1989

Radio-Electronics

# ELECTRONICS EXPERIMENTERS handbook™

JANUARY

## 164 Pages Crammed With More Than 31 Articles Including 17 Exciting Projects and Lots of Electronics Know How!

### TELEVISION
- Stereo Sound Decoder
- Commercial Zapper
- High Definition

### YOUR HOME
- Acid Rain Monitor
- Electronic Xmas Tree
- Outdoor Light Controller

### HOW TO
- Soldering Technology

### YOUR CAR
- World of 21st Century
- Digital Tachometer
- Digital Speedometer
- Headlight Alarm

### TELEPHONE
- Phonlink
- Cellular Phones
- Blue Box & Ma Bell

### TECHNOLOGY
- Triac's and SCR's
- Conductive Inks

### SURFACE MOUNT
- Introduction To SMT
- Hand Soldering SMT's
- Conductive Inks

### TEST GEAR
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- Multi-Tone Generator
- Audible Logic Tester
- Poor Man's Storage Scope

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- Sound-Effects Generator
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### SMT PROJECTS
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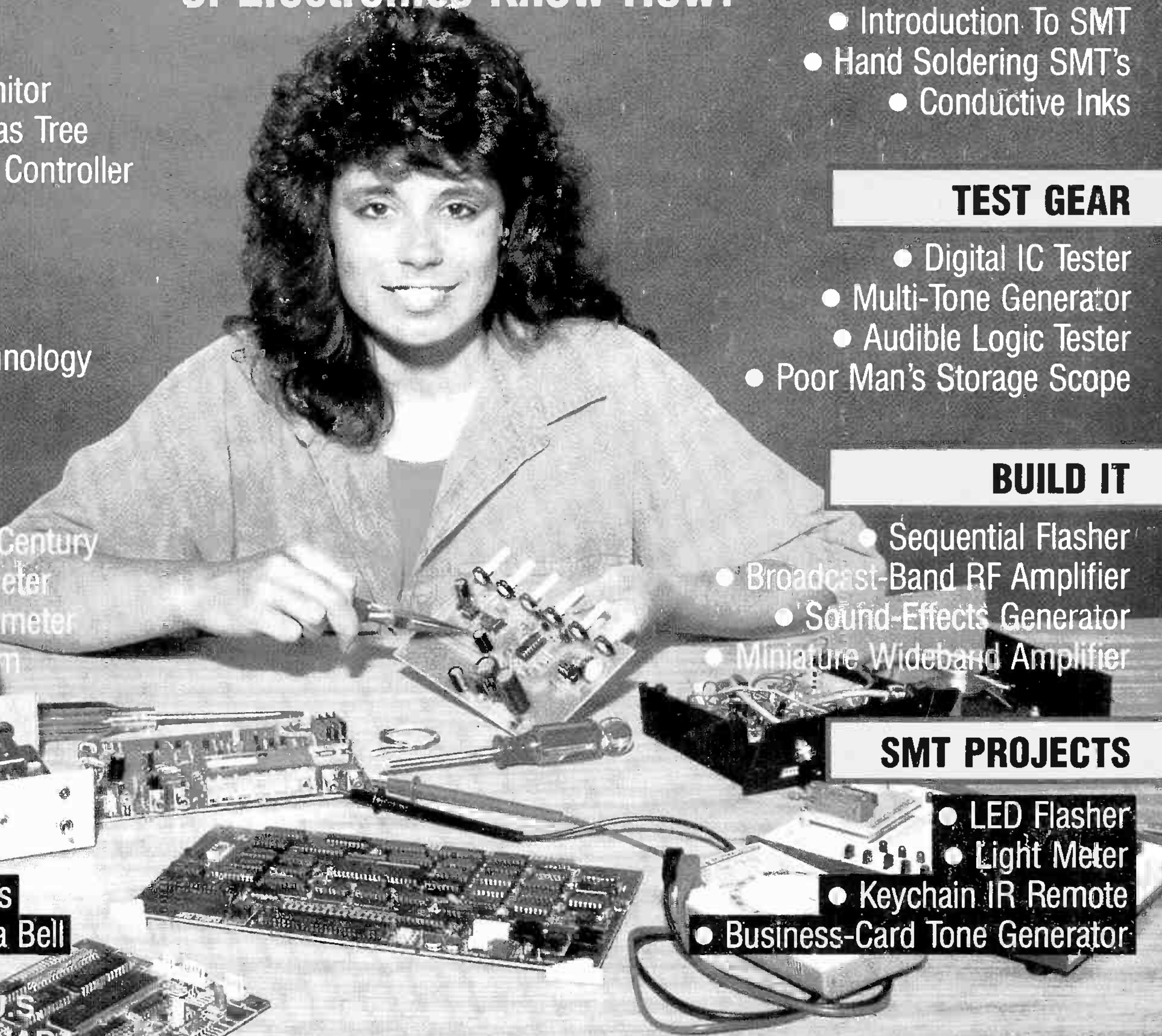
- Light Meter
- Keychain IR Remote
- Business-Card Tone Generator



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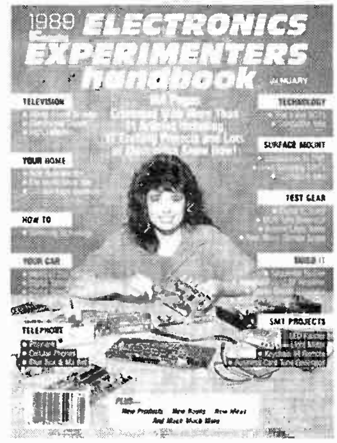
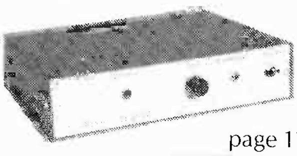
# 1989 ELECTRONICS EXPERIMENTER'S handbook

Radio-Electronics




## BUILD THIS



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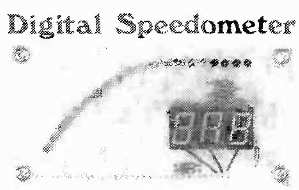


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## TECHNOLOGY

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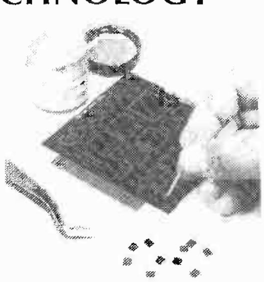
## SURFACE-MOUNT TECHNOLOGY



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## 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 Radio-Electronics ELECTRONICS EXPERIMENTER'S handbook**

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M. Harvey Gernsback, editor-in-chief, emeritus

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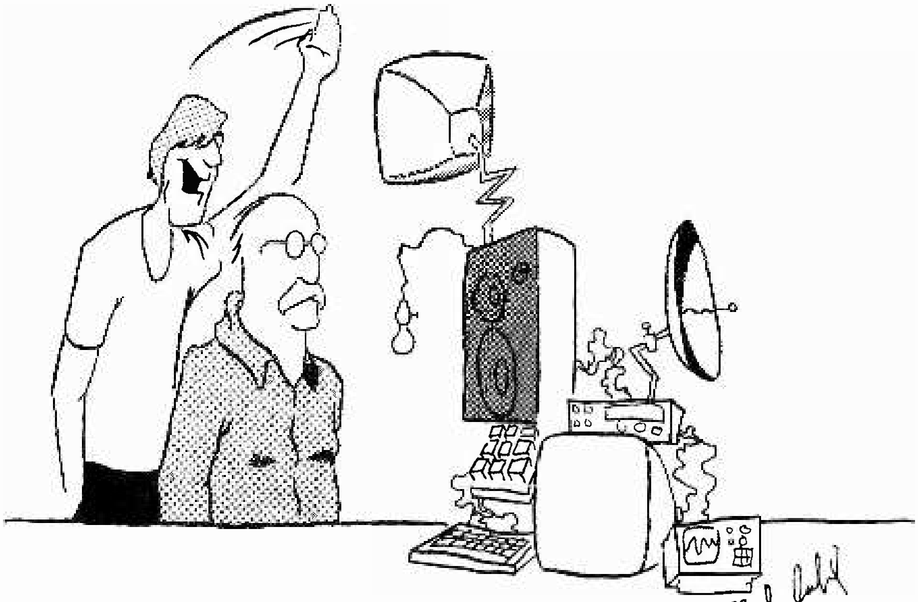
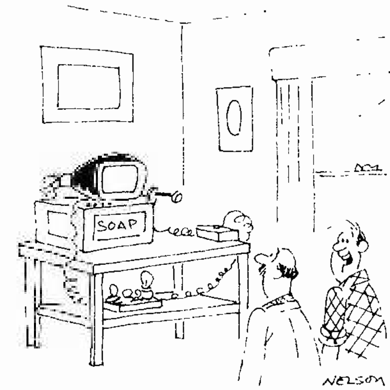
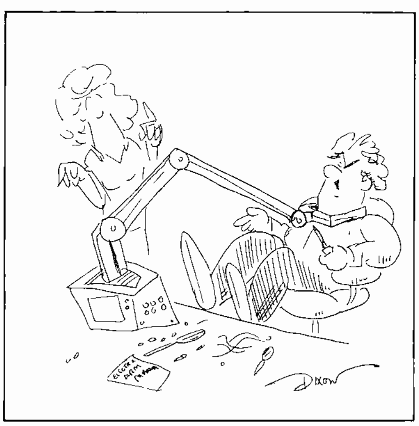


*It started as a TV, then a computer. I thought, like wow, why not a stereo-satellite system too!*




*I built the TV myself from a kit.*

# SOUND FAMILIAR ??

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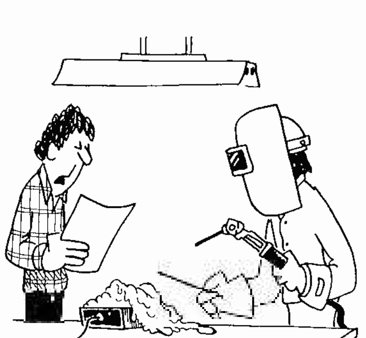
*Yeah, yeah. . .it works! Now disconnect the battery!*

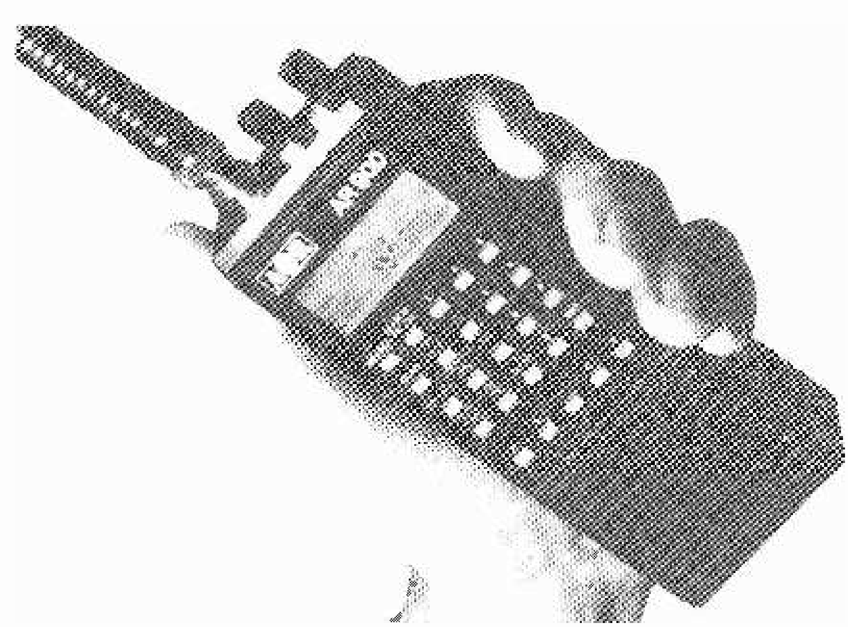
*You answer it! You couldn't wait to build a musical doorbell!*




*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 backlighted 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

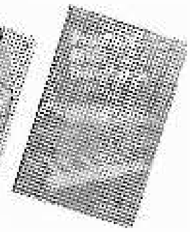
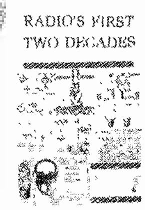
Max *Airwaves* include a five-foot tall palm tree and the colorful geometric shapes. All ten models in the medium-size group use a 1-way, 25-watt speaker (8 ohms).

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-

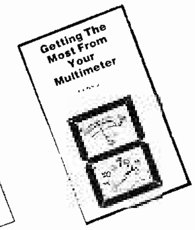
# Electronics Paperback Books

## GREAT PAPERBACKS AT SPECIAL PRICES







☐ **BP173—COMPUTER MUSIC PROJECTS ..... $6.95.** Shows how to use your home computer to produce electronic music. Many circuits. Mostly jargon free.

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☐ PCP103—PRACTICAL MIDI HANDBOOK ... $9.95. Explains what MIDI (the Musical Digital Interface) can do and how you can put it to work. Covers Keyboards, drum machines, sequencers, mixers, guitars and computer music

☐ **RFTD—RADIO'S FIRST TWO DECADES ..... $3.50.** This story of radio's early days makes for fascinating reading. Spark-gap transmitters, KDKA's beginnings, and much more.

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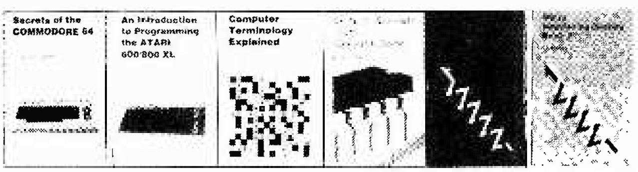
☐ **BP195—INTRODUCTION TO SATELLITE TV..... $9.95.** A definitive introduction to the subject written for the professional engineer, electronics enthusiast, or others who want to know more before they buy. 8 × 10 in

☐ **BP146—THE PRE-BASIC BOOK ..... $6.95.** A book on the BASIC programming for those who have not yet bought a computer as well as those who have trouble learning how to program.

☐ **BP239—GETTING THE MOST FROM YOUR MUTLIMETER..... $5.95.** Covers basics of analog and digital meters. Methods of component testing (includes transistors, thyristors, resistors, capacitors and other active and passive devices



☐ **BP135—SECRETS OF THE COMMODORE 64 ..... $5.75.** Masses of useful info and programming tips not found in any user's manual

☐ **BP130—MICRO INTERFACING CIRCUITS—BOOK 1 ..... $5.75.** Practical add-ons transform your computer into control or measurement equipment

☐ **BP143—INTRO TO PROGRAMMING THE ATARI 600/800 XL ..... $5.95.** Perfect complement to the Atari user's manual. Even shows how to use animated graphics.

☐ **BP131—MICRO INTERFACING CIRCUITS—BOOK 2 ..... $5.75.** Interfacing sound and speech generators, temperature and optical sensors, motor controllers, and more

☐ **BP148—COMPUTER TECHNOLOGY EXPLAINED ..... $5.50** Explanations for computer terms often encountered. A dictionary for computer lingo

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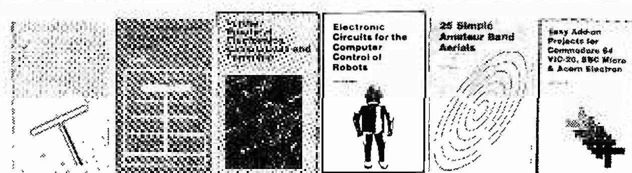

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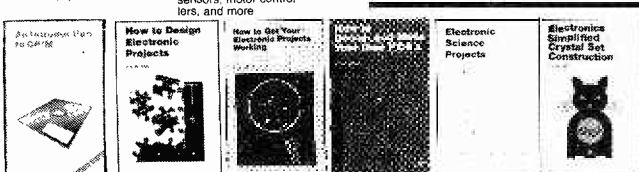
## Quality Paperbacks



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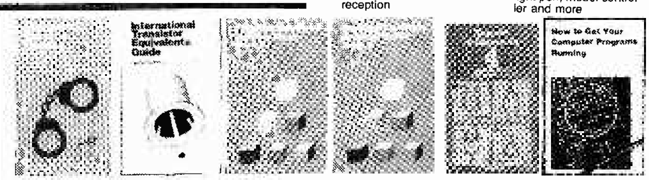

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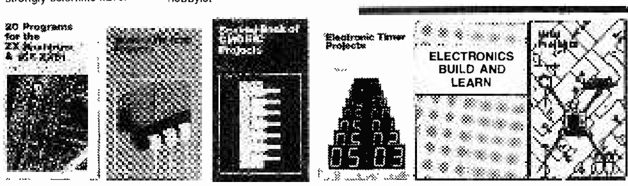
☐ **BP169—HOW TO GET YOUR COMPUTER PROGRAMS RUNNING ..... $5.95.** Have you ever written your own programs only to find that they do not work? This book shows you how to find errors.

## Affordable Prices



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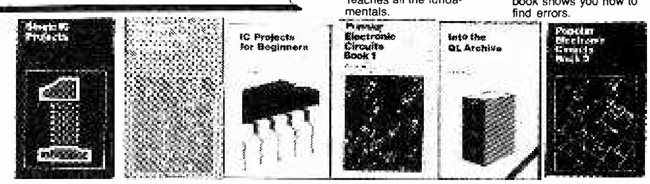

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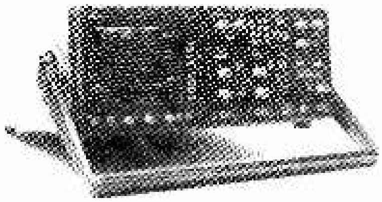
cros are 12 inches or less in their longest dimensions.

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

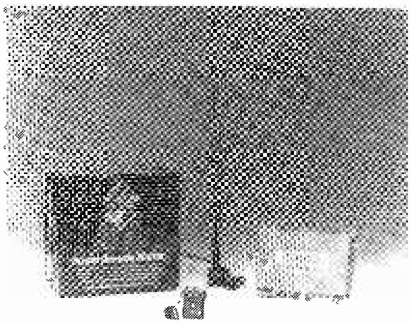
Other automatic-measurement functions are RMS voltage, percentage overshoot and preshoot for step functions, and continuously variable rise and fall times—including the two preset options of 10–90 percent and 20–80 percent for ECL applications. The *PM 3320A* also provides automatic pulse width, duty-cycle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



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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.

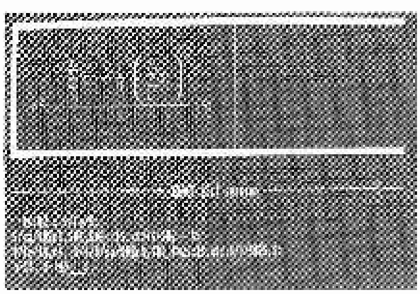
The *Smart Remote Starter* can easily be programmed to respond to as many as three additional Clifford remote controls, even if each one uses a different digital code or is of a different type.

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.**

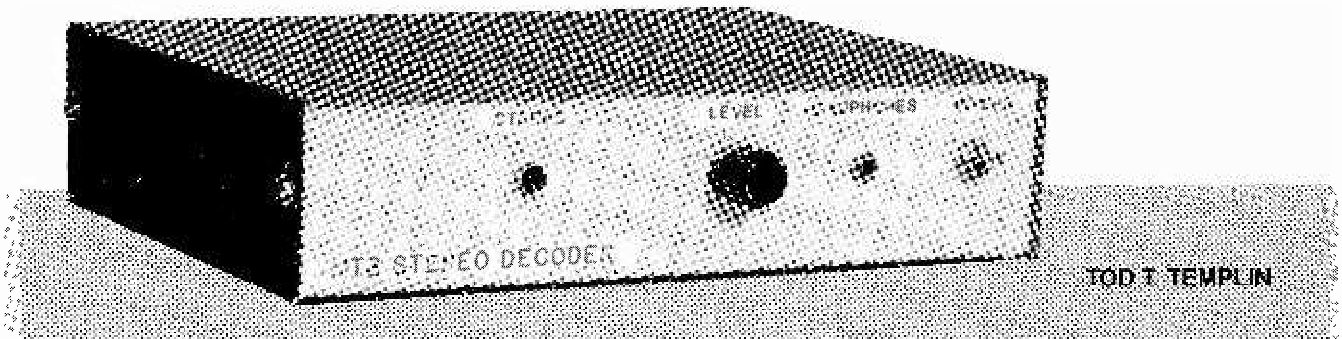
Understanding propagation phenomena is crucial when planning communications links and designing systems to minimize interference. Aimed primarily at electrical and electronics engineers, *Radio Wave Propagation* provides a complete, practical overview of the field.

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

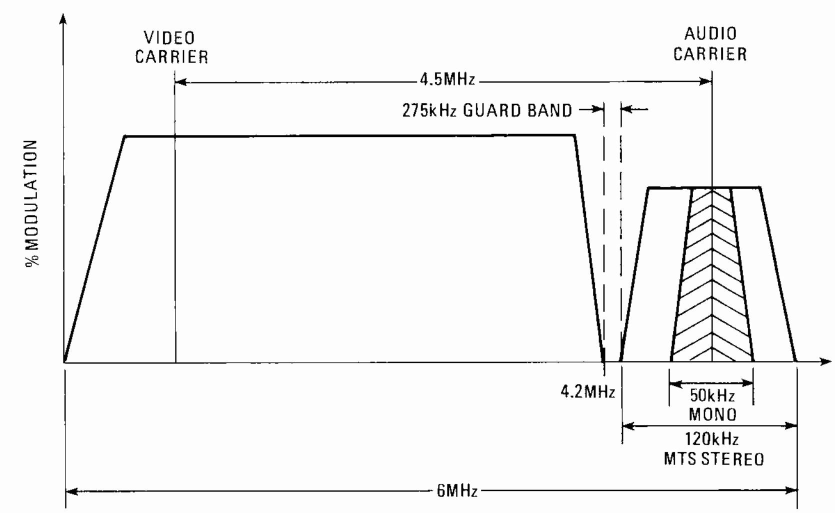



**FIG. 1—STEREO-TV AUDIO requires about twice the bandwidth of a mono signal.**

## 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.

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

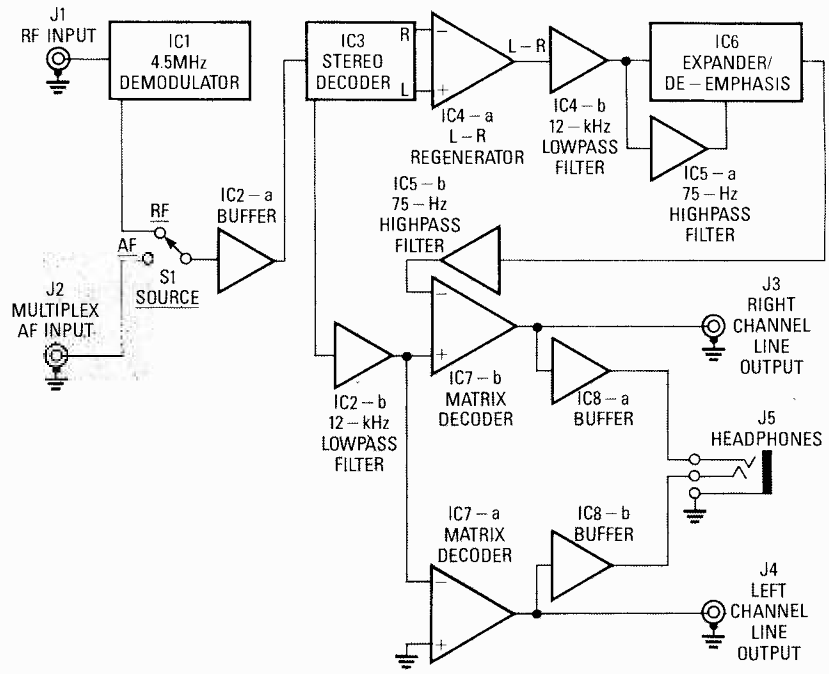



**FIG. 2—EIGHT INEXPENSIVE IC'S are all it takes to provide a high-quality MTS decoder.**

### 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.**

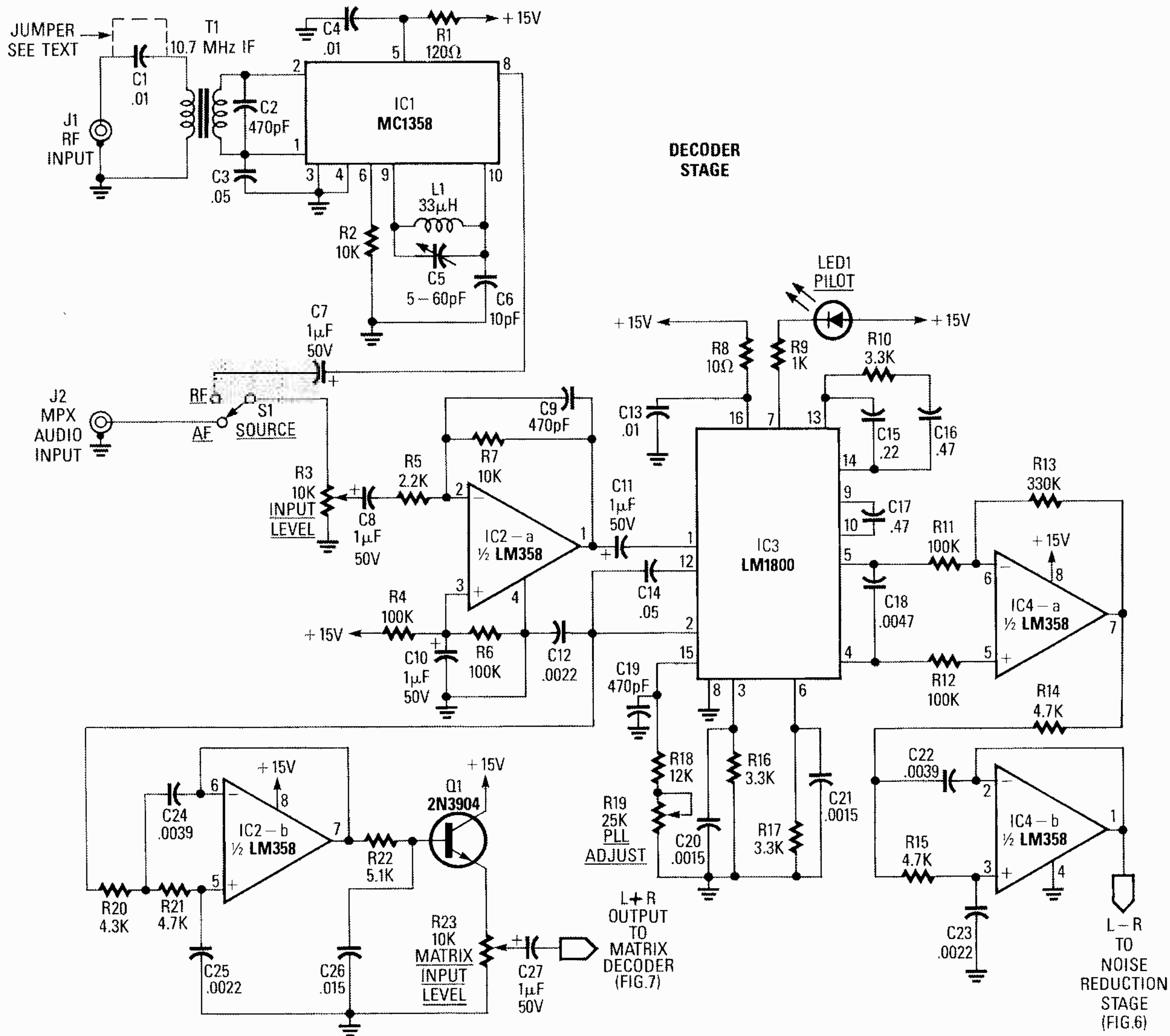



**FIG. 3—THE DECODER STAGE converts the multiplexed audio signal into L + R and L − R signals.**

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.

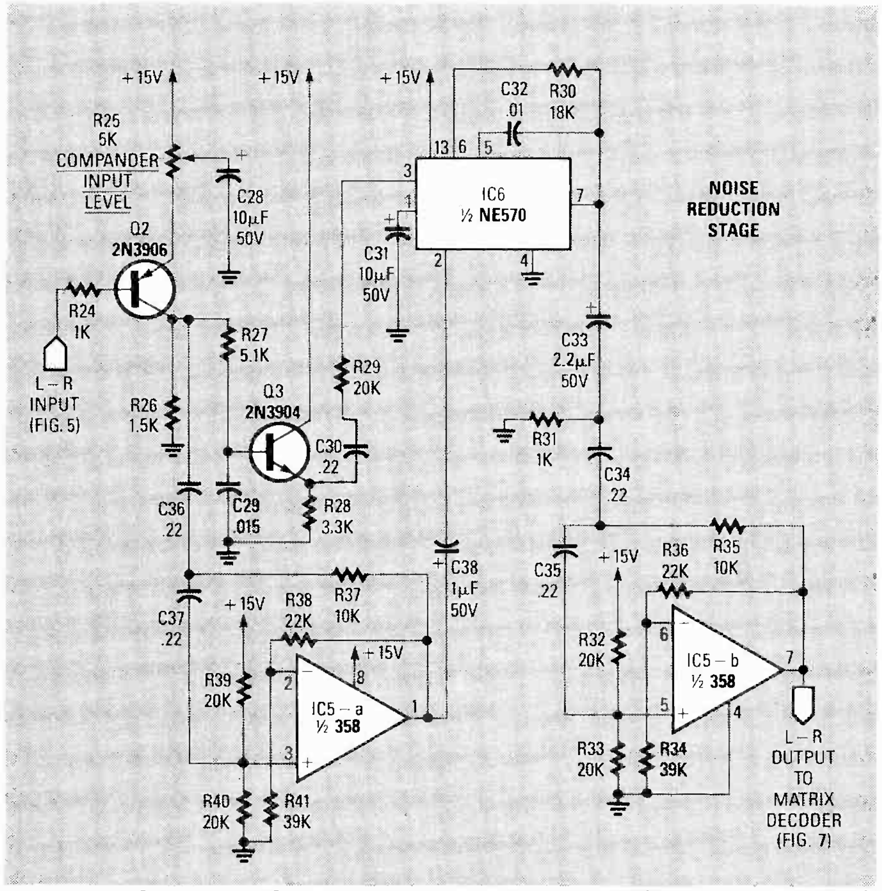



FIG. 4—THE NOISE-REDUCTION STAGE de-compands the L − R signal, and emulates dbx-style processing. As described elsewhere in this article (see box), true dbx procesing is not currently possible in a home-built circuit due to the inavailability of the dbx IC's.

