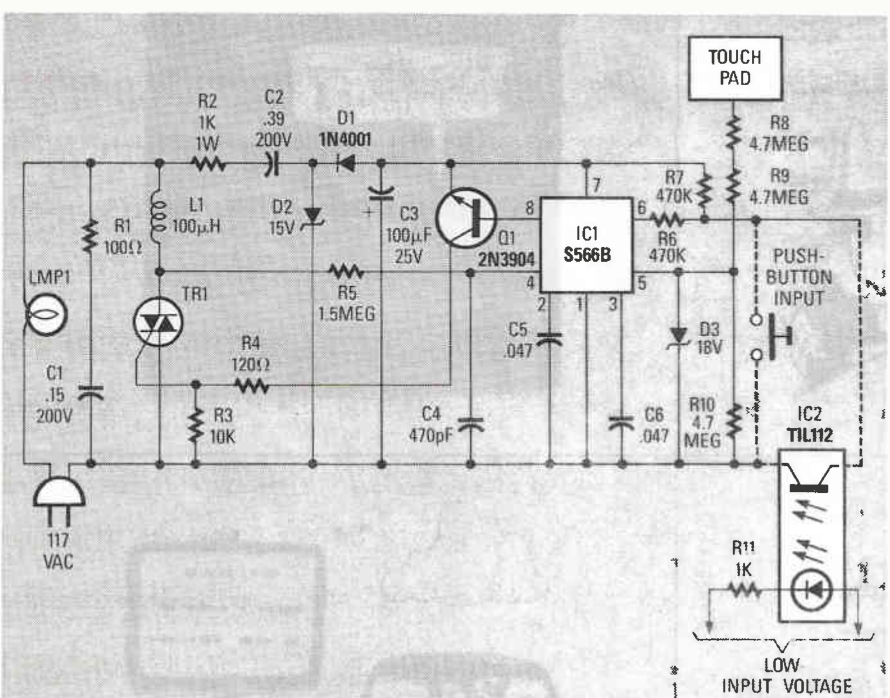


FIG 26—SMART LAMP DIMMER controlled by a Siemens S566B.

power, and if the mark/space ratio is 1:3 it generates only one quarter of maximum power. The net effect is that the heater does not switch fully off, but generates just enough output power to match the thermal losses of the room precisely. As a result, the circuit provides very precise temperature control.

Lamp-dimmer circuits

A Triac can be used to make a lamp dimmer by using the phase-triggered power-control principles discussed last time. In that type of circuit, the Triac is turned on and off once in each line half-cycle, its M/S ratio controlling the mean power fed to the lamp. All circuits of that type require the use of a simple LC filter in the lamp's feed line to eliminate RFI.

The three most popular methods of obtaining variable phase-delay triggering are: (1) Diac plus RC phase-delay network; (2) line-synchronized variable-delay UJT trigger; (3) special-purpose IC as the Triac trigger.

Figure 23 shows the circuit of a Diac-triggered lamp dimmer. A defect of that type of design is that it suffers from considerable control hysteresis or backlash.

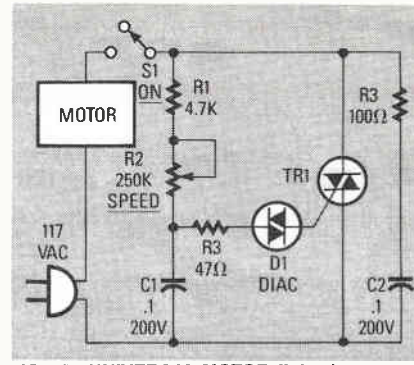


FIG 27—UNIVERSAL-MOTOR light-duty speed controller.

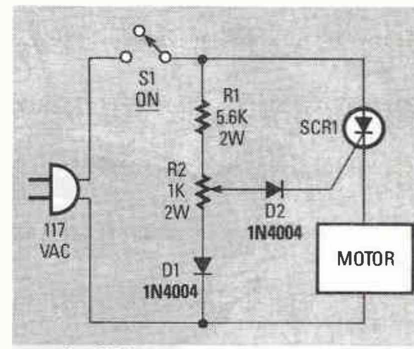


FIG 28—SELF-REGULATING UNIVERSAL-MOTOR heavy-duty speed controller.

If the lamp is dimmed by increasing the R2's value almost to maximum, the lamp will not go on again until R2 is reduced to about 80% of the former, at which it burns at a fairly high brightness level. Backlash is caused because the Diac partially discharges C1 each time the Triac fires.

Backlash can be reduced by wiring a 47-ohm resistor in series with the Diac, to reduce its effect on C1. An even better solution is to use the gate-slaving circuit shown in Fig. 24, in which the Diac is triggered from C2, which "copies" C1's phase-delay voltage, but provides discharge isolation through R3.

If backlash must be eliminated altogether, the UJT-triggered circuit shown in Fig. 25 can be used. The UJT (Q1) is powered from a 12-volt DC supply built around Zener diode D2. The UJT is line-synchronized by the Q2-Q3-Q4 zero-crossing detector network, in which Q4 is turned on (thereby applying power to the UJT) at all times *other* than when line voltage is close to zero.

So, shortly after the start of each half-cycle, power is applied to the UJT circuit via Q4, and some later time (which is determined by R5, R8, and C2), a trigger pulse is applied to the Triac's gate via the UJT.

Figure 26 shows how a dedicated IC, the Siemens S566B "Touch Dimmer," can be used to build a smart lamp dimmer that can be controlled by several devices simultaneously: a touch pad, a pushbutton switch, or an infrared link.

continued on page 164

(CODE CAPERS)

by JACK SCHMIDT

POOR MAN'S STORAGE SCOPE

DUKE BERNARD

With nothing more than an oscilloscope, a video camera, and a VCR, hobbyists can have many of the advantages of fancy logic analyzers and digital storage scopes.

WHEN A NEWLY DESIGNED PIECE OF ELECtronics equipment or an existing piece of equipment that has gone bad is being debugged, it's common practice to trace signal paths by using an oscilloscope. With digital equipment, logic analyzers are often used to check timing and even store the waveforms on floppy disk for future evaluation. Such equipment is very convenient to use, but very expensive.

When professional designers do a thorough job of evaluating a new design, they record the waveforms at each major node in the system. Traditionally, that has been done by taking Polaroid photographs of oscilloscope traces. The process requires fastening the scope probe to a circuit trace on a printed circuit board long enough to take the photograph, developing the print, recording the appropriate oscilloscope scales, and then moving on to the next location to repeat the process. Things proceed in an orderly manner when documenting a new design that is working properly, though it surely helps to have an assistant. However, when either a new design or an existing system is faulty, circuit tracing usually becomes less orderly, with the scope probe stuck here and there looking for suspect signals.

Life gets even more interesting when the system works perfectly 99% of the time, but has a glitch that causes an error every few hours or so. In industry, troubleshooting such a glitch generally calls for powerful logic analyzers that can be triggered by the fault condition and then recall the signals that preceded the error. Unfortunately, the hobbyist and the small-business electronics professional generally cannot afford the tens of thousands of dollars that such equipment costs.

With a little ingenuity, however, commercially available video equipment can be made to do many of the tasks of much more expensive equipment, and in some cases do it better. Unlike most commercial logic analyzers, which record only one's and zero's, the technique described in this article works well for either digital or analog signals. It was first used by the author to find an intermittent failure in an asynchronous coupled multi-CPU digital system. It has subsequently been used for debugging simpler systems. It can also be used to turn a simple oscilloscope into a storage scope for reviewing transient waveforms.

The concept is simple and rather straightforward. All that is required is a VCR with top-quality special effects; that is, clean, jitter-free stop frame, fast forward and reverse, and slow motion such as that provided by the top-of-the-line four-head units or the new digital VCR's that feature digital frame storage. A video camera and a video monitor complete the list of required equipment.

A word about the video camera: A high-end unit is not required; a simple black-and-white surveillance camera will do fine. However, if an expensive color camera is used, to prevent burning the image tube care should be taken not to leave the camera pointed at a very bright trace on the scope for long periods of time. That is less of a concern if the camera uses a solid-state imager.

More savings

In addition to the obvious savings in equipment cost, it's interesting to compare the number of oscilloscope traces that can be recorded on a two hour roll of VCR tape versus the cost of trying to capture the same amount of information on film. Assume that for recording the waveforms of a new system, each point in the system is recorded for 10 seconds. That is generally enough time to record the scope settings and what point in the circuit is being monitored on the voice track. That yields six traces recorded per minute, or 720 in two hours. At about 50 cents a print for instant film, to record as many traces the cost would be $360. Compare that to the cost of even the highest quality T120 tape. At even faster recording speeds an even greater savings can be realized.

While hard copies are often desired in addition to the tape recordings, the taped waveforms can be reviewed at leisure and the most important ones photographed off the TV monitor, although with some lim-

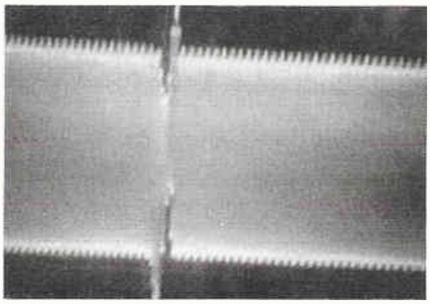


FIG. 1—USING A VCR, this glitch in the system clock waveform was found.

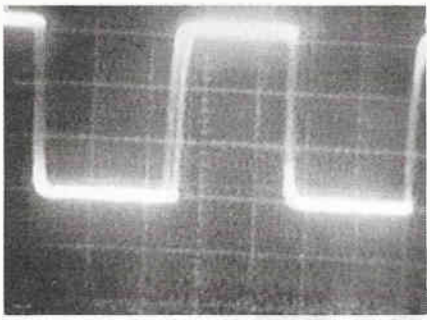


FIG. 2—FURTHER INVESTIGATION found a waveform with a timing shift during alternate leading edges.

itations. Meanwhile, a very extensive set of waveforms have been captured, which can be reviewed later if the system develops a problem.

A typical application

The problem that initiated the effort to record oscilloscope traces with a VCR was one of those periodic, hard-to-trace glitches that had cropped up during the testing of a new design. In frustration, we decided to record various oscilloscope waveforms with a VCR until one was found that changed appreciably just before the system being tested recorded an error (since the system being tested had a real time clock, it was possible to let it run to give an indication of when an error occurred).

Once an error was noted, the VCR tape was advanced to the approximate time of the error and the waveforms were examined. Finally, a glitch was found on the system's clock waveform; that is shown in Fig. 1. At first, the glitch was thought to be the direct cause of the error, but it wasn't. However, by knowing what to look for, the same conditions that created the glitch in the clock waveform (several high-current devices switching simultaneously) were programmed, and more waveforms were recorded.

The waveform shown in Fig. 2, a subclock signal, was found to be the culprit. As shown by the dual-trace leading edge, the signal's timing changed on alternate leading edges during the time that the system clock had the disturbance, causing a synchronization problem. That timing change was further traced to ringing on the waveform, as shown in Fig. 3.

Budget storage scope

Having found the VCR so useful in recording occasionally occurring waveform disturbances for future review, we looked into using a VCR as a "poor-man's" storage oscilloscope. Events that happen as a transient rather than a repetitive occurrence are hard to capture on an ordinary oscilloscope. One example is speech. With so much interest in speech synthesis and speech recognition, it's often necessary to observe the patterns created by different words and compare their similarities and differences. But since speech waveforms are transient in nature, it's hard to do comparative work using only a standard scope.

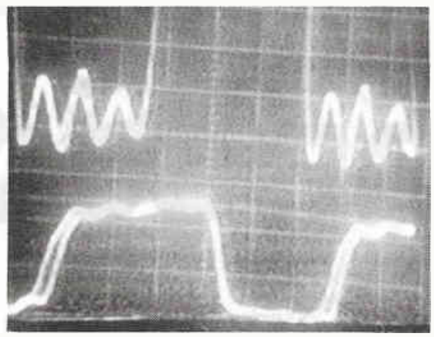


FIG. 3—RINGING ON THE WAVEFORM was finally found to be the cause of the problem.

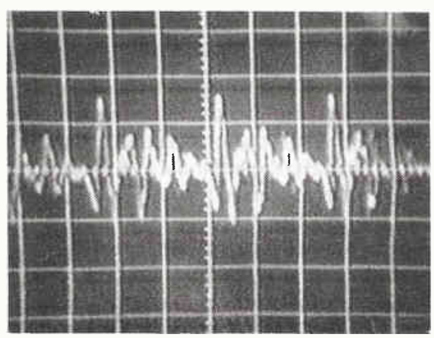


FIG. 4—THE WORD "HELLO" as captured by a video camera and a VCR. The varying intensity of the trace is caused by using a time base longer than a single TV field (about 16 milliseconds).

Recording a waveform on a VCR and then playing it back a frame at a time allows the repetitious patterns in certain speech sounds to be observed. Part of the word "hello" as captured by a VCR is shown in Fig. 4. Note the non-uniform appearance of the trace. That is caused by using a time base that is longer than the TV field rate of 16 milliseconds (1/60 second). Then, the camera can not capture a trace in a single field; instead it does so over two or more fields, causing a stroboscopic effect. The fainter parts of the image are seen only because of image persistence on the CRT screen and/or in the camera pickup. That does not prevent you from examining the waveform, since you can use the frame advance to examine the event one frame at a time, but it does make it difficult to obtain a good hard copy (photograph) from the monitor, as evidenced by Fig. 4.

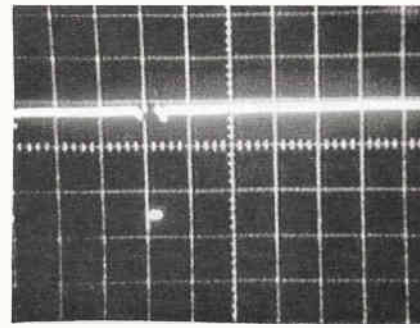


FIG. 5—A CAMERA/VCR SETUP is ideal for viewing short duration transients, such as a voltage interruption caused by a relay's contact bounce.

To get good results when using a VCR's frame-advance feature as a poor-man's storage scope requires some experimenting to obtain the proper trace intensity. Since most video cameras can accomodate fairly low light levels, a trace barely visible when viewed directly may show up quite well when viewed on a TV monitor. To set intensity, then, repeatedly trigger the scope, adjusting the trace intensity until it looks right on the monitor.

Let's close out our discussion by looking at a simple application. One problem that plagues circuit designers is that of contact bounce, a mechanical problem that all mechanical switches and relays are subject to.

Figure 5 shows the output waveform from a relay. When the contacts close, the voltage goes high, triggering the scope. A few milliseconds later, however, the contacts bounce open and closed, creating a momentary voltage interruption.

The transient caused by the bounce can disrupt the proper operation of a circuit and is often difficult to eliminate. But by using a VCR to record the scope trace, you can study the waveform at leisure, allowing you to be certain that your fix is working properly.

Other uses

As you can see, a VCR can make collecting and analyzing data over long periods of time much easier, especially if you can't afford an expensive logic analyzer or a storage scope. And a VCR can be used to record any instrument's readings over time.

For example, the author has used a VCR to record changes in an oscillator's frequency versus temperature. After connecting them to the circuit under investigation, a frequency meter and an electronic thermometer were placed side-by-side and their readings were recorded by a VCR as the circuit was warmed. Fast-forward scanning was later used to find appropriate temperature intervals, allowing the oscillator frequency-versus-temperature data points to be recorded very quickly. **R-E**

BLUE BOX

continued from page 32

office to silence the ringing signal. When Pop released S4, the folks can talk to Junior without Junior getting charged because his AMA tape did not show his call was answered—the DC loop must be closed for at least three-seconds for the AMA tape to show Junior's call was answered. All the AMA tape showed is that Junior let the phone ring at the old homestead for almost 30 minutes; a length of time that no Bell Operating Company is likely to believe twice!

A modern Red Box is simply a conventional telephone that's been modified to emulate the vintage 1940 military field telephone. Aside from the fact that the operating companies can now nail every Red Box user because all modern billing equipment shows the AMA information concerning the length of time a caller let the target telephone ring, it's use has often put severe psychological strain on the users.

Does getting electronics mixed up with psychology sound strange? Well it isn't because it's what helped Ma Bell put an end to indiscriminate use of the Red Box. The heyday of the Red Box was the 1950's and 1960's. Mom and Pop were lucky to have finished high school, and almost without exception, both elementary and high schools taught honesty and ethics. Mom and Pop didn't have the chance to take college courses in *Stealing 101* that masqueraded under quaint names such as *Business Management*, *Marketing*, or *Arbitrage*. When Junior tried to get the old folks to use his "free telephone" they just wouldn't go along. So Junior installed the Red Box at his end. He gave one ring to notify the family to call back. When Pop called Junior, it was Junior who was using the Red Box. Problem was, Junior didn't know that the AMA tape for Mom and Pop's phone showed a 20- or 30-minute ringing. When Ma Bell's investigators showed up it was at the old homestead; and it was only then that the folks discovered their pride and joy had been taught to steal.

There are no hard facts concerning how many Red Boxes were in use, or how much money Ma Bell lost, but one thing is known: she had little difficulty is closing down Red Boxes in virtually all instances where the old folks were involved because Mom and Pop usually would not tolerate what to them was *stealing*. If you as a reader have any ideas about using a Red Box, bear in mind that the AMA (or its equivalent) will get you every time, even if you use a phone booth, because the record will show the number being called, and as with the Blue Box, the people on the receiving end will spill their guts to the cops. **R-E**

WIDEBAND AMPLIFIER

continued from page 34

tween the NE5205 case and the groundplane. If you prefer, electrically-conductive epoxy may be used for that.

Capacitors Cl, C2, and C3 are 0.1-μF surface-mounted high-frequency ceramic chips. A small drop of quick-drying adhesive such as *Crazy Glue* will hold them stationary during soldering. Solder coupling capacitors Cl and C2 to their respective pads on the input and output signal traces. Bridge the gap between V_{CC} and the small ground plane with decoupling capacitor C3 and solder it into place.

The last step in the assembly portion of the project is to strap the top and bottom ground planes together. Don't run long wires to do that. A better, and a far easier way to accomplish the task is with inexpensive, self sticking ¼-inch copper tape; the kind used in making stained-glass windows. (The tape can be purchased at most craft centers.) Wrap the tape around the edge of the board to the top and bottom ground planes and then flow-solder the tape to the copper foils.

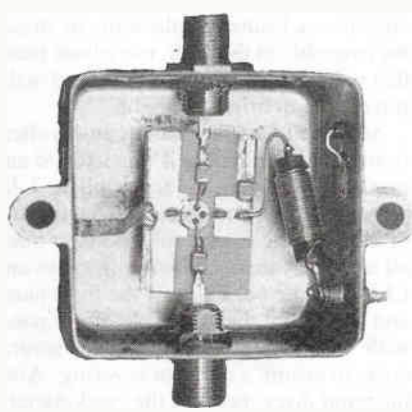


FIG. 7—THE AMPLIFIER CAN BE BUILT into existing equipment, or made part of a stand-alone device, such as this CATV amplifier.

