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THE MAGAZINE FOR ELECTRONICS & COMPUTER ENTHUSIASTS

$149 200-Watt Digital Stereo Power Amplifier

What's New In Op Amps

Device	Single/Split Supply Voltage	Supply Current	Input Type	FP*/UG** Bandwidth	Input Bias	Input Offset
A[illegible]170	2~12/ ±1-±6	250 μA	MOS	NA/700 kHz	pA	1 mV
A[illegible]351C	NA	NA	Bipolar	70 MHz/ 350 MHz	NA	NA
A[illegible]549L	NA/±15	200 μA	JFET	NA/700 kHz	[illegible]0 fA	500 μV
OP[illegible]-128L	NA/±15	NA	JFET	NA/500 kHz	[illegible]5 fA	500 μV
OP[illegible]-128K	NA/±15	NA	JFET	NA/500 kHz	50 fA	500 μV

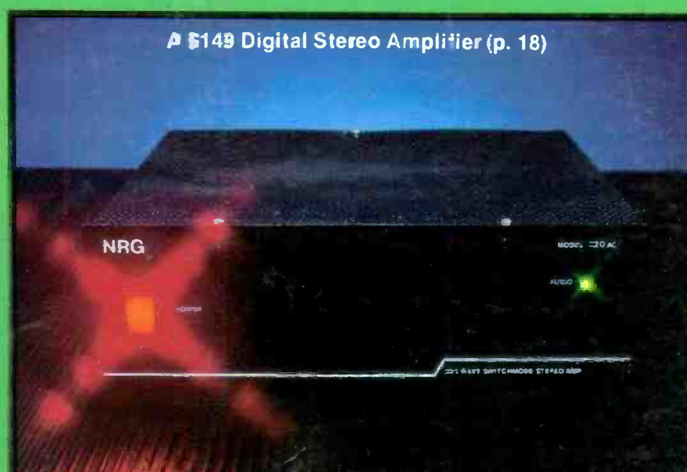
The State of Op Amps (p. 34)

Full Construction Plans:

- Testers . . . Testers
  - * 16-Channel Digital ICs
  - * Transistors/Diodes/SCRs
  - ... Model Airplane Battery
- ...ng Unauthorized ...istance Dialing
- An Automatic Printer Power Controller

Reference Extra:
1987 Annual Article Index

...er 2000—A Champion Program (p. 80)



A $149 Digital Stereo Amplifier (p. 18)

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The excellent sensitivity of the 1200H makes it ideal for use with the telescoping RF pick-up antenna; accurately and easily measure transmit frequencies from handheld, fixed, or mobile radios such as: Police, firefighters, Ham, taxi, car telephone, aircraft, marine, etc. May be used for counter surveillance, locating hidden "bug" transmitters. Use with grid dip oscillator when designing and tuning antennas. May be used with a probe for measuring clock frequencies in computers, various digital circuitry or oscillators. Can be built into transmitters, signal generators and other devices to accurately monitor frequency.

The size, price and performance of these new instruments make them indispensible for technicians, engineers, schools, Hams, CBers, electronic hobbyists, short wave listeners, law enforcement personnel and many others.

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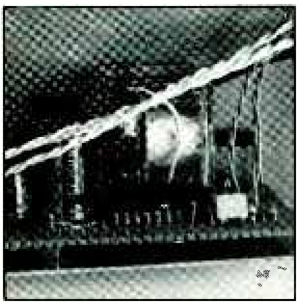
MODERN ELECTRONICS

THE MAGAZINE FOR ELECTRONICS & COMPUTER ENTHUSIASTS

DECEMBER 1987 VOLUME 4, NUMBER 12

42



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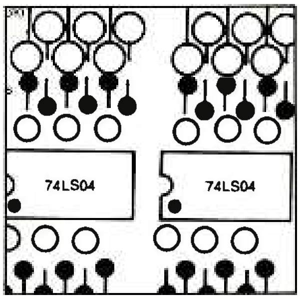

60

18

FEATURES

COLUMNS

DEPARTMENTS

Offices: 76 North Broadway, Hicksville, NY 11801. Telephone: (516) 681-2922. Modern Electronics (ISSN 0748-9889) is published monthly by Modern Electronics, Inc. Application to mail at second class rates pending at Hicksville, NY and other points. Subscription prices (payable in US Dollars only): Domestic—one year $17.97, two years $33.00, three years $48.00; Canada/Mexico—one year $20.00, two years $37.00, three years $54.00; Foreign—one year $22.00, two years $41.00, three years $60.00. Foreign Air Mail—one year $75.00, two years $147.00, three years $219.00.

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CIRCLE 47 ON FREE INFORMATION CARD

EDITORIAL

At Year's End

Examining the 1987 Cumulative Article Index that appears in this issue gave us an opportunity to weigh the editorial material that appeared in *Modern Electronics* during the past 12 months.