### 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.

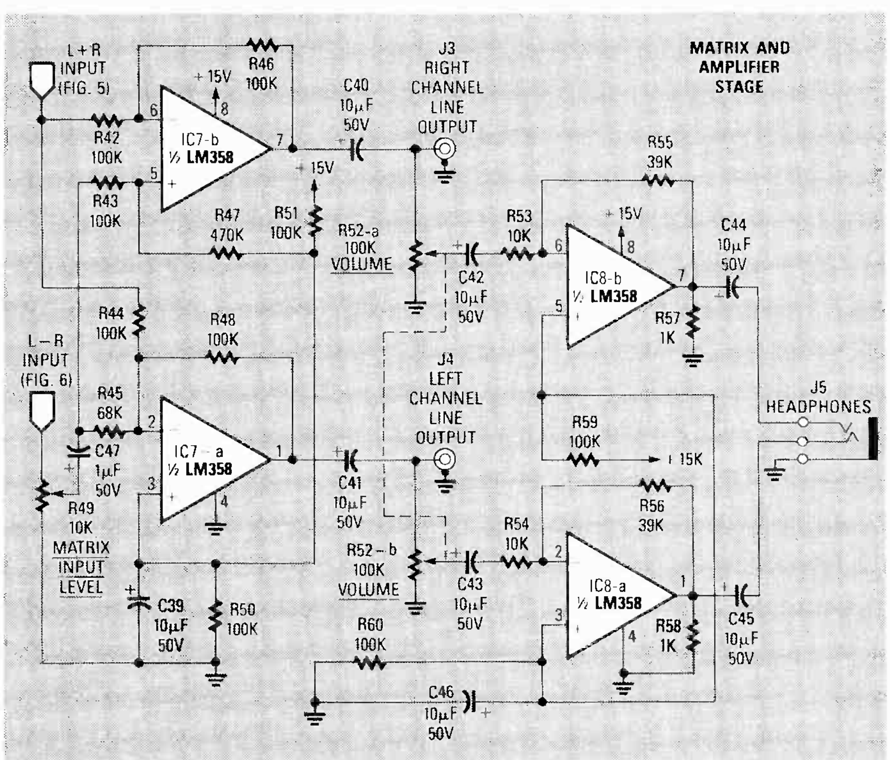



FIG. 5—THE MATRIX STAGE separates the L + R and L − R signals into the left- and right-channel components. Op-amp IC8 and associated components provide an optional headphone output. If you do not wish to drive a pair of headphones, or plan to use your amplifier's headphone jack for that purpose, all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

### 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)

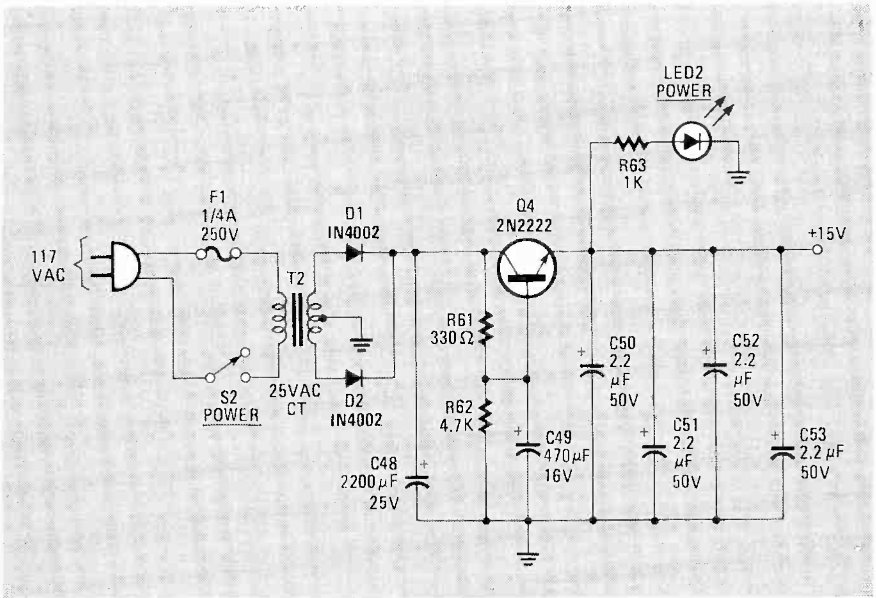



FIG. 6—THE UNREGUALTED POWER SUPPLY shown here provides extremely low ripple for the MTS decoder.

## 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**

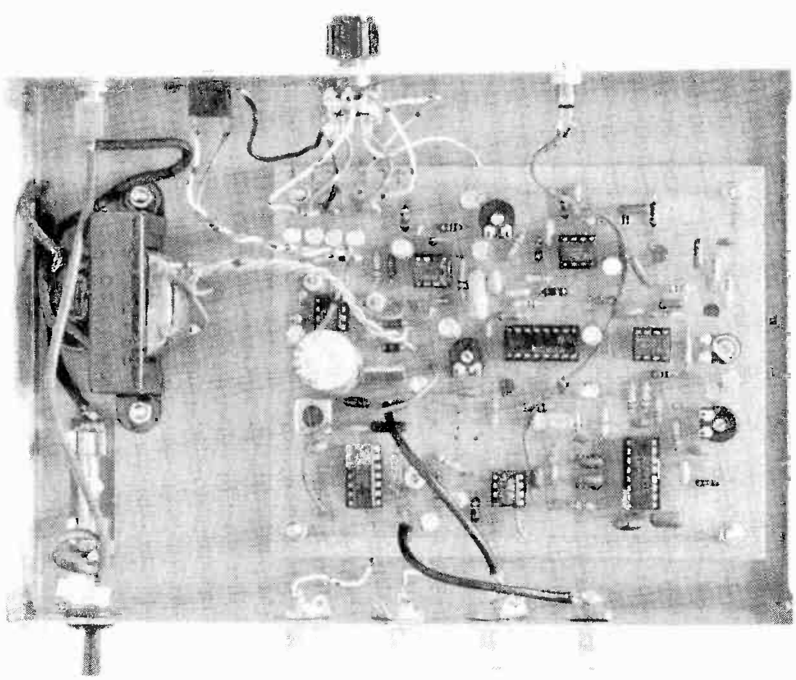
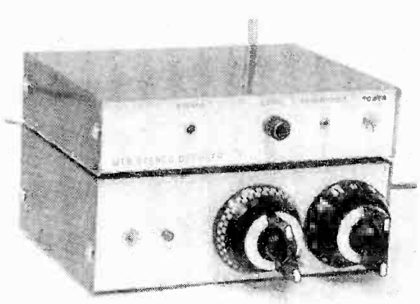


FIG. 7—THE COMPLETED STEREO DECODER BOARD. Next time, we'll show you how to build the circuit shown here.



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 PC 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**


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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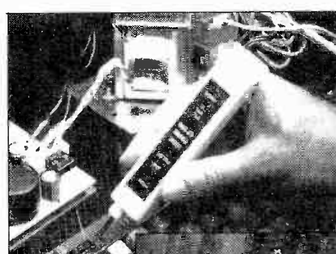

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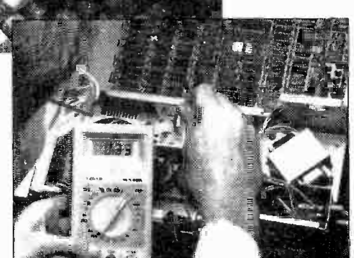

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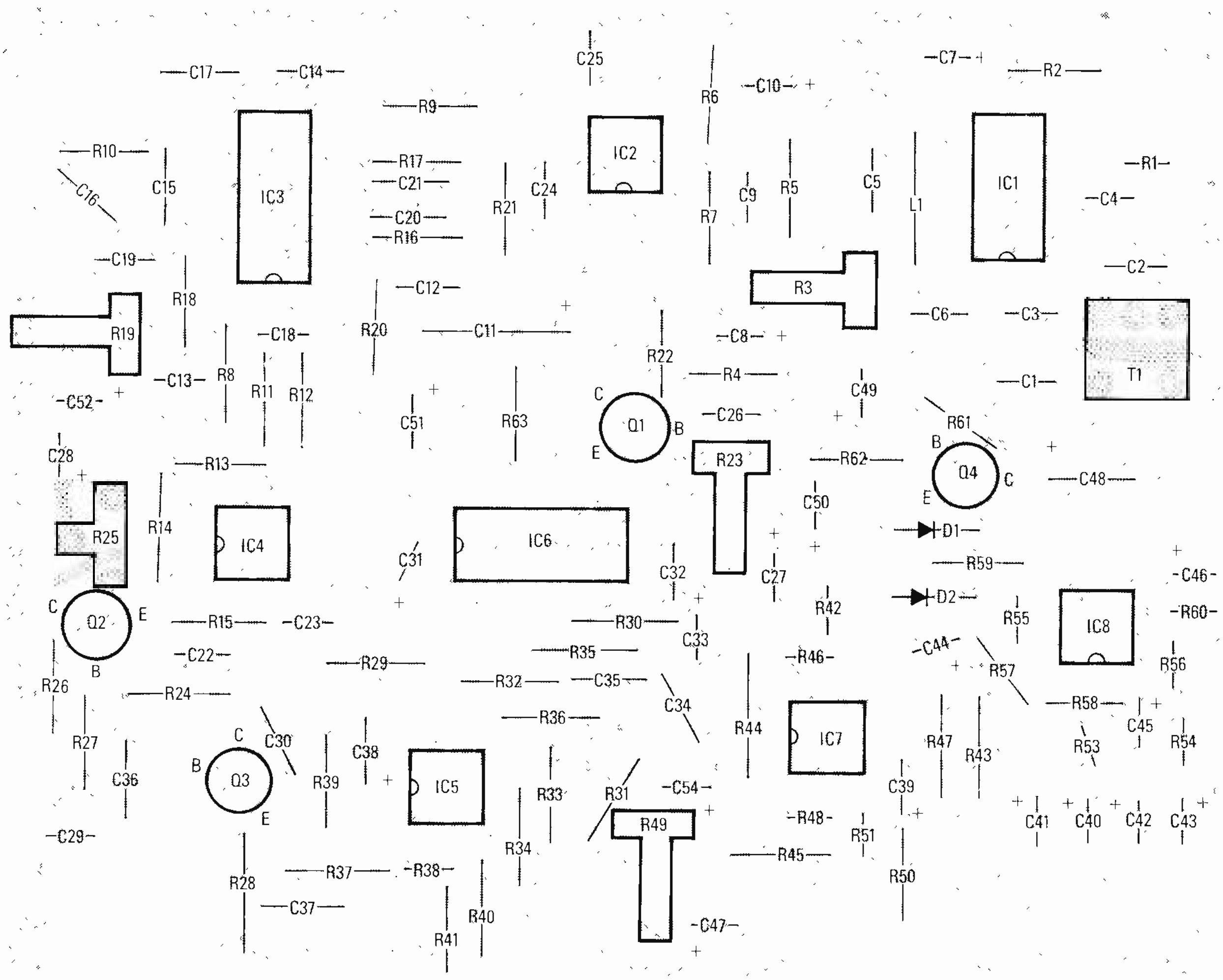



FIG. 7—MOUNT ALL ON-BOARD COMPONENTS on the MTS decoder's PC board as shown here.

## 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—19,000 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 compandor
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 T[3] Research Inc., 5329 N. Navajo Ave., Glendale, WI 53217 for $10 plus $0.75 postge and handling. WI residents add 5% sales tax.**

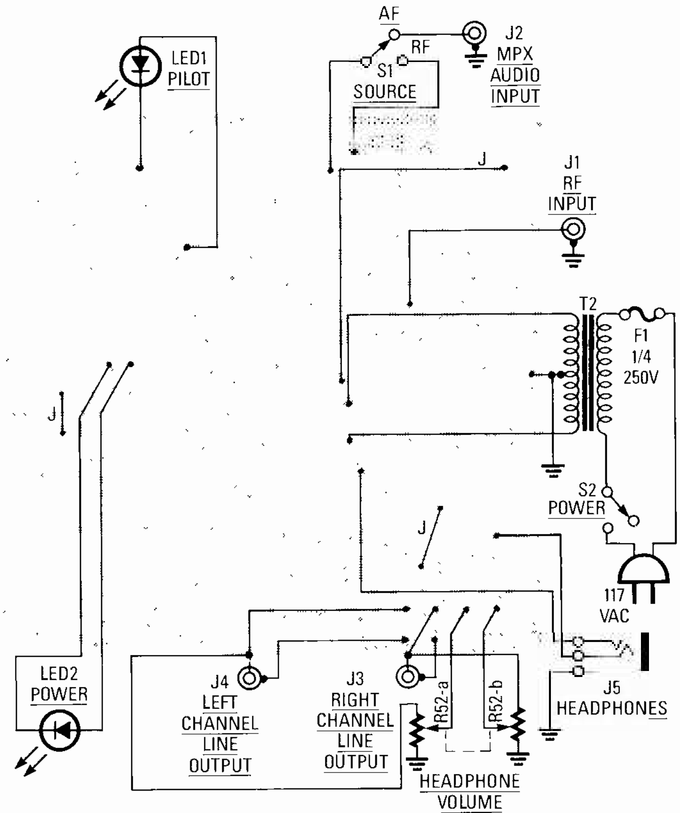



**FIG. 8—THREE JUMPERS AND ALL OFF-BOARD components mount as shown here.**

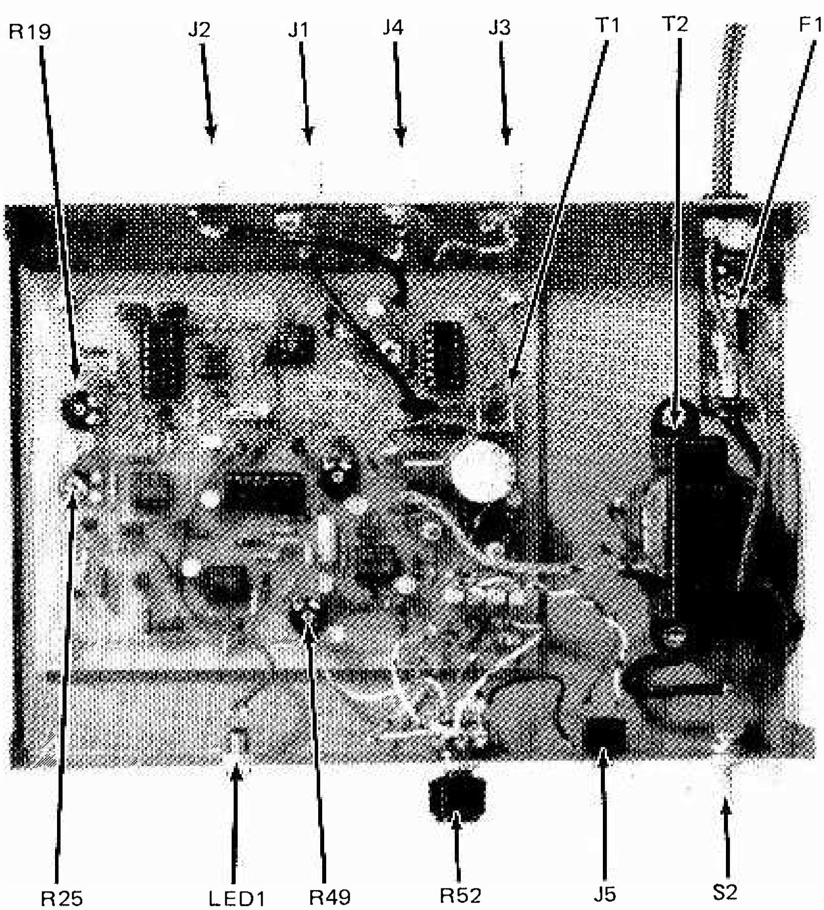



**FIG. 9—THE COMPLETED DECODER appears as shown here. The board shown was an early prototype, so it doesn't match the parts-placement diagrams (shown in Fig. 7 and Fig. 8) exactly.**

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*.

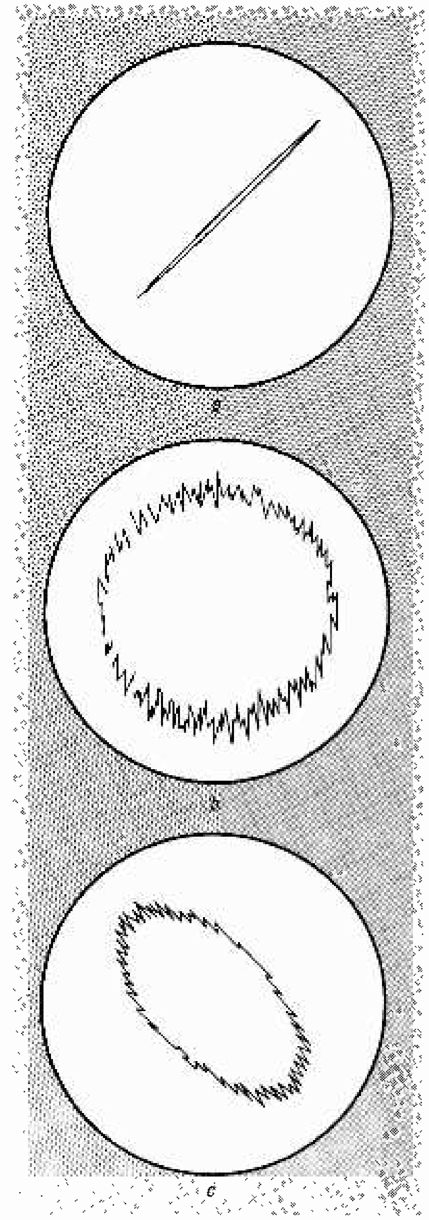



**FIG. 11—OSCILLOSCOPE DISPLAYS of the decoder's left and right outputs. Shown in *a* is a mono signal (L + R); in *b* is a signal with proper left/right separation; in *c* is a signal with too much L − R.**

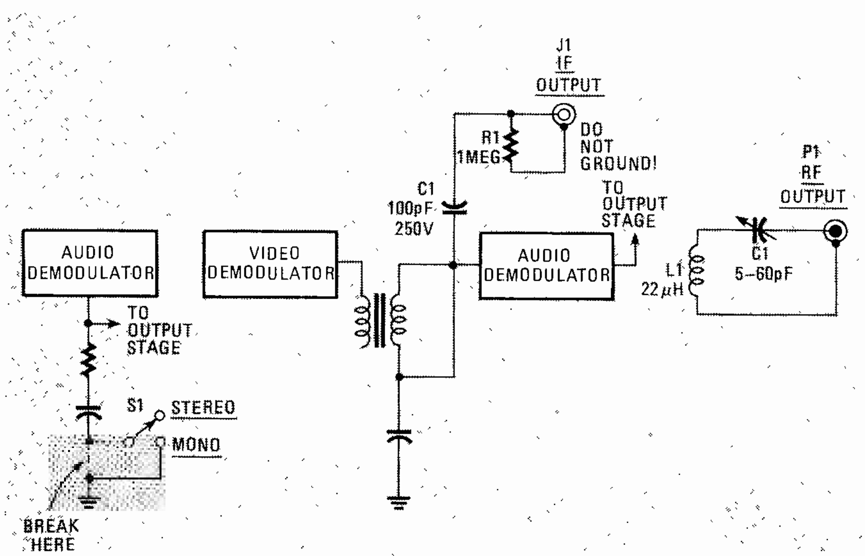
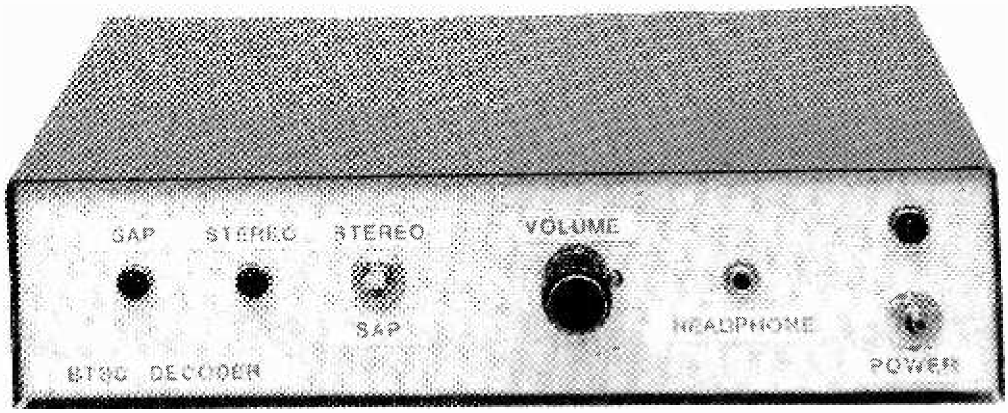



**FIG. 10—INTERFACING THE DECODER to a TV or VCR can be accomplished in various ways: via the audio demodulator (*a*), at the output of the video demodulator (*b*), or indirectly via an RF probe (*c*).**

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**




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

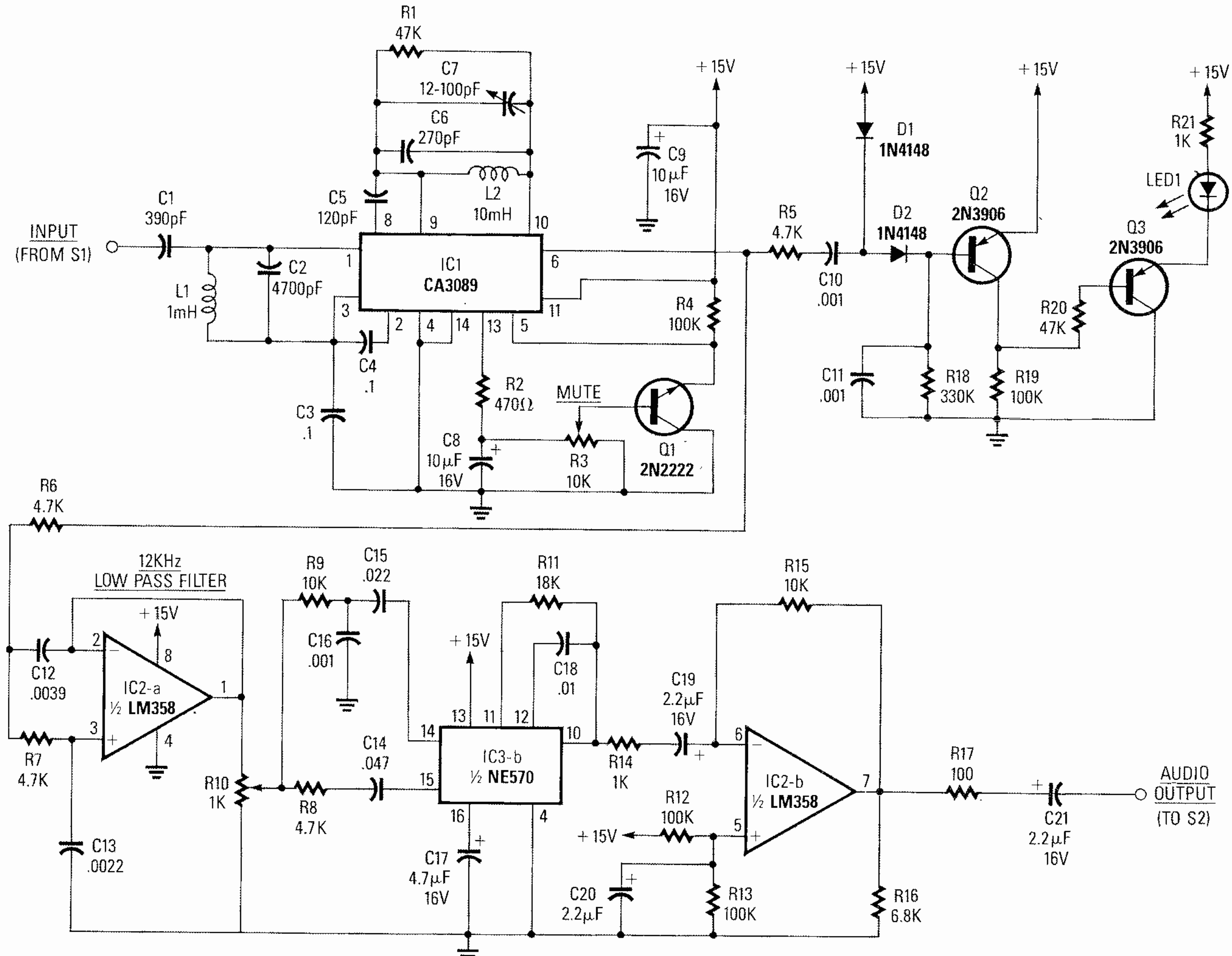



**FIG. 1—THE SAP ADAPTER SCHEMATIC. Easily added to your stereo decoder, it will allow you to hear the SAP channel.**

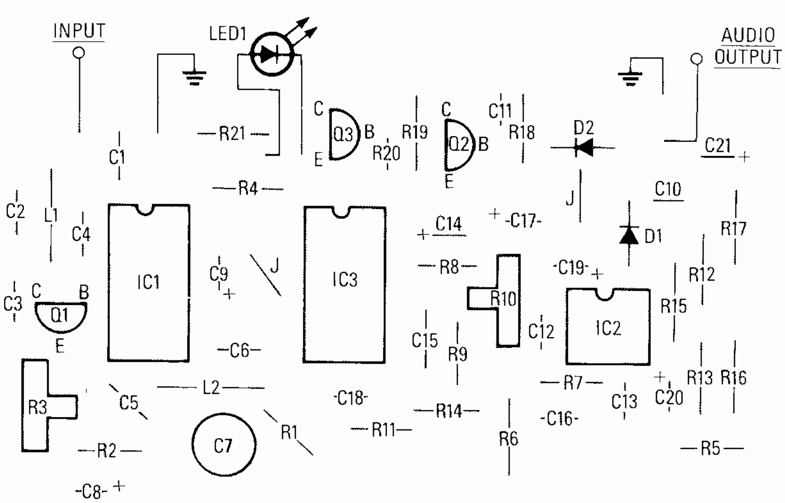



**FIG. 2—FOLLOW THIS DIAGRAM for correct placement of the SAP board's components.**

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

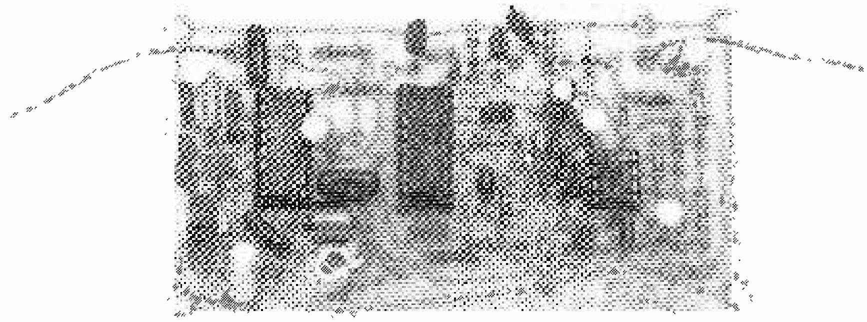


**FIG. 3—THE COMPLETED SAP BOARD. Notice that only two wires have to be connected to the stereo decoder.**

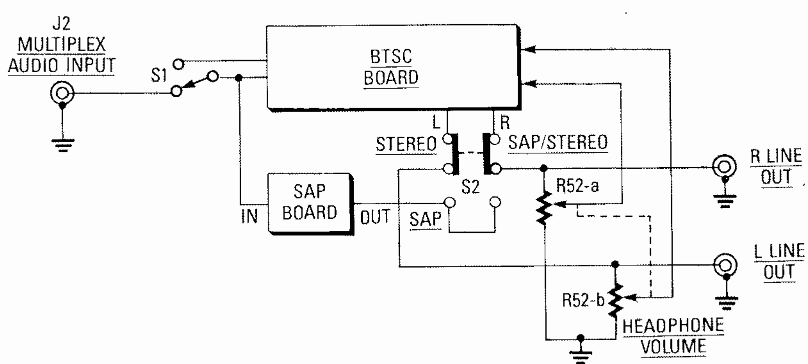



**FIG. 4—THIS IS HOW S2 is connected into the system to allow for switching between SAP and stereo decoding.**

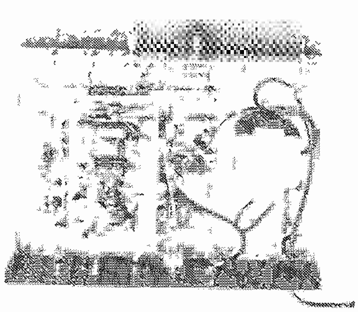


**FIG.5—THE SAP BOARD MOUNTS directly onto the BTSC board. Notice the modifications (extra switch, wiring, LED, etc.) that have been made to the chassis in order to accommodate the SAP decoder.**

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

MICHAEL RINGENBERGER

# PHONY BURGLAR ALARM

*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.