Applications

The amplifier can be used in a wide variety of applications, such as a CATV line amplifier, a 70-MHz satellite amplifier, or a composite video amplifier. The circuit can also improve the operation of 2- to 160-meter amateur radio equipment; AM, FM, CB, and shortwave radios; 50-ohm test equipment; frequency counters; and oscilloscopes. By using a phantom power source on the signal lead, it can even be used as a rooftop antenna preamplifier, such as shown in Fig. 6. Your application will determine whether or not a case is needed. The board either can be incorporated in a piece of existing equipment or mounted in an RF-tight case (see Fig. 7) for stand-alone use. **R-E**

GRAVITY

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ponent arriving from other directions such as vectors *a* and *b* will be largely canceled because those vector components are not parallel with the electric field in the capacitor; leading to reduced gravity components *a'* and *b'*. Only the gravity components arriving along a line through the observer's meridian and the center of the earth will be most effective in exciting the capacitor element of the gravity detector.

Gravity telescope

The gravity-signal detector "sees" the zenith of the observer's celestial sphere through a very small aperture. That small aperture "beam" sweeps across the celestial sphere (at the observer's latitude) at the rate of the earth's rotation. In that respect, the earth's rotation has a period of 23 hours, 56 minutes, and 4.1 seconds of civil (ordinary) time, and that period is called a *sidereal day*.

As shown in Fig. 9, the Milky-Way galaxy center as observed on the author's meridian appears predictably about four minutes earlier each day with respect to standard (civil) times. Also note that another gravity event occurs approximately 35 seconds before the galaxy-center appears, which was used by the author as a marker. The author suggests that the chart recordings are gravity signals emitted from the Milky-Way galaxy center, and *not* random electrical fluxuations that traditionalists call noise.

To locate astronomical objects, use a circular-type-chart star finder, which is more generally known as a planisphere. The charts are calibrated for different Earth latitudes in standard (civil) times for each day of the year.

The sky charts, or planispheres, are also calibrated in terms of right ascension and declination, so that objects may be located in terms of those parameters if they are known. For example, the galaxy center is known to be located in the Sagittarius constellation region in the southern hemisphere at about 17.7 hours right ascension and about -29° declination. Locating that spot on the meridian of the observer's celestial sphere will enable the experimenter to use the planisphere to determine the day and time of day when the Milky-Way galaxy center will appear there.

The gravity detection process is shown in Fig. 10 for two common galactic gravity events. A Supernova implosion will generate an oscillatory modulation of the g-field to an observer at position "A". A Black Hole, on the other hand, will actually reduce the g-field for an observer at position "B". The effects of those cosmic events, and others, will now be considered in more detail.

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COMMERCIAL ZAPPER

continued from page 40

sure that the buffer amps (IC1-a-IC1-d) are not in the same physical package as the processing amps (IC2-a-IC2-d). Also, good decoupling capacitor should be used with high-frequency op-amps such as TL074. Use a 1-µF tantalum or a 10-µF electrolytic (C15) for decoupling.

Alignment and troubleshooting

To align the commercial killer, adjust the detector-gain potentiometer (R41) to maximize the number of comparator transitions during commercials. Begin by connecting the commercial killer to the stereo receiver's tape-monitor loop. Set the receiver to FM and select the tape-monitor mode. Because the audio level may vary from station to station, tune to the station of greatest intended use. And remember, the commercial killer works best with easy-listening formats. During commercials, adjust R41 to maximize attenuation by watching the FADE LED. Slight readjustment may be necessary to provide the fewest zapping errors without performance degradation.

If the commercial killer fails to work, make sure that the power supply is providing the correct voltage, and that V_{REF} is about 13.5 volts.

If the voltages are correct, then verify that you can obtain waveforms like those shown in Fig. 3–Fig. 5. If the peak signal level at the inverting input of IC2-b cannot be adjusted (via R41) to exceed 2.5 volts, the signal level out of the receiver may be unusually low, so the value of R41 may need to be increased.

If the rate of transitions at TP4 is low during music and high during commercials (but attenuation is not proportional to the rate of transitions), verify the following.

- When there is no signal present, the voltage at TP5 should be within 0.2 volts of the voltage at the non-inverting input of IC1-c.
- During a commercial, the voltage at TP5 should be at least three volts less than the voltage at the non-inverting input of IC1-c.

If the first condition is not met, there will be attenuation during music. Diode D4 should be reverse-biased with no signal present. If it is not, and if the voltage at TP4 is about eight volts, it may be necessary to reduce R18.

If the second condition is not met, there will be insufficient attenuation during commercials. If TP4 is approximately eight volts with no signal present, it may be necessary to decrease R19 or R20.

Last, if fading occurs, but the LED does not light, it may be connected to the circuit backwards. **R-E**

DIGITAL SPEDOMETER

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voltage at the appropriate pins of each IC. After debugging any problems, apply a test signal to the speedometer. Connect a sinewave generator to P1 and apply a one-volt peak-to-peak signal. For test purposes, set S1 so that the first three switches are off, the next three are on, and the last two are off (00011100). Also, set the generator's frequency to 138 Hz. If everything is working correctly, the seven-segment LED's should display a value of 60, and at least some of the discrete LED's should be lit.

Installation

The most difficult part of construction is installing the speedometer in an automobile. The two main tasks are installing the PC-board assembly and installing the magnetic sensor and magnets.

To install the boards, first choose a suitable mounting location for the unit, one that provides a good view of the device, but does not obstruct the driver's field of vision. After choosing your mounting location, prepare it to receive the speedometer. Whether you are building a custom enclosure or planning to install the assembly in the dash, use a front panel that will both protect the display and make it readable in bright sunlight.

Smoked Plexiglass makes an excellent front panel, especially if it is lettered and masked. Masking is accomplished by painting the area not occupied by displays or LED's. The easiest method is to mask all areas that are occupied by displays and LED's on the *back* side of the front panel and then paint the back side of the panel with black spray paint. Apply several coats to ensure a uniform covering. After the paint dries, peel off the masking tape and install the front panel.

The next step is to secure the magnets to the driveshaft (or output shaft) and mount the pick-up coil to the body or chassis of the automobile. To do that, you'll probably have to drive your car up on ramps. If you do not have a set of ramps, borrow or buy a set. Never get under a car that is supported only by jacks. It's also a good idea not to work under a car alone.

After raising the car, find a suitable location for mounting the magnets. On rear-wheel-drive vehicles, the best location is at the front of the driveshaft, near the transmission. At that place the driveshaft has the least vertical movement, so the magnets will maintain a constant distance from the pick-up coil. To mount the magnets, locate them around the driveshaft at 90° intervals and secure them in some way. The magnets we used in our prototype come with a strap that simplifies installation; you can purchase the set at a local auto-parts store or from the source mentioned in the Parts List.

On a front-wheel-drive vehicle, the magnets can be mounted reliably to the outer ring of the constant-velocity joint's dust boot near the transaxle. In that type of installation, there should be a metal strap on each side of the dust boot. Mount the magnets to the strap that is located nearest the transaxle, and secure the pick-up coil and its metal strip. If the boot is not easily accessible, the magnets may be mounted directly to the output shaft or one of the drive shafts, but be sure to place them where the least amount of vertical movement takes place.

Next mount the pick-up coil to the underside of the automobile using a strip of inch-wide metal. Of course, the length of the strip and the locations of the mounting holes will depend on your installation. But you'll probably want to bend the strip so that the front of the mounting coil and its bolt are about ½ inch from the magnets. Figures 7-*a*–7-*d* indicate several mounting schemes for driveshaft and transaxle installations.

After the magnets and pick-up coil are installed, run the signal wires from the pick-up coil through the fire wall to where the PC boards are located. Use plenty of wire ties or plastic tape. If you purchase the pick-up coil mentioned in the Parts List, you must replace its connector with a Molex-style connector.

Run a power wire from the mounting location to the fuse box and connect it to a circuit that is active only when the ignition key is in the *on* position. Remember to hook the ground wire to the chassis ground of the automobile.

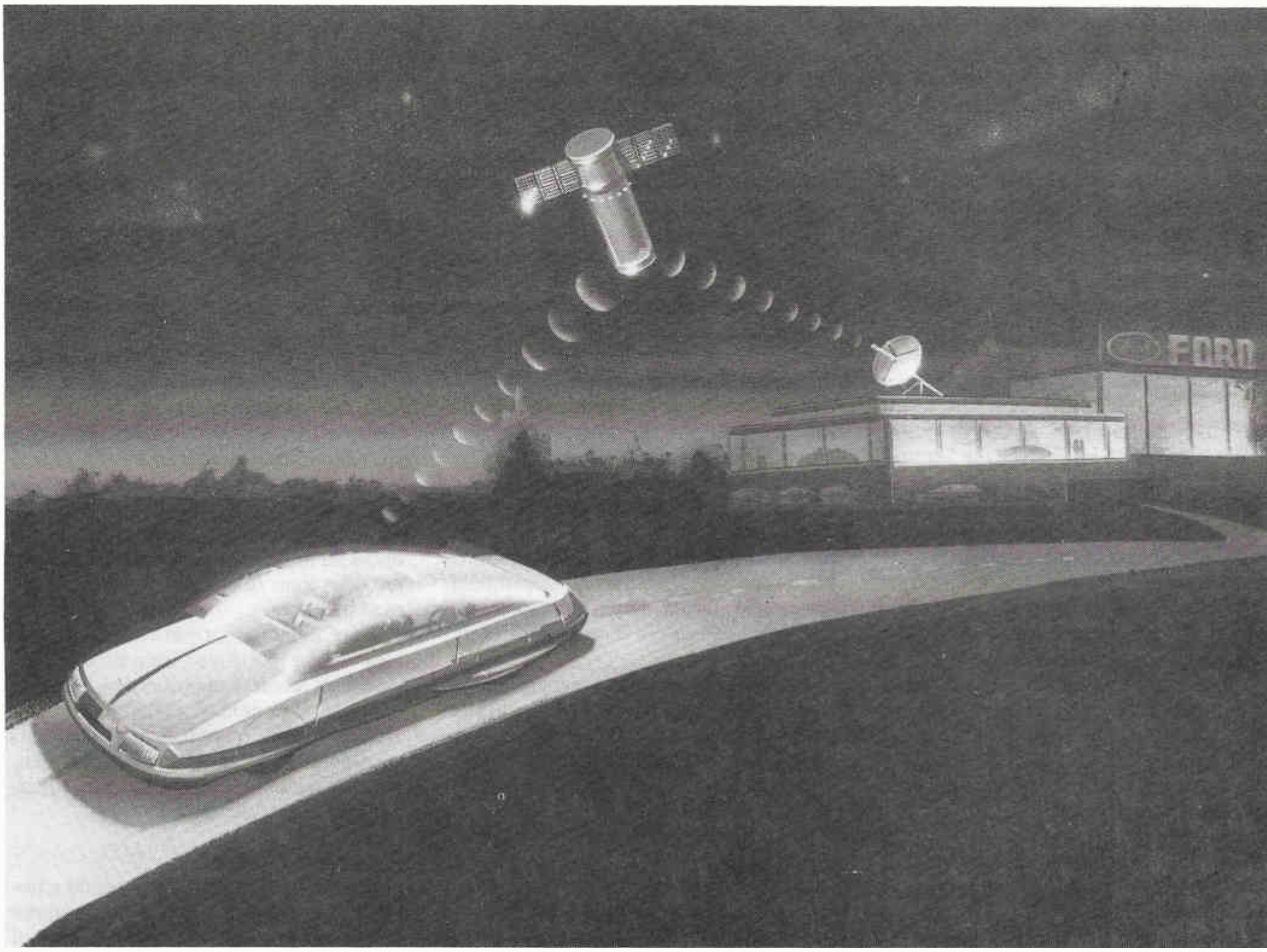
Calibration

To calibrate the speedometer, first decide whether you want the readout to be in miles or kilometers per hour. The next step can be accomplished in several ways. You can either calculate the speed of your driveshaft as discussed in the text box, or you can use the trial-and-error method.

To use the trial and error method, have a friend drive on an open stretch of highway, and, while watching your old speedometer, try setting S1 in different positions until the speedometer displays the correct value. Make sure your friend watches the road and his speed while you calibrate the speedometer! Next, have your friend drive at the "red line" speed, and set R34 so the first red LED lights up.

If the digital speedometer reads erratically while the vehicle is standing still, reduce the value of R6 from 470 ohms to 330 ohms or less. That reduces input sensitivity and prevents the unit from picking up electrical noise.

After calibration is complete, it's time for final installation. Mount the unit in its permanent housing, then secure and conceal all cables. **R-E**



THE AUTOMOTIVE WORLD OF THE 21st CENTURY

You're invited to test drive Ford's new 2001 model

Donald E. Petersen

ANY ATTEMPT TO DESCRIBE THE FUture is a hazardous exercise at best. By definition, it's an excursion into a world of fantasy. But fantasy can range from chimerical nonsense to a commonsense projection of a rational vision.

What follows here is the latter: a reasonable extrapolation of current automotive trends and technologies reaching out 14 years; a vision of the future of the automobile firmly based on technologies now emerging. Product planners and creative thinkers at Ford Motor Company have devoted considerable energies looking beyond conventional planning horizons—and into the 21st century.

When you think about it, 14 years ahead is not all that distant. Consider the fact that 14 years back was 1973—the year of the first OPEC-inspired energy crisis. To some of us, that doesn't seem very long ago at all.

Based on what we've learned since that time, however, it's safe to make one all-important prediction about the future: The businesses that survive into the 21st century will be the ones that have become obsessively customer-centered. We will realize the importance of producing products that meet the customers' demand for quality and supply their precise needs. We will learn, more skillfully than ever, to tap the remarkable reserves of talent, energy, and unique ideas that the people who work in our plants and offices can bring to their jobs. We will discover new and more productive ways to energize that crucial resource and use it.

In the process of looking ahead, teams of Ford futurists have identified dozens of technologies that can be applied to our future vehicles—to their designs, to their onboard features, to the materials used in them, and to the way that they are manufactured. The technologies can provide automatic navigational guidance, security-alert protection, and adaptive peripheral vision systems.

For the driver, those technologies would mean on-board, direct-to-satellite communications links with dealer service departments allowing automatic diagnosis of any developing problems; high-efficiency air-purification systems; automatic passive-restraint systems; electronic light-emitting surfaces; auxilliary electrical power systems using photovoltaic cells integrated into the roof; and special glass coatings that reduce vision distortion from rain, repel dust, and retard formation of condensation.

Our vision of the future features modular construction of the automobile—using modules that can be easily reconfigured for urban use, for family vacations, or for long-distance travel.

But rather than just listing the features of the future car, let me invite you to imagine what it would be like to enter the showroom of a Ford dealer featuring the newly introduced 2001 model.

A future vision

As you enter the showroom, your first glimpse of the car conveys its strikingly aerodynamic appearance. As you move closer, you notice that its appearance results from more than just the "clean" basic shape. There are no apparent door handles, rear-view mirrors or antennas. The glass, which comprises all of the vehicle above the belt line, is flush with the lower body and shaped with compound curves to conform to the car's smooth aerodynamic form.

A Customer Information Specialist (CIS) introduces herself and explains the vehicle's overall Airflow Management System—which includes such automatic features as variable ride-height control, variable skirts and spoilers that cancel all induced lift, and variable air inlet/outlet ducts—all under the coordinated control of a central electronic command system.

She points out the wide tires that blend into smooth, disc-like, body-colored wheels and explains how the tire-reinforcing cords are continuous with, and flow into the molded plastic wheels, resulting in a perfectly balanced, light-weight, high-performance integral element.

As you stroll around the car, you wonder at the apparent lack of turn-signal indicators, side marker lamps, or tail/brake lights. The CIS explains that all of those functions are now accomplished by electronic light-emitting surfaces, which have been integrated into the glass and selected body areas, and are almost invisible unless they are lighted.

When lighted, the areas become highly visible and vary in intensity, color, and shape to clearly communicate the driver's intent and the vehicle's operating condition, such as its rate of deceleration or acceleration. She illustrates her explanation by activating the left turn signal. Instantly, you see a large, bright, flashing yellow arrow appear on the bottom left region of the rear window area.

To open the car door, the CIS demonstrates the Keyless Entry feature, which is activated by a coded sequence of touches to sensitive areas on the side window. In response to the proper code, the door automatically opens; an exterior handle is no longer needed.

Now that the door is open, the CIS invites you to slide into the driver's seat. The seat momentarily feels alive as it automatically adjusts to conform to your body, like a fluid-filled bean-bag chair.

She continues by explaining that the Automatic Total Contour Seat is part of an overall Individual Occupant Accommodation package that also provides individually selectable climate control and audio programming for each occupant.

The CIS points out that in place of rear-view mirrors, there are multiple electronic cameras that are individually programmable for the best direction and size of field. Those cameras are small and "look out" through the glass, so they are almost impossible to detect.

They display on a 3-segment screen located on the upper rim of the Driver Information Module and portray the environment behind and to both sides of the car. There are absolutely no blind spots, and the system senses non-visible infrared radiation; it works equally well at night and during inclement weather.

She points out that the same technology also operates a forward-looking infrared system that provides driver vision during heavy fog, rain, or snow conditions in the form of a heads-up display on the windshield where driver attention focuses.

The CIS now invites you to watch a short video presentation that illustrates some of the car's construction details.

Modular construction

The holographic video show introduces the automobile as a breakthrough in the development of modular construction. You watch as 3-D representations of the vehicle's basic building blocks appear out of nowhere and slowly rotate into correct positions, while a voice explains the advantages of that modular assembly.

You learn that the basic vehicle module is an occupant-protecting "cage" constructed of heat-treated alloy steel preforms that are bonded together with structural adhesives to form an incredibly strong and resiliant structure. The narrator states that two-, four-, and six-passenger modules are available.

Front and rear-end modules attach to the central occupant cocoon with what appear to be about a dozen bolts. The integrated engine/transmission powertrain is itself a sub module that can be installed in either a front or rear module. For applications where 4-wheel drive is required, or where "dual power" is considered an asset, a powertrain module may optionally be installed in both the front and the rear.

Required tailoring of parameters such as suspension rates, damping characteristics, and brake proportioning is accomplished by appropriate programming of the central electronic control system.

The steering is also under electronic control—which automatically orchestrates complex 4-wheel steering responses to completely normal driver inputs. That effectively extends the performance range of the vehicle during any radical maneuvers.

The video show concludes by showing how the completed assembly of modules—which is basically a drivable vehicle—is skinned by large plastic panels which are corrosion-proof, damage-resistant, and easily replaced if required. A full-length, smooth plastic underpan reduces air turbulence under the vehicle and provides some drag-free "ground effects" road handling.

The CIS points out that additional modules will be introduced from time to time as market research uncovers new consumer needs. She emphasizes that all modules will be readily interchangable, and it is even possible to rent a module and temporarily reconfigure the vehicle for short-term purposes such as vacations.