It was interesting to observe that electronics accounted for about two-thirds of the content, computers about one-fifth and departments about one-seventh. More than half of the total was in the form of construction projects. These major articles represent more than just plans to build a product, of course. They give practical insight to how electronic devices and the circuits in which they operate actually work, so it becomes an educational tour even if one does not build any.

A host of changes taking place in the electronics/computer world became more apparent in '87. On the video scene, camcorder (camera/VCR combinations) sales increased 39 percent as compared to '86, so this format is clearly entrenched now. Sales of color TV sets with built-in stereo increased more that 29 percent, while monochrome TV sales dropped about 17 percent. Super-VHS VCRs were announced, so these new machines (and video tape) will be given the market acid test next year.

In the audio world, compact disc players are still the driving force. Digital audio tape (DAT) promises to make a strong impact in '88, assuming that the equipment finally comes to market here. (It's being sold in Japan and it was announced that sales will be starting now in West Germany.)

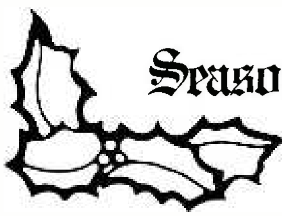
The computer world is churning heavily, as usual, with speedier machines, more memory addressing capacity, et al, introduced. IBM debuted its PS/2 systems, leapfrogging to new performance heights (and prices), while killing its XT and advanced XT models. Clone makers continue the line, as well as AT compatibles, at astoundingly low prices. Apple Computer, meanwhile, entered a bevy of new Macintosh models and finally opened its architecture for user expansion. Both fronts are pushing desktop publishing systems.

In electronics, surface-mount devices and ASICs continue to make inroads into manufactured electronic equipment. Test equipment continues along its road, with cheaper and higher-performing digital test gear and wider-bandwidth dual-trace oscilloscopes.

Looking ahead, we plan to cover the new happenings in '88, and then some. Starting in January, we will burst forth with three new columns. They will be devoted to new electronic devices and how they work, the electronics entertainment equipment scene, and the personal computer world. The latter two will also have electronic mail facilities available to *Modern Electronics* readers.

Here's wishing you all a Merry Season and a Happy New Year. We're looking forward to traveling down the electronics/computer road with you next year.

Art Salsberg



Seasons Greetings from the Staff of Modern Electronics

LETTERS

Changes

• The "Proportional Temperature Controller" in the October 1987 issue of *Modern Electronics* interested me. However, the Parts List gave the value of R4 as 1,000 ohms, while in the schematic it is 10,000 ohms. Which is correct?

Lee Dunlap
Washington, DC

The correct value is 10,000 ohms.—Ed.

• With regard to the "Electric Hand Dryer" (November 1987), I.P.C. Sales, the supplier of the motion-detector assembly, has changed its name to Micor and telephone number to (617)521-2221. The old telephone number will still be in service for a while, and mail sent to I.P.C. Sales will reach Micor, but anyone who wishes to place an order now should make note of the changes.

While I'm at it, readers should note that this project and "Building and Applying Active Minispeakers" (September 1987) will appear in a book, *Twenty Electronic Projects for Your Home*, (Tab Books).

Joseph O'Connell

A Cut-Up

• *Modern Electronics* gets my highest award for the first issue received, which I cut to pieces. That's not as bad as it sounds because I cut it to preserve its contents: The scope article on Lissajous patterns, which I never really understood; the Hall Effect article, which I never understood; the stepper-motor article, which I . . . . I guess you get the point—great stuff. Hoping that *Modern Electronics* continues to keep amateur and commercial license holders advised of new developments at the FCC.

Ed Jones
Somerset, NJ

• Thank you for producing one of the best general-coverage electronics magazines the industry has today. I receive many trade publications, hobbyist magazines, etc., but *Modern Electronics* is my favorite. I am particularly drawn to Forrest Mims' work and treasure each copy.

Dale Whitworth
Zephyrhills, FL

Prices, Please

• Got my first copy of your magazine last week because I saw on the front cover a reference to a temperature probe, which was just what I wanted. Looking over the article, I realized that an address was given to purchase it, but the purchase price was not given.

Since I am especially interested in buying either the LM34CZ or LM35CZ, please inform me of the cost.

John H. Paepe
Mercer Island, WA

Price of both of these ICs is the same—$4.81—which were listed in the Digi-Key ad in the same issue.—Ed.