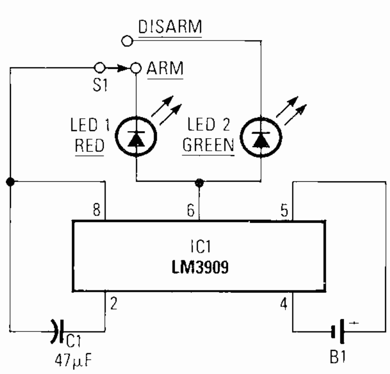



**FIG. 1—IT'S NOT A REAL BURGLAR ALARM, but this "electronic scarecrow" can do almost as good a job as a real one when it comes to scaring away a burglar.**

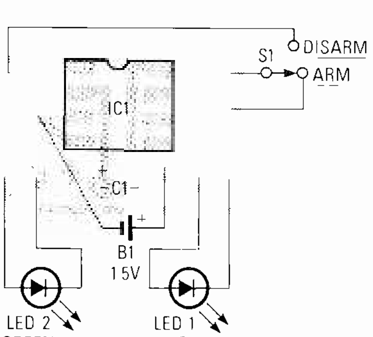



**FIG. 2—THE CIRCUIT CAN BE BUILT on a tiny PC board. The pattern is provided in our PC Service section.**

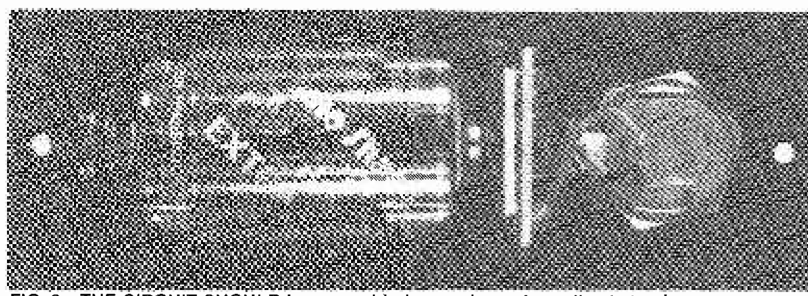


**FIG. 3—THE CIRCUIT SHOULD be assembled on a piece of anodized aluminum.**

## 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.

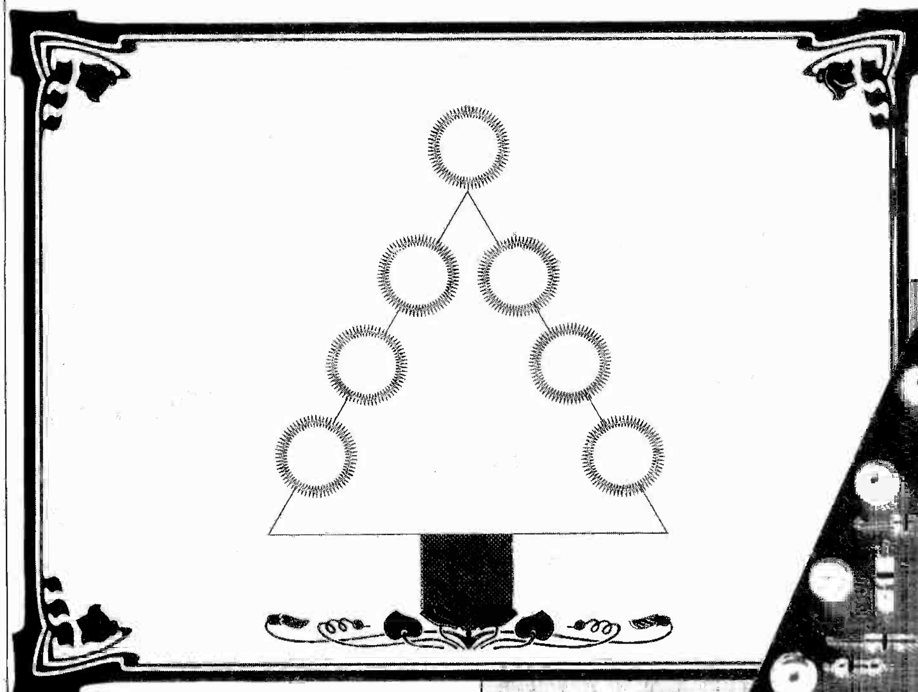
The circuit is mounted on a piece of anodized aluminum. Size is not critical, as long as it is appropriate for the task. The author's prototype was 1½ × 4 inches. The other side of the aluminum piece will serve as the dummy status-panel.

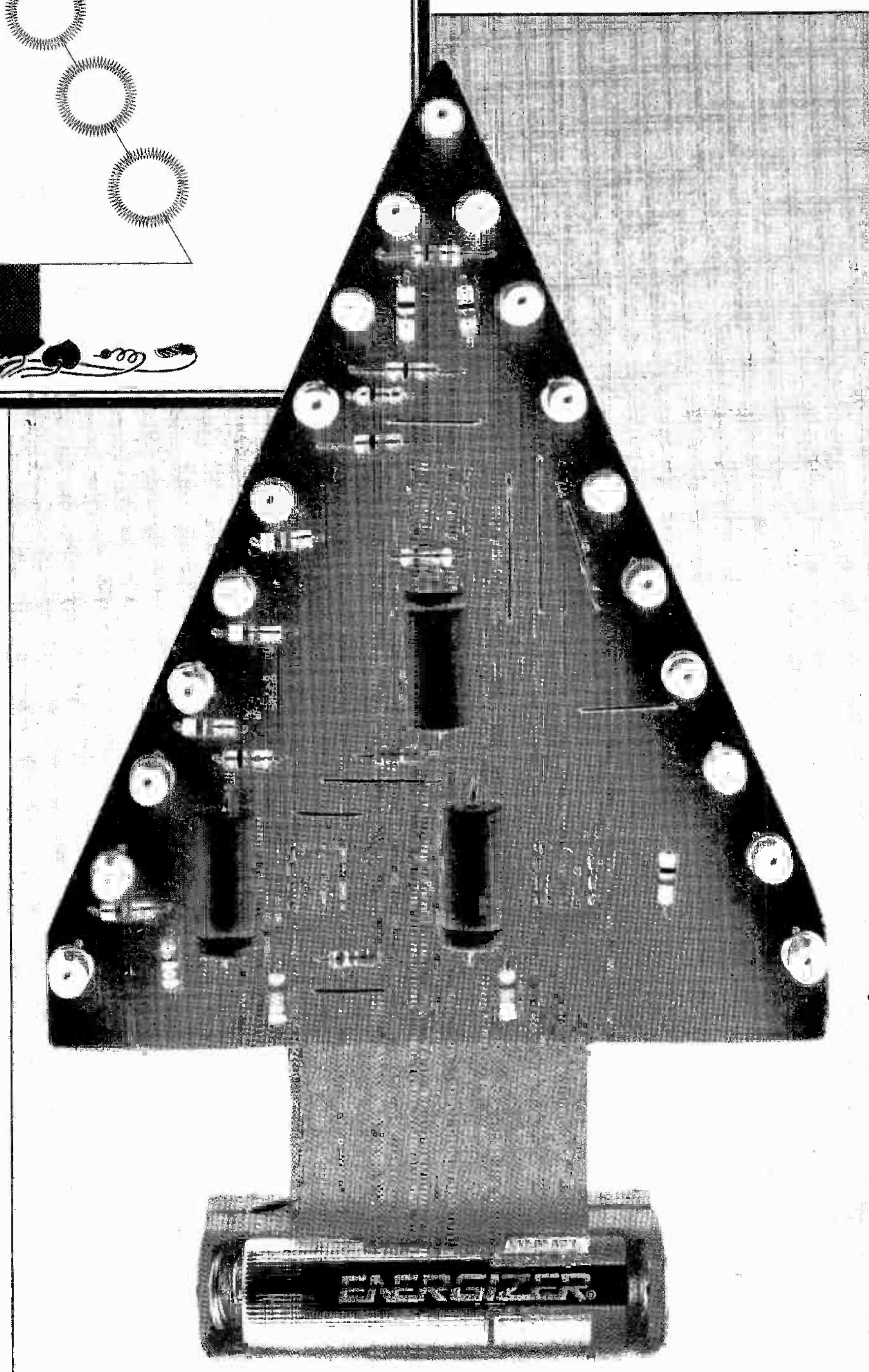
Begin by drilling holes for the two LED's and the key switch; also drill two mounting holes. Be careful, as a neat, "professional" looking job will help enhance the effect. Next, secure a "C"-cell

*continued on page 150*

# ELECTRONIC XMAS TREE

THOMAS L. JOZWIAK






*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.

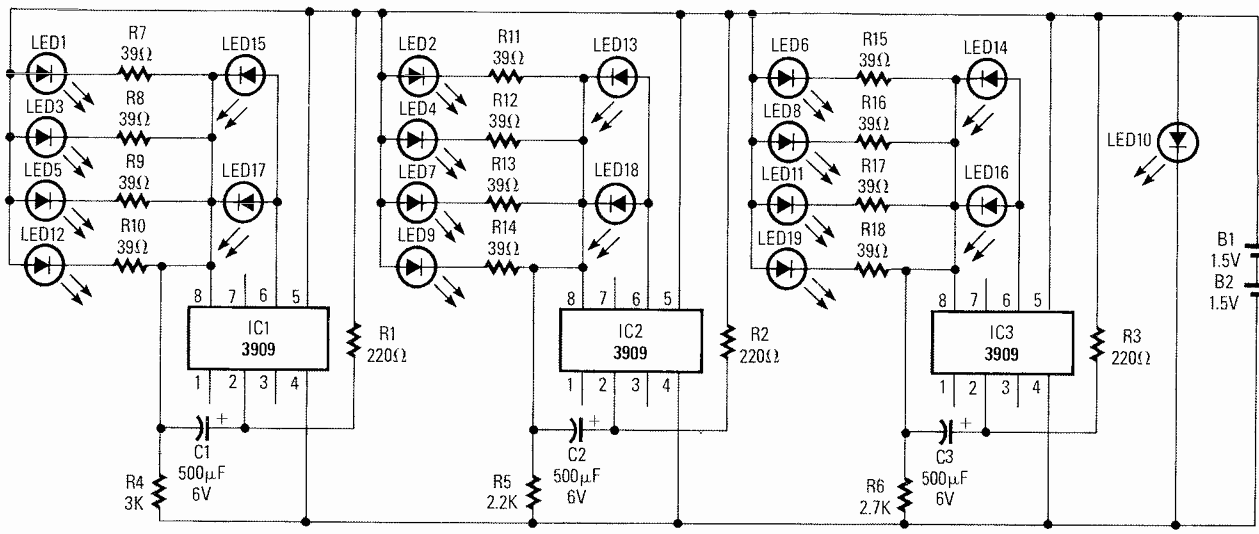



**FIG. 1—THREE INDIVIDUAL FLASHER CIRCUITS having unrelated flash rates create a pseudo-randown blinking of the LED's because the LED's from each individual circuit are intermixed around the edges of the tree.**

### 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.

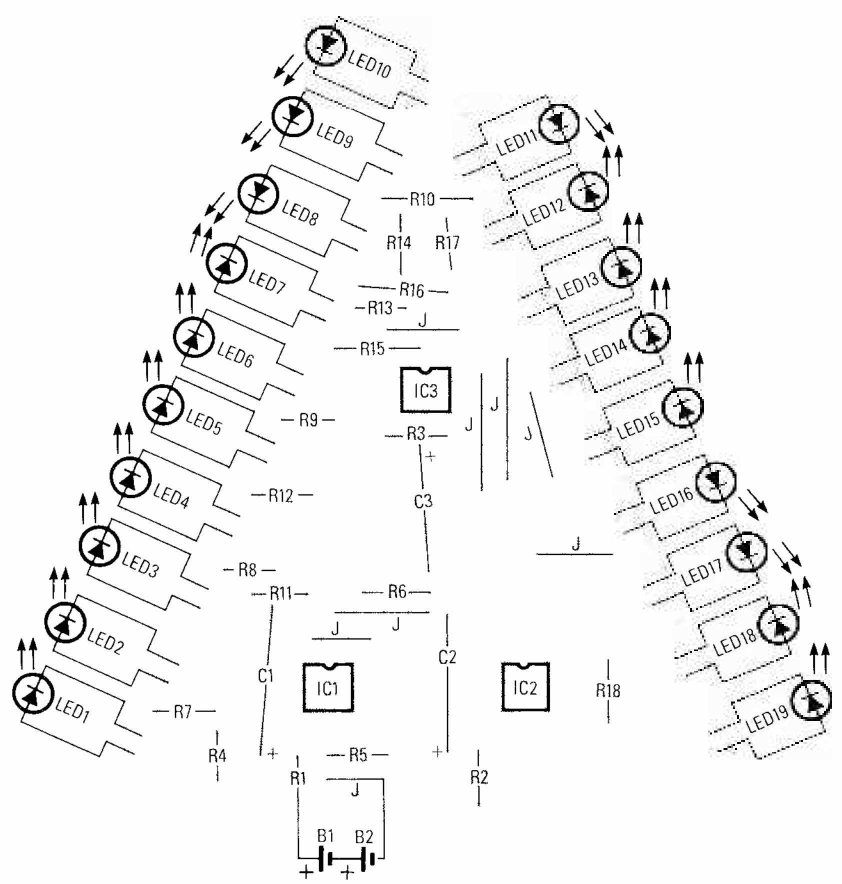



**FIG. 2-TAKE EXTRA CARE THAT THE LED'S are installed with the correct polarities. If you want to decorate the "tree", do it before drilling the mounting holes for the components.**

## 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.

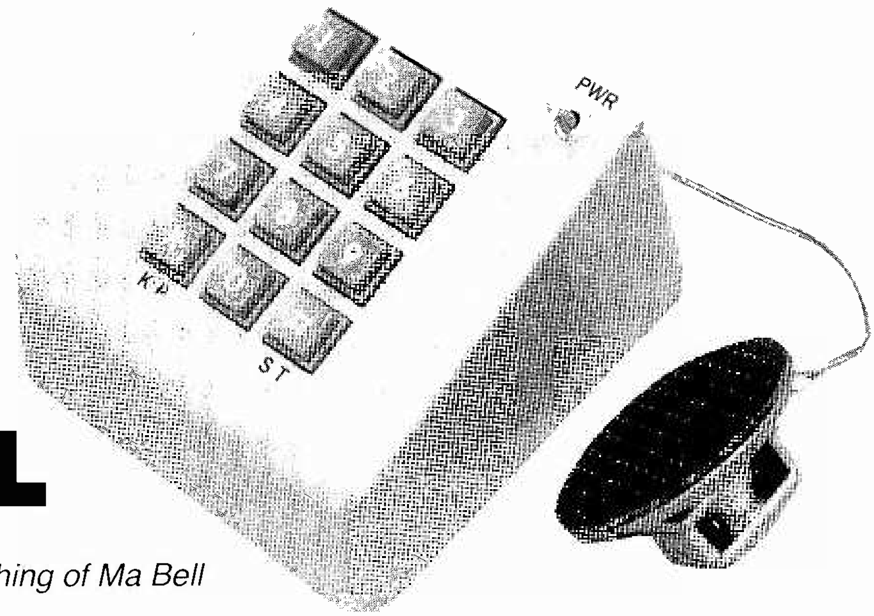
**Note: An etched and drilled PC board is available for $11 postpaid from Fen-Tek P.O. Box 5012, Babylon, NY 11707-0012. NY residents must add appropriate sales tax.**

Note in particular 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."


*a* *b*

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

**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 |
| Code 12 | 900 + 1700 | OPERATORS |
| KP | 1100 + 1700 | PRIME (START OF PULSING) |
| KP2 | 1300 + 1700 | TRANSIT TRAFFIC |
| ST | 1500 + 1700 | START (END OF PULSING) |

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.

### 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,

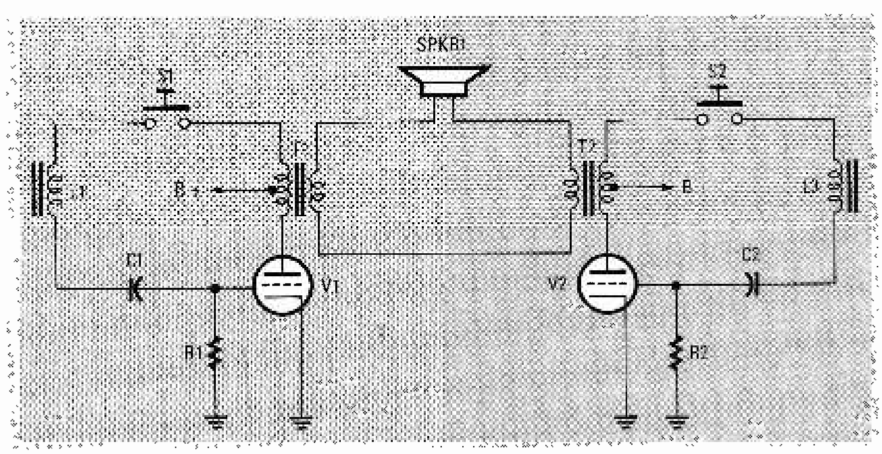



**FIG. 2—A POPULAR BLUE BOX DESIGN used two phase-shift oscillators, vacuum tubes, and a simple speaker connection that mixed both oscillators into a single two-tone output.**

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.

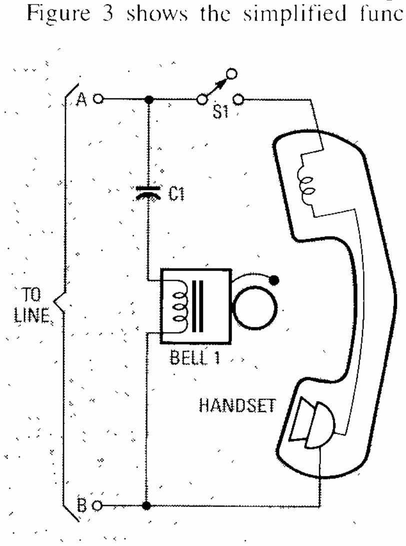



**FIG. 3—A SIMPLIFIED TELEPHONE circuit. The handset is connected across the line when hook switch S1 is closed. The handset closes the DC loop with the telephone company's switching equipment.**

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.

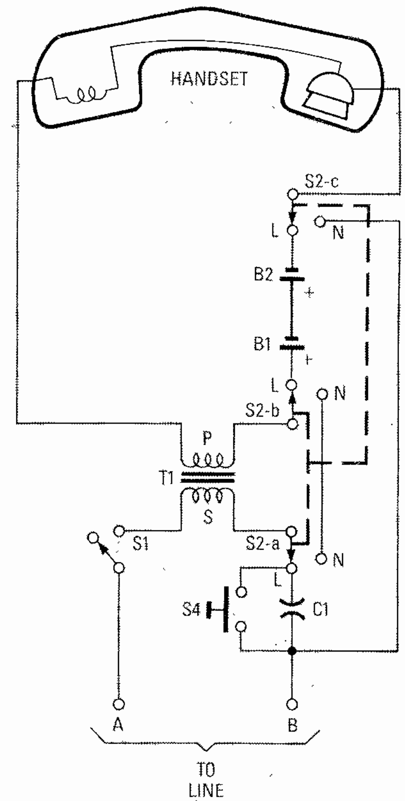



**FIG. 4—A SIMPLIFIED RED BOX. Switch S2 lifts the handset from the telephone line and connects two D-cells as a local power supply. The circuit is DC-isolated from the telephone line even when hook switch S1 is closed.**

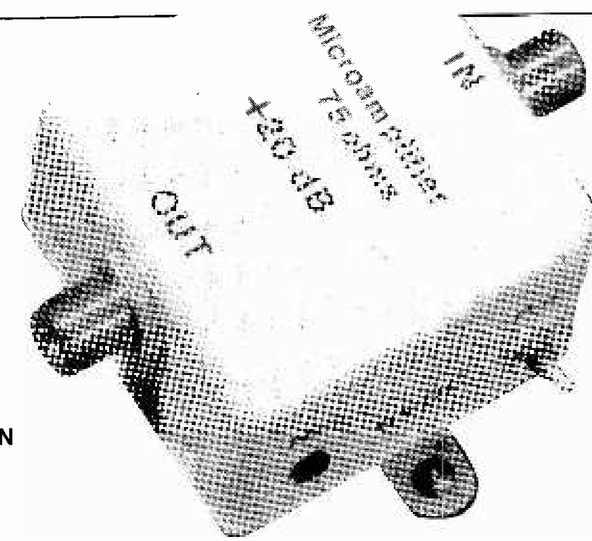
To use the field telephone as a Red Box, switch S2 is set to L (LOCAL). Switches S2-b and S2-c connect batteries B1 and B2 in series with the handset and the transformer's primary, which constitute an active, working telephone circuit. Switch S2-a connects T2's secondary to one side of the telephone 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*

# 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.

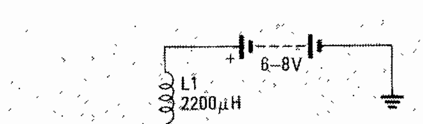



**FIG.1—EXCEPT FOR THE COUPLING and decoupling capacitors, IC1 is a complete wideband amplifier having a fixed gain of 20 dB to 450 MHz. No external compensation is required.**

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.

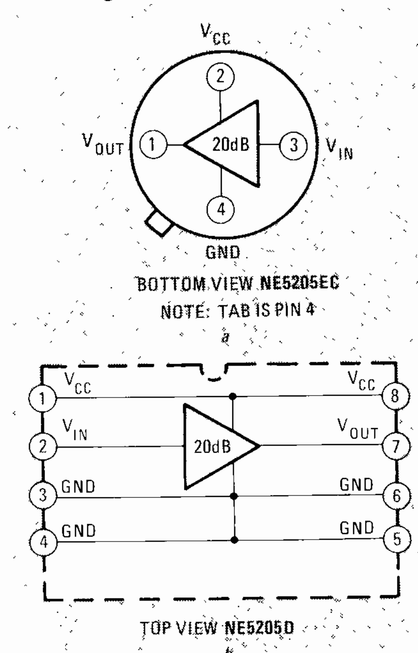



**FIG. 2—THE NE5205 IS AVAILABLE in two configurations: a pinout for a conventional TO-46 metal can whose tab provides the ground connection is shown in a. An SO-8 DIP pinout is shown in b. The grounded metal case of the TO-46 version extends the response from 450 MHz to 650 MHz.**

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.

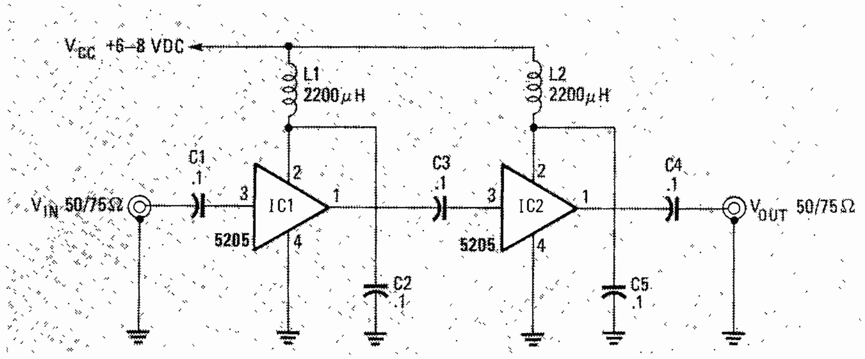



FIG. 3—**SINCE THE NE5205 FUNCTIONS** as a gain block, two or more can be easily cascaded to provide additional amplification. In this circuit, which uses two NE5205s, the overall gain is 40 dB.

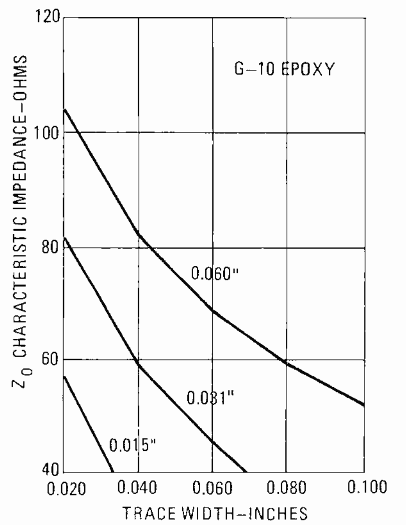



FIG. 4—**USE THIS CHART** to determined microstrip trace width for various impedances and thicknesses of G-10 epoxy board.

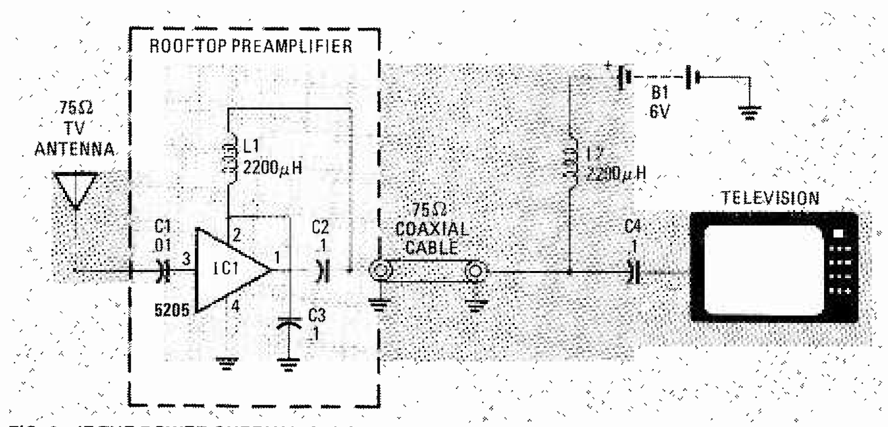



FIG. 6—**IF THE POWER SUPPLY** is fed through the signal-carrying coaxial cable, the amplifier can be mounted in a weatherproof enclosure directly at the antenna.

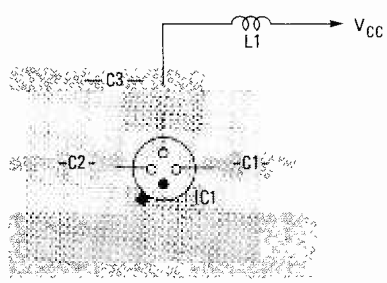



FIG. 5—**THIS IS THE COMPONENT LAYOUT** for the basic amplifier. All components are on the soldering side of the board.

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 microstrip 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.

## 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.

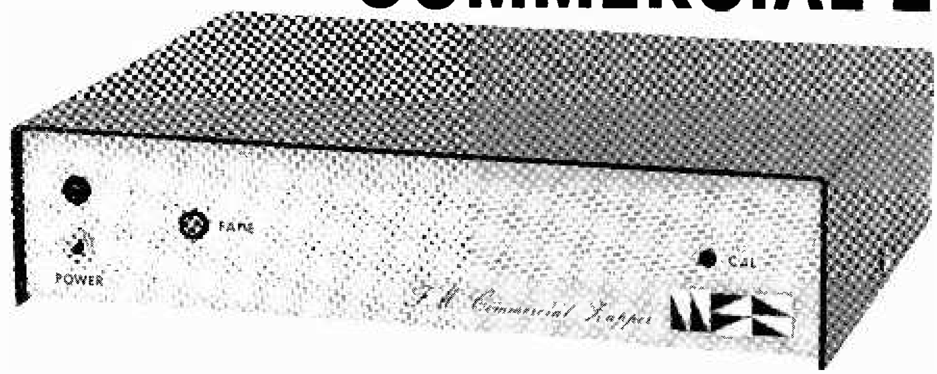
If you want to expand the foil pattern to include another NE5205, keep all new signal paths short and as straight as possible. The groundplane should be extended beyond each edge of any added traces by no less than the trace width.