Flying the simulator

The CIS suggests that you spend a few minutes in the dealer's vehicle simulator which will demonstrate the operation of various features. She explains that the simulator is based on aerospace flight-simulator technology.

Upon entering it and closing the door you are amazed at how life-like the experience is. The CIS joins you on the passenger side and gives you an operator authorization code that's needed to activate the simulator.

Of course, the conformable seat has already adjusted to you, but you've experienced that earlier. You adjust the Adaptive Peripheral Vision sensors and the sound system to your preference. You notice that the sound system couples low-frequency response to your body directly through your seat, greatly enhancing the realism.

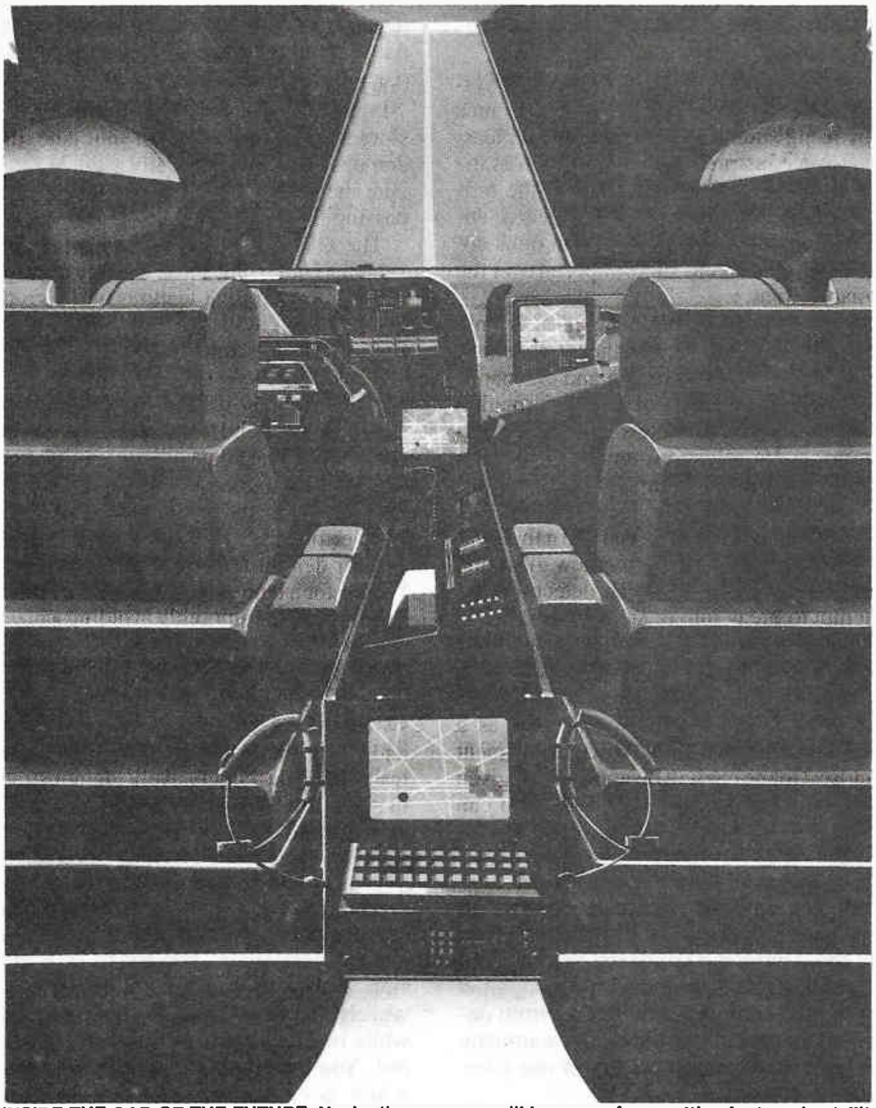
The CIS explains that you can now make several more personal-preference adjustments. The first is Climate Control. You select a temperature of 68° F, whereupon she reaches for her individual Occupant Accommodation control pad and selects a temperature of 72° F for her side.

Now you begin to "drive" the simulator while the CIS uses a special control to call up a range of road surfaces. As you begin to acquire a feel for the "vehicle," she suggests that you experiment with the driver-preference controls which determine effective suspension-spring rates and damping characteristics. Also, you experiment with the controls that program the steering effort, steering sensitivity, and simulated road-feel feedback. You converge on a combination of settings which feels best for you.

Since you are now "driving" the simulator in a more spirited fashion, the CIS asks if you would like to experiment with the instrument format. You sequentially review each of the 12 basic pre-programmed information formats as they appear on the colored flat-panel display of the Driver Information Module. Ultimately, you opt for an electronic representation of a few basic analog gauges augmented by a variable color bar-chart which graphically displays that all of the vehicle's critical systems are operating within their normal range.

As you really extend yourself at simulated high speed along a twisting road, you feel the conformable seat grip you tighter. Also, the instrumentation display simplifies to an easier-to-read, less-distracting format.

After several minutes of that, you do manage to find the limit and spin-out. You shut off the simulator and remark to the CIS how useful that experience was to you. You had no previous idea that a "road car" could be stably controlled at such high rates of lateral acceleration. You mention that you will probably now be a better driver should an emergency situation arise. She agrees and explains that the simulator has been used effectively for advanced driver training. But now it's time to try the real thing.



INSIDE THE CAR OF THE FUTURE. Navigation screens will keep you from getting lost, and satellite telephone hookups will put you in touch with the outside world from the start to finish of every journey.

21st-century automotive serivce

On your way to the parking area where the demonstrator vehicle is parked, you pass by the dealer's service area and the CIS introduces you to the service manager. He describes the recent changes that have occurred in his department.

First, the new vehicle's central control-system contains a self-diagnostic feature that pinpoints the source of virtually all problems. Because of the car's highly modular construction, the preferred repair technique is to replace the offending module. In most cases, that can be accomplished in a couple of hours. The modules that are removed will be repaired either at the dealer's facility or at regional service centers, or they will be returned to a factory where they will be completely remanufactured and reissued.

Continuing his explanation, the Service Manager informs you that redundant systems and "limp home" features make it highly unlikely that the vehicle would ever break down on the road. If it should occur, however, its on-board direct-to-satellite, two-way communication system will automatically contact the nearest dealer. The dealer system will analyze failure data and determine whether the problem can be fixed in the field using replacement modules in inventory.

If the problem is not field-correctable, a service van will drop off a loaner vehicle and transport your car back to the dealer's service department for repair.

When the Service Manager finishes his explanation, you ask about the "two-way satellite communication system" and "on-board navigation system"—two features you had not heard about before. The CIS assures you that the demonstrator contains both systems and that they will be explained during the test drive.

Driving the demonstration vehicle

As you slide into the driver's seat in the demonstrator, the CIS hands you the driver ID card that she programmed in the simulator. That card also contains the authorization code for this vehicle. Inserting the card in a slot in the Driver Information Module, you start the engine while all driver-adjustable systems automatically adjust to your preference.

It's a cold fall day—well below the 68°F setting of your Individual Occupant Accomodation control, and you're aware that you are being bathed by a gentle stream of warm air. The CIS explains that that is a Quick Heat feature, which uses energy from an auxilliary electrical power system that generates electricity using photovoltaic cells integrated into the roof glass. It stores that power in a high-energy-density solid-electrolyte battery.

As you pull out of the dealer's lot, the CIS begins to explain the communication and navigation systems. She informs you that the demonstrator you are driving has automatically established contact with a geosyncronous orbiting satellite.

She switches on the navigation system, and a map of the dealer's neighborhood appears on a flat-panel display on the right side of the Driver Information Module. A flashing dot indicates the exact location of your car. As she dials-down the resolution, the neighborhood map "zooms" to a full-city map; but the position of your car is still readily apparent. She points to the map and suggests that you head for a near-by freeway.

She then programs the navigation system to guide you to the freeway entrance by using audible commands, and a pleasant voice instructs you: "Turn right at the next intersection and move into the left-turn lane for access to the freeway entrance ramp." The same instructions appear on the screen, superimposed over the map display.

You also learn that navigation is only one function provided by the satellite link. She pushes another button and the map is replaced by a display of local information topics including: hotels/motels, restaurants, route selection, amusements, museums, and local events.

The CIS continues by explaining the Security Alert feature. You learn that sensors integrated into the window glass and in other key locations can detect any attempt to break into or steal the car. When the sensors are stimulated, the communication and navigation systems will automatically link up with a central Customer Security Services facility operated as a customer service. The police department closest to the car will be notified and given the car's exact location. The system can also be activated manually for any necessary emergency assistance.

By now you have reached the freeway-entrance ramp. As you accelerate to the 70 mph speed limit, the CIS introduces you to the Automatic Guidance feature. You learn that this feature uses the navigation system in conjunction with data from on-board sensors to provide totally automatic vehicle guidance on certain of our interstate highways.

This particular highway has been "mapped," so the CIS shows you how to engage the guidance feature while continuing to explain that within a few years, a complete interstate "grid" of highways will be "mapped" and reserved exclusively for automatic-guidance-equipped vehicles.

As the automatic system takes over, you release the controls and observe that the demonstrator vehicle tracks smoothly down the center of the lane at a constant 70 mph. As you gradually close in on a slower-moving car ahead in your lane, the demonstrator automatically signals for a lane change and pulls smoothly to the left, passing the slower vehicle.

The CIS explains that even when the vehicle is not being automatically guided, constantly operating features of the guidance system will prevent unsafe lane changes and passing maneuvers. The system will also detect upcoming road hazards, such as an ice patch, and help the driver to respond appropriately. In an emergency, that constantly operating system will take over so that it is almost impossible for the car so equipped to hit another object.

Your demonstrator completes its pass, signals for a lane change and pulls into the right lane while smoothly avoiding a piece of truck-tire tread lying in the road between lanes. The CIS suggests that you take the upcoming exit ramp, so you switch off the automatic guidance system and notice that it does not relinquish control until you conclusively demonstrate that you are back in command.

The road back to the dealership is lightly traveled and twisting so you engage in a mild version of the performance driving you enjoyed in the simulator. The demonstrator confirms all of your simulator impressions. You try to skid to a stop, but your car refuses to lock its wheels. It just stops rapidly, but smoothly, while maintaining your full steering control. You try to spin the wheels on gravel when accelerating away from construction at an intersection, but you can't do it. The car just accelerates smoothly, automatically determining the maximum rate it can attain.

Nearing the dealership, you pass a road-repair crew generating a cloud of dust and spreading hot tar on the road's shoulder. As you pass this scene, you realize that you did not detect the expected odor of tar "The air-purification system filtered it out," the CIS explains. You also remark that no dust stuck to the windshield even when you stopped momentarily in the dust cloud. "It's electrostatically repelled," she explains, and she also mentions that the windshield has a special coating inside and out which reduces vision distortion from rain and greatly retards the formation of any condensation on the glass surfaces.

As you near the dealership, the CIS explains that this car can electronically communicate with others. Soon, all new vehicles on the road will have that feature. That capability also functions as an adjunct to audible horns and sirens, and is a particularly useful way for emergency vehicles to warn near-by drivers, particularly in urban areas where sirens are used less often.

Placing your order

As you return to the showroom, the CIS accompanies you to an interactive Vehicle Specification Selection and Order Coordinating Terminal where you work out the exact combination of features and options you wish to order.

She helps you to consider the relative virtues of the various powertrain options. You select a higher horsepower unit for rear module/rear drive installation. That basic engine adapts to various fuels—including gasoline and alcohol. You select gasoline, since that's the prevalent fuel in your area.

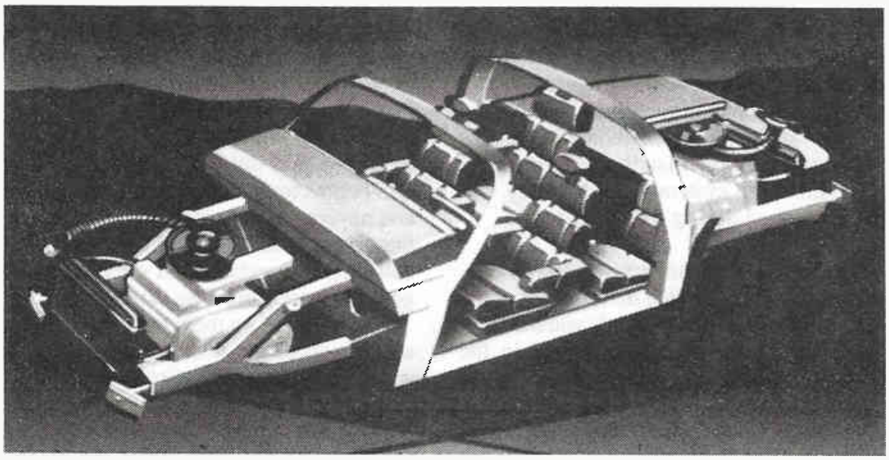
The CIS mentions that a hydrogen-fueled powertrain with high-performance capabilities is in the final stages of development and suggests that you may be interested in trading in your gasoline-fueled powertrain and upgrading to the hydrogen unit in a couple of years.

When you finish the specification process, the CIS explains that your order is now being entered, analyzed, and scheduled at the factory. Just as she finishes her explanation, the terminal displays a message that your order has been placed and your car will be delivered to your dealer—exactly 15 days from now.

After thanking the CIS for her help, she invites you to tour the manufacturing complex where your car will be constructed. The complex is only about 120 miles away, and a tour takes about half a day. That sounds great to you, and it is conveniently arranged.

21st-century manufacturing

The first stop on your tour of the manufacturing complex is a small auditorium where your tour guide explains that you will see a short film that explains some of what you'll see later. You learn that all engineering and manufacturing processing is now accomplished on an integrated, computer-driven engineering, design,



MODULAR CONSTRUCTION will allow your car to be custom built and upgraded as new modules are introduced. You'll also be able to rent modules to temporarily reconfigure you car—to take a family vacation, for example.

processing and testing network that ties together all design and production centers. Even key suppliers are tied into selected parts of this network.

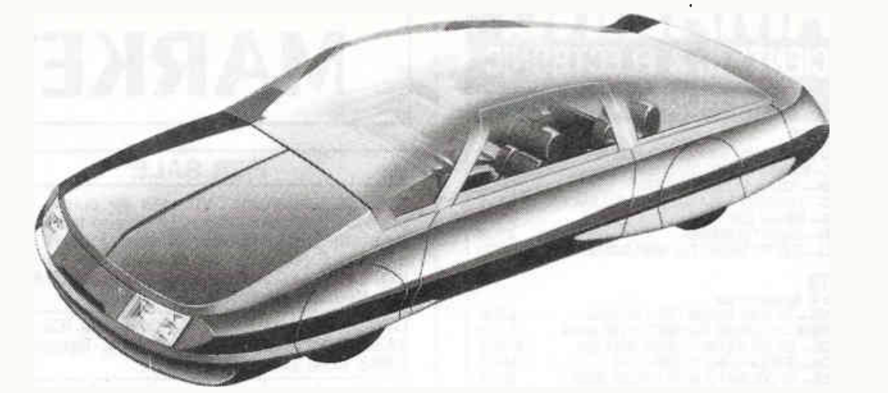
The film presents an overview of the manufacturing complex. You learn that the central Vehicle Final Assembly facility is responsible for assembling completed modules and sub-assemblies into a finished automobile. Those modules are supplied on a just-in-time basis from a ring of surrounding plants which use highly automated but flexible processes to manufacture, and remanufacture, a variety of components. Those factories are operated by a highly trained staff.

Not all manufacturing operations are represented at the complex you will tour. Engine blocks, steel structural pre-forms and major glass components are all supplied to the module-fabrication plants from central facilities. The film concludes by presenting those operations.

You see one-piece aluminum engine block/cylinder head/transmission case casting with ceramic inserts being processed by evaporative-casting techniques. You watch large pieces of thin glass being laminated to transparent plastic and molded into complex shapes which are lightweight but shatterproof.

The film's concluding sequence shows steelmaking in which plasma melting techniques are used to produce carefully controlled, high-purity alloy steel, which is cast into a thin slab requiring minimum hot rolling before it is cold-rolled into a finished sheet. Some of the sheet steel is electrolytically coated with a nickel alloy for outstanding corrosion resistance and is supplied in that form to other Ford manufacturing locations. Other sheet material is roll-formed into a structural preform which is cut to length, stretch-formed and selectively heat-treated by lasers.

The real tour starts in the Powertrain Module Factory. There you watch as robots that, in your guide's words, can "see," "learn" and "think for themselves," perform the complex task of assembling a high specific output, high



THE ALL-GLASS TOP OF FORD'S 2001 MODEL is flush with the body, giving the car execellent aerodynamic performance.

RPM, internal combustion engine within a "monoblock" casting which also houses the integral Continuously Variable Ratio transmission.

The highly automated assembly process makes it difficult for you to see all of the operations, but you are able to visually confirm your tour guide's claim that many of the engine's internal components are fabricated from high performance plastic composite materials.

The guide also points out that the engine's various covers and "pans" are installed with structural adhesives and are not removable in the field.

As you study the finished powertrain modules at the end of the assembly line, you notice that they are all fully integrated units, devoid of any "hung-on" accessories. For control purposes, a single electrical umbilical is provided to plug into the vehicle's central control-system.

Your next stop is the Greenhouse Fabrication Factory where you watch large formed-glass pieces being unloaded from trucks onto a line for Magnetic Vacuum Sputter Deposition. That process, your guide explains, is used to deposit multiple thin films of exotic materials to insulate the car's interior from the sun.

That, you are told, allows smaller/lighter air conditioning systems and prevents degradation of the car's interior materials from ultraviolet radiation. The coatings also impart cosmetic color to the glass, control glare, and reduce the tendency to fog. In other operations, various sensors and antennas required for features such as keyless entry, intrusion detection and satellite communication are integrated into the greenhouse structure.

You next visit the Exterior Panel Fabrication Factory where large panels are injection-molded from high performance thermoplastics or formed from reinforced thermoset plastic composites with finished color gel coats in large presses.

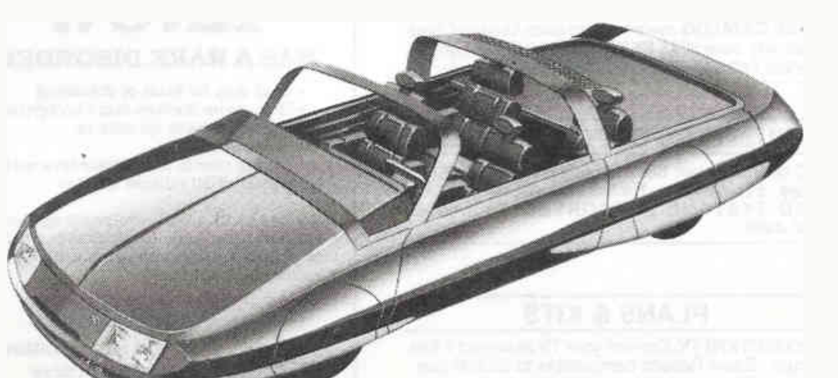
Your tour also includes stops at the Suspension Module Assembly plant and the various structural module fabrication plants where you watch robots apply fast-curing structural adhesives to bond elements into an integral structure.