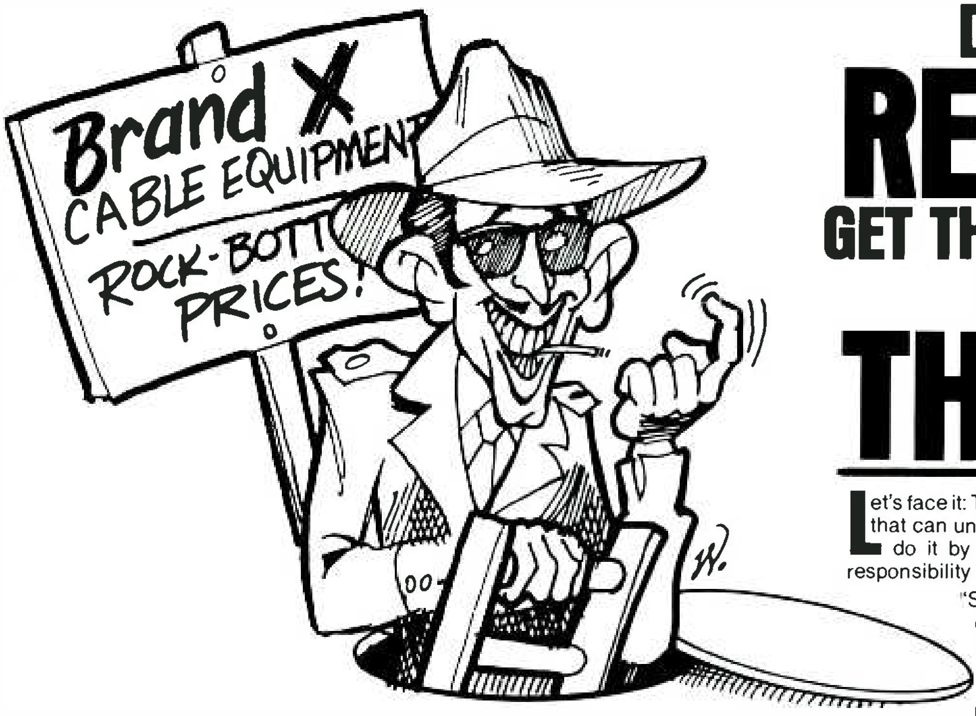
MODERN ELECTRONICS NEWS

THE ENGINEERING SCENE. Research & Development engineers earn more money than their counterparts in manufacturing, according to a survey by the American Association of Engineering Societies, with the median for the former being $51,000 annually and the latter, $43,500....Non-U.S. nationals increased their already high share of Ph.D's in U.S. universities in 1986, accounting for 55 percent of the 3,400 engineering doctorates and 23 percent of science doctorates, a rise of 7 and 6 percent, respectively, from 1985.

NOISE-CANCELLATION ADVANCES. Reducing noise is an ongoing quest. Dolby Labs made us all aware of the possibilities with its noise-reduction system for audio and broadcast purposes; publicity surrounding the U.S. silent-submarine technology secrets sold (illegally) to the U.S.S.R. illustrated noise-reduction techniques in another area. Now, Noise Cancellation Technologies, Inc., Great Neck, NY, has a computerized system that cancels low-frequency repetitive noise and vibration, such as from a ship's engine or noise inside helicopter that mars two-way radio communication. We observed a demonstration of the system, thanks to a lead from Tim Rose, Sandhurst Securities (NYC), who sells NCT stock. When the anti-noise circuit was activated, noise was indeed substantially reduced.

COMMUNICATIONS HAPPENINGS. More than 15,000 radio amateurs participated in a Simulated Emergency Test in October, sponsored by the American Radio Relay League. The goal was to prepare ham radio operators to provide better-coordinated communications services to agencies such as the Red Cross, Civil Preparedness, the News Media, etc. Robert Warren, Chief of Army Military Amateur Radio System, said that it would cost at least a billion dollars for the government to attempt to duplicate this communication network. Local SET groups use a variety of mock emergencies to recreate real disasters as closely as possible, scoring the results at their conclusion....Southwestern Bell, now in the competitive retail market, is offering for sale its FV-1000 voice-activated Freedom Phone. It stores up to 63 telephone numbers that can be "dialed" automatically with simple voice commands. A child can dial the local fire department just by saying "Emergency Fire" into the mouthpiece, for example. $449.95.

DISK CATALOGS. Guardian Electric developed "Comp-U-Sol," a computer data disk to aid engineers who specify solenoids. Menu-driven, the disk leads a user from one selection criteria to another. Stringent specs are called out and "what if" capabilities are at hand to see the effect of any parameter change. Designed for use with an MS-DOS computer and only a single 360K floppy drive, 256K memory, and DOS 2.1 as a minimum, the disk is available FREE from Guardian by writing to them at 1550 W. Carroll Ave., Chicago, ILL 60607....Motorola, too, has introduced a data disk to provide design engineers with speedy selection of power transistors. The IBM-compatible disk requires 384K of RAM and features device information for over 1,600 bipolar power transistors and MOSFETs, plus more than 3,500 cross references. Cost is $2 to Motorola Semiconductor Products, Literature Distribution Center, P.O. Box 20924, Phoenix, AZ 85063.



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"So, you want that Jerrold 450 combo? The one that **Pacific Cable Co., Inc.** is offering for $199⁰⁰? Well, that's a good price, but here's what I'll do..." What may happen is that you may save a couple of bucks at the time. But suppose there's a problem (and it happens to the best of them,) and you call that "Dealer"... This could be what you'll hear:

"No, Steve isn't here. He moved out, the bum! And he owes me $437⁰⁰ on the phone bill! No, I don't know about any guarantees on your Gerald, who's that? Listen, if you see that creep..." etc.