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*

# 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

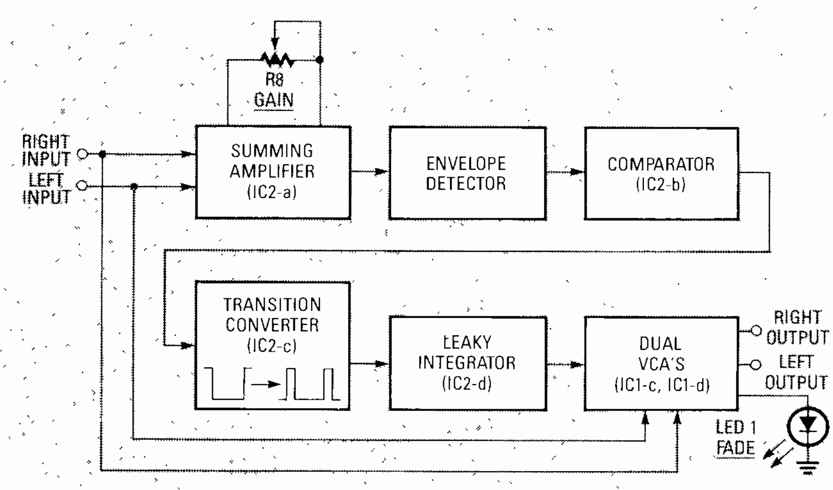



**FIG. 1—BLOCK DIAGRAM OF THE COMMERCIAL KILLER: The envelope of the signal is used to vary the pulse rate from IC2-c. The pulses are integrated; the resulting signal controls the gains of a pair of VCA's.**

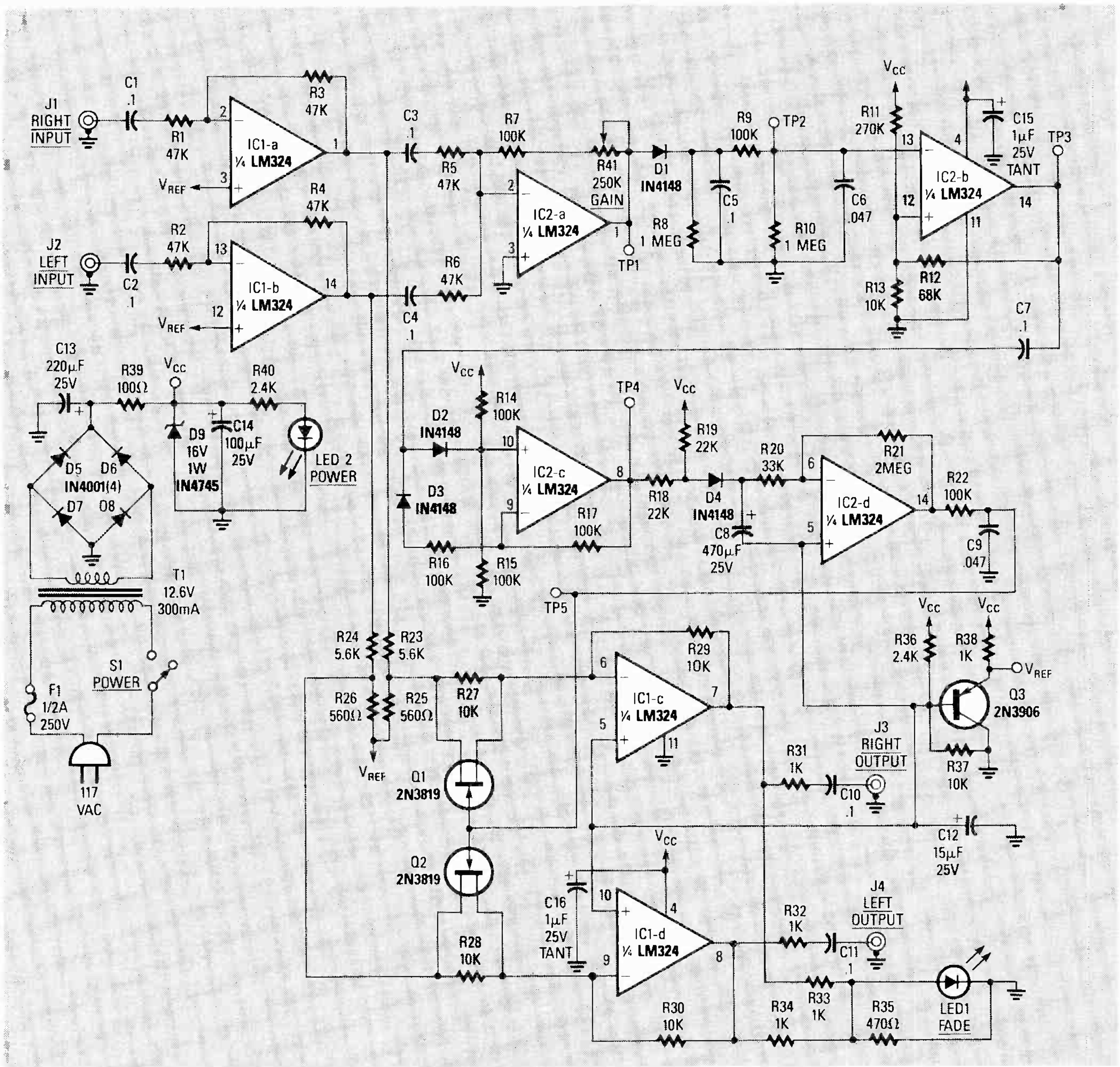



**FIG. 2—THE COMMERCIAL KILLER'S SCHEMATIC:** Q3 provides a reference voltage for the op-amps; Q1 and Q2 control the gain of IC1-c and IC1-d.

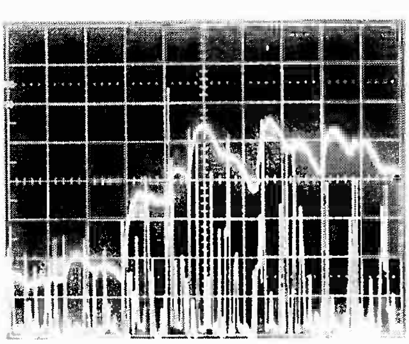


**FIG. 3—THE SPIKES represent L + R audio, and the smooth trace, the output of the envelope detector.**

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

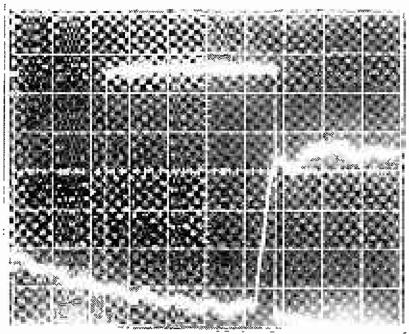


**FIG. 4—THE SQUARE WAVEFORM represents the output of the comparator; the other waveform is the output of the envelope detector.**

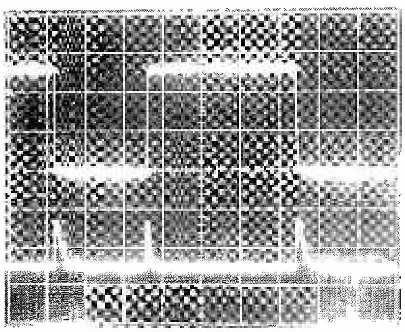


**FIG 5—THE COMPARATOR'S OUTPUT is shown in the upper trace; the output of the transition converter is shown in the lower trace. Every time the comparator changes state, another pulse is generated.**

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.

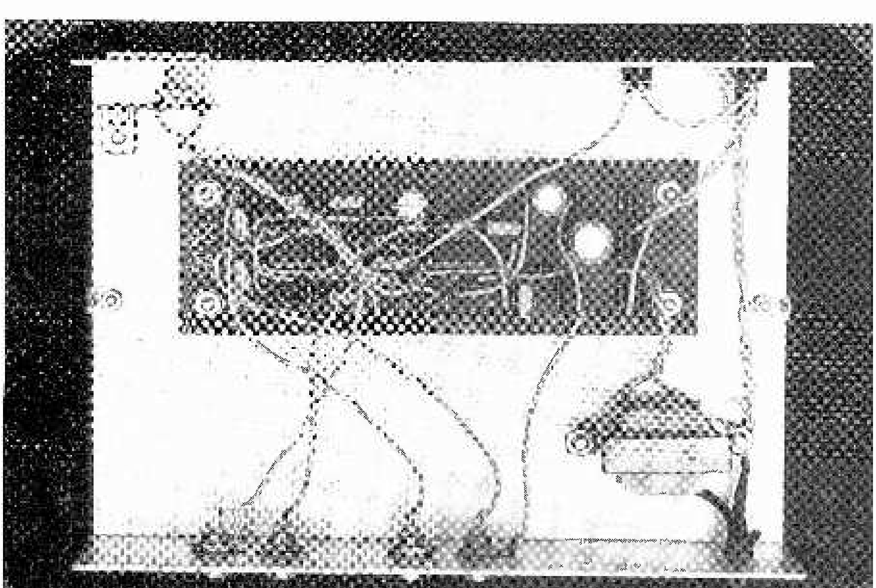


**FIG. 6—THE AUTHOR'S PROTOTYPE was built on a piece of perfboard using point-to-point wiring. Keep your lead lengths short, and be careful with the 117-volt primary circuit.**

### 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-

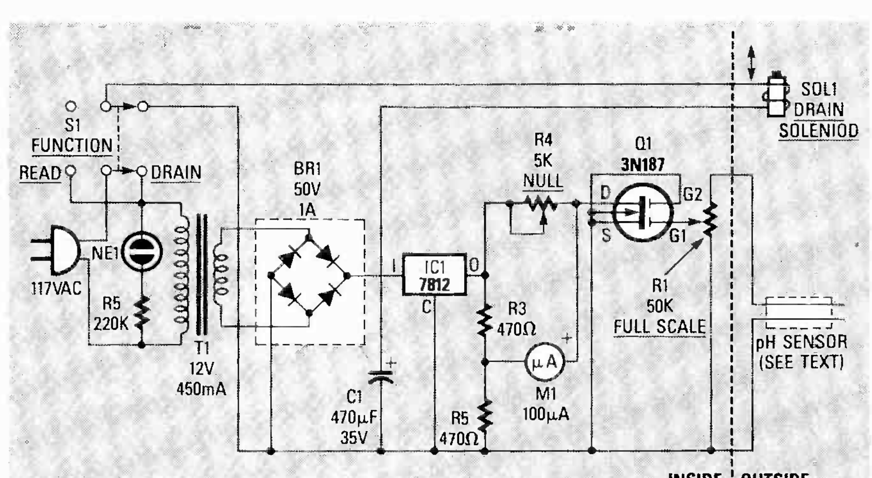



**FIG. 1—THE DRAIN-TO-SOURCE RESISTANCE of Q1 varies depending on the acidity of the sample presented to Q1's gate circuit. That variable resistance varies the current flowing through the bridge; that current is proportional to pH.**

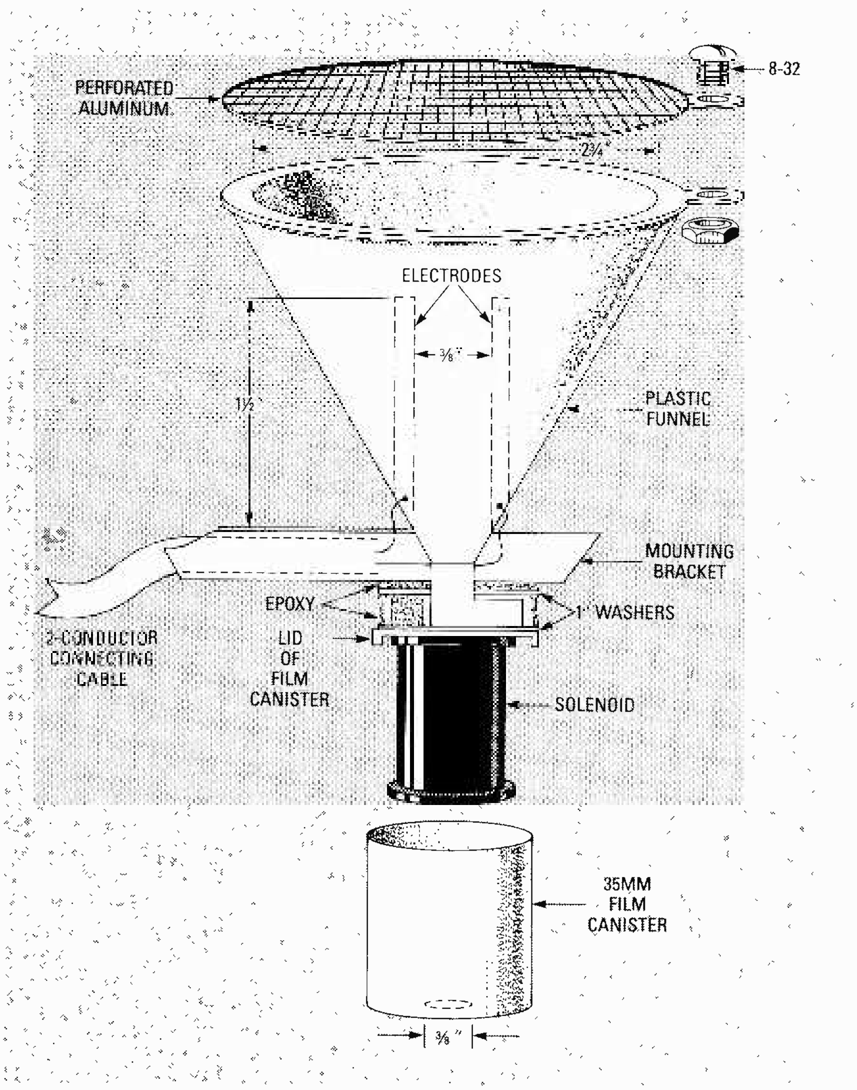



**FIG. 2—TWO ¼-INCH ELECTRODES, made of copper and lead, are mounted inside the funnel, spaced ⅜-inch apart. A solenoid valve attached to the mouth of the funnel is used to drain it as necessary.**

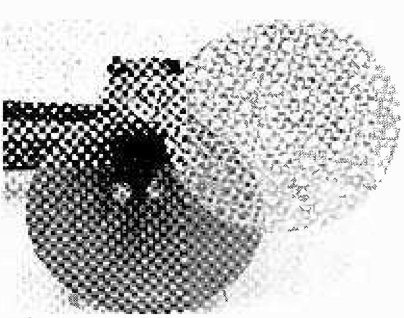


**FIG. 3—CLOSE-UP OF THE FUNNEL assembly: the screen keeps foreign matter, which could affect pH, out of the funnel.**

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 |

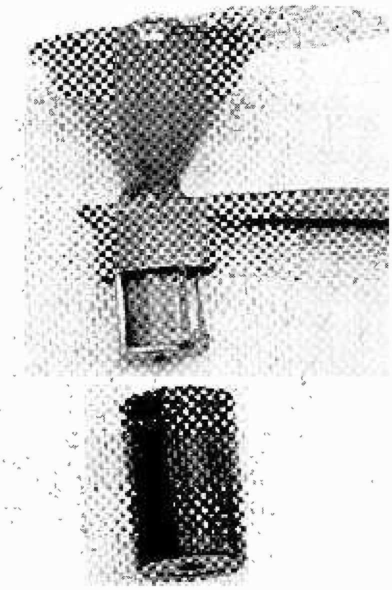


**FIG. 4—A 35mm FILM CANISTER provides a water-tight enclosure for the solenoid valve.**

## 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

*continued on page 153*

# 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:

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

For example, with a speed of 600 RPM on an eight cylinder engine, breaker-point frequency is 600 · (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 a 4-, 6-, or 8-cylinder engine, the input frequency must be multiplied by a value of 6, 4, or 3, respectively.

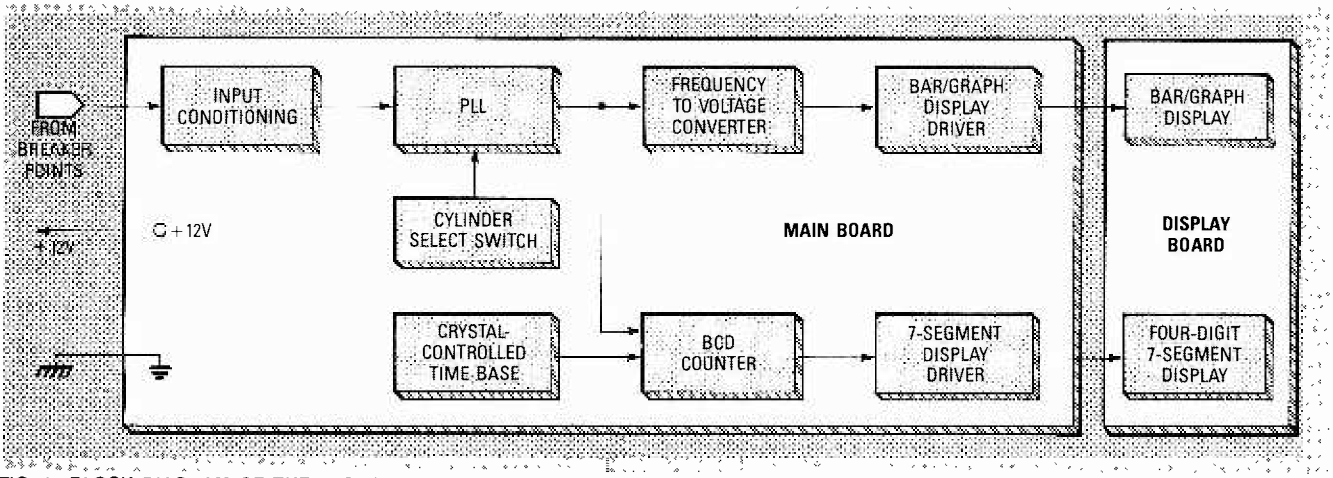



**FIG. 1—BLOCK DIAGRAM OF THE TACHOMETER: The PLL scales the breaker-points signal for display directly in RPM.**

## 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.

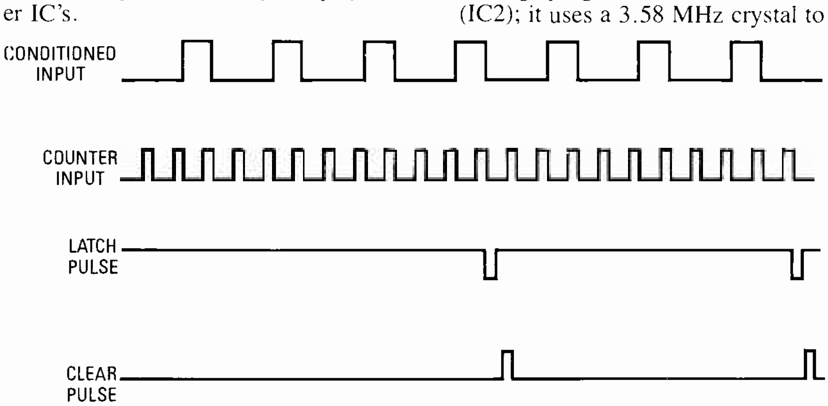



**FIG. 2—THE SIGNAL FROM THE POINTS** is multiplied by the PLL and counted until a latch pulse is received. The counter is then reset.

## 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.

## 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.**

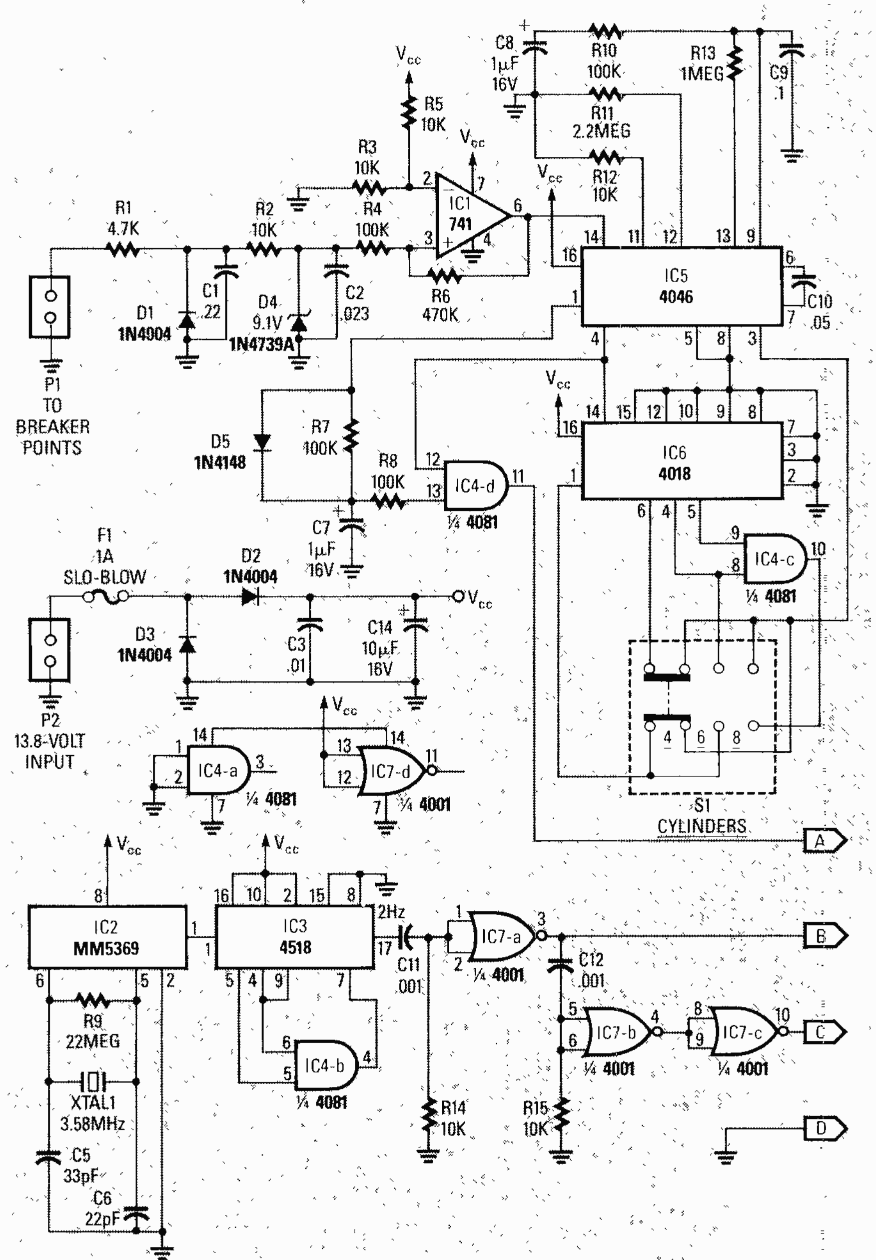



**FIG. 3—THE TIMEBASE, INPUT CONDITIONING, and PLL circuits are shown here. Op-amp IC1 functions as a comparator that squares up the input signal for processing by the PLL.**

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.

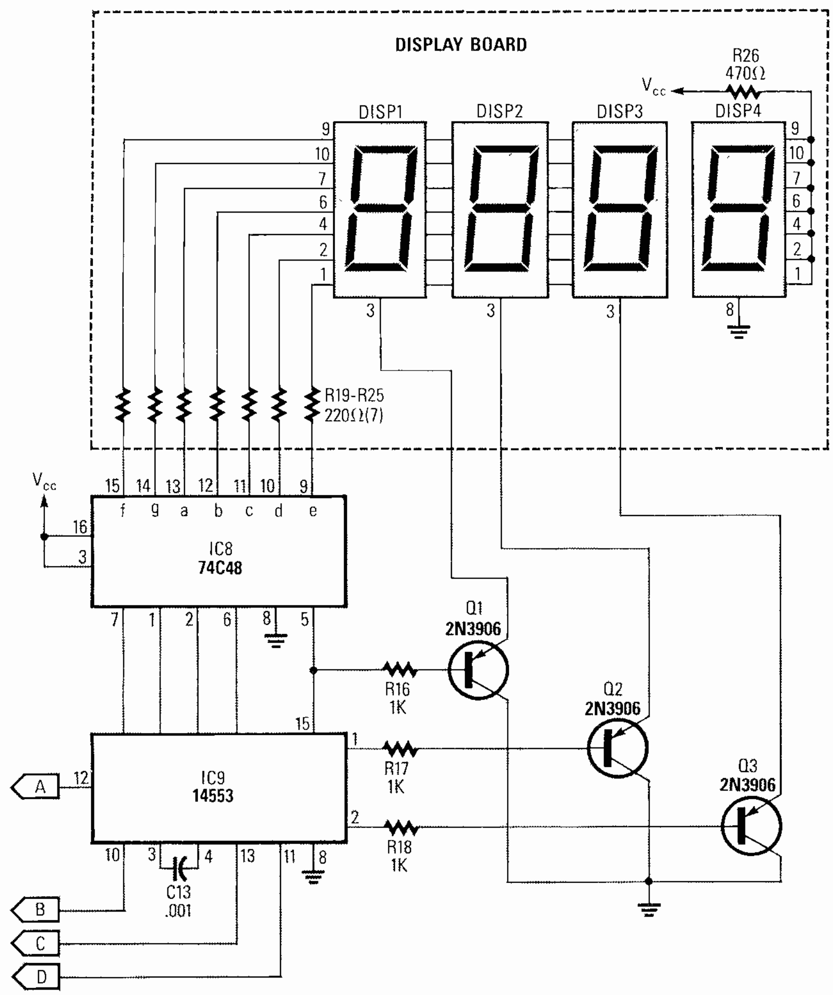



FIG. 4—THE TACHOMETER'S DIGITAL DISPLAY is a conventional decoder/driver circuit.

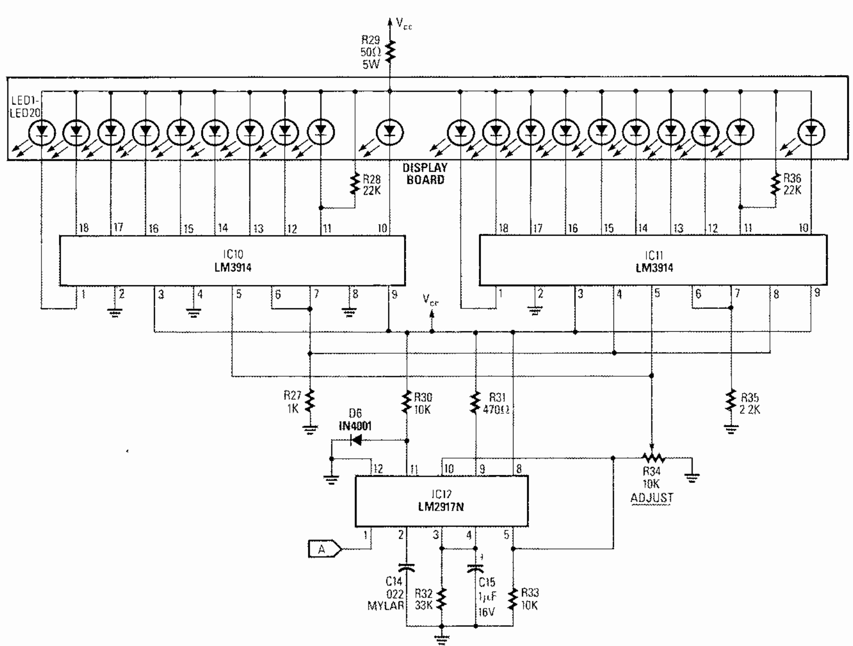



FIG. 5—THE TACHOMETER'S ANALOG DISPLAY is built around a frequency-to-voltage converter (IC12) that drives two bar/graph drivers (IC10 and IC11).

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

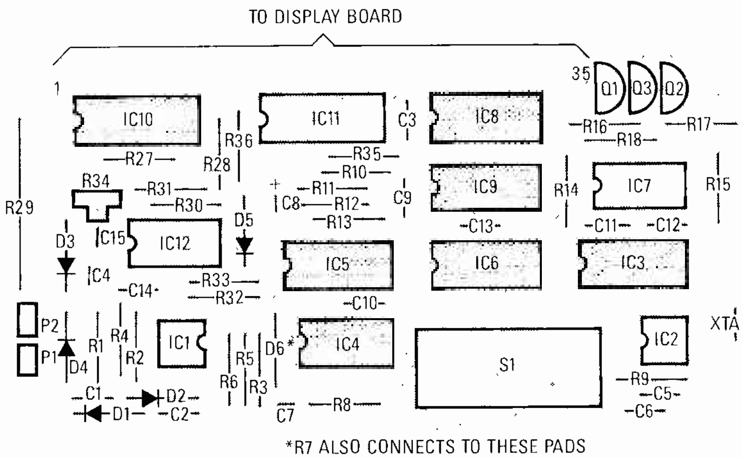



**FIG. 6—STUFF THE TACHOMETER'S MAIN BOARD as shown here. Use clipped resistor leads to make the connections to the display board.**

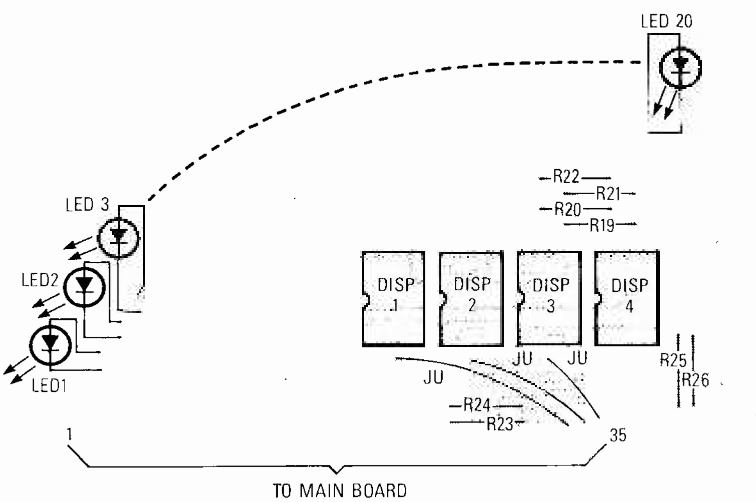



**FIG. 7—STUFF THE DISPLAY BOARD as shown here. The flat side of each LED should point toward the bottom of the board. The two boards are sandwiched together, and corresponding pads on the boards are connected with short pieces of stiff wire.**

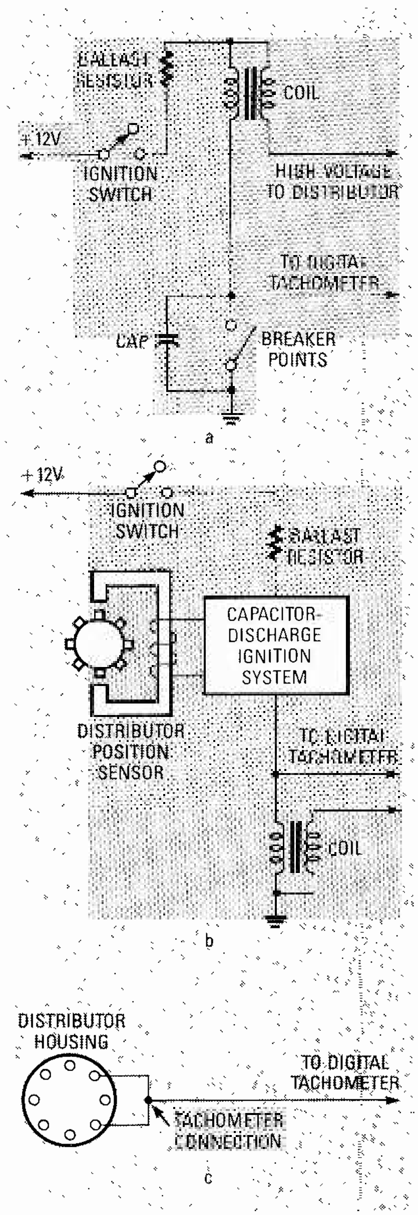



**FIG. 8—TO INTERFACE THE TACHOMETER, follow one of these circuits. A conventional (Kettering) ignition system is shown in (*a*), a capacitor-discharge system in (*b*), and a General Motors hook-up in (*c*).**

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.