All modules leave their various assembly plants complete with all sensors, actuators and control electronics and a single electrical power-distribution bus.

Your tour ends at the Final Vehicle Assembly plant where all modules arrive on a coordinated, just-in-time basis and are assembled by robots, with minimum human assistance, into a completed vehicle. A comprehensive computer-directed final checkout procedure completes the manufacturing process.

On your drive home from the plant tour, you think about the seven days remaining until you take delivery. You can hardly wait! **R-E**

Well, there you have it. A look at 21st century transportation technology, materials, and manufacturing processes as we at Ford Motor Company now anticipate them to be. To me, it's a fascinating prospect. But getting from here to there will be even more fascinating. While I expect to be happily retired and playing golf in Palm Springs when 2001 comes around, what we do for the remainder of this decade and into the 1990's will determine whether or not this scenario comes anywhere near reality. And, as I noted at the outset, how we treat our customers and how we treat our own people will make all the difference.—Donald E. Petersen



THE INTERIOR OF FORD'S FUTURISTIC automobile is revealed in this photo by the removal of the glass top.

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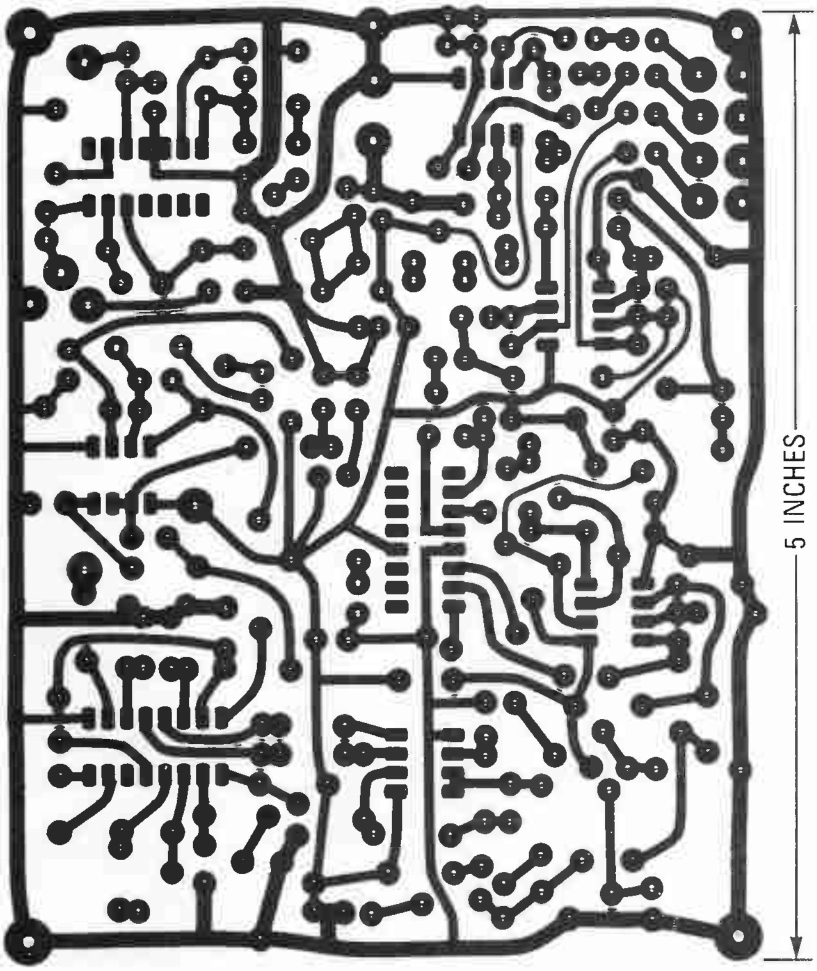
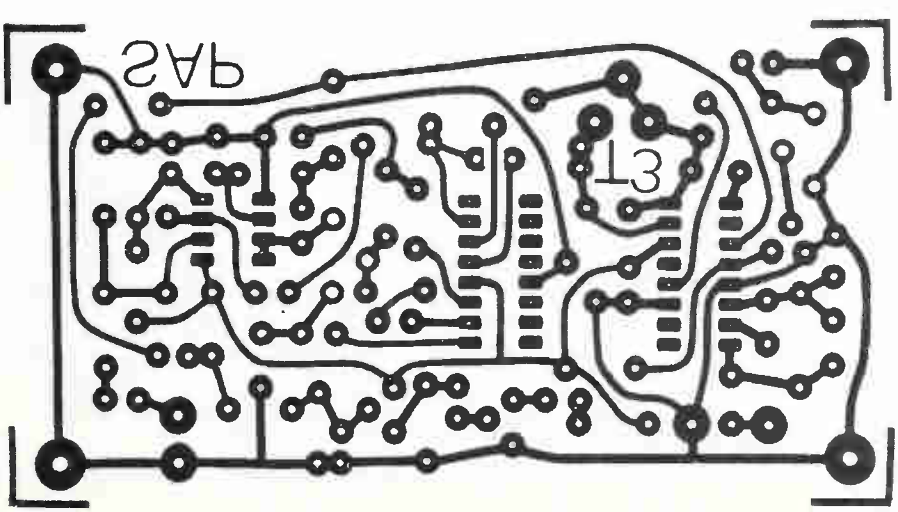
PC SERVICE



ENJOY THE BENEFITS OF MULTICHANNEL TV SOUND with our stereo-TV decoder. The foil pattern for the PC board is provided here; constructionand installation informtion can be found beginning or page 11.



One of the most difficult tasks in building any construction project featured in **Radio-Electronics** is making the PC board using just the foil pattern provided with the article. Well, we're doing something about it.

We've moved all the foil patterns to this new section where they're printed by themselves, full sized, with nothing on the back side of the page. What that means for you is that the printed page can be used directly to produce PC boards!

Note: The patterns provided can be used directly only for *direct positive photoresist methods.*

In order to produce a board directly from the magazine page, remove the page and carefully inspect it under a strong light and/or on a light table. Look for breaks in the traces, bridges between traces, and in general, all the kinds of things you look for in the final etched board. You can clean up the published artwork the same way you clean up you own artwork. Drafting tape and graphic aids can fix incomplete traces and doughnuts, and you can use a hobby knife to get rid of bridges and dirt.

An optional step, once you're satisfied that the artwork is clean, is to take a little bit of mineral oil and carefully wipe it across the back of the artwork. That helps make the paper transluscent. Don't get any on the front side of the paper (the side with the pattern) because you'll contaminate the sensitized surface of the copper blank. After the oil has "dried" a bit—patting with a paper towel will help speed up the process—place the pattern front side down on the sensitized copper blank, and make the exposure. You'll probably have to use a longer exposure time than you are probably used to.

We can't tell you exactly how long an exposure time you will need but, as a starting point, figure that there's a 50 percent increase in exposure time over lithographic film. But you'll have to experiment to find the best method for you. And once you find it, stick with it. Don't forget the "three C's" of making PC boards—care, cleanliness, and consistency.

Finally, we would like to hear how you make out using our method. Write and tell us of your successes, and failures, and what techniques work best for you. Address your letters to:

Radio-Electronics
Department PCB
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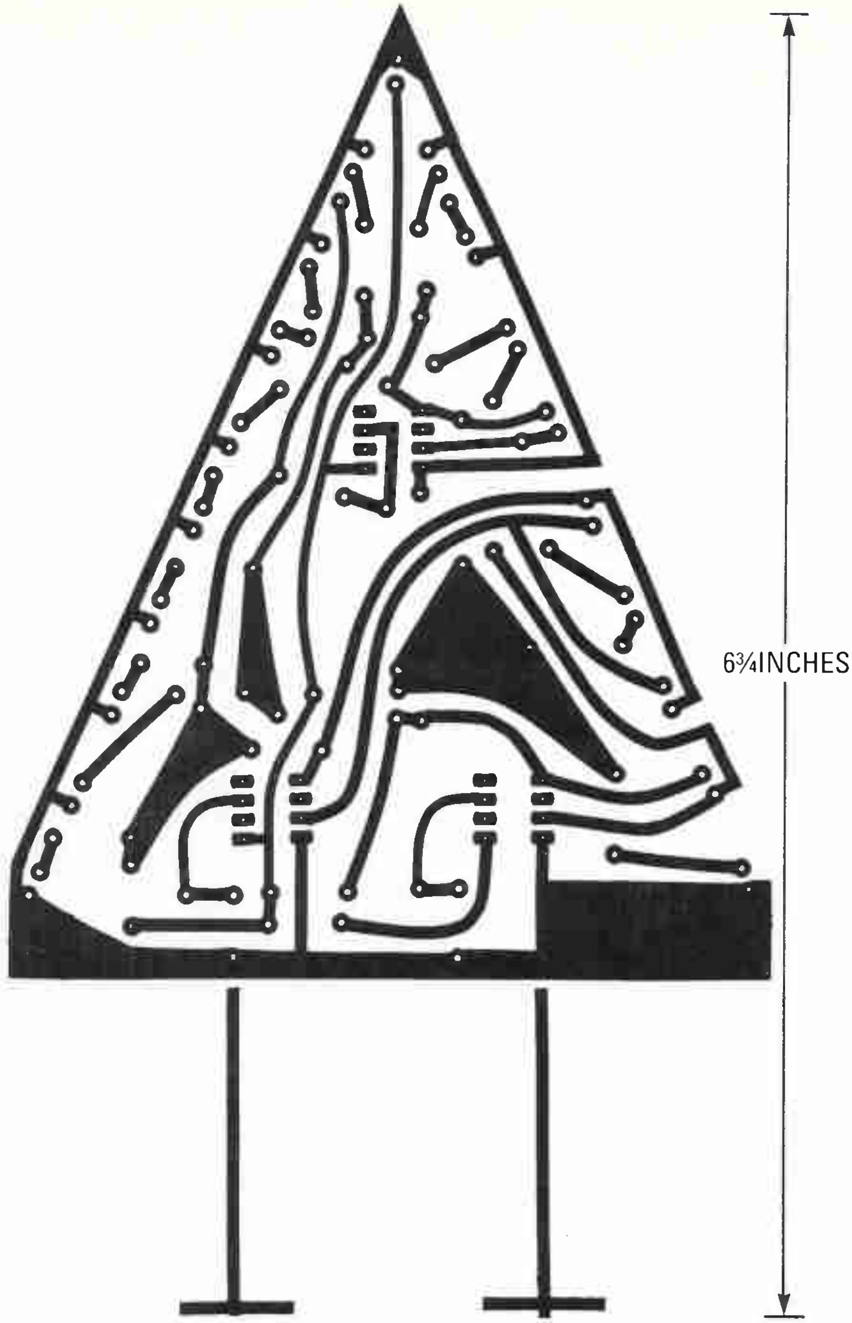
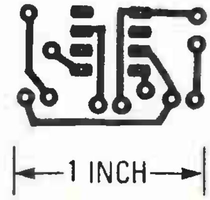
Farmingdale, NY 11735

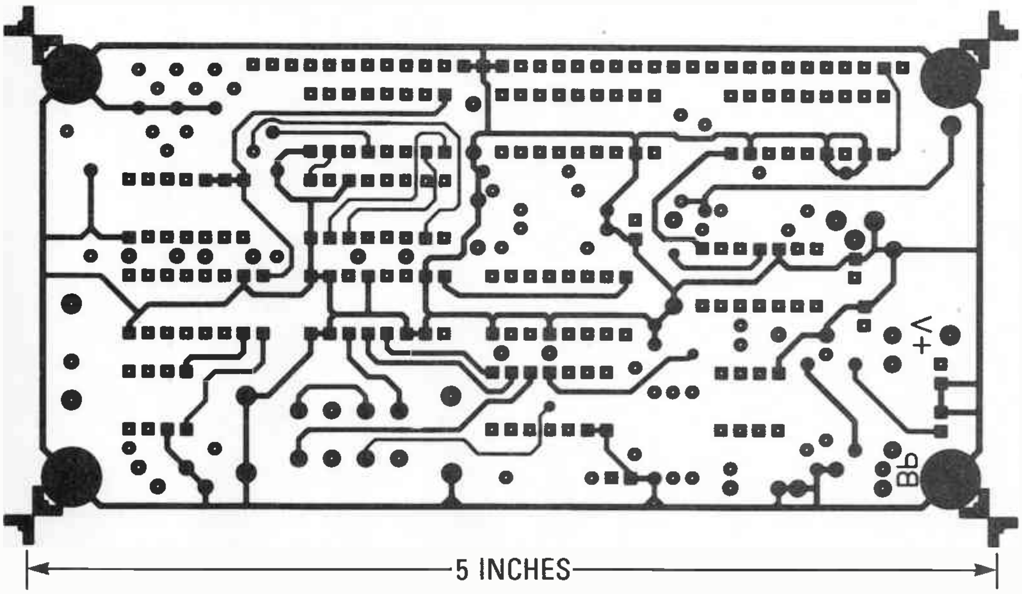
THE SAP ADAPTER'S PC pattern is shown at left.



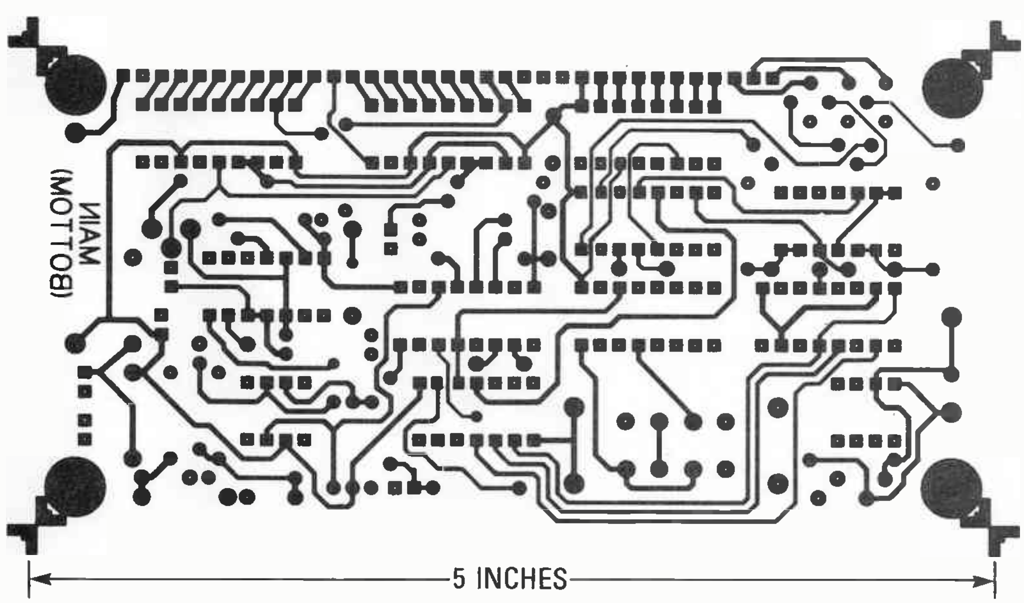
LIGHT UP THE HOLIDAYS with the electronic Xmas tree. The PC board for that project is shown here.



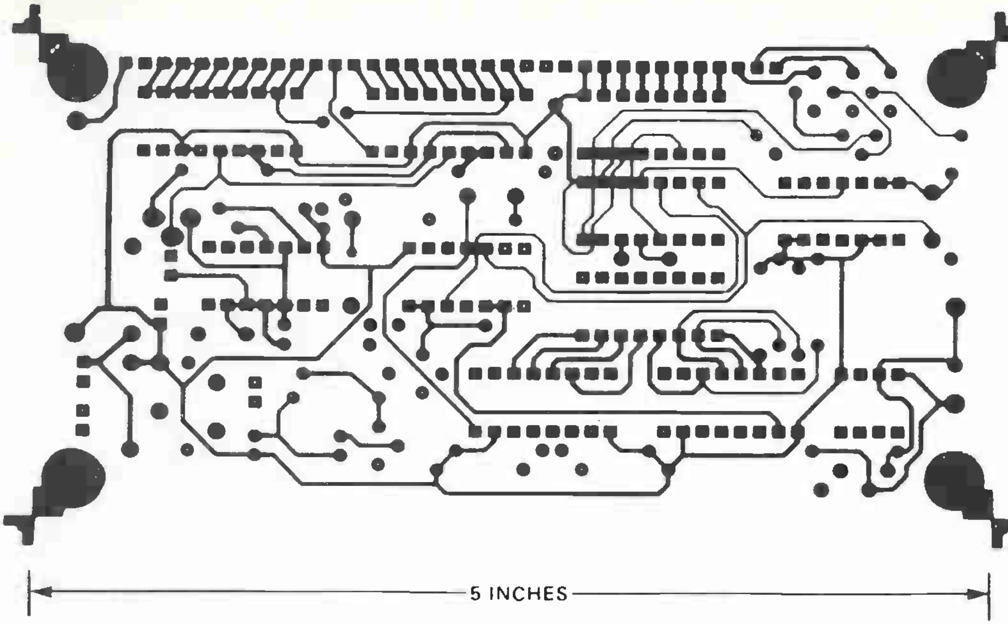
OUR ELECTRONIC SCARECROW can help chase away a less than determined burglar. If you chose to build that circuit on a PC board, here's a pattern that's approriate.



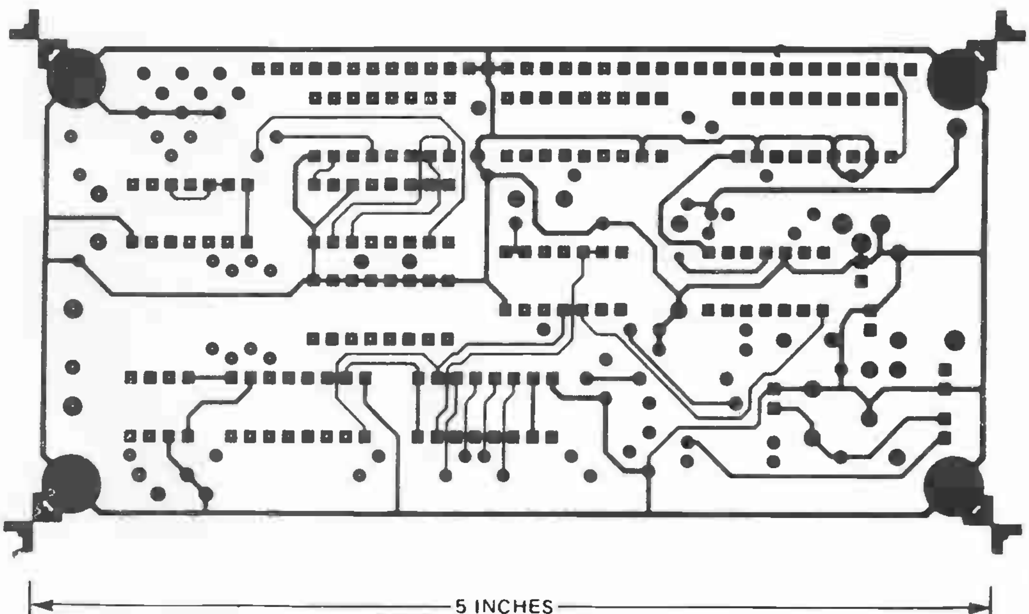
THE COMPONENT SIDE of the digital tachometer.