At **Pacific Cable Co.**, you've got an established company who will be here for you, time after time. We may be tough competitors, but we've got a soft spot for our clients! Try us, and be treated right—and we'll prove it by giving a one-year warranty on everything we sell.

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RCA 36 Channel Converter (Ch.3 output only)	29.00	18.00	*Minicode (N-12)	89.00	58.00
Panasonic Wireless Converter (our best buy)	88.00	69.00	*Minicode (N-12) with Vari Sync	99.00	62.00
400 or 450 Converter (manual fine tune)	88.00	69.00	*Minicode VariSync with Auto On-Off	145.00	105.00
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Jerrold 400 Hand Remote Control	29.00	18.00	Econocode with VariSync	89.00	56.00
*Jerrold 450 Combo	199.00	139.00	*MLD-1200-3 (Ch.3 output)	99.00	58.00
*Jerrold 450 Hand Remote Control	29.00	18.00	*MLD-1200-2 (Ch 2 output)	99.00	58.00
Jerrold SB-Add-On	89.00	58.00	*Zenith SSAVI Cable Ready	175.00	125.00
*Jerrold SB-Add-On with Trimode	99.00	70.00	Interference Filters (Ch.3 only)	24.00	14.00
*M-35 B Combo unit (Ch.3 output only)	99.00	70.00	*Eagle PD-3 Descrambler (Ch 3 output only)	119.00	65.00
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DECLARATION OF AUTHORIZED USE — I, the undersigned, do hereby declare under penalty of perjury that all products purchased, now and in the future, will only be used on cable TV systems with proper authorization from local officials or cable company officials in accordance with all applicable federal and state laws.

Dated: ______ Signed: ______

NEW

Only NRI gives you a 27" high-resolution stereo color TV you build to prepare you for today's video servicing careers.

Become one of America's most sought-after technicians . . . put your talents and spare time to work for you in the "explosive-growth" world of home entertainment electronics.

Train in state-of-the-art video/audio servicing and become a fully qualified service professional the uniquely successful NRI way. It's hands-on training, at home . . . designed around the latest electronic equipment you build and keep as part of your training. You start from scratch and "discover by doing." You conduct key experiments . . . perform vital tests . . . build your own systems . . . and do it all at the pace that suits you best.

There's no stopping the incredible boom in consumer electronics. Soaring sales, new and improved video products, entirely new technologies have opened up new opportunities for the trained technician as never before.

Now at $26 billion in annual sales, the consumer electronics industry is creating a whole new servicing, installation, and repair market. This year, TV sales alone are expected to hit 16.2 *million* units. Every day, sales of home VCRs, a product barely conceived of 10 years ago, reach 20,000 units. Every day!

And the revolution has spread to the business sector as tens of thousands of companies are purchasing expensive high-tech video equipment used for employee training, data storage, even video conferencing.

The Video Revolution Is Just Starting

Already, disc players can handle audio CDs and laser video discs. And now there are machines that will accommodate laser computer disks as well. Camcorders are becoming smaller, lighter, and more versatile . . . 8 mm video equipment produces high-resolution pictures and digital audio. By 1990 our TVs will become interactive computer terminals, giving us entertainment, information, and communications in one sophisticated video/computer/audio system.

Join the Future or Be Left Behind

Can you see the opportunity? The servicing and repair market that's there already . . . and the enormous future need created by the millions upon millions of electronic devices yet to come? If you're looking for a high-potential career . . . if you'd like to get started in a field that's still wide open for the independent businessperson . . . even if you'd like to find a way to make extra money part-time, look into NRI at-home training now.

Start Right and There'll Be No Stopping You!

NRI training in video/audio servicing is the perfect way for you to profit from the new explosive growth in consumer electronics. You study at home in your spare time at your own pace. No classroom pressures, no night school grind.

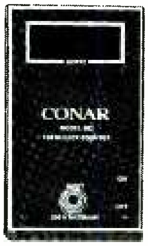
Even if you've never had electronics training, NRI prepares you properly with a thorough grounding in the fundamentals . . . a foundation that you build on to achieve advanced electronics skills. With this kind of understanding and practical bench experience built into NRI's exclusive training methods, you're on your way to take advantage of the new opportunities opening up every day.