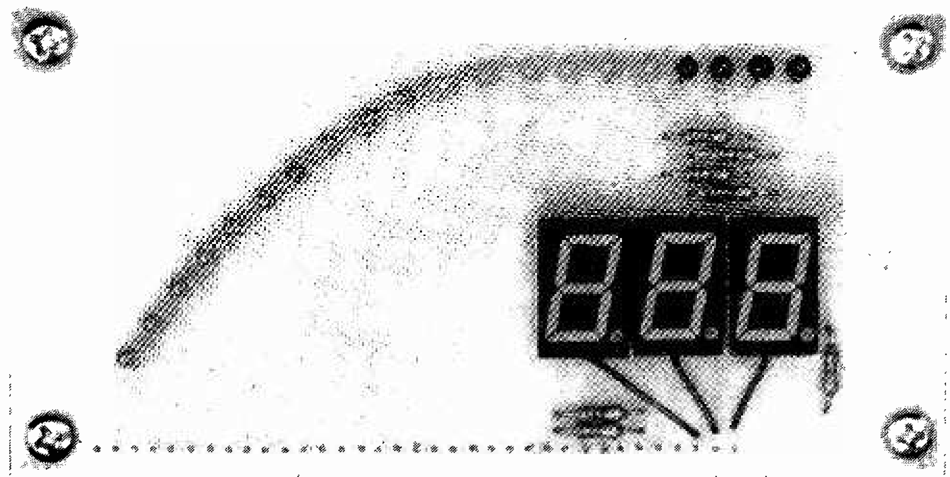
After building your enclosure, mount the PC-board assembly in it, and then install the enclosure in your vehicle. Be sure to install it and the connecting wires so they will not present a safety hazard. Now plug in the power and signal connectors. The installed digital tachometer is now ready to display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

## 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

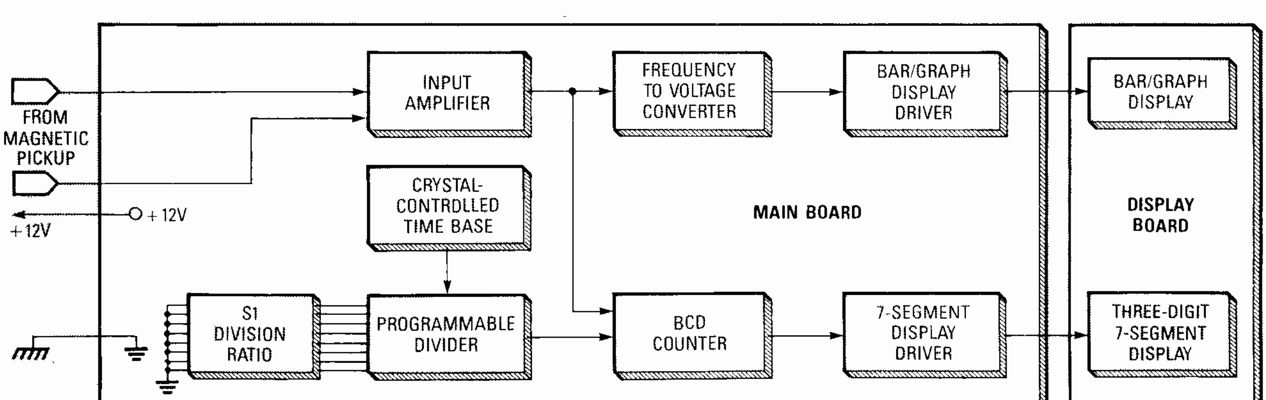



**FIG. 1—BLOCK DIAGRAM OF THE SPEEDOMETER: The input amplifier conditions the signal from the magnetic pickup for processing by the counting and display circuitry.**

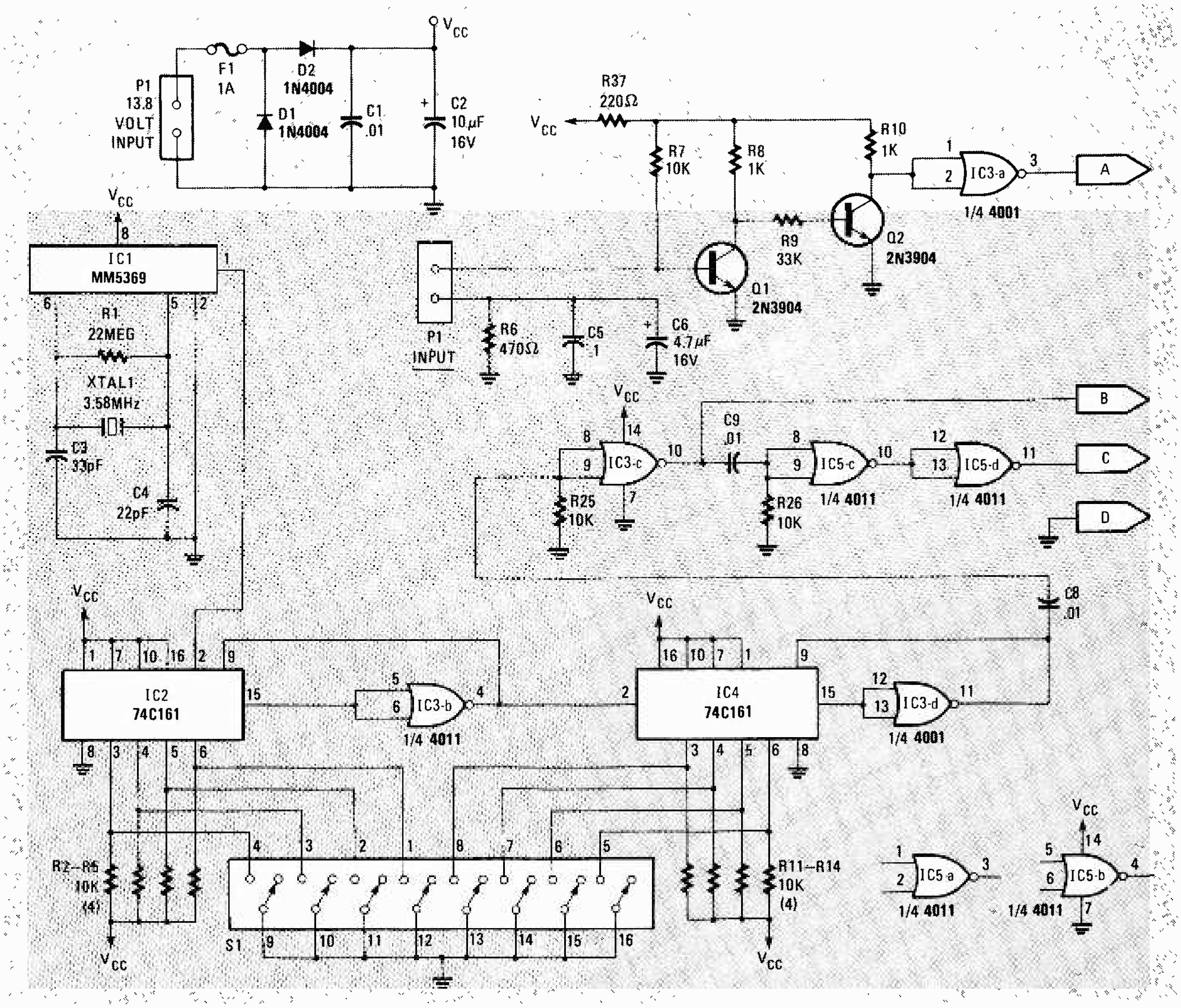



**FIG. 2—THE INPUT AMPLIFIER AND TIMEBASE circuitry are shown here. DIP switch S1 sets the divide ratio for calibrating the speedometer.**

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 color-burst 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.

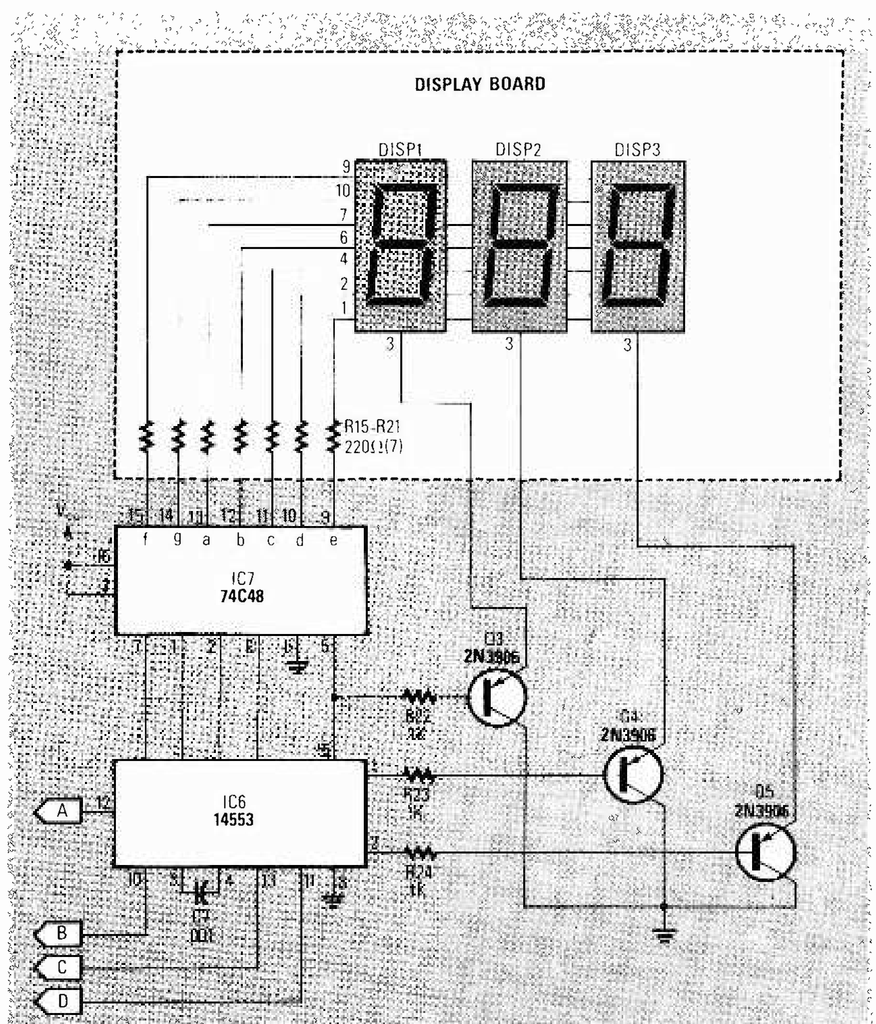



**FIG. 3—THE DIGITAL DISPLAY section of the circuit uses a 14553 (IC6) to count pulses, and a 74C48 (IC7) to display the count.**

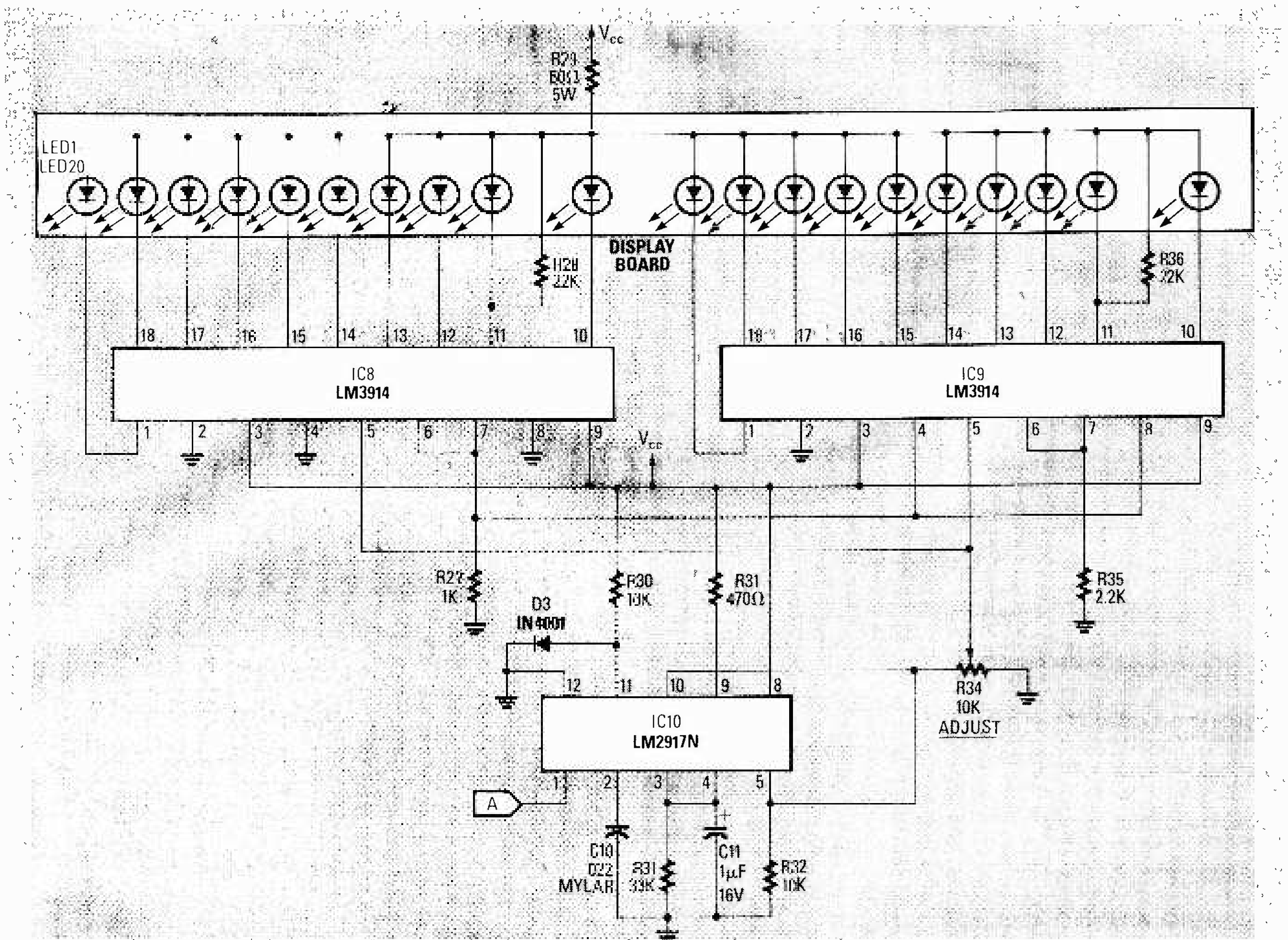



FIG. 4—THE ANALOG DISPLAY uses a frequency-to-voltage converter (IC10) to convert the counted pulses into displayable form.

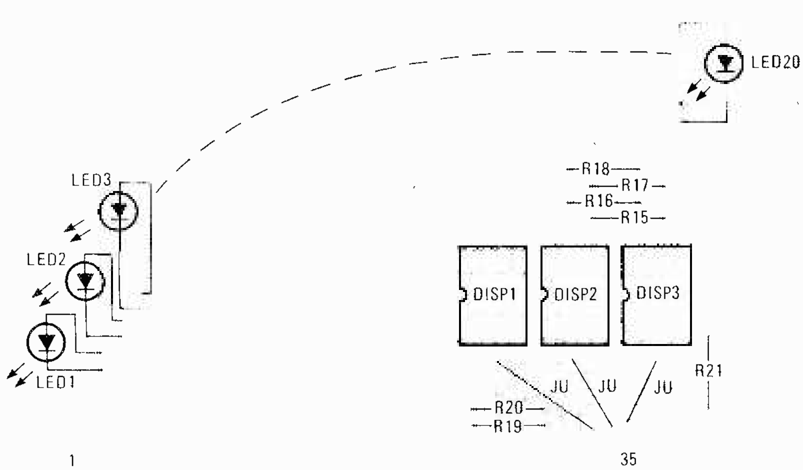



FIG. 5—STUFF THE DISPLAY BOARD as shown here. Don't forget to install the three jumpers. The flat sides of all LED's should face the row of holes at the bottom of the board.

## 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

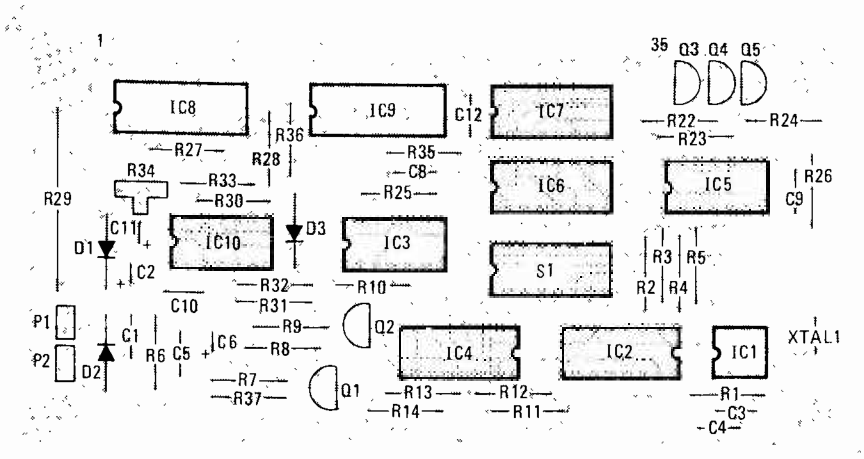



**FIG. 6—STUFF THE MAIN BOARD as shown here, and, after checking both boards for errors, connect them together with 35 pieces of short bare wire. The solder sides of the board should face each other.**

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 × 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: Ø1ØØ1ØØ1.

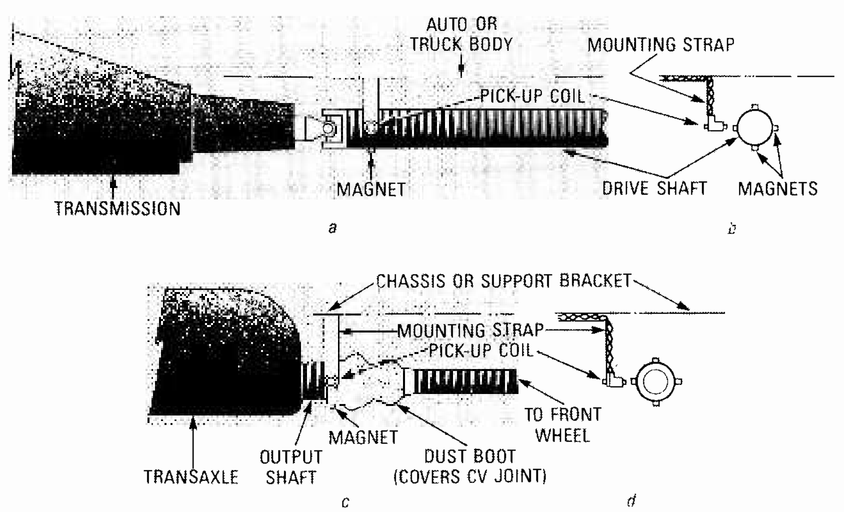



**FIG. 7—MAGNET AND PICKUP-COIL MOUNTING METHODS: For a car with a transmission and driveshaft, mount the magnets and pickup coil as shown in *a* and *b*, respectively. For a car with front-wheel drive, mount those parts as shown in *c* and *d*.**

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*

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AD

# Soldering:
# OLD TECHNIQUES & NEW TECHNOLOGY

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

**VAUGHN D. MARTIN**

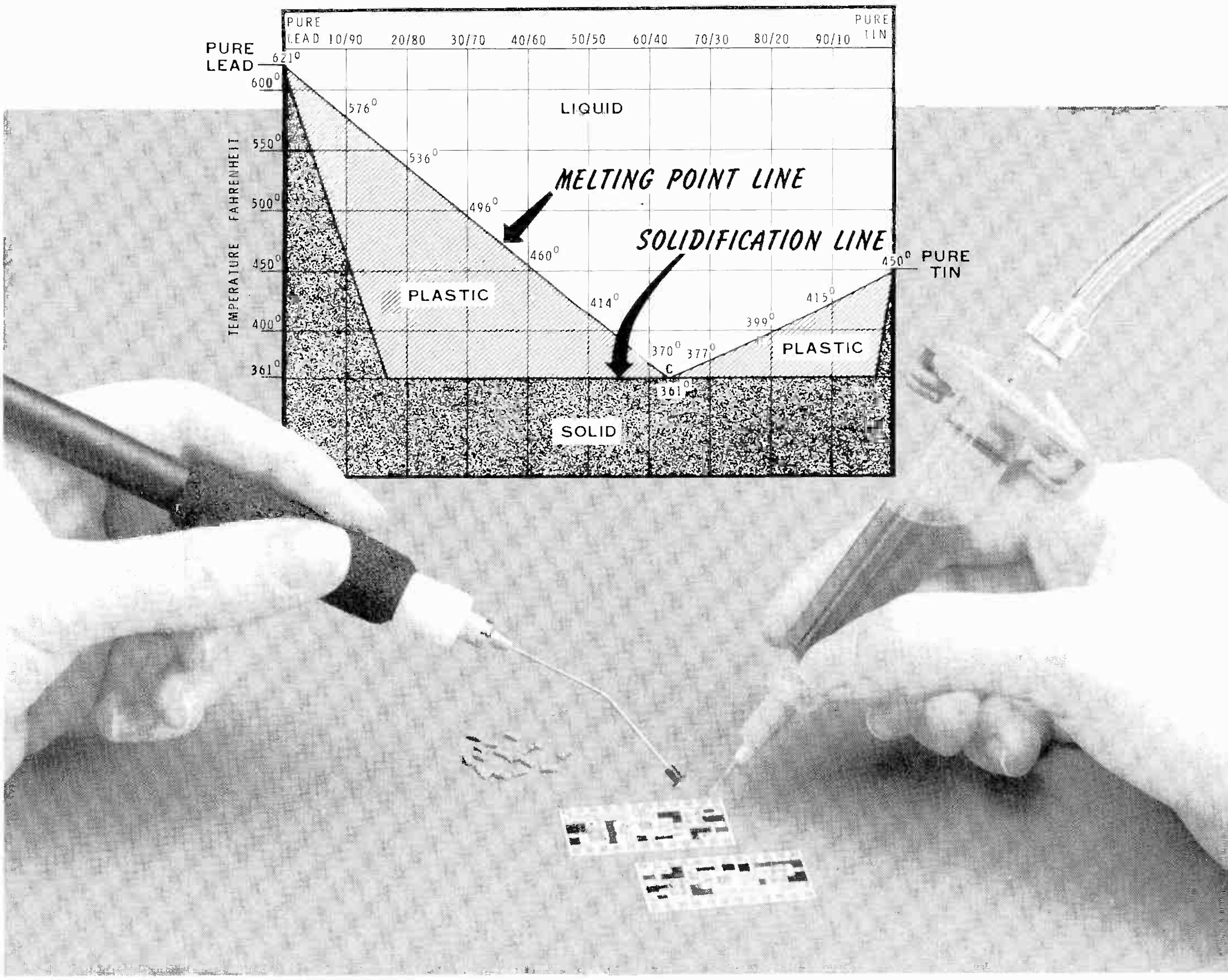
SOME CLAIM IT WAS GUGLIELMO MARCONI himself who said "Soldering is an art"—as he used a blowtorch and a five-pound bar of lead to assemble the transmitter that finally broadcast a radio signal across the *big pond*. While we no longer use a plumber's blowtorch for precision soldering, it often appears 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-



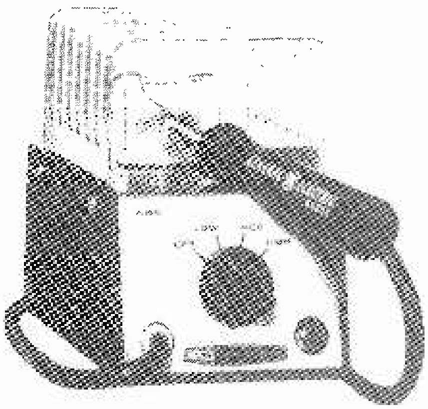


**FIG. 1—ADJUSTABLE-HEAT soldering irons allow you to adjust the tip-temperature adjustment. Other soldering irons have a single controlled tip-temperature.**

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

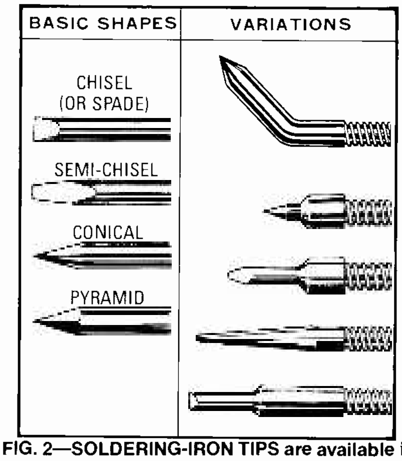



**FIG. 2—SOLDERING-IRON TIPS are available in a wide variety of sizes and shapes. They come as complete tips, interchangeable elements, or tips for interchangeable elements.**

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

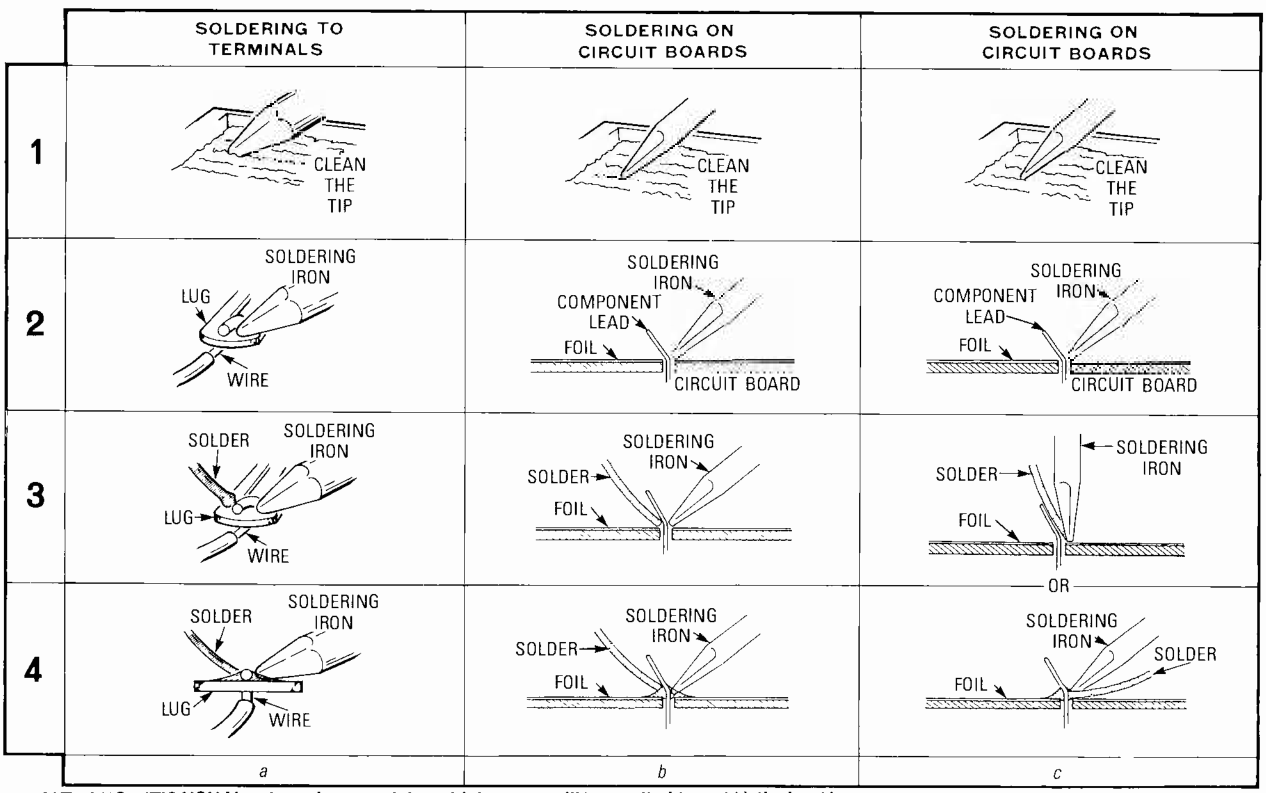



**FIG. 3—ALTHOUGH IT'S USUAL to heat the material to which solder will be applied (*a* and *b*), the heat is applied to the solder (*c*) when soldering hairline printed-circuit traces.**

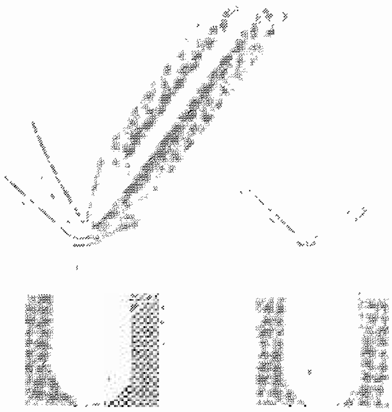


**FIG. 4—A PROPERLY-SOLDERED terminal connection looks like this.**

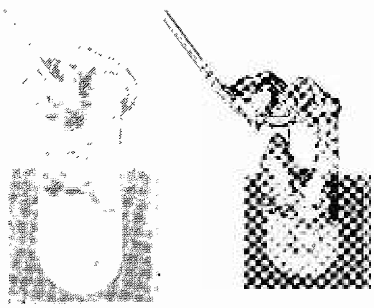


**FIG. 5—A COLD SOLDER JOINT may resemble *a* or *b*. One is as bad as the other.**

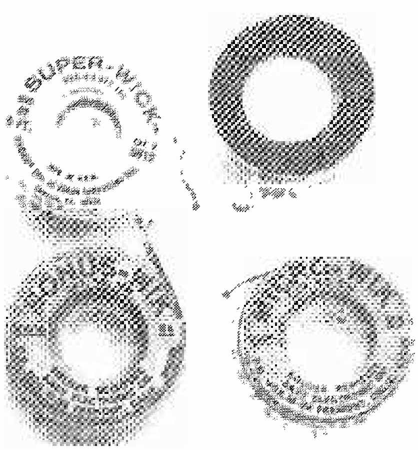


**FIG. 6—SOLDER-REMOVAL BRAID is available in several widths to accommodate everything from hairline printed-circuit traces to oldfashioned terminal lugs.**

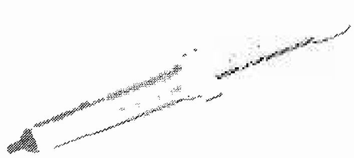


**FIG. 7—A SOLDER-SUCKER removes solder from a one-surface component-mounting hole or a plated-through connection.**

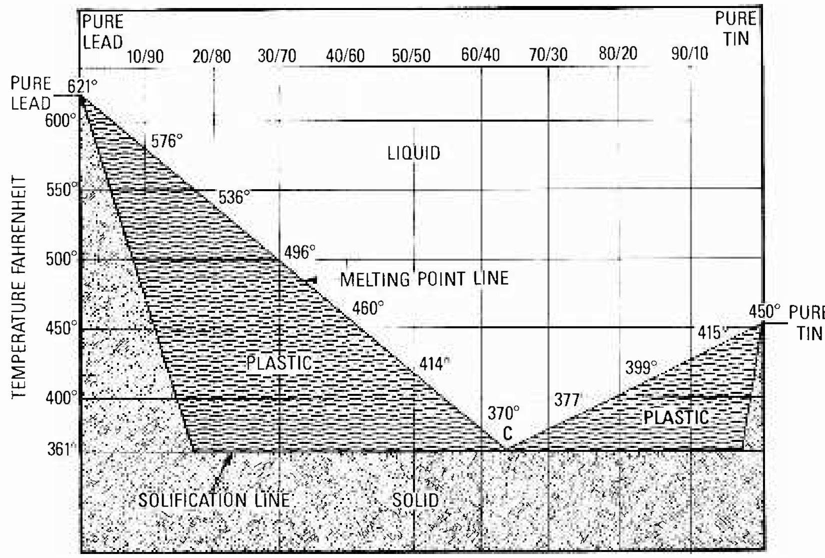



**FIG. 8—A SOLDER'S MELTING POINT is determined by its composition. Eutectic solder goes from solid to liquid without passing through a plastic state.**

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.