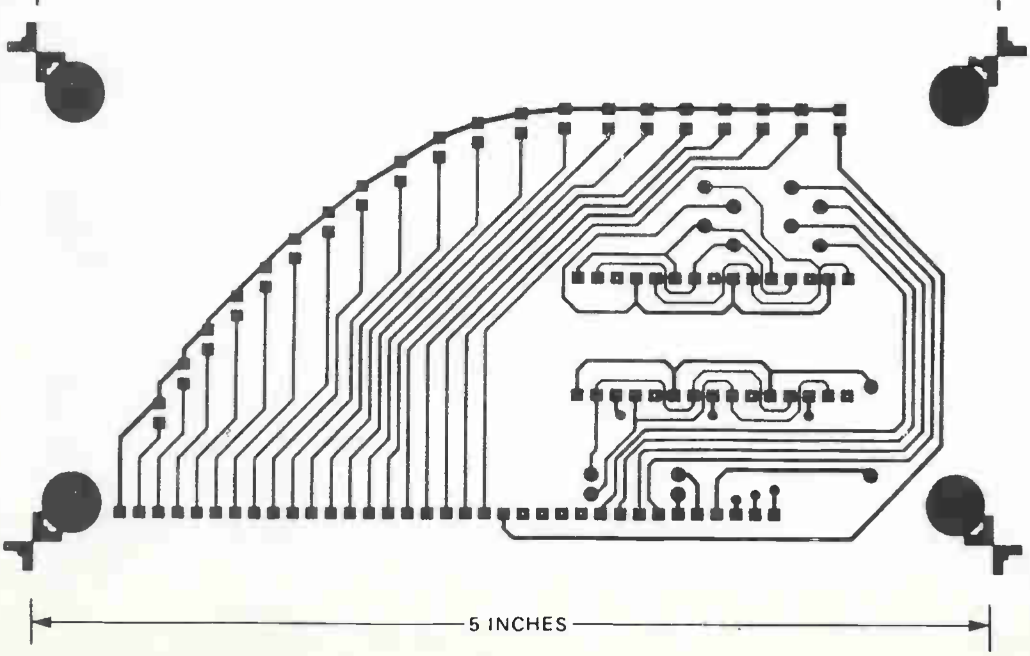
THE SOLDER SIDE of the digital tachometer is shown here.



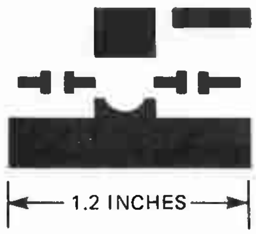
THE SOLDER SIDE of the speedometer's main board is shown here.



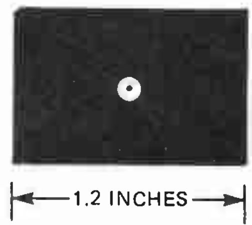
THE COMPONENT SIDE of the speedometer's main board. When mounting components, be sure to solder all leads completely.



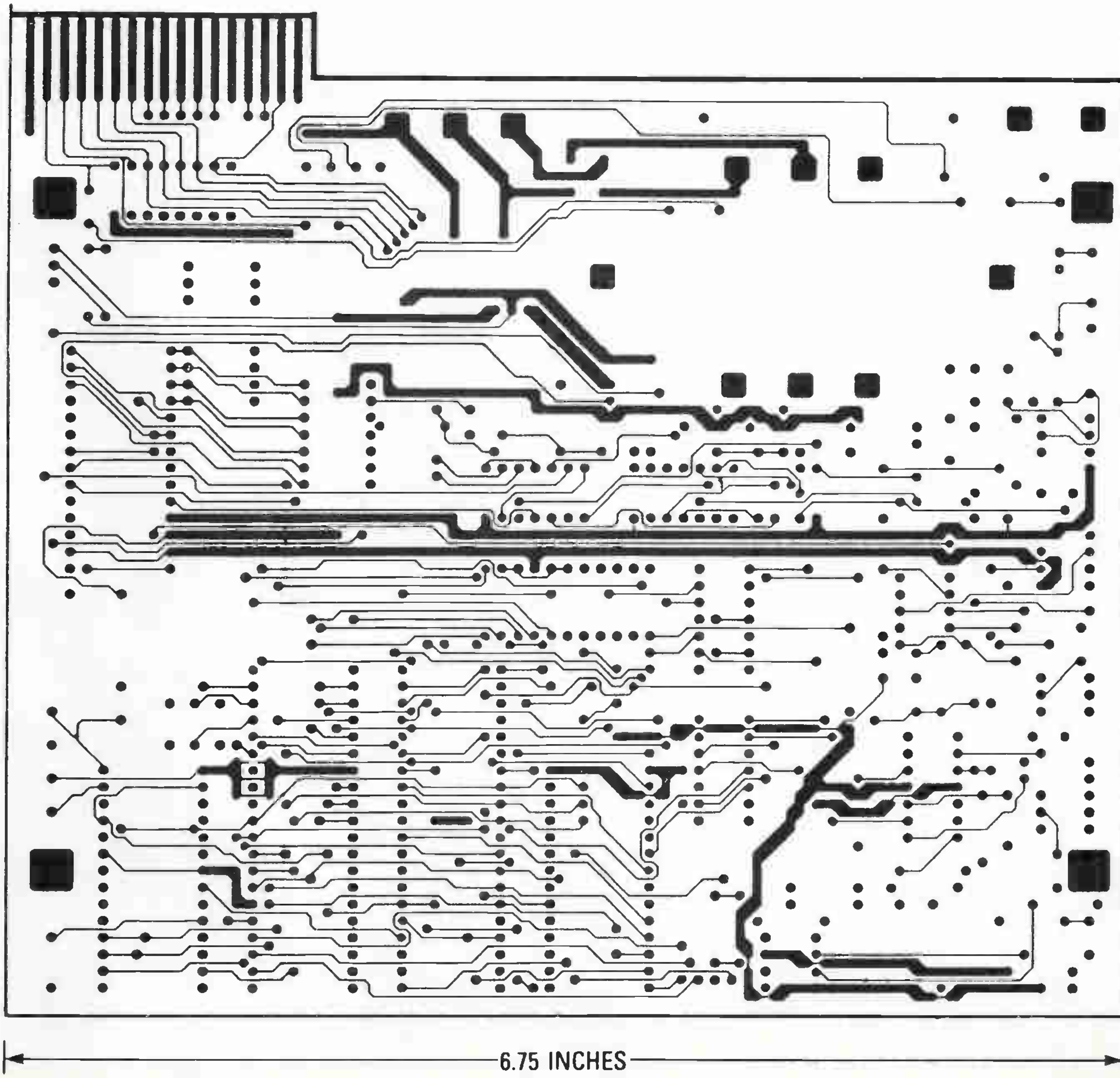
THE SPEEDOMETER'S DISPLAY BOARD. It is connected to the main board using 35 jumper wires.



SOLDER-SIDE DIRECT-ETCH FOIL PATTERN for the wideband amplifier. The story begins on page 45.

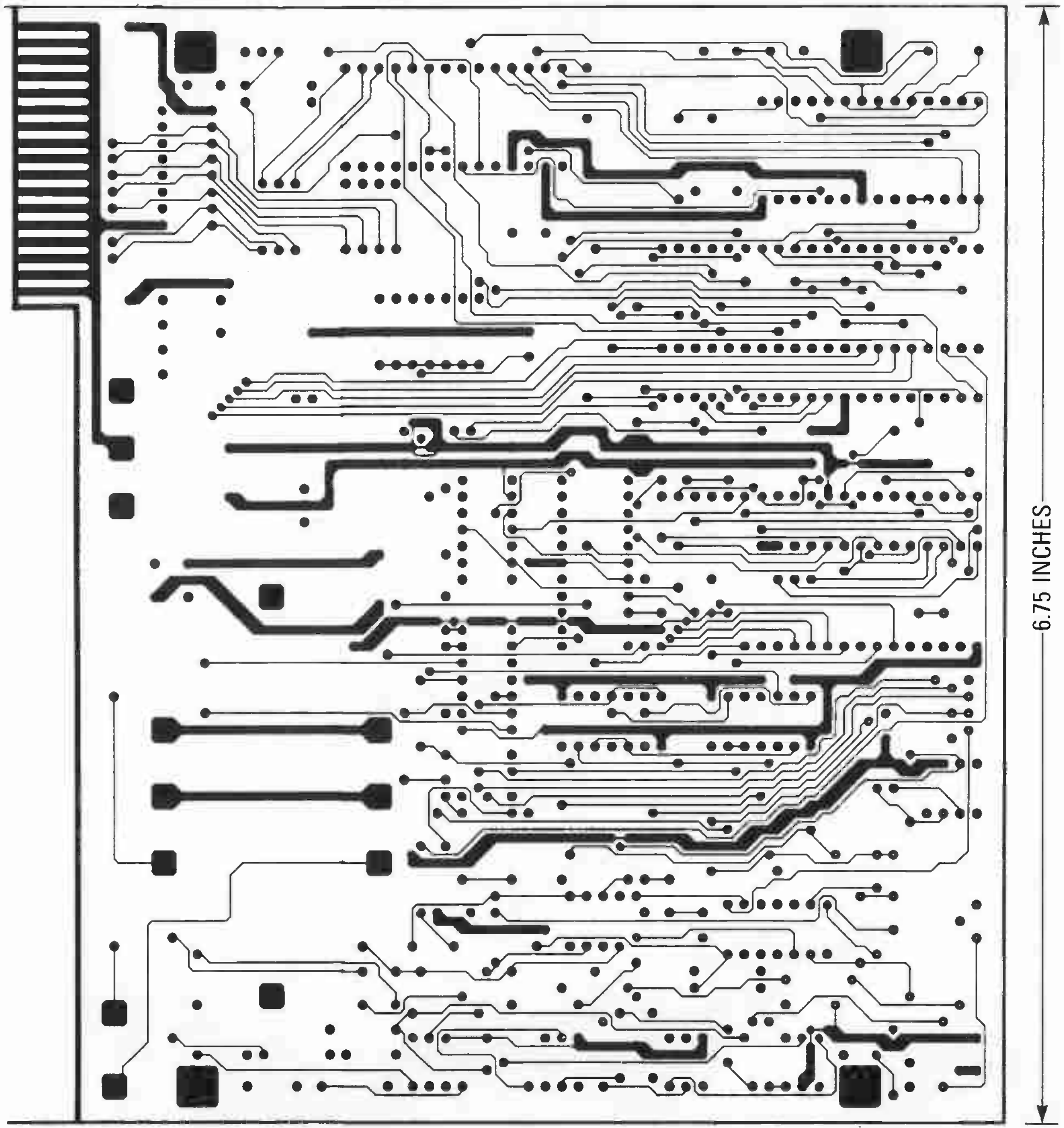


COMPONENT-SIDE DIRECT-ETCH FOIL PATTERN for the wideband amplifier.



THE COMPONENT SIDE of the double-sided Phonlink PC board.

PC SERVICE



THE SOLDER SIDE of the Phonlink PC board is shown here.

ACID RAIN

continued from page 42

points. Connect the circuit to a VOM, and adjust the potentiometer for a reading of 94 μA. Then disconnect the sensor assembly from the main circuit and connect the battery-potentiometer combination in its place. Adjust R1 until the meter reads exactly 100 μA, which corresponds to a pH of 2.5.

The other pH points are established by feeding a known current to the circuit and noting the position of the needle. Those positions correspond to the pH's shown in Table 1. If you want to interpolate in-between values, keep in mind the fact that the scale is not linear.

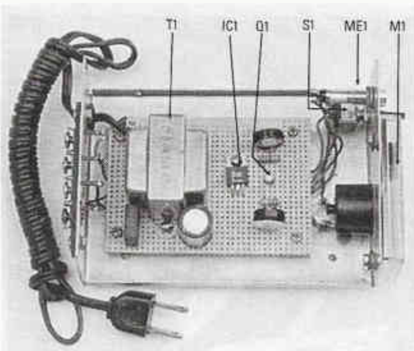


FIG. 5—THE ELECTRONIC COMPONENTS mount on a piece of perfboard; they are connected by point-to-point wiring. The terminal strip provides connections to the remote-mounted sensor and solenoid.

Installation and use

The best location for the sensor assembly is on a post, as shown in Fig. 6, away from trees and buildings. If it's mounted on the side of a house, be sure that the bracket you use is long enough to place the funnel beyond roof or eave run-off.

Don't be alarmed if the meter indicates some acidity. A pH of 6.0 to 6.5 is normal and unharmful. However, environmentalists warn of dire consequences for continuously higher readings.

For example, at continuous pH levels of 5.0 to 5.5, lawns and garden plants will begin to turn brown, and soil will need added lime. A pH of 4.5 in ponds and lakes will start killing fish, and, when pH reaches a level of 4.0, a clear blue appearance, although beautiful, will indicate a "dead" body of water. A pH of 3.5 will cause rapid deterioration of painted surfaces. A continuous pH of 3.0 will result in erosion of structural limestone, and entire forests will die. Last, if the meter indicates 2.5 or less, you may be living near an active volcano!

After taking readings from accumulated rainfall, the funnel should be drained, leaving S1 in the DRAIN position only long enough to drain the funnel, as most inexpensive solenoid valves are not designed for continuous duty. Inspect the electrodes several times a year, and if any corrosion forms, swab it off with a weak ammonia-water solution, and then flush the electrodes with distilled water.

For studying the long-term effects of acidity, the output of the meter could be connected to a chart recorder. And the meter may also be used to test your local tap, pond, and stream water by pouring a sample into the funnel. **R-E**

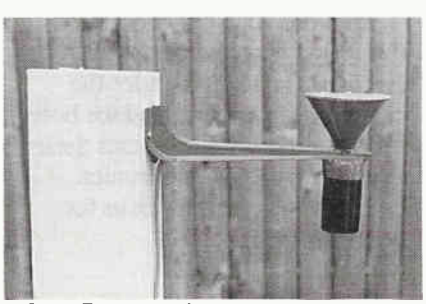


FIG. 6—THE SENSOR ASSEMBLY should be mounted on a long bracket that is screwed to a post. The post should be mounted away from overhanging eaves; and don't mount it under a tree.

BURGLAR ALARM

continued from page 26

battery holder to the panel using RTV adhesive; the holder should be located just below the holes for the LED's. Then mount the key switch in the appropriate hole. Wire the switch and the battery holder to the appropriate points on the board, keeping lead lengths as short as possible. Bend the LED's 90° so that they are parallel with the board. Position the LED's in the holes you previously drilled for that purpose so that they protrude about ⅛ inch. Finish up by securing the board to the top of the battery holder with a piece of double sided tape. Fig. 3 shows how it should look.

The unit can be installed just about anywhere. We suggest mounting it in your door frame for a professional look.

Although the circuit doesn't actually do anything, you should make it a habit to "arm" and "disarm" it as appropriate. That little bit of theater will help convince a burglar who is "casing" your home that it is indeed protected as advertised. **R-E**

DIGITAL DASHBOARD FOLLOW-UP

As a follow-up to "Build This Digital Tachometer for your Car" and "Build This Digital Speedometer for your Car", I would like to note a few minor corrections that may help any readers who are building those projects.

First, in the digital-tachometer article, D2 and D4 on the parts-placement diagram should be interchanged, and so should D5 and D6. The 10-μF capacitor labeled C14 on the schematic is C4.

In the digital-speedometer article, the schematic reference to IC5 should be labeled 4001 instead of 4011. The pick-up coil input should read P1 not P2. Also on the schematic, C12, a 0.1-μF bypass capacitor, was omitted. Getting on to the parts-placement diagram, the set of pads between S1 and IC6 should be labeled C7.

After several units were built using IC's from different manufacturers, a problem developed that caused the digital readout to occasionally jump to a reading of "000" during normal opertion. That timing problem can be corrected by soldering a .001-μF capacitor across pins 8 and 10 of IC7 on the tachometer; across pins 11 and 13 of IC5 on the speedometer.

The cause of the problem is that the MC14553 needs a minimum amount of time between the latch and reset pulses. If the CD4001 NOR gate used to build the projects is too fast—has too little propagation delay—the reset pulse will arrive before the internal latches have stabilized and locked in the current reading.

Because of the exceptional response to the digital tachometer and digital speedometer, and a significant number of requests for kits, Dakota Digital (R.R. 5, Box 179-E, Sioux Falls, SD 57107) has expanded its product line as follows:

For the digital tachometer: Display board (#430103), $6.95; main board (#430104), $12.95; parts kit (#2002-KIT), $75.00; Assembled and tested (#3002-UNIT), $99.95.