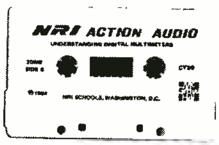
Totally Integrated Hands-On Training

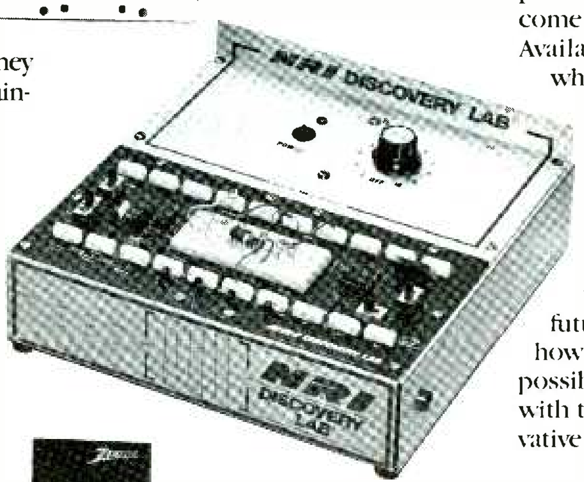
Since NRI training is built around "learn by doing," right from the start you conduct important experiments and tests with your professional digital multimeter. You assemble the remarkable NRI Discovery Lab and perform a complete range of demonstrations and experiments in the process.

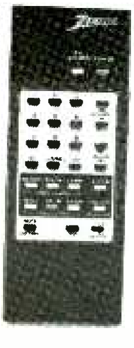
Hands-On Training As You Build a 27" Stereo TV

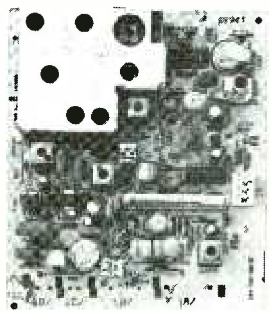
In just hours you assemble an exceptional state-of-the-art TV receiver using easy to follow, step-by-step instructions. During this assembly process, you learn to identify and work with components and circuits used in actual commercial circuitry. Then through tests, adjustments, and experiments you quickly master professional troubleshooting and bench techniques.











NRI's commitment to you goes beyond providing you with equipment appropriate to the latest technology. Of equal importance is our dedication to training techniques that let you master TV, video and audio troubleshooting and repair quickly and easily. Best of all, we ensure that in the learning process you acquire the very skills that will make you a professional service technician on the job.

NRI has purposely designed your training around equipment that has the same high-tech circuitry you'll encounter in commercial equipment. That means your training is real-world training. And *that's* unique.

Inside Your TV

This new state-of-the-art Heath/Zenith 27" TV included with your training has all the features that allow you to set up *today* your complete home video center of the future. Flat screen, square corners, and a black matrix to produce dark, rich colors. Cable-compatible tuning, built-in stereo decoder to give you superb reproduction of stereo TV broadcasts . . . even a powerful remote control center that gives you total command of video and audio operating modes.

Your NRI Training Has Another Special Element

Also built into your training is the enormous experience of NRI development specialists and instructors. Their long-proven training skills and enthusiasm come to you on a one-to-one basis. Available for consultation and help whenever you need it, your instructors ensure your success both during your course and after graduation.

Step Into the Future Today

The richest reward you gain from your NRI video/audio training is a firm grip on the future. Your knowledge and know-how provide you with the soundest possible foundation for keeping up with the rapidly evolving, highly innovative video industry.

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Now is the time to act. Send the postpaid card to us today. You'll receive our 100-page catalog free. It's filled with all the facts you'll want to know about our training methods with full details on the equipment you'll use and keep as part of your hands-on training. You'll see how our more than 70 years of experience in uniquely successful at-home career training makes us the leading technical school today. (If someone has already used the card, write to us at the address below.)

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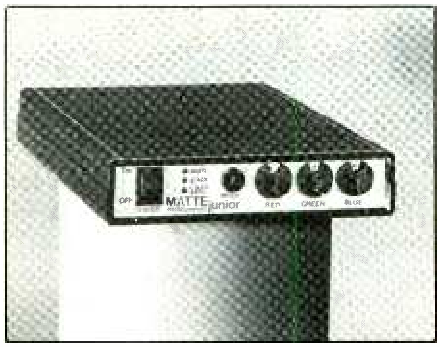
NEW PRODUCTS

For more information on products described, please circle the appropriate number on the Free Information Card bound into this issue or write to the manufacturer.

Video Signal Generator

Rock River Video's (Rockford, IL) "Matte junior" is an electronic video signal generator aimed at the serious hobbyist, industrial/educational video producer and video service technician. Principally a video color generator, Matte junior produces standard video signals for use in video special effects. Color and brightness of the output can be continuously adjusted with front-panel controls. Other features include a standard color-bar signal for servicing and equipment set-up and an internal crystal-controlled TV sync and subcarrier generator that serves as a stable source for use with other TV equipment.



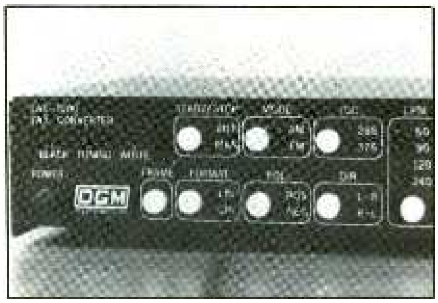
This instrument is claimed to have correct phasing for the color subcarrier to horizontal so that it is compatible with today's TV receivers that use comb filters. It can be used to generate any screen color and brightness level. A "black burst" output is provided for synchronizing several pieces of video equipment when setting up a system.