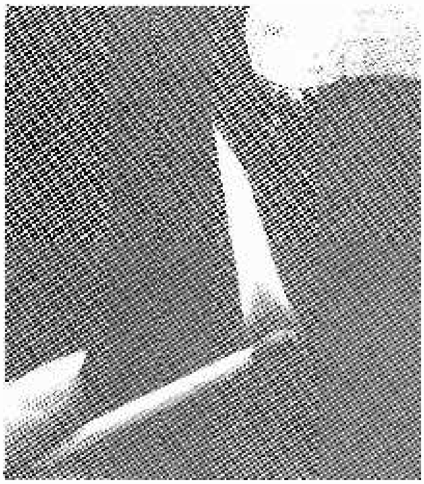


FIG. 9—THE HEAT FROM A MATCH is enough to melt a bar of indium fusible-alloy solder.

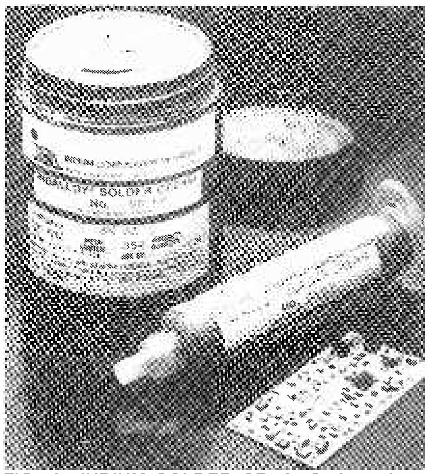


FIG 10—INDIUM SOLDER CREAMS, featuring oxide-free spherical powders, are available in various alloys that are specifically packaged for dispensing, screening, and stenciling.

## 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.

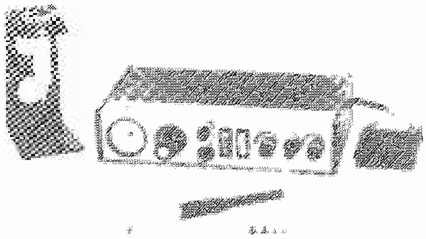


FIG. 11—A COMBINED CREAM DISPENSER and vacuum-operated component-holding device simplifies the positioning and soldering of SMD and other micro-miniature components.

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.

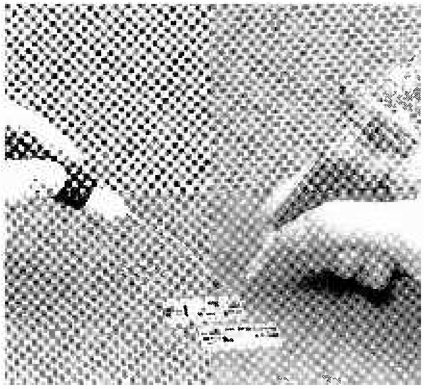


FIG. 12—IT TAKES TWO HANDS to position an SMD device on a PC-board: one for the cream dispenser, the other for the vacuum holder.

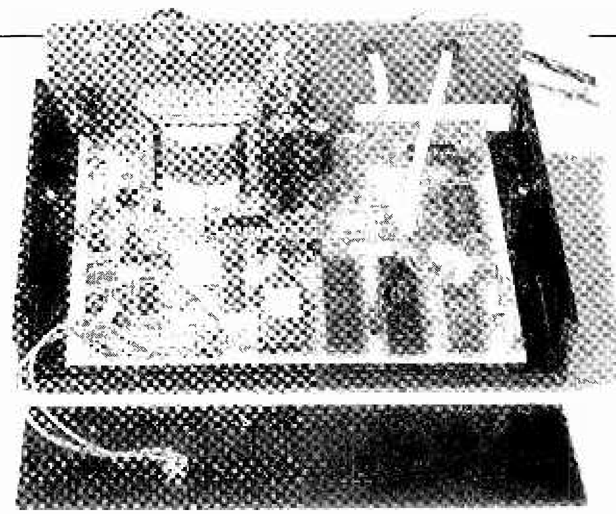
Before reflowing solder cream, be sure to cure it to avoid spattering and solderballing. Substrate type, flux type, the metal content of your solder, and the amount of solder cream deposited on the board will determine the appropriate curing parameters.

## 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**

BUILD THIS

# 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

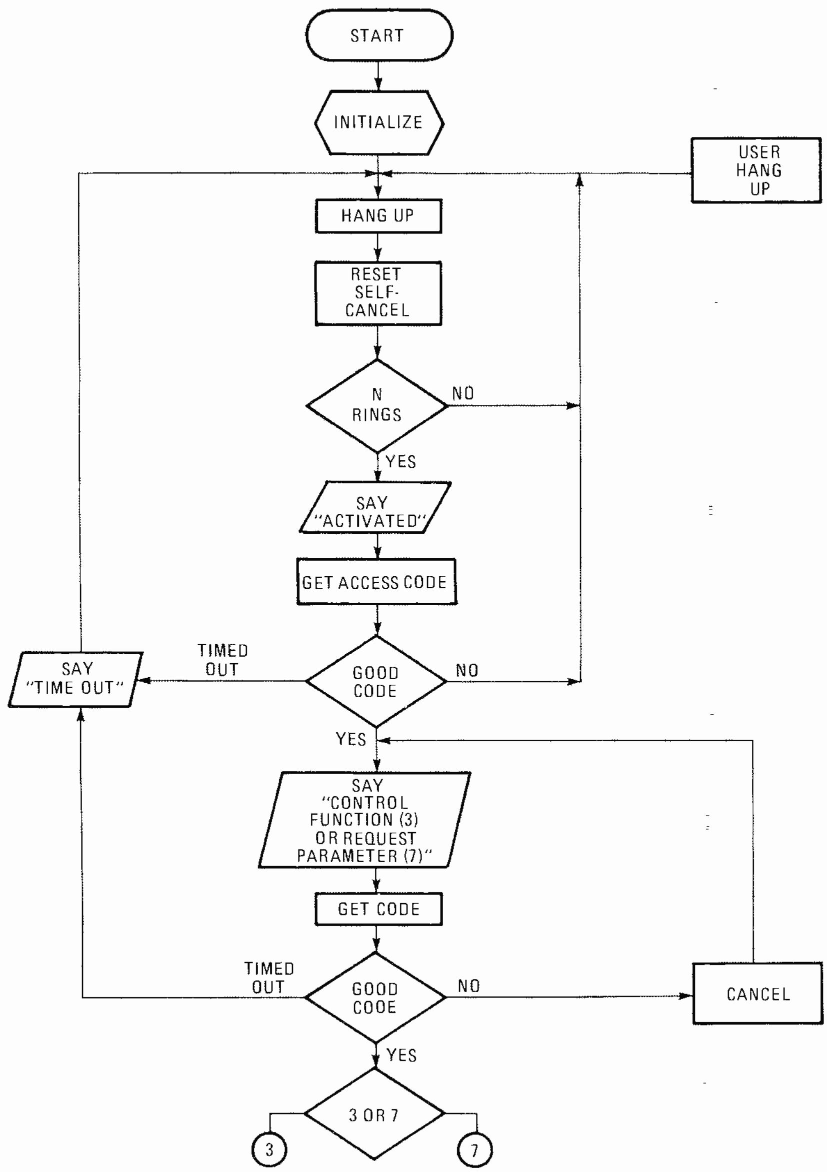



FIG. 1—FLOWCHART OF THE CONTROLLER'S MAIN LOOP: After initialization, the program gets a user-entered code and then transmits data to the user or turns the remote circuits on or off.

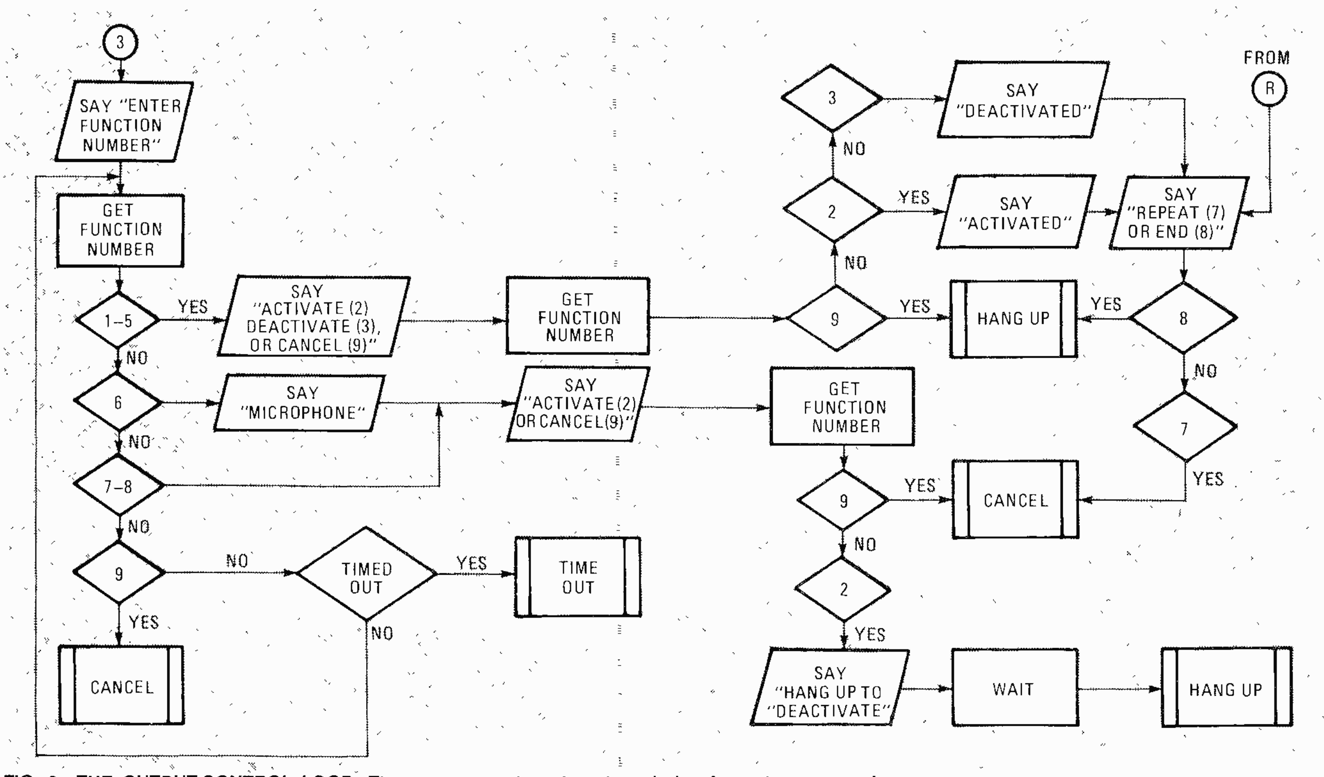



**FIG. 2—THE OUTPUT-CONTROL LOOP: The program gets a function choice from the user and performs the desired action. Code 9 initiates the Cancel function.**

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.

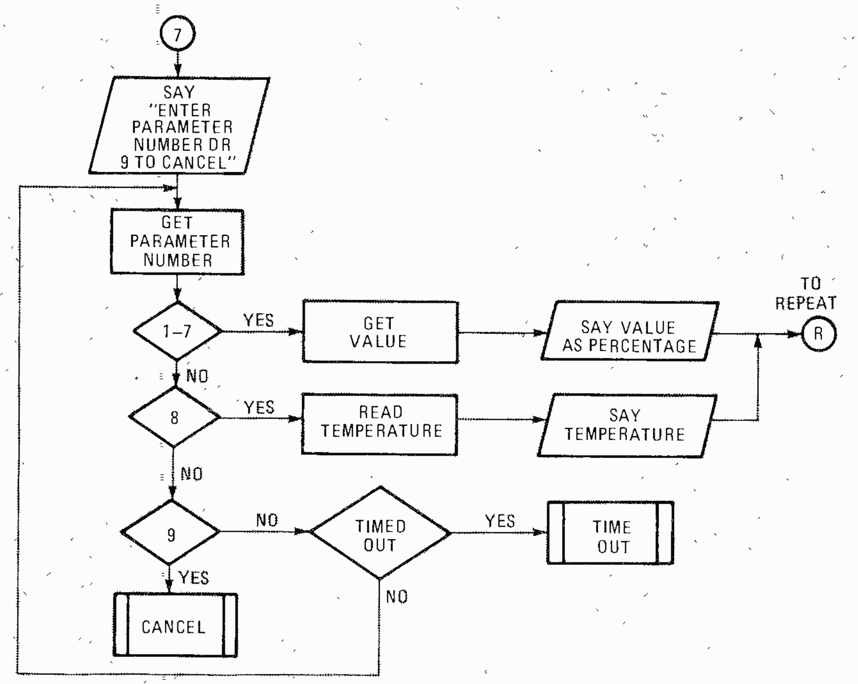



**FIG. 3—THE INPUT-CONTROL LOOP: A choice of Code 1–Code 7 causes the program to report the corresponding analog value as a percentage of five volts. Local temperature will be reported when Code 8 is chosen. Code 9 cancels operation.**

## 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.**

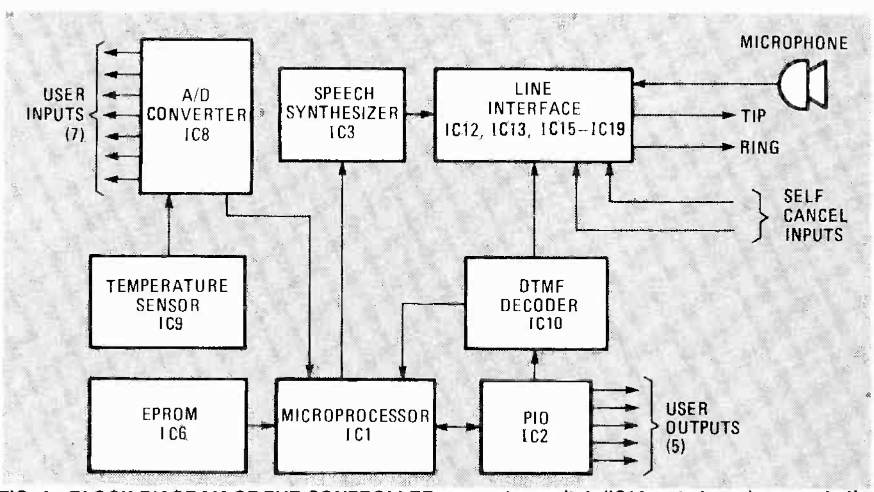



**FIG. 4—BLOCK DIAGRAM OF THE CONTROLLER: an analog switch (IC14, not shown) connects the internal microphone, the speech synthesizer, or one of the self-cancel inputs to the phone line.**

(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**

# PHONLINK

## 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.

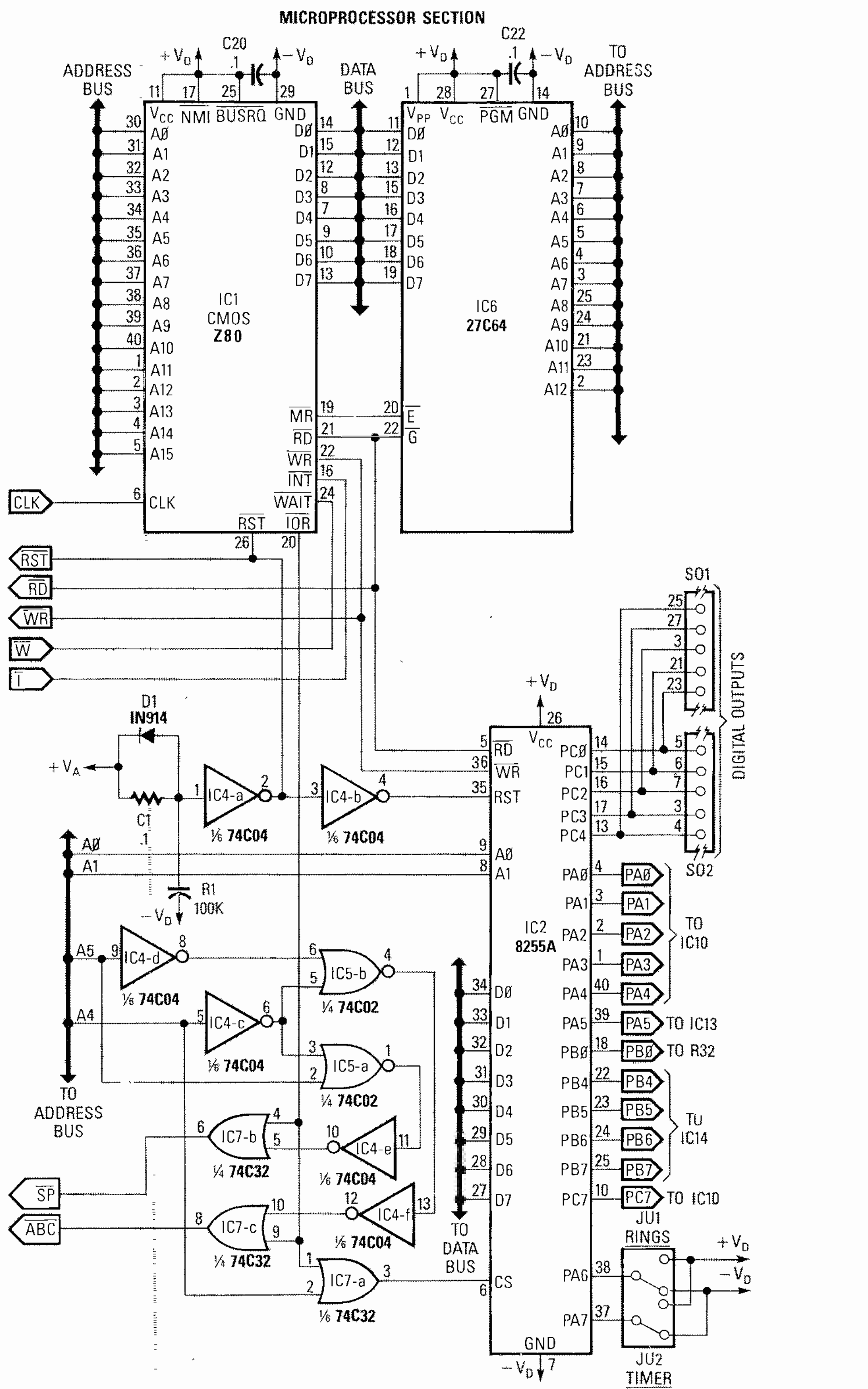



FIG. 5—THE CONTROLLER IS BASED ON A CMOS Z80; the design uses no RAM external to the Z80!

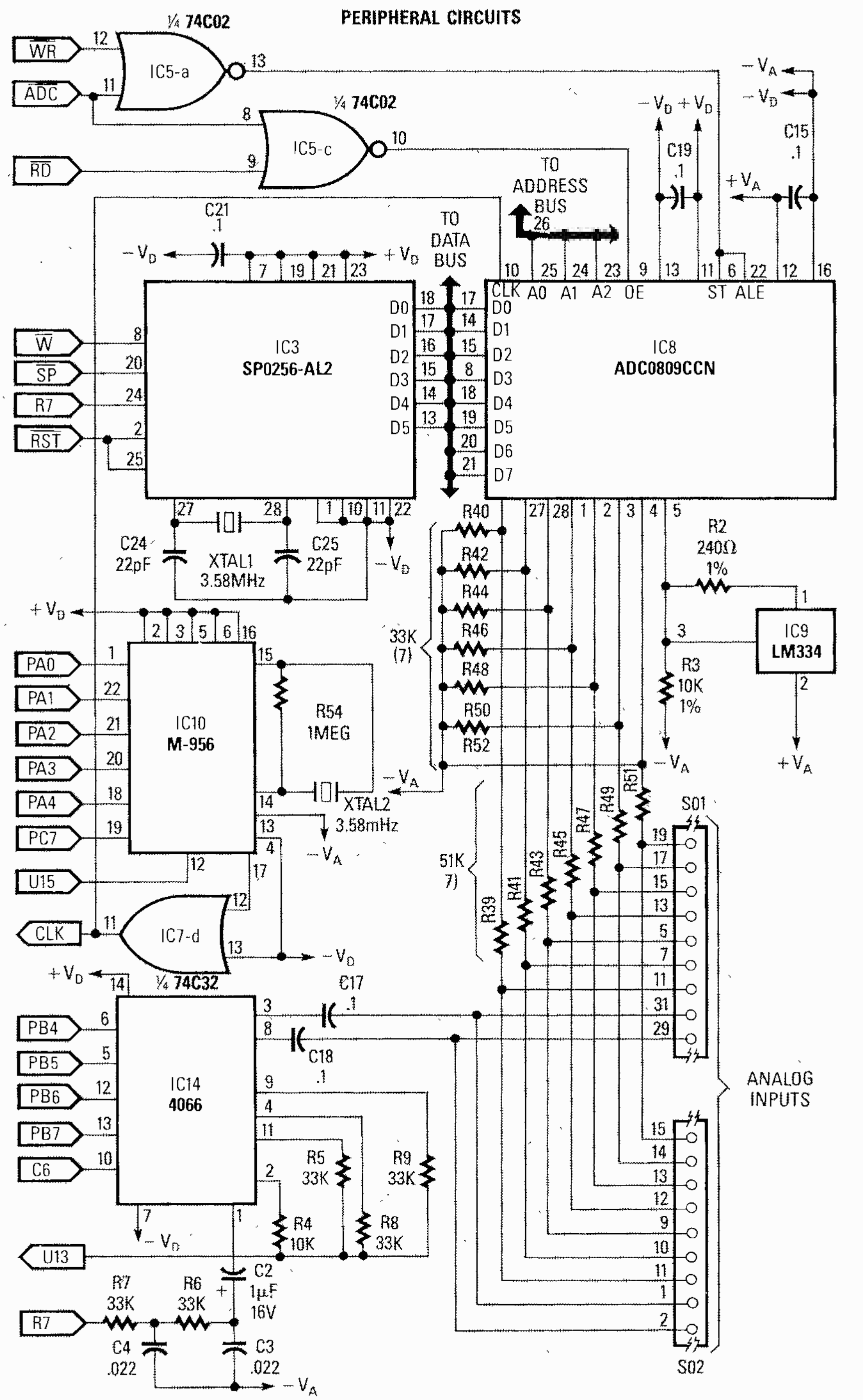



FIG. 6—THE ANALOG-INTERFACE CIRCUITS, including a speech synthesizer (IC3), an A/D converter (IC8), and a DTMF decoder (IC10) are shown here.