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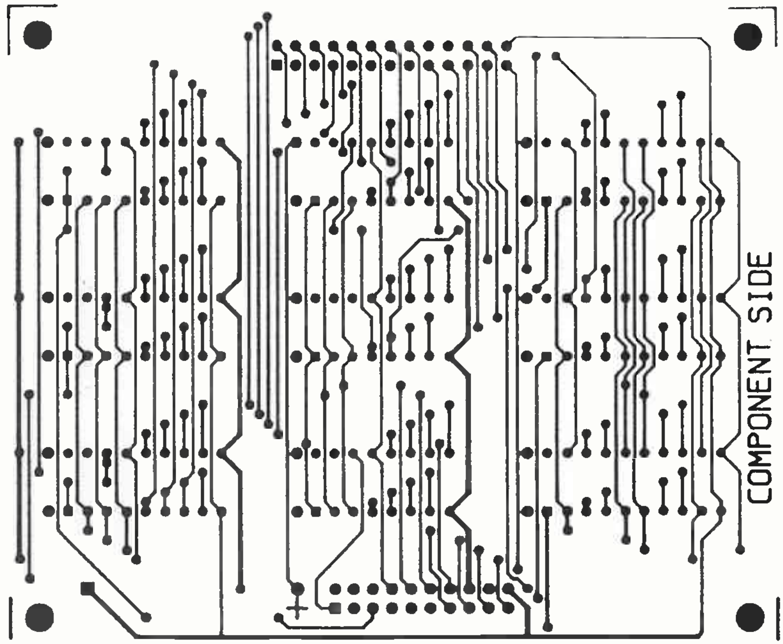
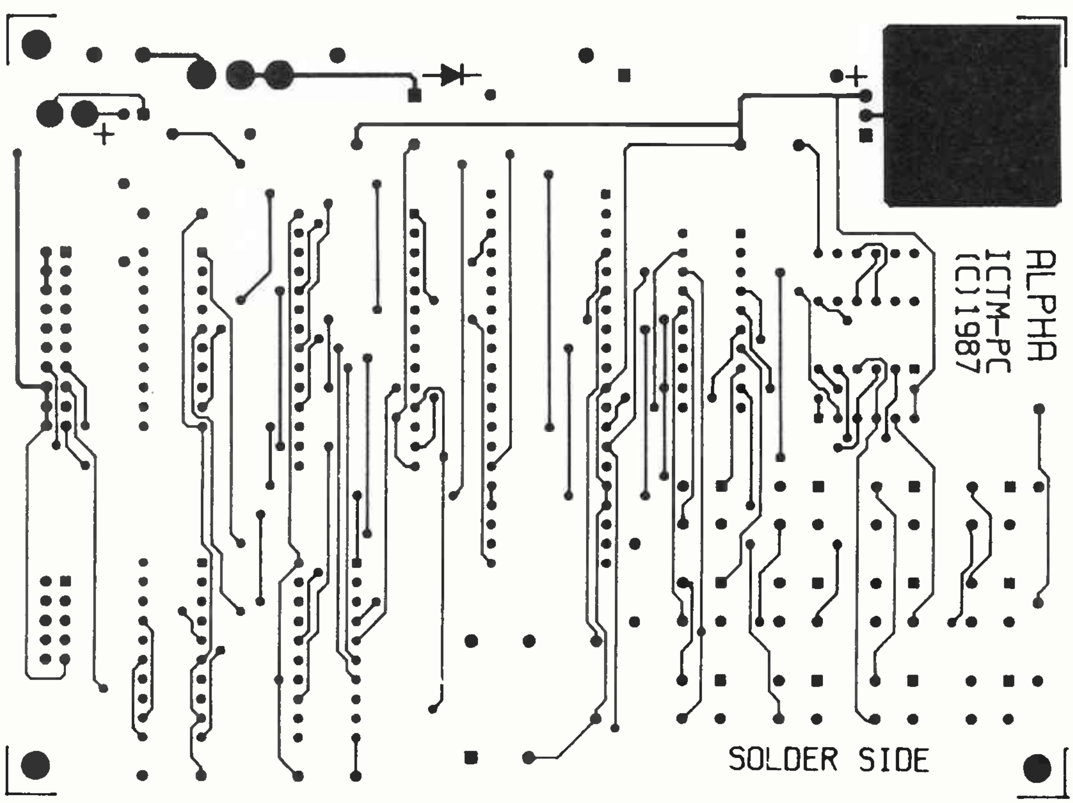
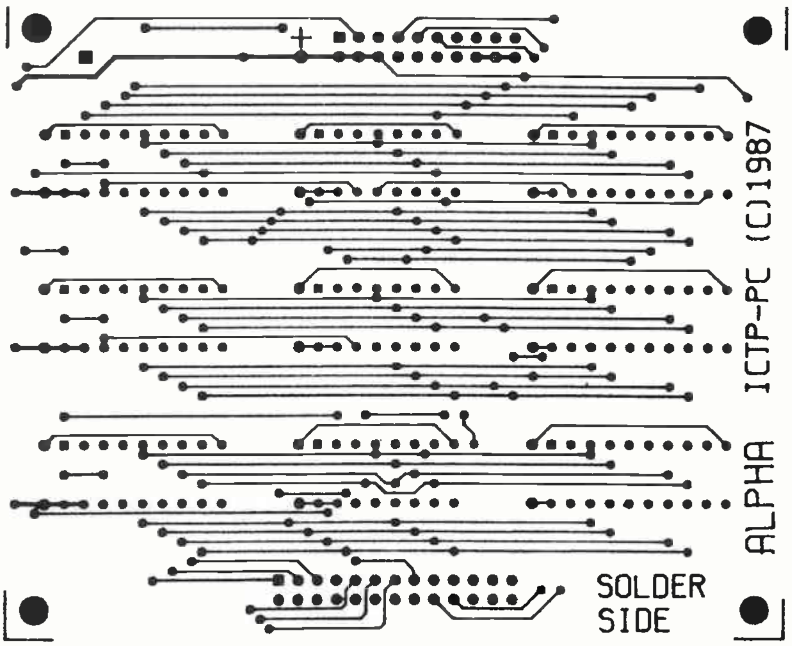
ROSS ORTMAN **R-E**



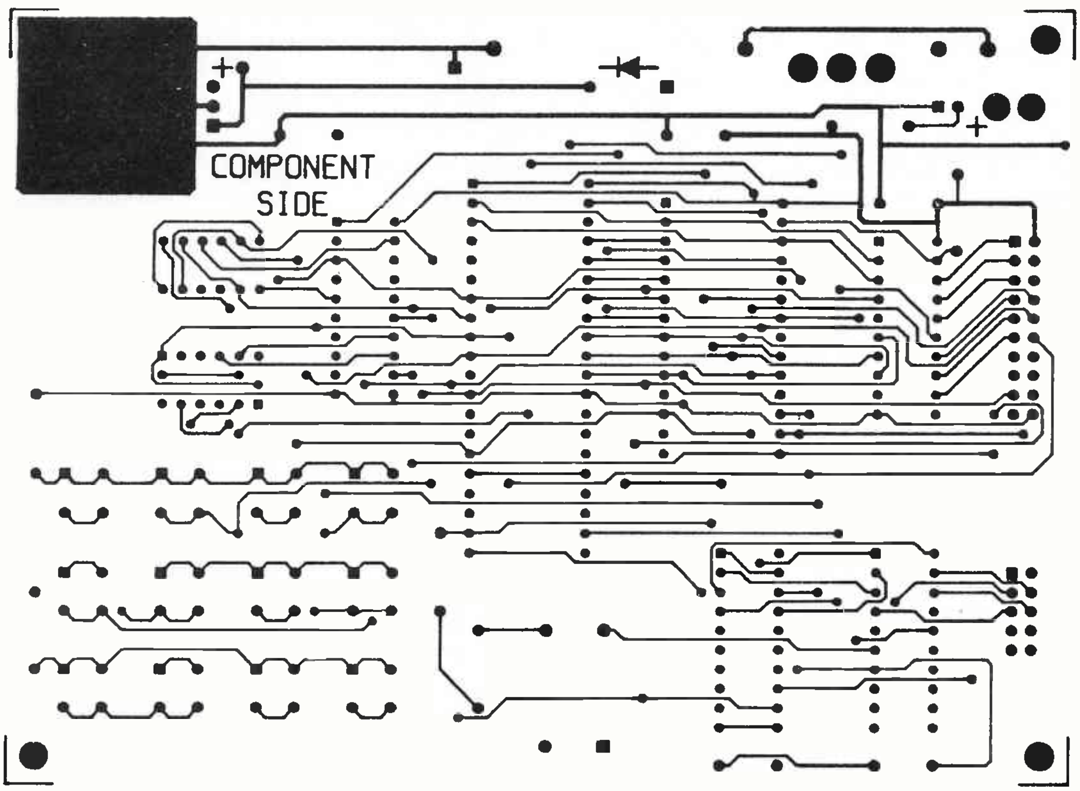
THE IC TESTER'S DRIVER BOARD. The component side is shown at left.



THE SOLDER SIDE of the IC Tester's main board is shown above.



THE IC TESTER'S DRIVER BOARD. The solder is shown at left.



THE COMPONENT SIDE of the IC Tester's main board is shown above.

NEW IDEAS

Sound-effects generator

HERE'S A CIRCUIT THAT PROVIDES GREAT fun for kids. It can generate a European police-car siren, bird noises, spaceship sounds, etc. In addition, it can be put to serious use as a doorbell, an alarm, etc. It's easy to build, uses readily-available parts, and is inexpensive.

How it works

A block diagram of the circuit is shown in Fig. 1. As you can see, the circuit consists of four parts: a binary counter, a D/A converter, a VCO, and an audio output amplifier. The speed at which the counter counts depends on the frequency of the output of the VCO, which in turn is determined by the output of the counter. That feedback loop is what gives this circuit its characteristic output.

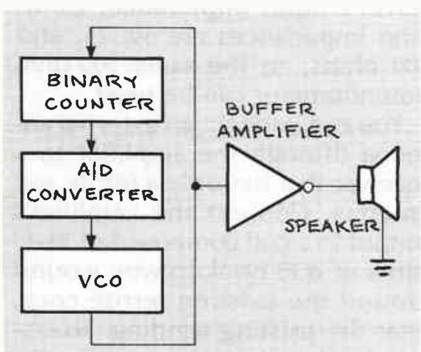


FIG. 1

Referring to the schematic in Fig. 2, the initial frequency of oscillation is determined by potentiometer R11. The VCO first oscillates at a relatively low frequency, and gradually picks up speed as the control voltage supplied by the D/A converter increases.

The D/A converter is simply the group of resistors R1–R8. When none of IC1's outputs is active, little current will flow into the base of Q1, so the VCO's control voltage will be low. As more and more counter outputs become active, base current increases, and thereby so does the VCO's frequency of oscillation.

The VCO itself is composed of IC2-a, IC2-b, Q1, and the timing network comprising D1–D4, C1, R10, and R11. The diode bridge functions basically as a voltage-controlled resistor.

The buffer amplifier is made up of the four remaining gates from IC2, all wired in parallel. Volume is sufficient for experimental purposes, but you may want to add an amplifier, speaker, or both.

Construction

Use any convenient means of wiring the circuit—point-to-point, wirewrap, etc. Layout is not critical; just be sure to connect the power supply to the IC's correctly.

Press S1; you should get a sound from the speaker. The sound you get will depend on the position of R11. To vary the effect, try tapping on S1.—*Edwin B. Tupue*

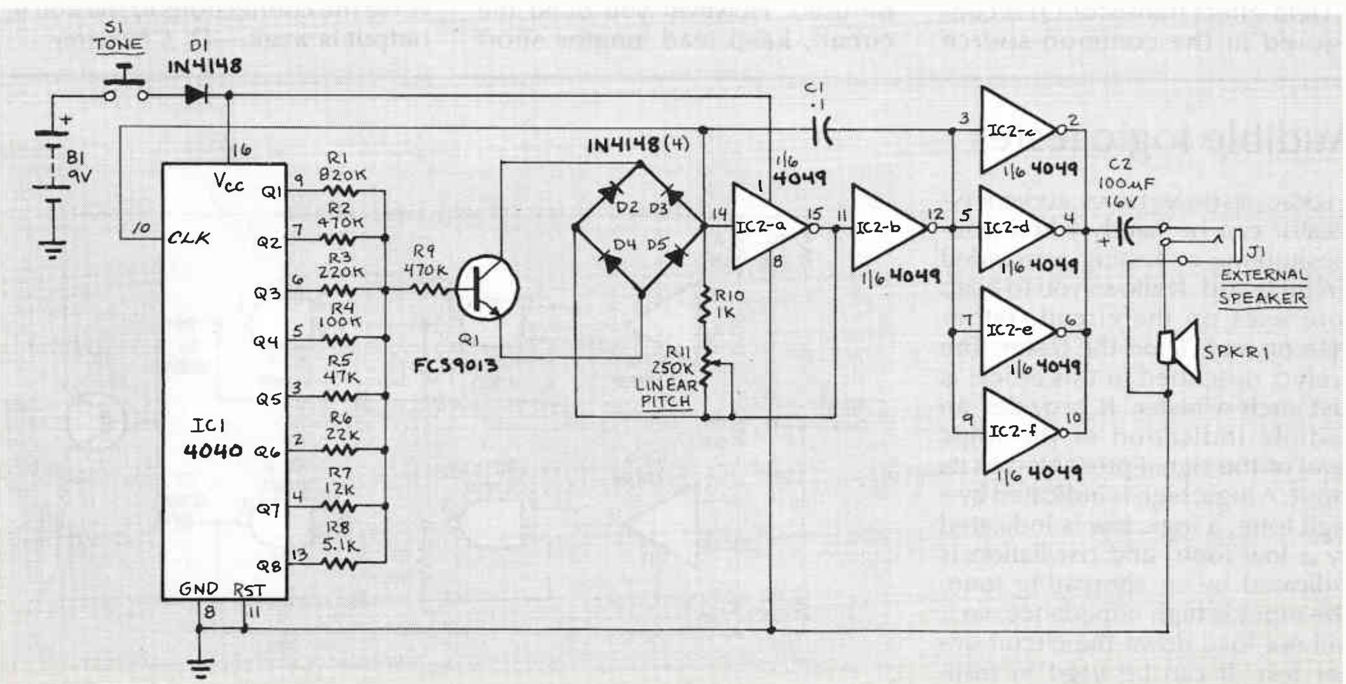


FIG. 2

Broadcast-band RF amplifier

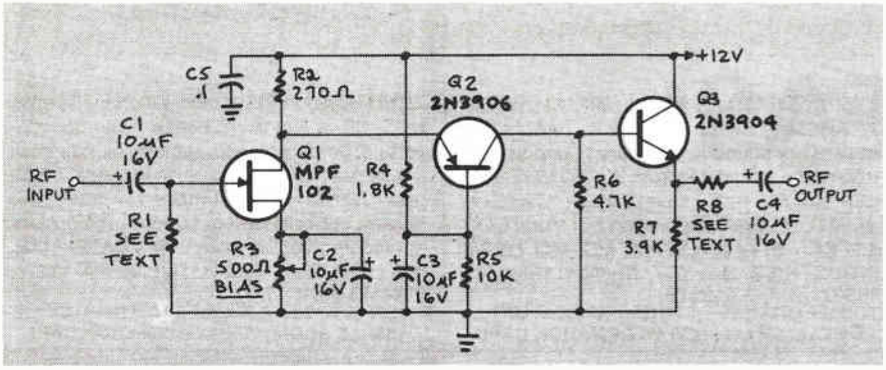


FIG. 1

UNLESS YOU OWN A TOP-OF-THE-LINE receiver or car radio, your AM reception may not be as good as it should be. The reason is that few low- to mid-price receivers and radios include RF amplifiers. By adding one yourself, however, you can improve reception at minimal cost. The RF amp shown here uses readily available parts, has wide bandwidth, and is very stable. In addition, by varying the values of several resistors, you can match the amplifier's input impedance to your antenna, and its output impedance to your radio.

How it works

The complete schematic is shown in Fig. 1. The circuit has a frequency response ranging from 100 Hz to 3 MHz; gain is about 30 dB.

Field-effect transistor Q1 is configured in the common-source self-biased mode; optional resistor R1 allows you to set the input impedance to any desired value. Commonly, it will be 50 ohms.

The signal is then direct-coupled to Q2, a common-base circuit that isolates the input and output stages and provides the amplifier's exceptional stability.

Last, Q3 functions as an emitter-follower, to provide low output impedance (about 50 ohms). If you need higher output impedance, include resistor R8. It will affect impedance according to this formula: $R8 \approx R_{OUT} - 50$. Otherwise, connect output capacitor C4 directly to the emitter of Q3.

Construction

The circuit can be wired up on a piece of perfboard; a PC board is not necessary, although one can be used. However you build the circuit, keep lead lengths short and direct, and separate the input and output stages. You may have space to install the amplifier in your receiver. Otherwise, installing it in a metal case will reduce stray-signal pickup. You'll have to provide appropriate connectors on the case. Connect the amplifier to the antenna and radio using short lengths of coax.

The circuit has only one adjustment. Connect a source of 12-volt DC power to the circuit, and adjust R3 so that there is a 1.6-volt drop across R2.

If you're not sure of the impedance of your antenna, connect a 500-ohm potentiometer for R1, and adjust it for best reception. Then substitute a fixed-value resistor for the potentiometer.

You may want to follow the same procedure with the output circuit (R8), if you're not sure of your receiver's input impedance. Common impedances are 50, 75, and 300 ohms, so the same 500-ohm potentiometer can be used.

You can connect an external antenna through the amplifier to a receiver that has only a ferrite rod antenna. Connect the amplifier's output to a coil composed of 10–15 turns of #30 hookup wire wound around the existing ferrite core, near the existing winding. To obtain best reception, experiment with the number of turns and their placement. You may need to reverse the connections to the coil if output is weak.—*D. J. Housley*

Audible logic tester

A LOGIC TESTER WITH AN AUDIBLE INDICATOR can be handy when troubleshooting or testing a crowded circuit board. It allows you to keep your eyes on the circuit, rather than on an LED on the tester. The project described in this article is just such a tester. It provides an audible indication of the logic level of the signal presented to its input. A logic high is indicated by a high tone, a logic low is indicated by a low tone, and oscillation is indicated by an alternating tone. The input is high impedance, so it will not load down the circuit under test. It can be used to troubleshoot TTL or CMOS logic.

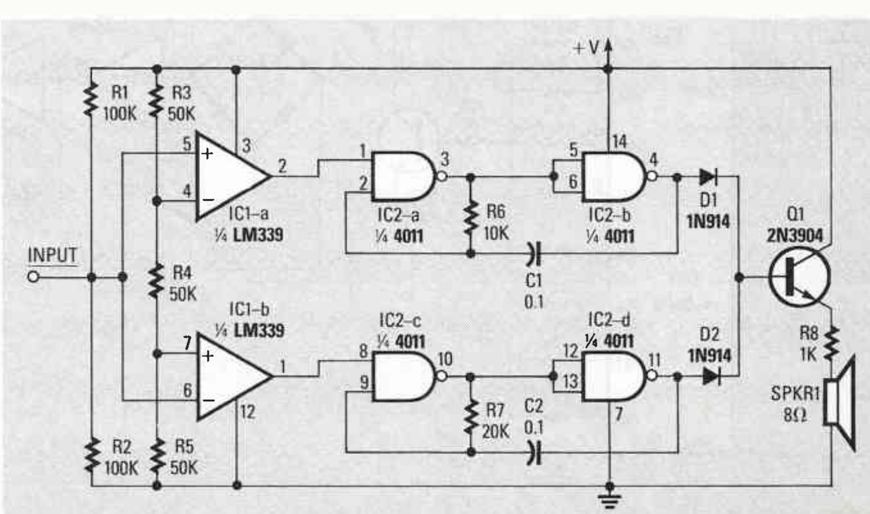


FIG. 1

Outdoor light controller

MOST AUTOMATIC YARD LIGHTS ARE controlled using just a simple photocell. However, since the ambient light levels at dawn and dusk change rather slowly, that approach usually results in some flickering just before the light fully locks on or off, which can significantly shorten bulb life. That can be avoided by using the controller shown in Fig. 1. That circuit *snaps* the light on or off, depending on whether ambient light levels are rising or falling.