The compact unit measures 10″W × 6.4″D × 1.4″H. It is powered by a separate plug-in ac adapter, which is supplied, as is a 1.8-meter RG-59/U cable terminated at both ends in a phono cable.

CIRCLE 1 ON FREE INFORMATION CARD

Facsimile Converter

The FAX-1000 Facsimile Converter from DGM Electronics, Inc. (Beloit, WI) connects between an hf communications receiver and Epson-graphics-compatible printer for printing weather charts, satellite pictures and press photos. It will copy AM facsimile signals sent by satellites or FM facsimile signals normally sent on hf frequencies. The converter copies all standard speeds and index of cooperations. Pictures can be inverted or printed in either direction. A 10-segment bargraph is provided for accurately tuning in the station being copied.



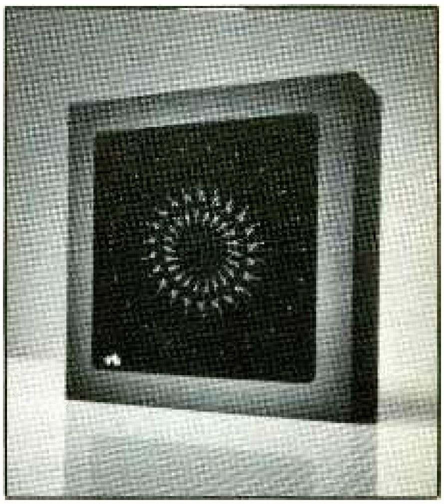
Automatic and manual modes are provided. In automatic mode, the converter waits for an appropriate signal from the sending station to start printing. In manual mode, the operator can start printing and manually frame the picture with a front-panel button. LEDs and pushbutton switches on the front panel simplify operation.

The FAX-1000 is housed in a compact, rfi-proof aluminum enclosure that measures only 7″W × 6″D × 2″H. It is powered by a 117-volt ac plug-in transformer, included with the converter. $299.

CIRCLE 2 ON FREE INFORMATION CARD

Sound Visualizer

The Lyte™ "audiovisualizer" from Clyde Industries America, Inc. (Cedar Rapids, IA) translates music into a real-time visual display of kaleidoscopic light patterns. It interfaces with home stereo systems, electronic keyboards, electric guitars and any



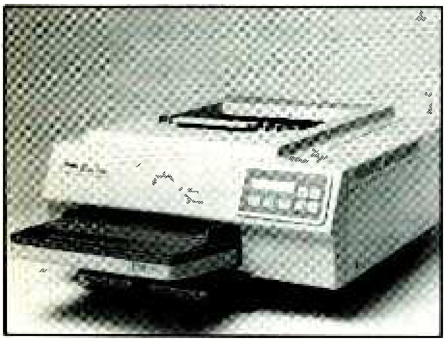
other audio device with a speaker jack or line output jack. Using 80 LEDs spinning at high rpm, The Lyte produces constantly changing electronic expressions of complex sounds. Solid-state electronics continuously monitors the amplitude of the signal and frequencies ascending from bass to treble. The output is displayed as colors and patterns against a black background.

The light-producing mechanism is housed in a black plastic case that measures 11.5 inches square by 3.5 inches deep and weighs 7.5 pounds. It comes with a connecting cable terminated in a phono jack and operates on standard 117-volt ac line power via a low-voltage, plug-in wall transformer.

CIRCLE 3 ON FREE INFORMATION CARD

Personality-Cards for Laser Printer

A new Kiss- plus series of laser printers based on the Canon SX engine and using interchangeable Personality Cards has been announced by QMS, Inc. Three Personality Card options are available, each with its own unique fonts, emulations and system memory and 300 × 300-dot per inch graphics capability. The cards are daughter boards, accessed from the side of the printer base. Personality Card 10 (¼-page) has 24 resident fonts, 512K of RAM and Epson FX-80, Qume Sprint 11, Diablo 630 and ANSI emulations. Personality Card 20 (½-page) has 34 fonts, 1M of RAM and IBM Proprinter, HP LaserJet+, Epson, Qume, Diablo and ANSI emulations. Personality Card 30 (full-page) has 34 fonts, 2.5M of RAM and HP 7575A graphics plotter language (HP-GL), Proprinter, LaserJet+, Epson, Qume, Diablo and ANSI emulations.



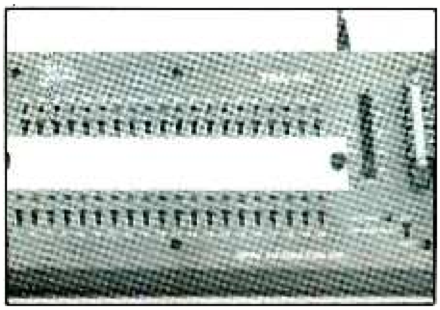
The Kiss plus series is designed to enhance personal productivity in office environments that require high-quality text or text and graphics output. Near-typeset-quality documents and presentation materials can be created by using the printers' resident fonts, dual font cartridges and download-font capabilities. For applications that require graphics, users can select the Personality Cartridge option with memory to match their specific needs.