### 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.

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-

### 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.

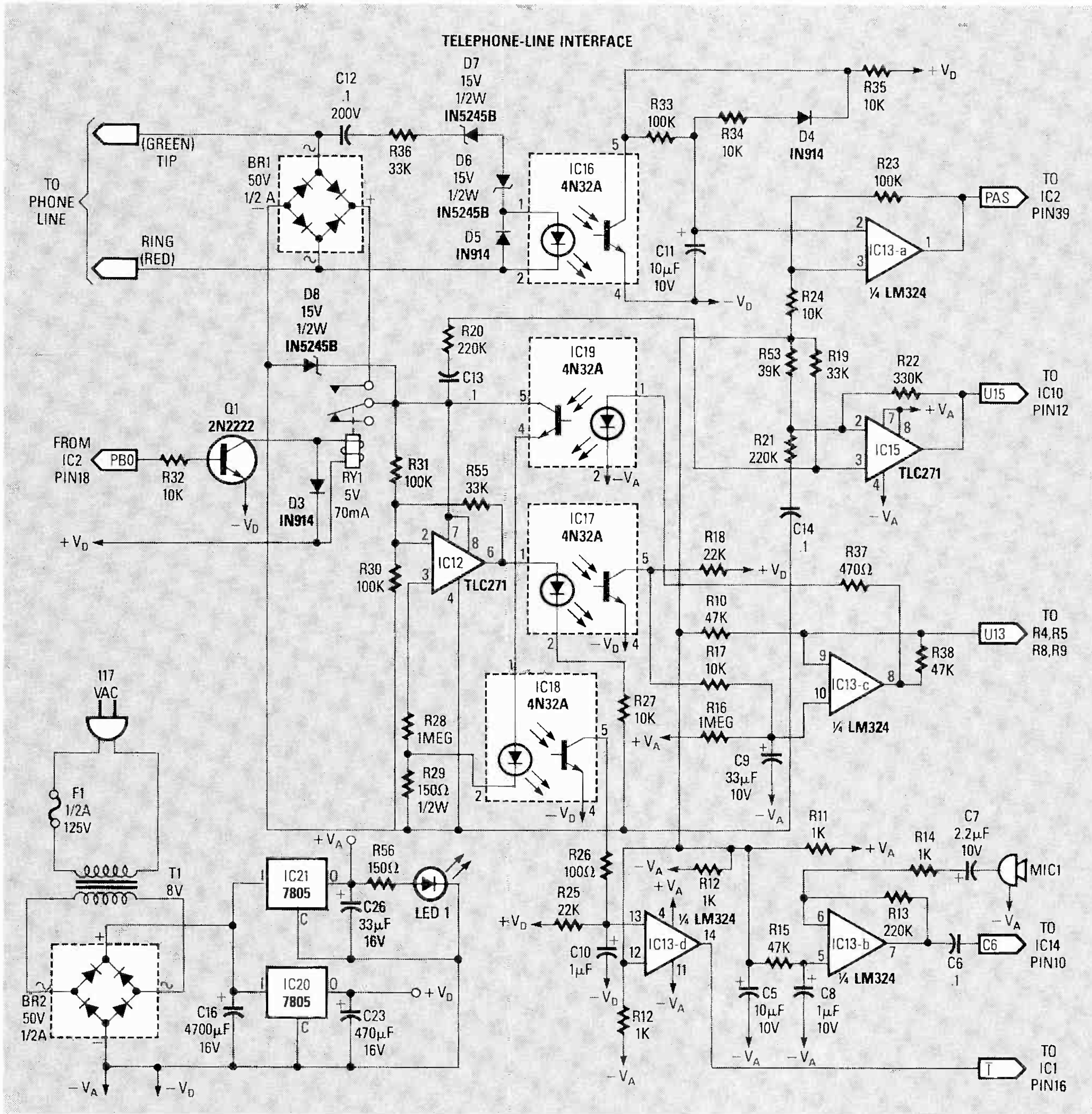



**FIG. 7—THE POWER SUPPLY AND TELEPHONE-LINE INTERFACE are shown here. There are separate supplies for the analog and digital circuits.**

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
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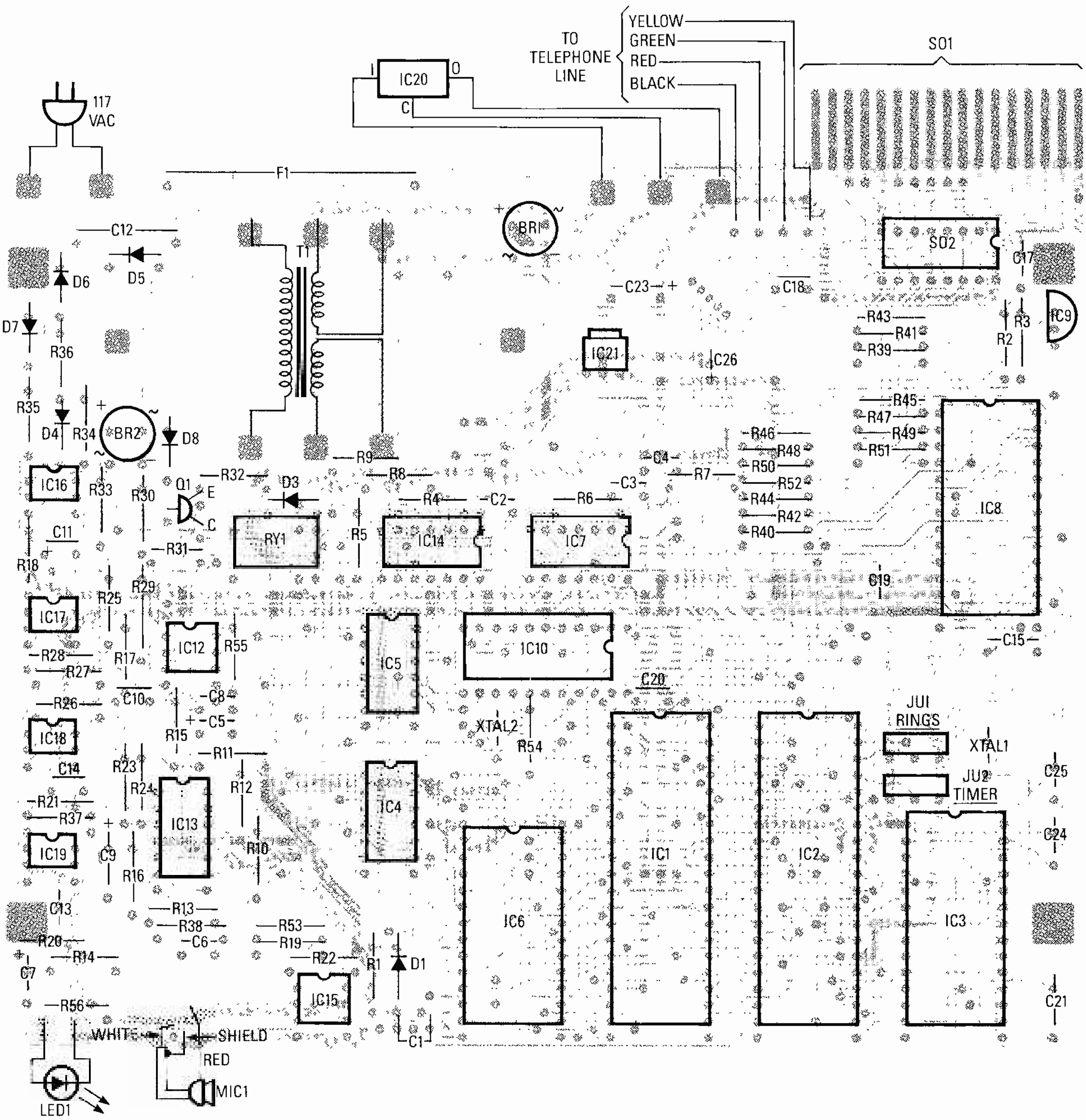


**FIG. 8—STUFF THE PC BOARD as shown here. Be sure to mount all electrolytic capacitors, semiconductors, and the power transformer in the correct orientation.**

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%
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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

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IC7—74C32, quad CMOS OR gate
IC8—ADC0809CCN, A/D converter
IC9—LM234Z, precision current reference
IC10—M-956, DTMF decoder (Teltone)
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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
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**Other components**
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XTAL1, XTAL2—3.58 MHz

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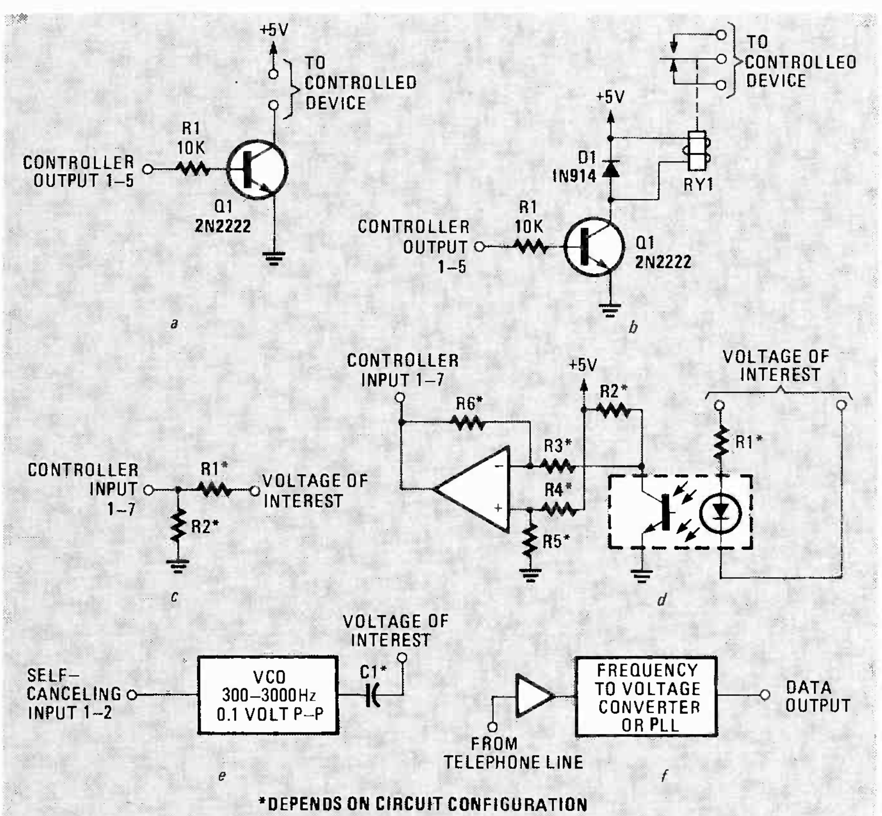


**FIG. 9—A VARIETY OF INPUT/OUTPUT CIRCUITS:** at *a*, an unisolated digital output; at *b*, an isolated digital output; at *c*, an unisolated analog input, at *d*, an isolated analog input. Shown in *e* and *f* are one means of transmitting digital data over the phone lines.

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 *High-Definition 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.

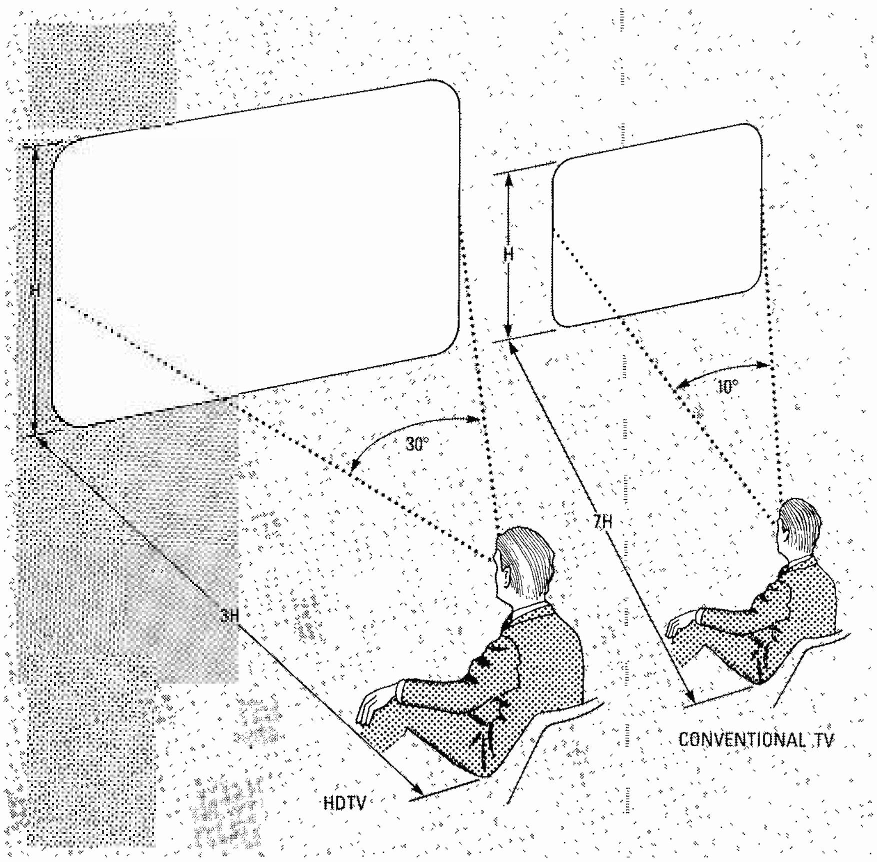


**FIG. 1—THE GEOMETRY OF TV VIEWING. With an HDTV image, a viewer can sit closer to the screen to attain a greater viewing angle, thereby improving the sense of realism. Because the signal has approximately twice as many scan lines as a conventional system, those lines are not visible at distances as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

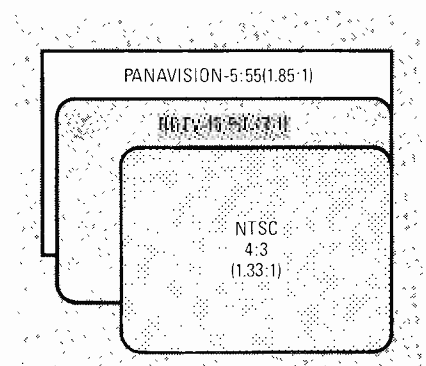


**FIG. 2—ASPECT RATIOS. Here, the aspect ratios of conventional-TV, HDTV, and Panavision motion-picture viewing screens are compared.**

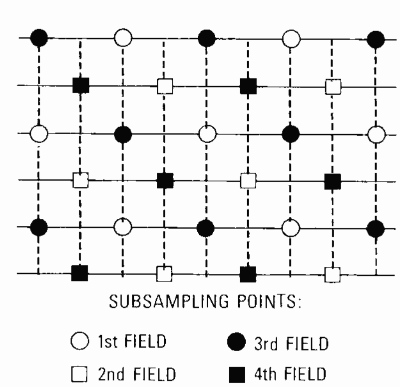


**FIG. 3—THE SAMPLING PATTERN used by NHK's MUSE system. Picture information is transmitted over four fields rather than the two of conventional TV.**

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

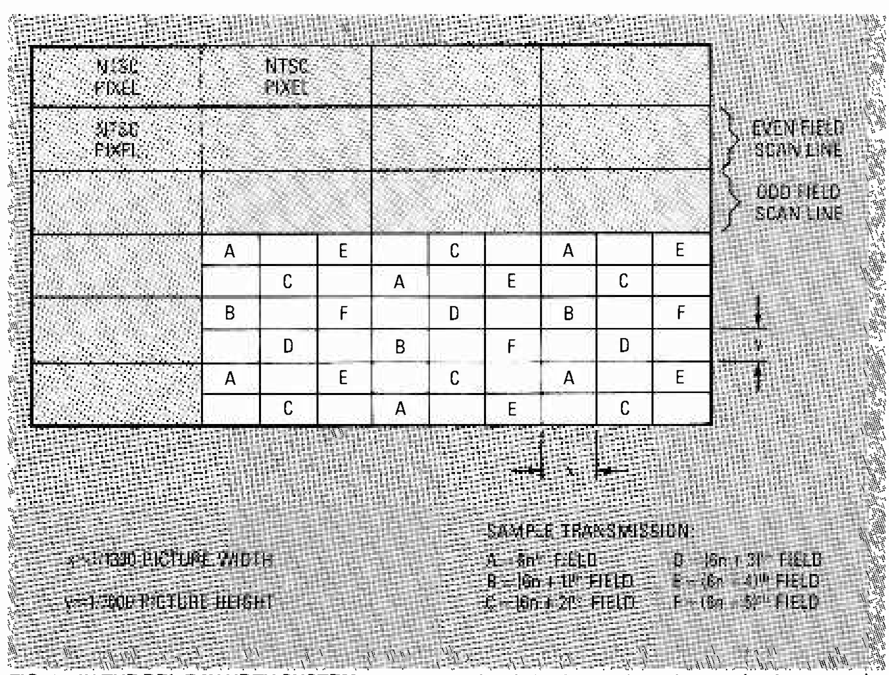


**FIG. 4—IN THE DEL RAY HDTV SYSTEM, each NTSC pixel is broken up into six samples for transmission. Picture information is relayed in a sequence of six fields.**

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 prerecorded 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*

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

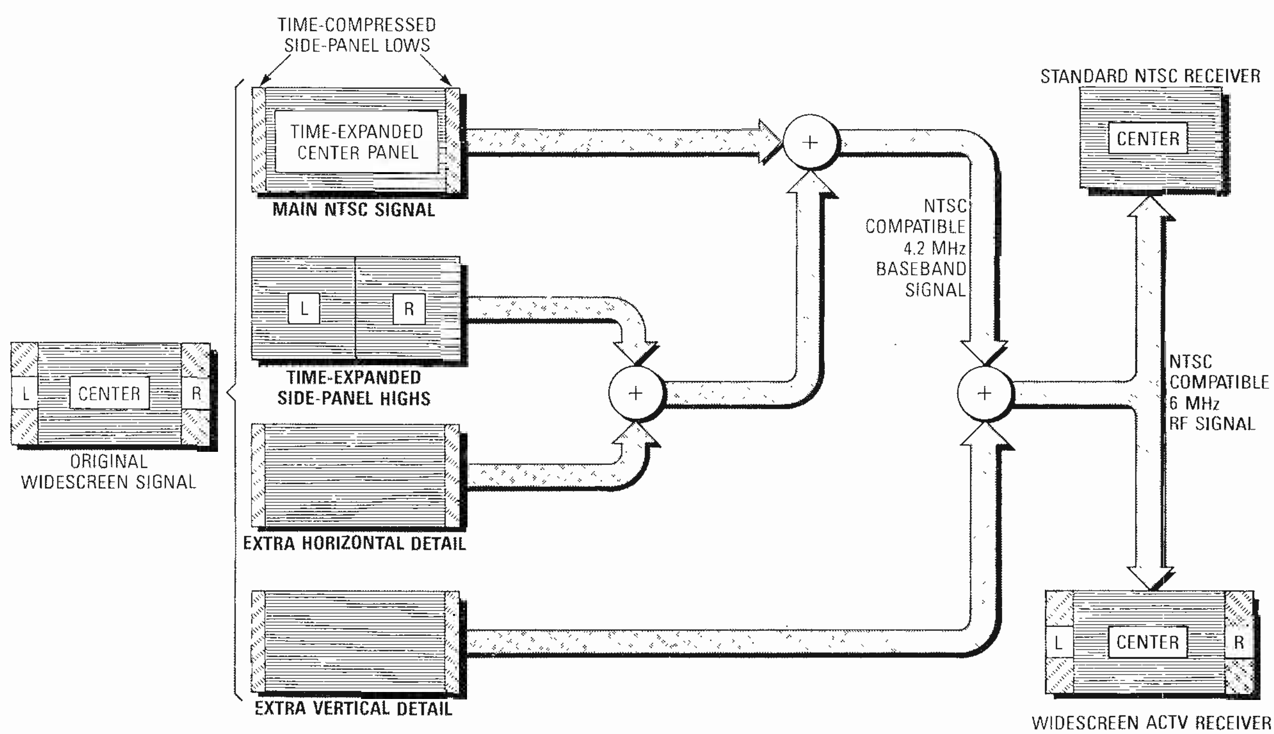


FIG. 1—THE ACTV SIGNAL starts with a widescreen picture that is separated into four components. Those components are digitally processed and combined using quadrature modulation techniques into an NTSC-compatible 6-MHz RF signal.

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**

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### 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.

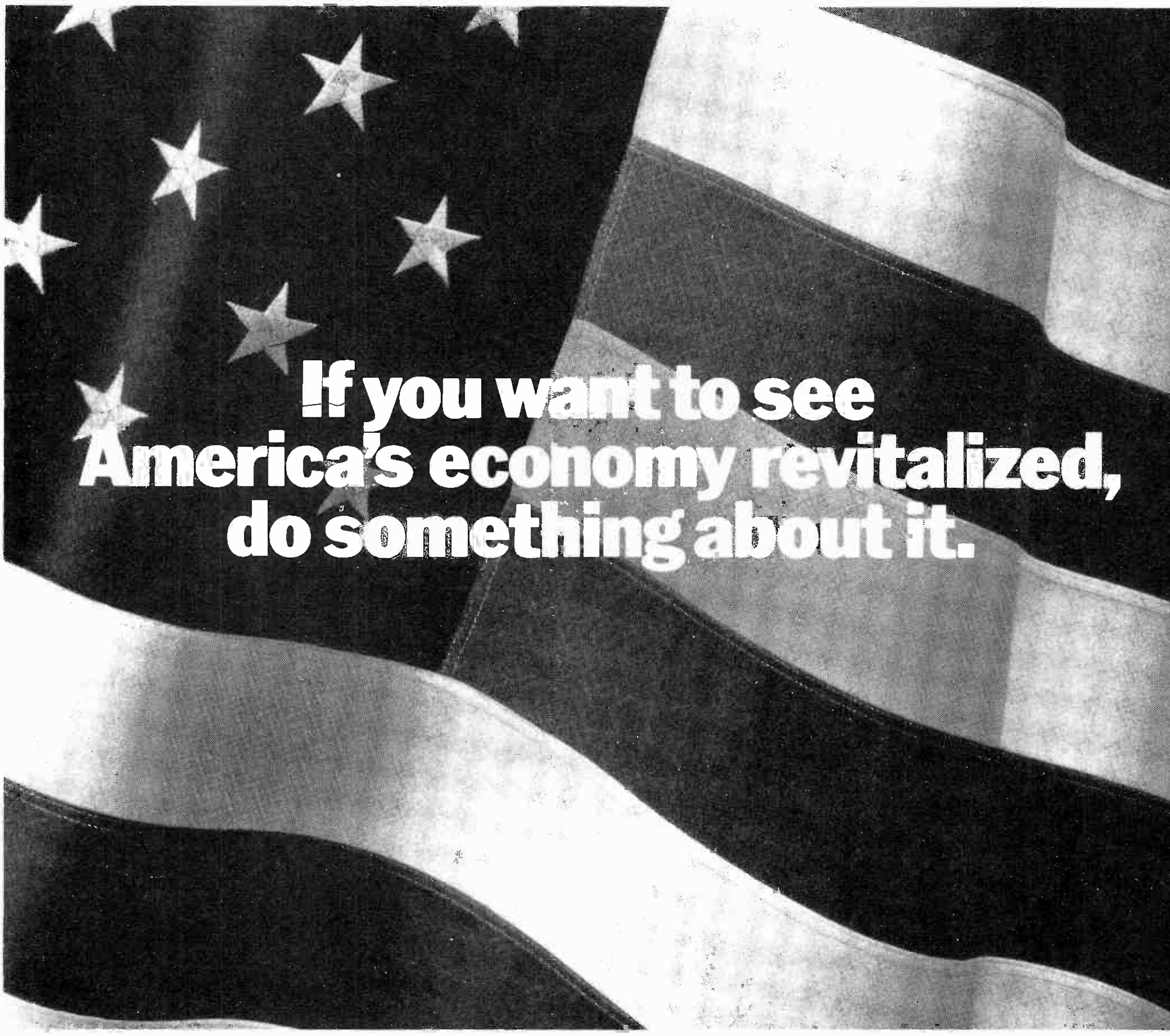
**Sacramento Historical Radio Society**—5724 Gibbons Dr., Sacramento, CA 95608.

**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**

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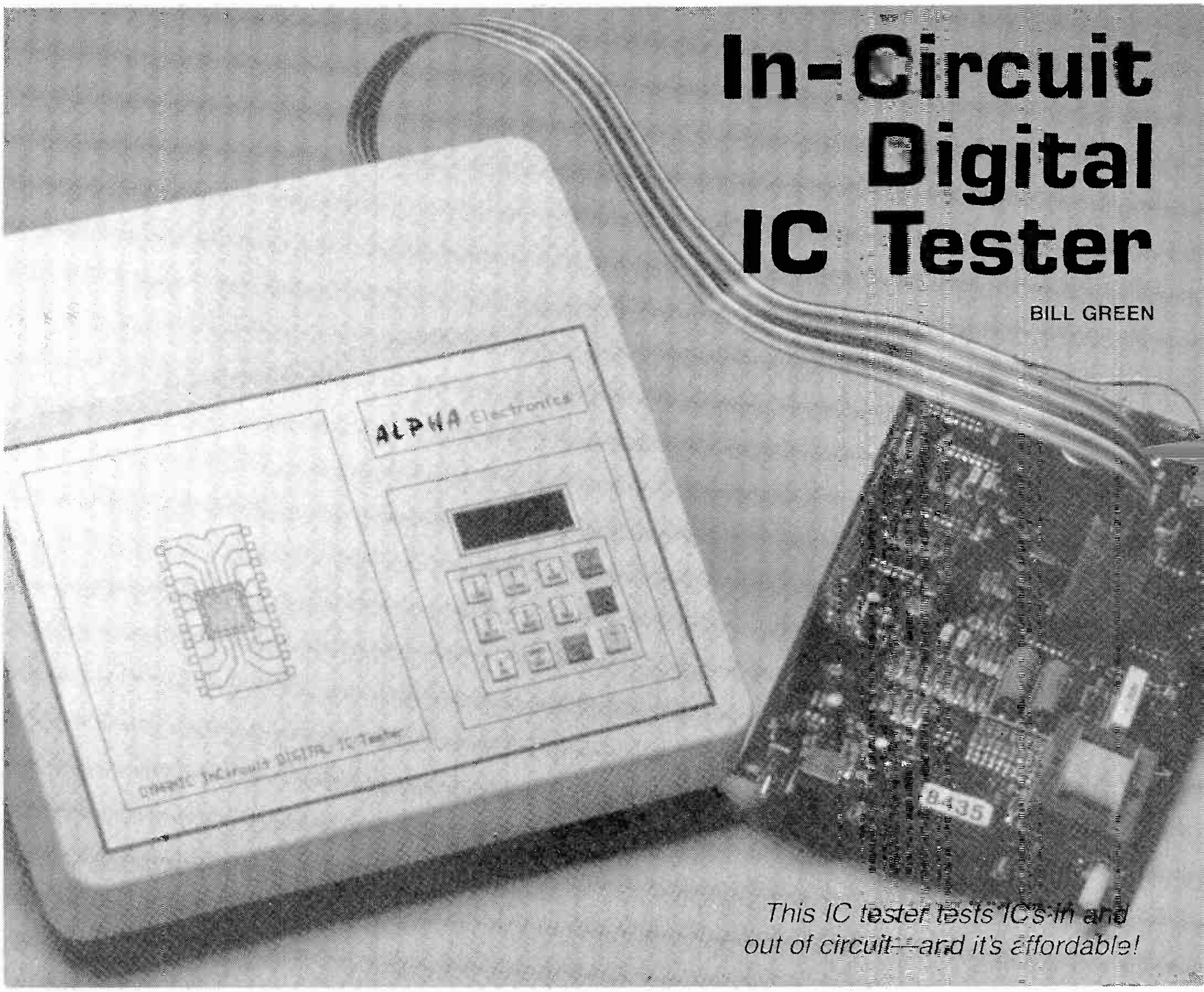
# In-Circuit Digital IC Tester

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 push-buttons 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 key-switches 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 (ˆ),

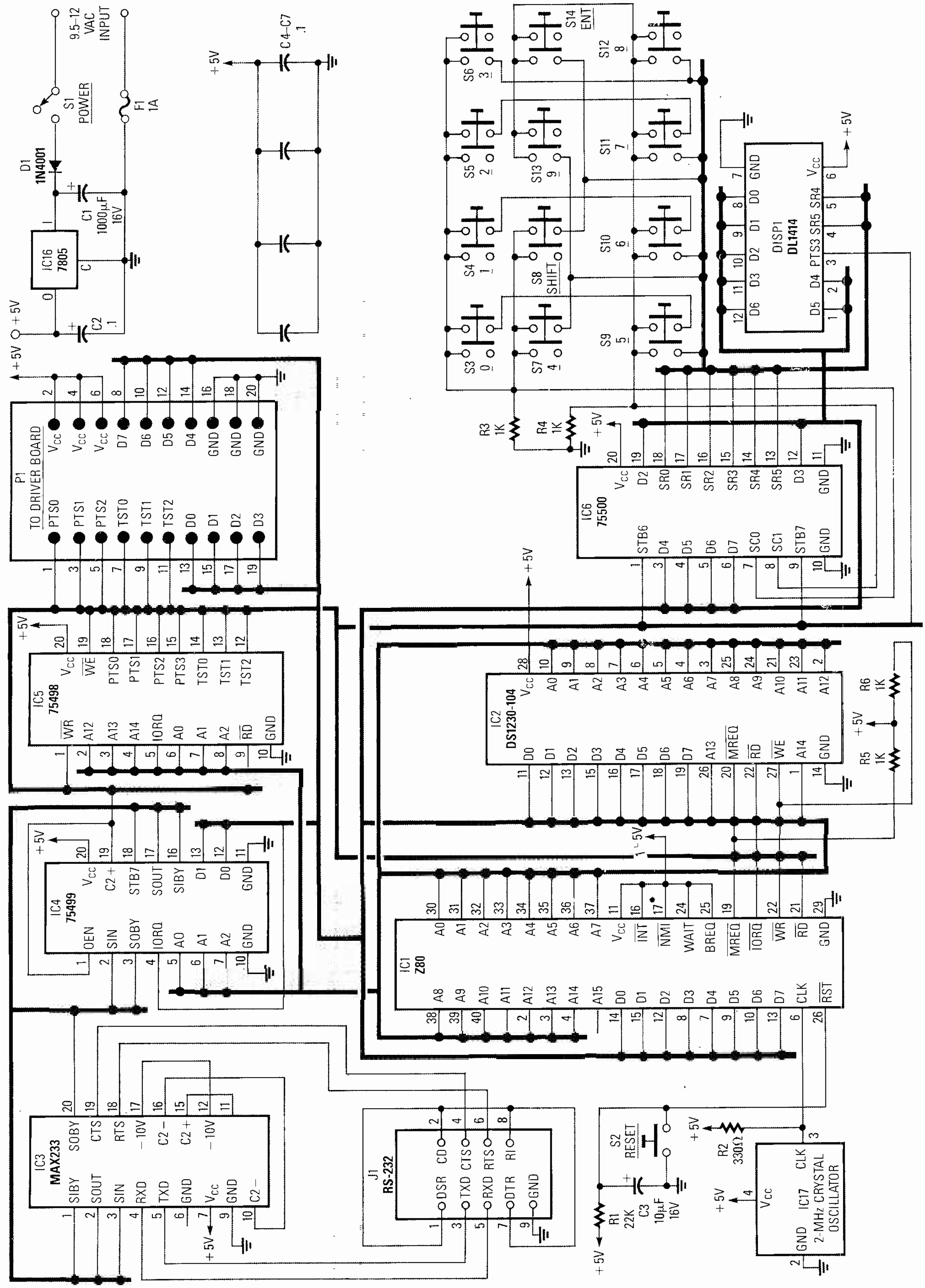



FIG. 1—THE IC TESTER'S MAIN BOARD is built around a Z80 microprocessor running at 2 MHz.