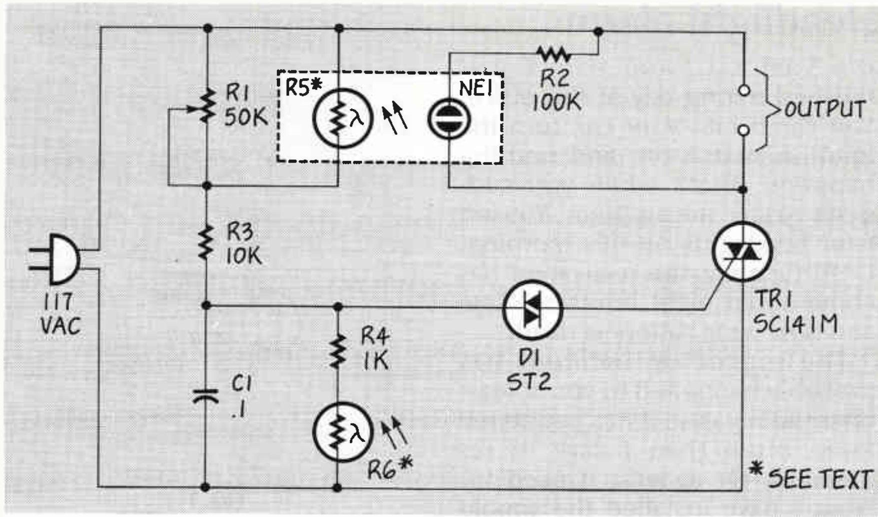


FIG. 1

How it works

The key to the circuit's operation is an optocoupler made up of a neon bulb (NE2 type) and a CdS photocell whose resistance varies inversely with light from 10K to 100K; those components are enclosed in a light-tight housing. A Diac/Triac combination is used to provide the snap-switch effect. A second CdS photocell acts as the main sensor.

As evening approaches the resistance of R6 begins to increase. When it reaches a threshold level, which is set by adjusting R1, the Diac triggers the Triac and causes the neon bulb to light. Even a momentary flicker of the bulb is sufficient to reduce the resistance of R5, causing the Diac to trigger the Triac, which lights the neon bulb, and so on.

As morning approaches, the process is reversed. The resistance of R6 begins to decrease until it drops below the threshold level. That causes the Diac to cease triggering the Triac, which extinguishes the bulb, which causes the resistance of R5 to increase, and so on.

Most of the components can be mounted on a piece of perforated construction board and placed within a small experimenters box. Parts placement is not at all critical. All resistors, except the potentiometer and the photocells are ½-watt units. Once the threshold level for the circuit has been established, the potentiometer can be replaced by a fixed resistor of the appropriate value. Before mounting R5 and NE1, place them in a light-tight enclosure. For my unit, the two were simply wrapped together using some black electrical tape.

Mount R6 so that it can be illuminated by the ambient light. However, take care to shield it from any artificial lighting. In my installation, the unit was mounted inside the lamp post, with the sensor looking out through a conveniently placed plastic lens.

To set up the unit, simply adjust the setting of R1 at dusk until the Triac is triggered. Remember that you are working with line voltages in this circuit, so take the appropriate precautions to protect yourself and others from potentially dangerous shocks.—*E.J. Holtke*

The circuit

A schematic of the circuit is shown in Fig. 1. The input section determines whether the logic level is high or low, and enables the appropriate tone generator; it consists of two sections of an LM339 quad comparator. One of the comparators (IC1-a) goes high when the input voltage exceeds 67% of the supply voltage. The other comparator goes high when the input drops below 33% of the supply. Resistors R1 and R2 ensure that neither comparator goes high when the input is floating or between the threshold levels.

The tone generators consist of two gated astable multivibrators. The generator built around IC2-a and IC2-b produces the high tone. The one built around IC2-c and IC2-d produces the low tone.

Two diodes, D1 and D2, isolate the tone-generator outputs. Transistor Q1 is used to drive a low-impedance speaker.

The tester can be built on a small piece of perforated construction board; a PC board could also be used, if desired. Layout is not critical. The completed board should be mounted in a case. The size of its case will most likely be determined by speaker's size.

Two notes on the IC's: The 4011 is a CMOS device. As with all other CMOS devices, extra care should be exercised in handling to avoid subjecting the IC to damaging static electricity. Also, ground all unused inputs on the LM339.

The tester is designed to draw its power from the circuit under test. Therefore, the power and ground leads should be terminated by small alligator clips. Connect a spare multimeter probe to the tester's input and you are all set.

Connect the power-supply lead to the positive supply rail of the circuit under test. Connect the ground lead to the circuit-under-test's ground rail. At this point, the tester should be silent. Now, touch the probe tip to the circuit's positive supply rail. The tester should produce a high-pitched tone. Next, touch the probe to the ground rail. The tester should produce a low-pitched tone. If all is well, your tester is ready for use.
—*Philip L. Kane*

Headlight alarm

IT'S 5:00 P.M., AND YOU'VE JUST finished a long day at the office. You climb into your car, turn the ignition switch on, and nothing happens. That's when you suddenly realize the problem: You left your headlights on this morning. Unfortunately, the realization has come about eight hours too late and now your battery is dead.

The preceding incident has probably happened to you at least once; in my case it has happened more often than I care to remember. Or at least it used to. Now, I have installed the simple circuit shown in Fig. 1 in my car. Of course, the circuit is a headlight alarm. It has saved me from embarrassment and aggravation on several occasions.

The circuit

While many cars are equipped with a headlight alarm, many more, unfortunately are not. For those cars, the circuit in Fig. 1 offers a low-cost way to add that valuable feature. Let's see how it works.

The base of Q1 is connected to the car's ignition circuit; the easiest point to make that connection

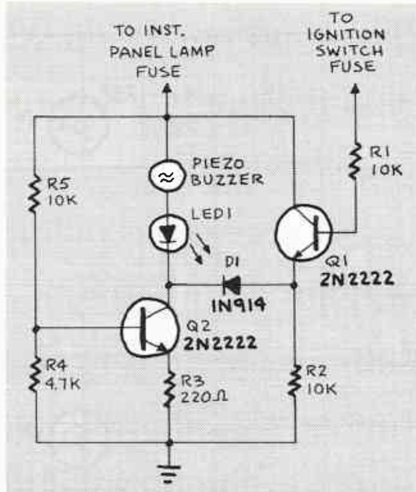


FIG. 1

is at the ignition switch fuse in the car's fuse panel. Also, one side of the piezoelectric buzzer is connected to to the instrument-panel light fuse; remember that when the headlights or parking lights are on, the instrument panel is lit too. When the headlights are off, no current reaches the buzzer and therefore nothing happens. What happens when the headlights are on depends on the state of the ignition switch. When the ignition switch is on, transistors Q1 and Q2 are biased on, effectively removing the buzzer and the LED from the circuit.

When the ignition switch is turned off but the headlight switch remains on, transistor Q1 is turned off, but transistor Q2 continues to be biased on. The result is that the voltage across the piezoelectric buzzer and the LED is sufficient to cause the buzzer to sound loudly and the LED to light. Turning off the headlight switch will end the commotion quickly.

Construction

The circuit can be wired together on a piece of perforated construction board. The buzzer I used was a Radio-Shack 273-065 PC-board mounting type, but almost any similar buzzer will do. Circuit parameters are not critical, so feel free to make appropriate substitutions from your junk box to further reduce the cost.

When you are finished, house the circuit in a small, plastic experimenter's box and locate the unit on or under the dash of your car. You could also locate most of the unit behind the dash were it will be out of the way and mount only the LED where it can be seen easily. One good place would be next to the headlight switch on your dash; that will provide more of a custom look.—*Charlie Lowell*

Use an FM radio as a transmitter

SEVERAL YEARS AGO I NOTICED THAT AN FM radio generates an interference signal that can be picked up on another FM radio turned 10.7 MHz above the first one. Out of curiosity, I tried injecting an audio signal into the RF-oscillator section, and found that I now had a small transmitter.

Now that I have a VCR, I use the same technique to broadcast the TV's sound on the FM band using a portable FM radio. The circuit I use is shown in Fig. 1. The 50K potentiometer allows you to adjust the modulation level to maximum without distortion. The RC network improves the fidelity of the transmitted signal and provides DC isolation. The component values shown are provided as a starting point. They are the ones I used for my setup but may vary somewhat for different radios. Note that if you can't get the signal at 10.7

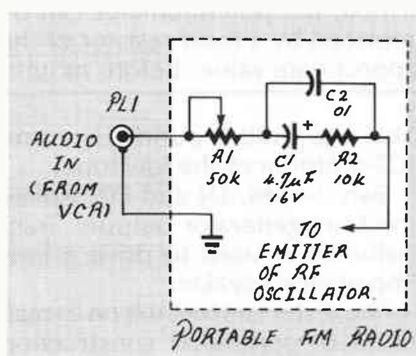


FIG. 1

MHz above the frequency setting of the first radio, try tuning at 10.7 MHz below. Also, note that both tuned frequencies must be unused, otherwise you will hear your audio on top of the audio that is already there. You might have to play with both frequencies until you find two blank spots that are 10.7 MHz apart.

When building the circuit, you can mount the components on a piece of perforated construction board or on a terminal strip; you can mount the board or terminal strip inside the radio if there is sufficient space. The 4.7-µF capacitor can be a tantalum, electrolytic, or non-polarized unit if you can find one, and the 0.01-µF capacitor is a ceramic disc. Use an RCA plug for PL1 so that you can plug it into your VCR's audio output jack or any other audio source you wish.

The circuit allows using a personal stereo as wireless headphones. To use it, I just tune my personal stereo to a blank spot in the upper half of the FM band and tune the portable FM radio until the sound comes through on the headphones. Just think; you can put a tape in the VCR, put the TV in the window, go out to the car and tune in the sound. Presto—instant drive-in!—*John E. Boser.* R-E

Sequential flasher

HERE'S AN EASY AND INEXPENSIVE WAY to liven up a store window, decorate a Christmas tree, or create a do-nothing toy for the kids. As many as ten lightbulbs can be connected to the circuit and arranged in a circle, or in ány other pattern. The lights flash sequentially; when the flash rate is about five or six Hz, an optical illusion of a "running dark spot" is produced.

How it works

As shown in Fig. 1, a 555 timer, IC1, drives a 4017 CMOS decade counter. Each of the 4017's first four outputs drives a CA3079 zero-voltage switch. Pin 9 of the CA3079 is used to inhibit output from pin 4, thereby disabling the string of pulses that IC normally delivers. Those pulses occur every 8.3 ms, i. e., at a rate of 120 Hz. Each pulse has a width of 120 μs.

Due to the action of the CA3079, the lamps connected to the TRIAC's turn on and off near the zero crossing of the AC waveform. Switching at that point increases lamp life by reducing the inrush of current that would happen if the lamp were turned on near the high point of the AC waveform. In addition, switching at the zero crossing reduces Radio-Frequency Interference (RFI) considerably.

Construction

CAUTION: The CA3079's are driven directly from the 117-volt AC power line, so use care in building the sequential flasher. Keep lead lengths short, use insulated wire, and mount the entire circuit in a rigid, insulated enclosure.

We didn't specify part numbers for the TRIAC's, because the type will depend on the lamps you will drive. The TRIAC's will almost certainly require heatsinks; the size of the heatsinks will depend on the amount of power the TRIAC's will have to dissipate, and that depends on the lamps you use.

You'll need a low-voltage source ($+V_{CC}$) to drive the 555, the 4017, and the bias inputs of the CA3079's. One possibility would be to wire up a 7805 regulator circuit and a step-down transformer.

It would also be possible to run the circuit from a 24-volt AC source. Doing so would allow the use of lamps with lower voltage and current ratings. The lower power required by the lamps would also allow use of smaller TRIAC's, smaller heatsinks, and a smaller enclosure. The circuit would also be much safer. See RCA Solid State's *Integrated Circuits for Linear Applications* for more information.—*Michael Ciric*

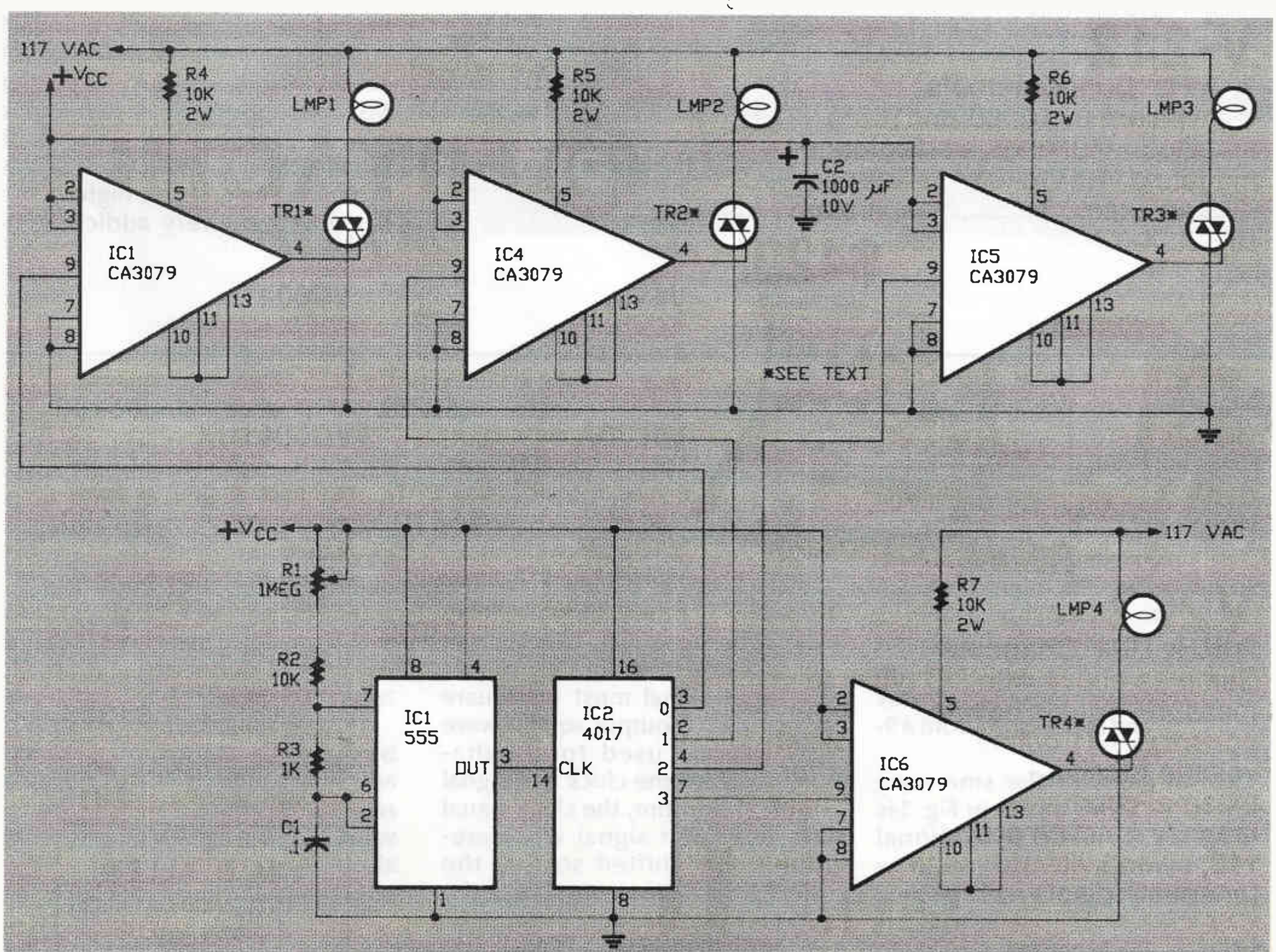


FIG. 1

Fingertip Olympics

THIS MONTH'S CIRCUIT IS A GREAT LITtle game that's ideal for developing hand coordination, or for putting couch potatoes in the mood for the upcoming Olympic games.

The heart of the circuit, which is shown in Fig. 1, is an LM2907 (National) frequency-to-voltage converter. That low-cost IC, which is available from several of the companies that advertise in the back pages of **Radio-Electronics**, provides a voltage output that's directly proportional to the frequency at its input. That frequency is "set" by alternately closing S1 and S2, two normally-open, momentary-contact pushbuttons. The faster they're closed in sequence, the higher the frequency.

The "skill level" of the game is set by R1. The smaller the value of that resistor, the faster you'll have to hit the switches to get a measurable output. As a rule of thumb, start with a value of about 510K; if you find that's too easy, or as you get better, substitute lower-valued units. You can also use multiple resistors and a rotary switch to set up multiple skill levels.

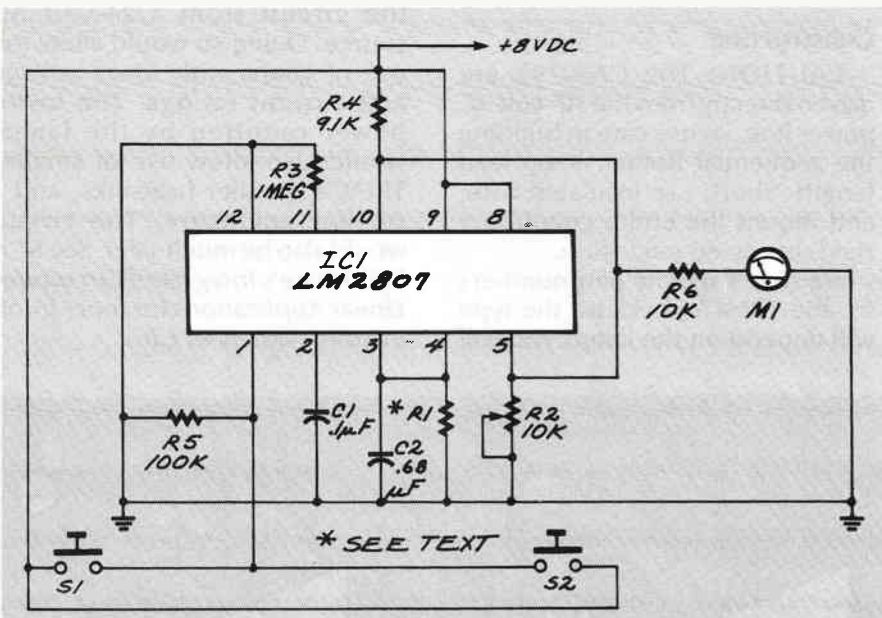


FIG. 1

Setup and use

Any construction technique can be used to build the unit, But point-to-point wiring on a piece of perforated construction board is probably the simplest. For best play, the switches should be mounted about six inches or so apart, so be sure that you use a big enough piece of board.

To test, set R2 fully counterclockwise (minimum resistance) and tap the switches to make sure that there's an output, as indicated by M1. If there is, you are ready to go.

To play the game, set R2 at about mid-range, then place the unit in your lap or on a table top and begin tapping. Use two hands and go as fast as you can. The faster you tap the switches in sequence, the higher the output current. When you are tapping away at about your personal limit, readjust R2 so that M1 reads about ¾ scale (a friend is very helpful for that). Then start tapping away to see if you can get the meter to go even higher. The game can get very addicting!—*Phil Blake.* **R-E**

Simple sine-wave generator

FOR PEOPLE WHOSE NEEDS DON'T WARrant buying an expensive feature-filled sine-wave generator, a simple, low-cost one might often be useful. The circuit shown here is just that. It features amplitude and frequency controls, is made from low-cost components that are easy to obtain, and is powered from a 9-volt battery.