A wide range of resident emulations provides instant compatibility with many popular software packages. Dual RS-323/parallel interfacing and a compact, desktop design allows the printers to be connected to most host computers and be located anywhere in an office. $1,995 basic printer; $395 Personality Card 10; $695 Personality Card 20; $1,495 Personality Card 30.

CIRCLE 4 ON FREE INFORMATION CARD

Logic Monitor/Controller

The TSA-40 logic monitor/controller from Beta Automation, Inc. (Newbury Park, CA) is packaged with 40 discrete connectors at the end of its ribbon cable for monitoring



separate points in a circuit instead of just a 40-pin IC. (Test leads and IC test clips are available in various sizes as options.) The TTL/CMOS-compatible monitor/controller features a separate LED logic level indicator for each of its 40 channels, and pulse trains and varying duty cycles are indicated by the brightness of the LED in any given channel.

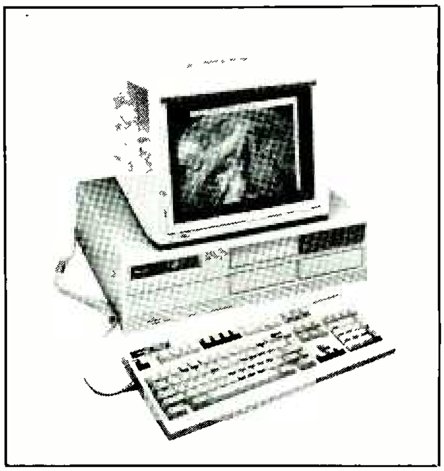
Each channel can be forced to logic high, logic low or floated (monitor only). The V+ in the power supply of the system being monitored is used as a reference only, since the monitor/controller has its own built-in ac-operated plug-in power supply.

An easy-to-change label can be used for user notes, such as functional names for IC pins, expected logic levels, etc. to customize the TSA-40 for a particular application. Forty test points, in parallel with the test cable, are provided for additional flexibility. Input impedance is 1 megohm. The instrument measures 10.4"W × 5.9"D × 1.3"H and weighs 1.5 lbs. Supplied are a 24" test cable, gold 40-pin IC test clip, 10 user labels, power converter and user's manual. $225.

CIRCLE 5 ON FREE INFORMATION CARD

80386 Personal Computer Kit

The Heath Company's new Model H-386 personal computer kit features the powerful Intel 80386 32-bit microprocessor running at 16 MHz and is socketed for an 80287 or 80387 numeric coprocessor. The IBM PC/AT-compatible computer comes with a 1.2-MB floppy-disk drive, enhanced 101-key keyboard, combined hard/floppy-disk controller, serial and parallel ports, five open expansion slots and ROM-based diagnostics plus MS-DOS 3.2+, disk-based diagnostics and Integrated 7+. The last is a menu-driven applications package that contains a spreadsheet, word processor, relational database manager, database merging, graphics, terminal emulation and PC-to-PC communications software. Available options include 1.2-MB and 360-KB 5.25-inch floppy-disk drives, 1.4-MB 3.5-inch microfloppy-disk drive and 80-MB hard-disk drives. The computer can accommodate up to two floppy- and two-hard-disk drives.

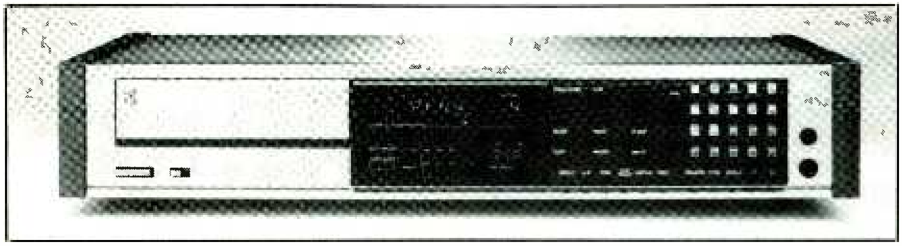


Graphics is provided by a port on the video board that gives 640 × 480-pixel color on Zenith's new flat-screen monitor. Another port drives EGA, CGA and TTL monochrome monitors. Both video-board ports automatically emulate common video formats for each system configuration.

According to Heath, the kit can be assembled in just two evenings without the need for special tools or equipment. The computer is said to be compatible with all MS-DOS 16-bit software written for the IBM PC and AT and can run the XENIX operating system for multi-user and multitasking operations. The system unit measures 21"W × 16.5"D × 6.5"H and weighs 35 lbs.

CIRCLE 6 ON FREE INFORMATION CARD

NEW PRODUCTS . . .