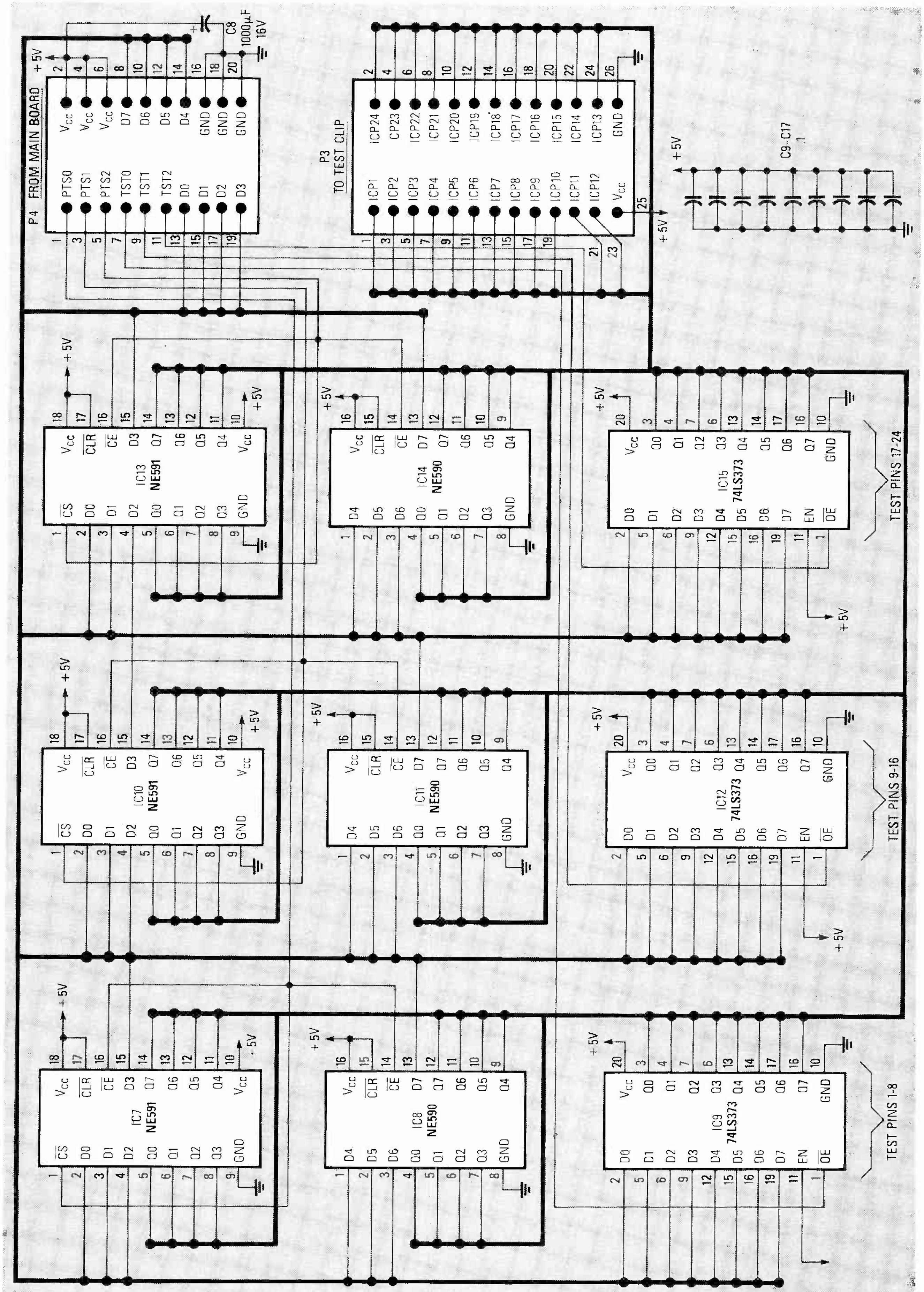



FIG. 2—THE IC TESTER'S DRIVER BOARD provides separate inputs, sourcing outputs, and sinking outputs for each of 24 test pins.

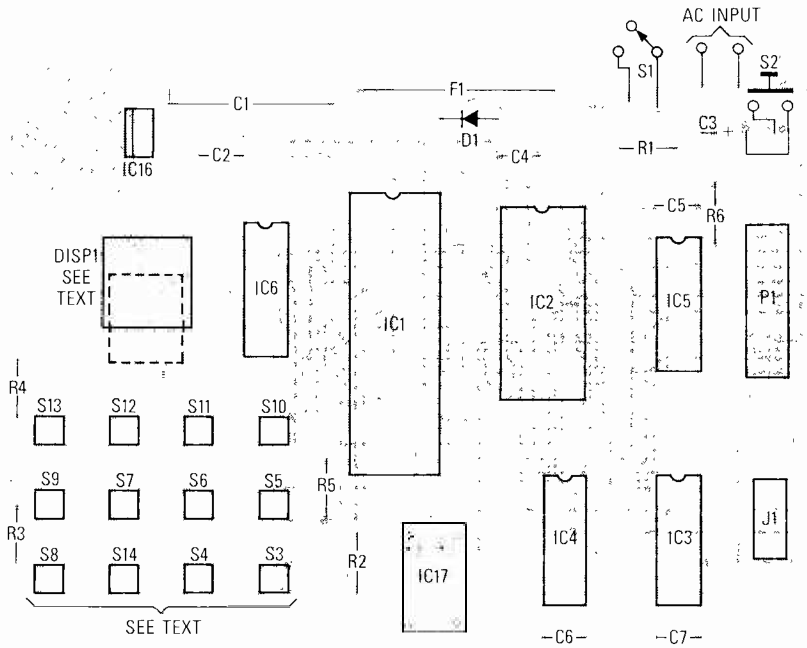



**FIG. 3—STUFF THE MAIN BOARD as shown here. Mount the display and switches S3–S14 on the foil side if you will install the tester in a case. Note that the display is oriented differently depending on whether or not the tester is installed in a case.**

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. 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 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

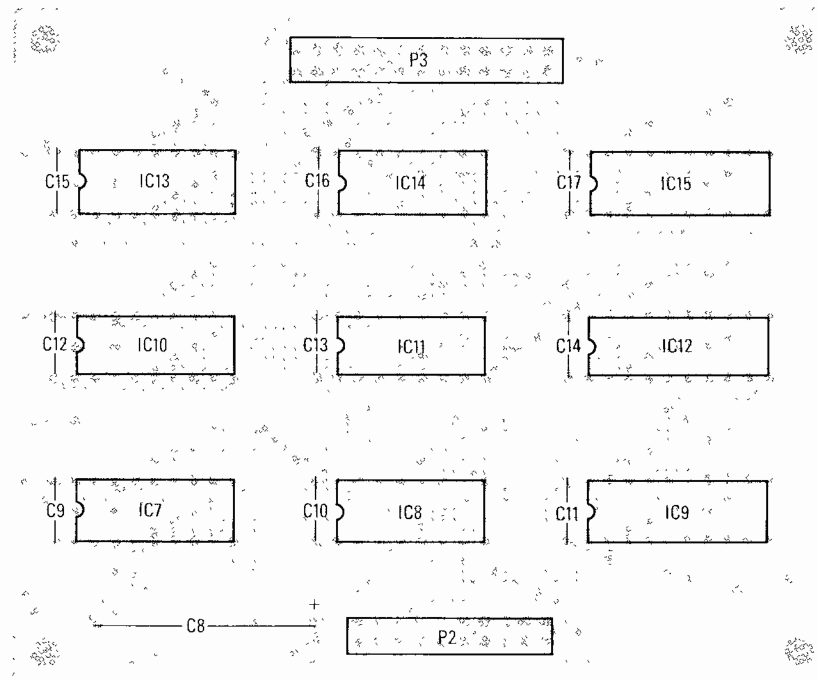



**FIG. 4—STUFF THE DRIVER BOARD as shown here. Mount all parts on the component side of the board.**

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

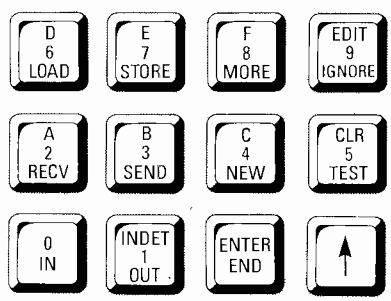



**FIG. 5—LABEL THE KEYS as shown here for installation in a case. Otherwise, reverse labels from left to right.**

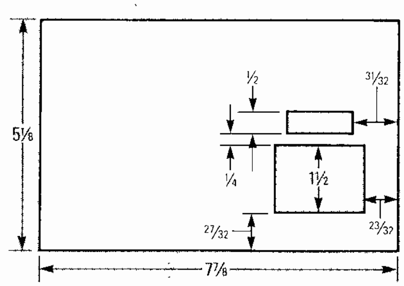



**FIG. 6—BASIC DIMENSIONS for the front panel.**

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.

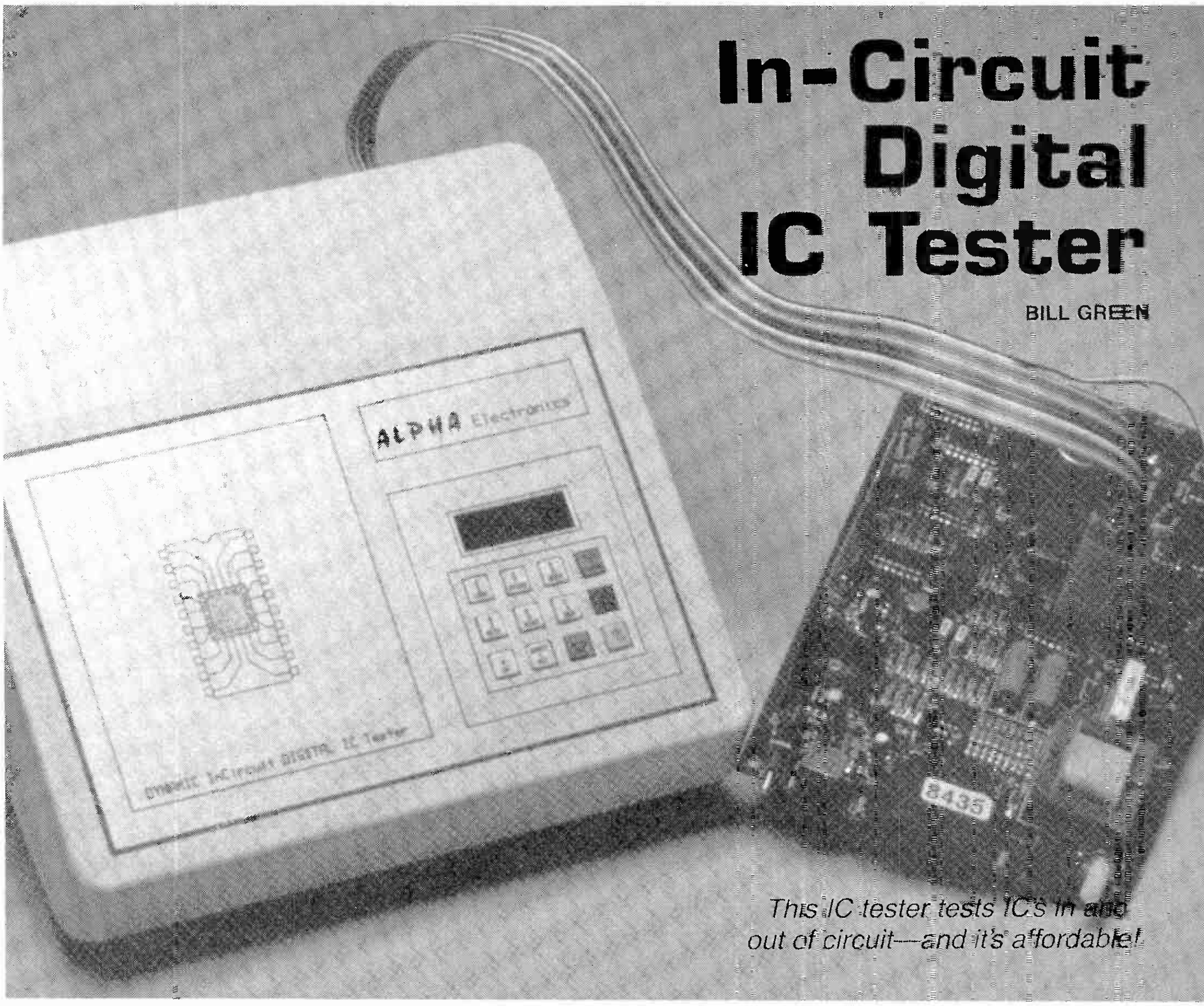
As a rule, you should turn the tester on first, followed by the circuit to be tested. Then connect the tester's ground clip, and last the IC test clip. If the test clip has more pins than the IC, "bottom justify" the test clip—when testing a 14-pin IC, for example, connect pin 8 of the clip to pin 7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

**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.

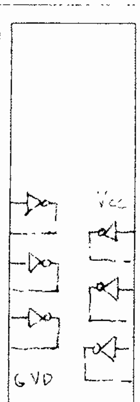
## Clocked logic

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 | 12 | 1010 1010 | AA | O |
| 1010 0101 = | AA | O | 4 | 11 | 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.

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

## 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
```

## 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
```

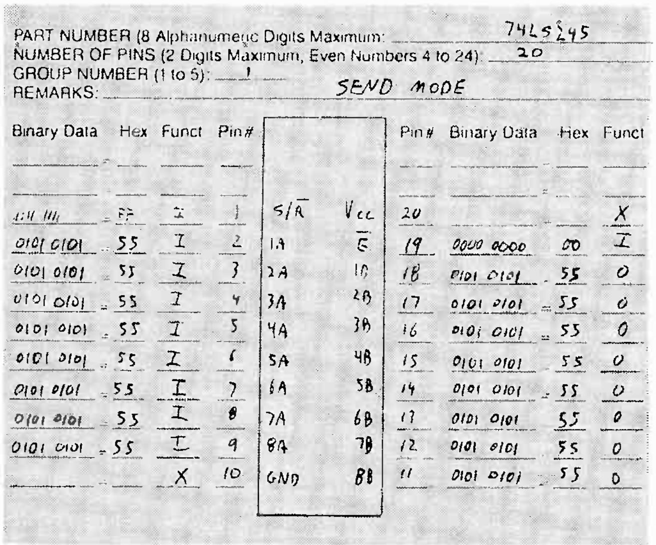



**FIG. 10—TEST SETUP FOR A 74LS245 octal bus transceiver in send mode.**

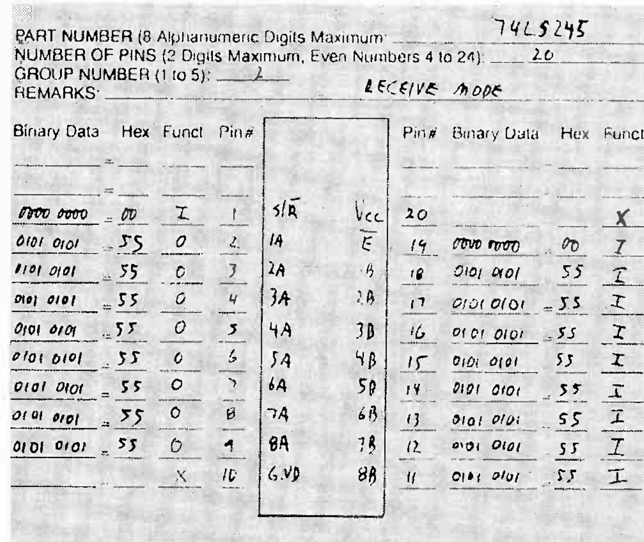



**FIG. 11—TEST SETUP FOR A 74LS245 octal bus transceiver in receive mode.**

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

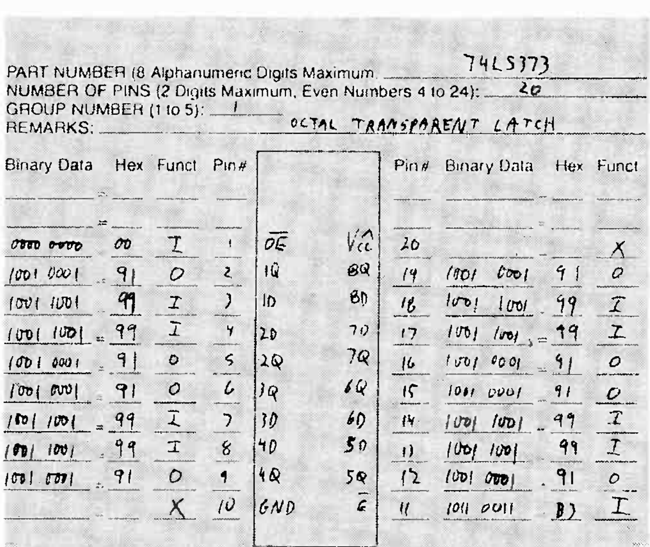



**FIG. 12—TEST SETUP FOR A 74LS373 octal transparent data latch. Whenever the enable line (pin 11) is high, each output follows the corresponding input.**

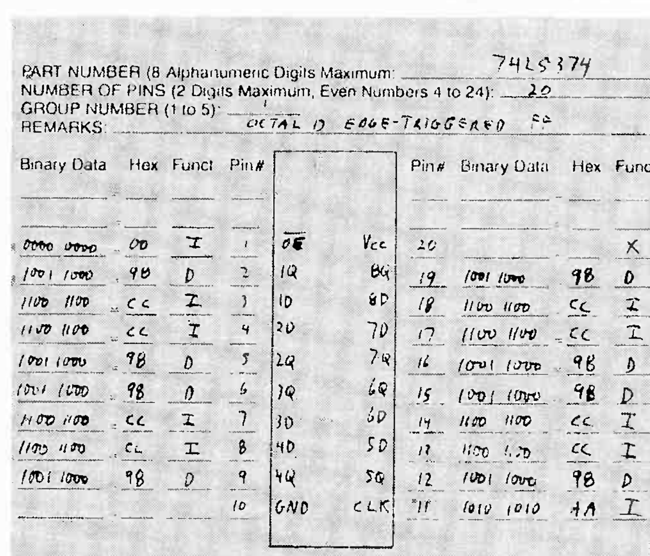



**FIG. 13—TEST SETUP FOR A 74LS374 octal D flip-flop. Data on each input is clocked into the corresponding output on the leading edge of each clock pulse. Clock pulses are applied to pin 11.**

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 | O |
| 1111 1111 | FF | 0 | 9 | Q8 | Q14 | 16 | 1111 1111 | FF | O |
| 1111 1111 | FF | 0 | 10 | Q9 | Q13 | 15 | 1111 1111 | FF | O |
| 1111 1111 | FF | 0 | 11 | Q10 | Q12 | 14 | 1111 1111 | FF | O |
| | | X | 12 | GND | Q11 | 13 | 1111 1111 | FF | O |

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 | O |
| 1111 0111 | F7 | 0 | 9 | Q8 | Q14 | 16 | 1111 1111 | FF | O |
| 1110 1111 | EF | 0 | 10 | Q9 | Q13 | 15 | 1111 1111 | FF | O |
| 1101 1111 | DF | 0 | 11 | Q10 | Q12 | 14 | [illegible] | 7F | O |
| | | X | 12 | GND | Q11 | 13 | 1011 1111 | BF | O |

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 | O |
| 1111 1111 | FF | 0 | 9 | Q8 | Q14 | 16 | 1111 1101 | FD | O |
| 1111 1111 | FF | 0 | 10 | Q9 | Q13 | 15 | 1111 1110 | FE | O |
| 1111 1111 | FF | 0 | 11 | Q10 | Q12 | 14 | 1111 1111 | FE | O |
| 1111 1111 | FF | X | 12 | GND | Q11 | 13 | 1111 1111 | FE | O |

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**

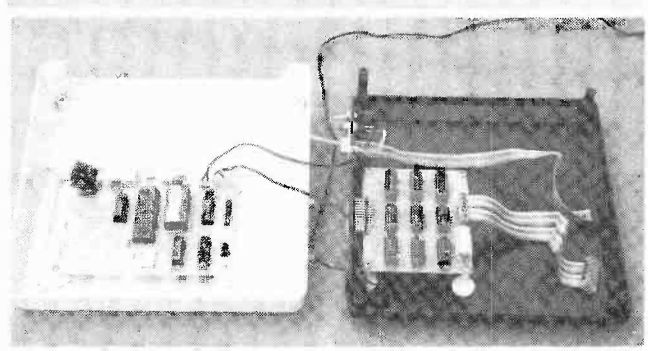
IC1—Z80 microprocessor
IC2—DS1230-104 32K nonvolatile RAM
IC3—MAX233 RS-232 interface
IC4—75499 custom decoder
IC5—75498 custom decoder
IC6—75500 custom decoder
IC7, IC10, IC13—NE591 open-emitter octal driver
IC8, IC11, IC14—NE590 open-collector octal driver
IC9, IC12, IC15—74LS373 octal latch
IC16—7805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

**Other components**

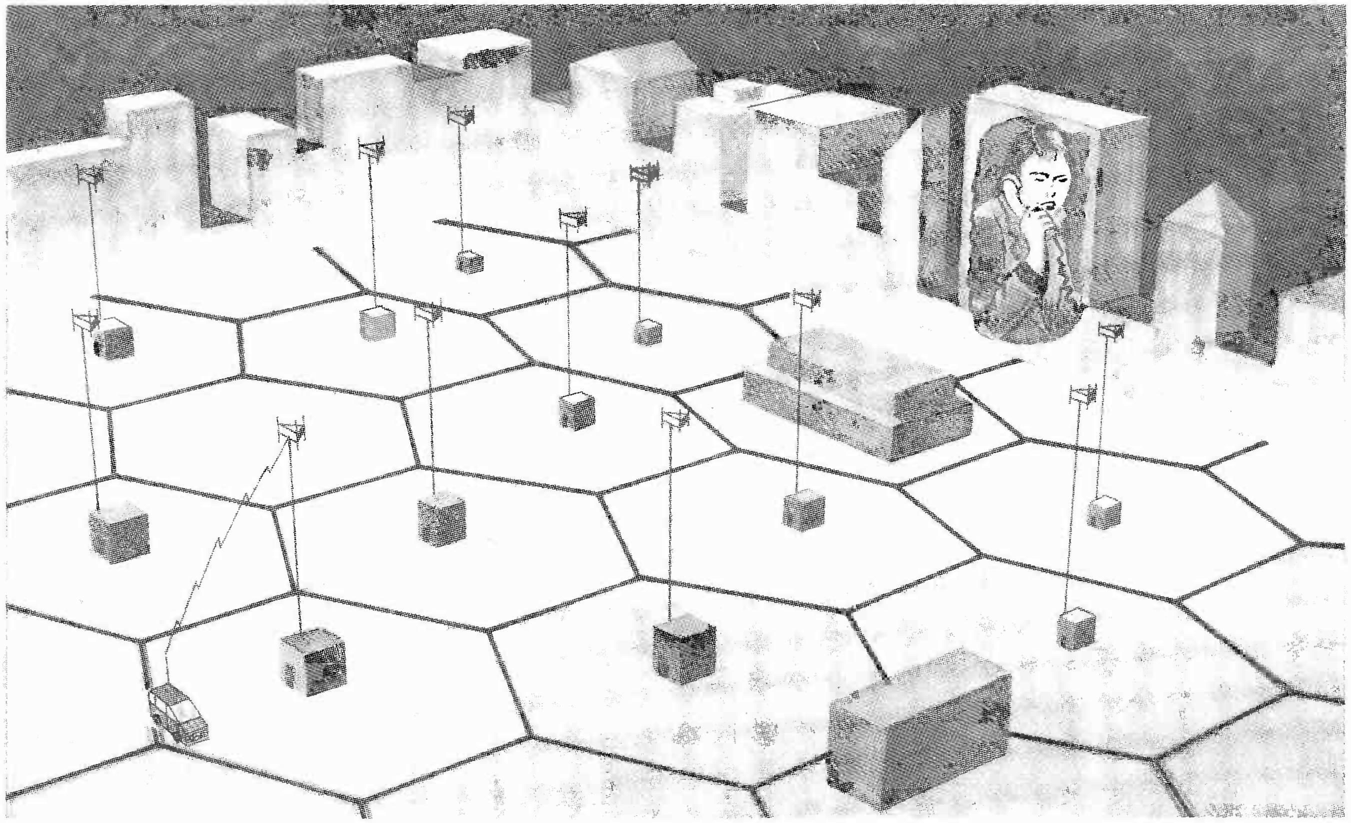
F1—1-amp pigtail fuse
J1—9-pin D connector
P1, P2—right-angle double-row 20-pin male header strips
P3—right-angle double-row 26-pin male header strips
S1—minature SPDT toggle switch
S2—momentary SPST pushbutton
S3–S14—momentary SPST keyboard switches
T1—Transformer, 9.5–12-volts, 1-amp, wall-mount

**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.

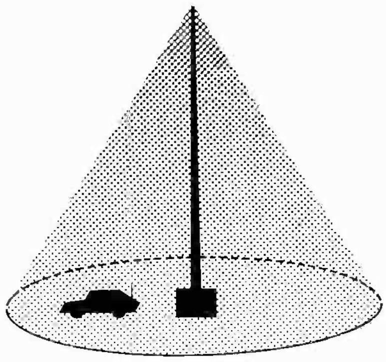


FIG. 1—EARLY, NON-CELLULAR, MOBILE-phone systems used a centrally located high-power transmitter. Only a few communications channels could be accommodated within a service region.

## 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-

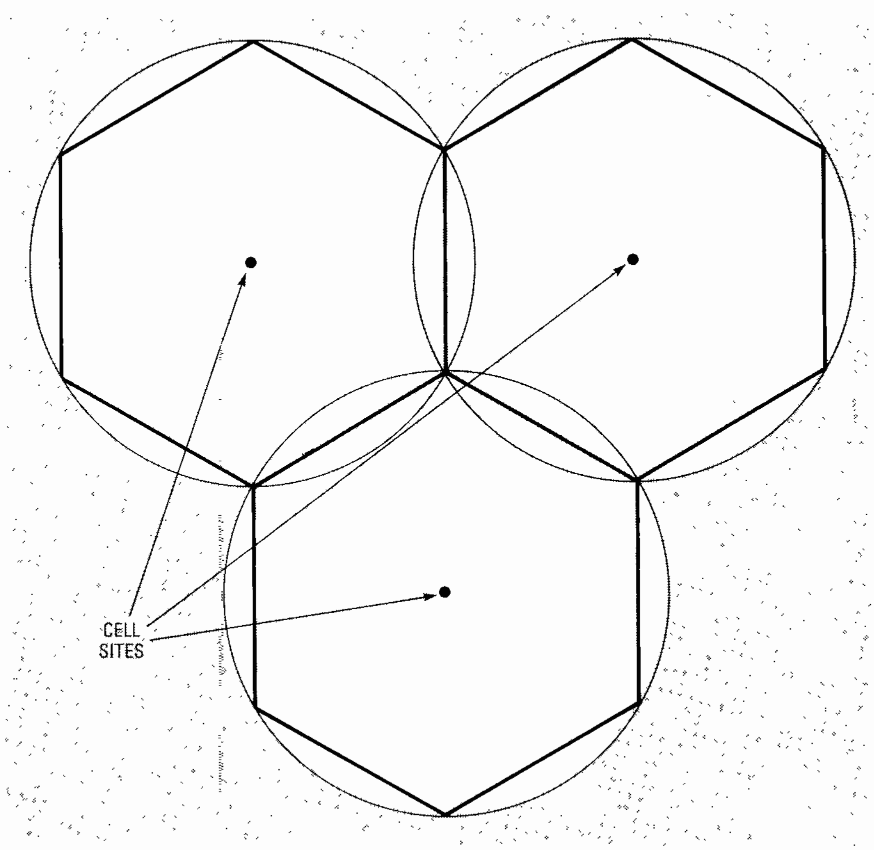



**FIG. 2—A CELLULAR SYSTEM DIVIDES its region of service into a number of small cells, each with its own cell site containing a low-power transmitter and receiving equipment. As a vehicle passes between cells, the signal is analyzed and any further communications are handed off to the cell best able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

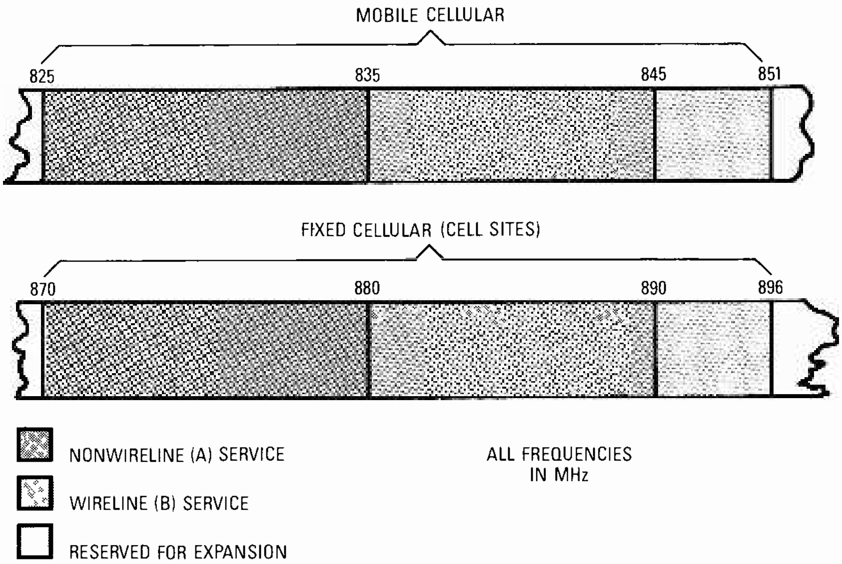



**FIG. 3—THE 666-CHANNEL CELLULAR PHONE RF spectrum is divided into bands for fixed and mobile equipment (cell sites and phones), and for non-wireline (A) and wireline (B) service.**

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

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