At the heart of the sine-wave generator circuit shown in Fig. 1 is an MF-10 IC made by National Semiconductor. It is part of a new generation of switched-capacitor filters that use an ingenious technique of switching internal capacitors to determine the cutoff frequency. The output frequency of the MF-10 follows the frequency of an external clock. A square-wave input signal is fed into the device, and only the frequency of the clock signal is allowed to pass through. All other components of the input signal are filtered out. Because both the clock signal and the input signal must be square waves, a dual-output square-wave oscillator is used to simultaneously drive the clock and signal inputs. Therefore, the clock signal and the input signal are correspondingly shifted so that the MF-10 always filters out all but the fundamental frequency of the input signal. The result is a nice clean sine wave at the output.

A 555 timer operating in the astable mode generates the driving pulses and two 4518 dual BCD (*B*inary *C*oded *D*ecimal) counters provide the square waves. A TL081 op-amp serves as an output buffer-amplifier, and potentiometers R1 and R2 are used in order to control the pulse's frequency and amplitude respectively.

The output-frequency range can be varied by changing C_x. For example, a value of 0.1 µF gives a range from about 0.1–30 Hz, and a value of 470 pF gives a range from about 10 Hz to 1.5 kHz. The maximum output frequency is 30 kHz.

The circuit can be built on a piece of perforated construction board using point-to-point wiring

Simple multi-tone generator

SOMETIMES YOU NEED A WAVEFORM having a particular shape, frequency, or amplitude that's not provided by your signal generator; or maybe you just don't own a signal generator. If you don't mind spending a bit of time experimenting with parts values, the multi-tone generator circuit described here might give you just the waveform that's needed.

The circuit shown in Fig. 1 can actually be built from parts you probably have lying around on the workbench. A bi-polar power supply is required; two 9-volt batteries wired in series, with their junction used as the "ground" will do.

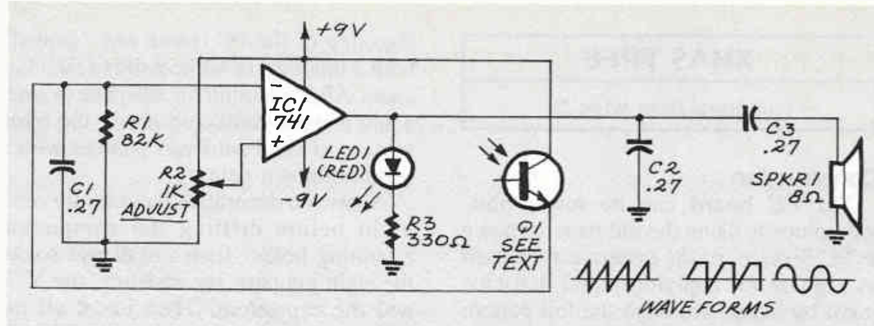


FIG. 1

How it works

Op-amp IC1 is used as a sensitive voltage comparator, whose trip level—the value at which the output changes state—is determined by potentiometer R2. The resistance of R1 in series with the resistance of phototransistor Q1 provides the feedback divider for IC1's inverting input. Since Q1's "dark" resistance—the resistance when there is no light—is very high. Very little voltage appears across R1; therefore, IC1's output will normally be high.

When power is first turned on, IC1 goes high, causing the LED to glow. However, the instant it glows it shines on Q1, causing a decrease in Q1's collector-emitter resistance, which causes a large voltage drop across R1. The comparator immediately switches to a low output, thereby turning the LED off, which restores Q1's dark resistance. The increase in Q1's resistance causes the cycle to repeat, thereby producing an oscillating output voltage.

Logically, the circuit should "lock up" because the LED and phototransistor would be competing with each other for control of the circuit, and IC1 would get stuck at some equilibrium state. Capacitor C2 prevents that from happening by keeping the LED lit slightly longer that the normal turn-off time. (C1 also helps avoid lock up, but its use isn't critical and it can often be eliminated.)

The output frequency can be changed by varying the values of C1–C3, but keep in mind that making their values too small will defeat their primary purpose, which is avoiding circuit lock-up.

The frequency, amplitude, and the shape of the waveform are determined by R2. Three of the typical waveforms that can be obtained by adjusting R2 are also shown in Fig. 1.

LED1 can be any red light-emitting diode. Q1 can be any phototransistor—try whatever you have lying around or can get cheaply. The only critical part of the assembly is the positioning of LED1 and Q1. They must be facing and close, and shielded from ambient light—perhaps by placing them inside a small cardboard or opaque plastic tube. Alternately, you could try substituting an opto-isolator for LED1 and Q1. However, bear in mind that the spacing between LED1 and Q1 provides some control over the output waveform; an opto-isolator would eliminate that degree of control.—Mohd Amjad Khan. **R-E**

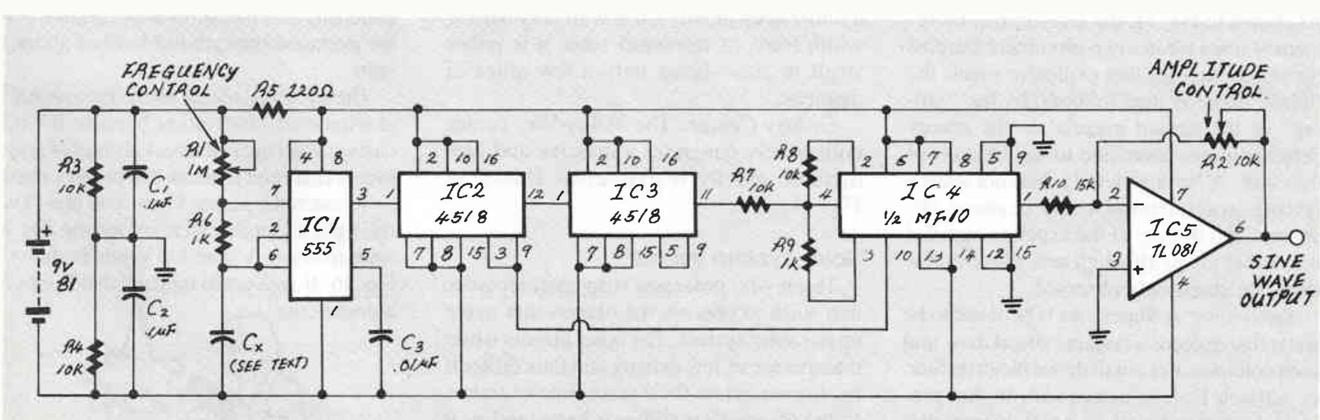


FIG. 1

techniques. Further, it is inexpensive to build, and therefore practical for use in dedicated applications where the sine-wave generator is permanently incorporated into another circuit or device.

For more information on the MF-10 switched capacitor filter IC, write to National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, California 95051.—*Dale Nassar.* **R-E**

XMAS TREE

continued from page 28

Construction

The PC board can be made photographically using the foil pattern shown in PC Service, or the pattern can be used as a guide for applying liquid and tape resist by hand. Although the foil pattern itself is only 5-inches high, the PC board material must be 6¾ inches high because the tree's 1¾-inch trunk is part of the PC board. Since etching large copper areas not only takes excessive time but also shortens the life of the etchant, we suggest you trim away the unwanted PC board material before you etch the board. Or, if you prefer to cut the tree to size after the pattern is etched, protect the foil of the large unused trunk area with resist and simply let the copper remain. As long as the trunk's foil doesn't come in contact with any of the circuit traces it makes no difference whether it's there or not.

If you want to decorate the front of the tree, do it before the holes for the components are drilled. For example, the author sprayed the component side with a bright automotive metallic-green paint. To prevent a defined line, a cardboard mask was held about ½-inch above the board. Then, the edge of the PC board was "dusted" with a fine mist of white paint to simulate snow. After allowing for adequate drying, again using a cardboard mask, the trunk portion of the board was painted with a metallic-brown paint.

Allow the decorative paint to dry overnight before drilling the component mounting holes. Then install and solder the eight jumpers, the resistors, the IC's, and the capacitors. Then insert all the LED's, observing the polarities shown in Fig. 2. Position the LED's so that they are raised approximately ½ inch off the board. To do that, turn the board over and lay it down on a flat surface, being careful not to allow any LED's to fall out; that can be done easily by holding a piece of stiff cardboard against the LED's while turning the board over. Keeping the board parallel to your work surface, solder one lead of each LED. Turn the board over and carefully look across the surface to see whether the LED's are straight and at the same height. If not, correct as needed. When you're satisfied with their alignment, solder the other lead of each LED.

Adding the base

Prepare the surfaces of the battery holders and the PC board for gluing by sanding the back of each holder and a ⅜-inch strip on both sides of the circuit board at the bottom of the trunk. Mix a small amount of a 5-minute epoxy and apply some to the ⅜-inch strip on both sides of the circuit board. With the battery polarities opposite each other, sandwich the PC board between the holders. Hold the assembly firmly on a flat surface that's covered with a piece of wax paper. You will have a few minutes working time before the epoxy sets to ensure proper alignment. Make certain that the holders are even and that the circuit board is centered and upright between the holders. In about 5 minutes the glue will have set up sufficiently, and the tree can be lifted from the wax paper. Use acetone or flux remover to clean excess glue from the bottom of the battery holders. As with most other cleaners, be careful not to touch the painted surface.

After allowing at least one hour for the epoxy to cure, solder a jumper wire at one end of the battery holders, across the adjacenet positive and negative terminal lugs. From the battery source ends, solder the positive and negative leads directly to the foil traces—as shown in Fig. 2. The LED's will start to flash as soon as the batteries are installed. Any LED that fails is most likely defective, or installed with reversed polarity.

You can add a final "dress up" by gluing a colorful felt material over foil traces on the back of the board. **R-E**

GRAVITY

continued from page 129

Galactic events

A few of the more prominent galactic events will be briefly described to aid the experimenter in recognizing their signatures.

Nova: A Nova is believed to be a star that ejects its outer layers in a violent explosion. As shown in Fig. 11, the large transit movement of mass creates two prominent features (or signatures) for that explosive event; the "blast" itself is then followed by the "tailing" of the blasted material as the gravity detector moves away due to the rotation of the earth. A Nova generally does not leave a lasting gravitational trace because the amount and density of the expelled material is not that great; although new Nova explosions are commonly observed.

Supernova: A Supernova is believed to be a star that exceeds a certain critical mass and then collapses to a small dense Neutron Star, or a Black Hole structure and, in that process, expels much of its gaseous material. The entire collapsing process, which occurs only in a few hundred milliseconds, is observable with the author's gravity detector. As shown in Fig. 12, a plot of a Supernova has certain prominent features. First, there is the actual collapse of the core of the star that generally appears as a sharp dip. The expulsion of the gaseous mass layer is now much more pronounced, which again gives rise to the tailing effect like the one of an ordinary Nova. Supernova, however, also shows a mass build-up due to shock-wave action, and that might appear as a bump in the tailing response.

Black Hole: A Black Hole-type structure is generally developed by a very massive Supernova event, and is usually developed 24 to 48 hours after the event. An ancient Black Hole, as shown in Fig. 13, appears as a rather deep gravity shadow of very narrow width (time of response) since it is rather small in size—being only a few miles in diameter.

Galaxy Center: The Milky-Way center collectively generates a massive and predictable gravity response, as shown in Fig. 14.

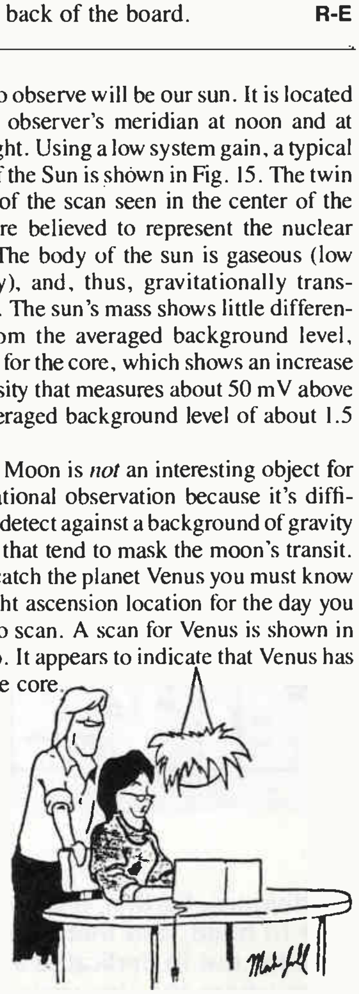
Solar system events

Those who possess a strip chart recorder may wish to observe the planets that make up our solar system. The outer planets while massive are of low density and thus difficult to observe unless their exact time of transit on the observer's meridian is know; and even then the results are often difficult to plot. The inner planets, while denser, must be observed in a background relatively free of other cosmic events. It is unfortunate, but the gravitational background of cosmic events tend to mask solar system gravity sources.

Probably the easiest local astronomical body to observe will be our sun. It is located on the observer's meridian at noon and at midnight. Using a low system gain, a typical scan of the Sun is shown in Fig. 15. The twin peaks of the scan seen in the center of the scan are believed to represent the nuclear core. The body of the sun is gaseous (low density), and, thus, gravitationally transparent. The sun's mass shows little differential from the averaged background level, except for the core, which shows an increase in density that measures about 50 mV above the averaged background level of about 1.5 volts.

The Moon is *not* an interesting object for gravitational observation because it's difficult to detect against a background of gravity events that tend to mask the moon's transit.

To catch the planet Venus you must know the right ascension location for the day you want to scan. A scan for Venus is shown in Fig. 16. It appears to indicate that Venus has a dense core.



I'm fixing your father's repair job on this radio.

CELLULAR TELEPHONE

continued from page 88

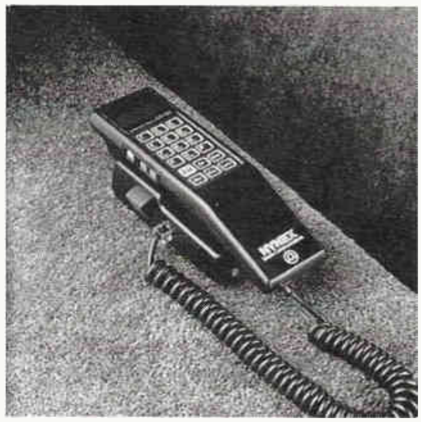
knowledge of A and B services to that indicator, causing it to flash if the service it encounters is different from the one you have selected. That notifies you that, if you have to switch services manually (perhaps you have locked into one or the other—the recommended method), that is the time to do so.

What else?

In addition to performing those invisible tasks, the sophistication of cellular phones and phone systems makes using them more convenient.

Of course, they provide such things as auto-redial, muting, and memories that can hold up to 32 phone numbers that can be dialed by just a keypress or two. But just about every phone these days has those features. Cellular phones provide even more!

A few cellular phones give you the luxury of speech recognition for hands-free dialing. It's really more than a luxury—the less your attention is diverted from your driving, the longer you're likely to be around to make more phone calls. One phone, available from AT&T, not only



THE MODEL *CDL205* is from Nynex Mobile Communications.

understands what you say to it but also talks back to you. When you pick up the handset it says, "Name please," and waits for you to tell it whom to call (it can also associate names with phone numbers). If the person you are calling is one of those stored in the phone's memory, the phone will dial the number after you speak the name. If you dial the phone manually, it will announce the digits entered as you punch them in. If the line is busy, you can later tell the phone to redial the number.

Cellular phones also use their intelligence to keep you informed of situations they encounter. We've already seen what the ROAM indicator can tell you. Another indicator, labeled NO SERVICE lights if the phone encounters no response on its control channels, meaning that there is no cellular service in the area you're in at the moment. That indicator also can be used to let you know when a call is terminated, or when a signal dropout occurs.

Because they already contain a clock circuit for the control of a microprocessor, cellular phones can also provide timekeeping services. The simplest just tell you the length of the last call you made. Others tell you how long you've been engaged in the call you're currently making (that can be quite useful, since cellular phone calls are billed on a per-minute basis). Some phones can tell you how long you've been talking, the total length of time you've used the phone (the timer can be reset to zero whenever you like), and the total number of calls you've made.

Finally, if you leave them on while you're away from them, most cellular phones are able to notify you when you return if you had a call in your absence. They can't tell you who called (although at least one firm has plans to introduce an answering machine for your car), but if you were expecting a call, at least you'll know that it probably came. **R-E**

EXPERIMENTERS ELECTRONICS HANDBOOK does not assume any responsibility for errors that may appear in the index below.

WORKING WITH TRIACS

continued from page 126

The IC, which provides a phase-delayed trigger output to the Triac, provides both on/off and proportional output control.

To do so, the S566B incorporates conditioning circuitry that recognizes a brief input as a "change stage" command. In addition, a sustained input causes the IC to go into the ramp mode, in which lamp power slowly increases from 3% to 97% of maximum. After reaching maximum, it ramps downward to a minimum of 3%, and then again reverses.

The touch pad used with the circuit may be simple strips of conductive material; the operator is safely insulated from the line voltage via R8 and R9.

Universal motor controllers

Domestic appliances are usually powered by a series-wound universal electric motor, so-called because they can operate from either AC or DC power. In operation, that type of motor produces a back EMF that is proportional to the motor's speed. The effective voltage applied to that type of motor is equal to the applied voltage minus the back EMF. That results in some self-regulation of motor speed, because an increase in motor loading tends to reduce speed and back EMF, thereby increasing the effective applied voltage and causing motor speed to try to increase to its original value.

Most universal motors are designed to provide single-speed operation. A Triac-based phase-control circuit can easily be used to provide that type of motor with fully-variable speed control. A suitable circuit is shown in Fig 27.

That circuit is useful for controlling lightly-loaded appliances (food mixers, sewing machines, etc.). However, heavy-duty tools (electric drills and sanders, for example) are subject to heavy load variations, and therefore require a circuit like the one in Fig. 28.

An SCR is used in that circuit as the control element; it feeds half-wave power to the motor, which results in a 20% or so reduction in available speed and power. However, during the half-cycles when the motor is off, its back EMF is sensed by the SCR and is used to adjust the next gating pulse automatically.

The network composed of R1, R2, and D1 provides only 90° of phase adjustment, so all motor power pulses have a minimum duration of 90° and provide very high torque. At low speeds the circuit goes into a "skip-cycling" mode, in which power pulses are provided intermittently, to suit motor-loading conditions. The result is that the circuit provides particularly high torque under low-speed conditions. **R-E**

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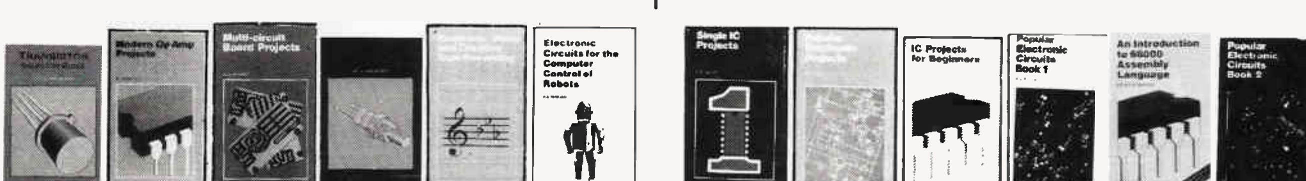

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