Audio/Video Receiver

Pioneer Electronics' Model VSX-3000 receiver lets you expand an audio/video system at your own pace. This receiver has three video inputs with two-way dubbing and simultaneous recording capability. Included are a built-in surround-sound processor, VCR noise filter and audio adapter loop. Except for the slide-type equalizer controls, all operations are performed with push-type switches.

Features include: quartz PLL synthesized tuning with 20-station random-access presets and automatic and manual station search; built-in 5-band graphic equalizer; video signal selector for switching audio and video separately; connections for two pairs of speakers; multi-function fluorescent window that displays a clock complete with programmable 24-hour digital timer; and antiresonance construction with copper-plated screws to reduce internal vibration and magnetic distortion.

A 40-key audio/video remote control transmitter included with the receiver is SR compatible. This "command center" accesses 53 possible functions to operate all the components that can be added to the system.

Rated continuous average output power is more than 60 watts/channel into 8 ohms from 20 to 20,000 Hz at no more than 0.05% THD. The receiver measures $16\frac{9}{16}$"W × $15\frac{1}{8}$"D × $4\frac{5}{16}$"H. $349.95.

CIRCLE 7 ON FREE INFORMATION CARD

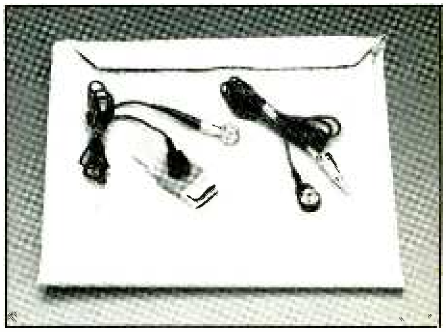
Benchtop Security Locker

A new Security Riser Assembly that safeguards test and research equipment between work shifts and when a worker is away from his workbench is available from Workplace Systems, Inc. (Londonderry, NH). The fully enclosed, all-metal assembly mounts directly to the workbench top or laboratory counter. Its hinged bi-fold front panel rests on top of the unit when open to provide unobstructed access to the interior. The panel also closes and padlocks to secure internal equipment. A standard size assembly measures 72"L × 24"H × 18"D and includes one fixed interior shelf for storage efficiency. An optional prewired wirethrough supplies additional power when needed.

CIRCLE 8 ON FREE INFORMATION CARD

Portable Static Kit

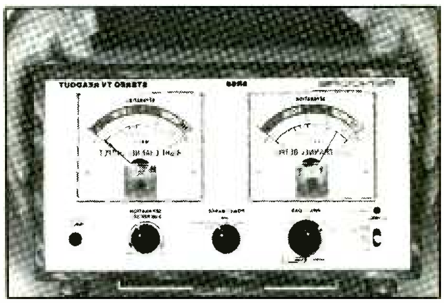
A static control companion kit has been designed by Jensen Tools to fit behind the upper pallet of a tool case or inside a briefcase. The kit is essential for protection of static-electricity-sensitive devices when working on them in the field. It opens up to 18 × 24 inches of static-dissipative work surface and has a 5-ft. grounding cord for the mat and an adjustable elastic wrist strap with a 4-ft. grounded cord for the user. Included are hardware and instructions for correct hookup to ensure the safety of both the static-sensitive components and user. The kit meets or exceeds all applicable military and EOS/ESD standards. $29.95.



CIRCLE 9 ON FREE INFORMATION CARD

Stereo TV Readout

Sencore's Model SR68 Stereo TV Readout allows the service technician to measure the outputs of audio amplifiers at either the line or speaker outputs. It incorporates dummy loads that provide up to 100 watts per channel of power dissipation to catch problems that may appear only when components are forced to operate under maximum amplifier stress. Dual meters provide visual monitoring of the amplifier's outputs and are used to measure audio levels directly in either decibels or watts. The SR68 allows the user to automatically measure audio separation of stereo circuits to as low as −40 dB, without having to refer to calculations, with the turn of a single knob.



The Stereo TV Readout is supplied as a basic bench-type test instrument. However, with addition of an optional rechargeable battery, it can

(Continued on page 90)

A $149 *Digital* Stereo Amplifier

This state-of-the-art basic stereo power amplifier features pulse-width-modulation design to produce distortionless high-power output

By C. Barry Ward

Here is a home audio amplifier that outputs 100 watts or more per stereo channel and weighs only seven pounds! Moreover, the 200-watt digital basic power amplifier described here offers the performance needed to complement demands of critical listeners.

Small size and light weight are the result of using advanced pulse-width modulation techniques and ultramodern power MOSFET output devices. Pulse-width modulation and peak current averaging yields a low-cost amplifier that works on a principle similar to that used in the lauded compact disc it fully complements.

This digital amplifier is an updated home version of the car "100-Watt/Channel Distortionless Digital Audio Amplifier Booster" that appeared in the December 1986 issue of *Modern Electronics.* It replaces the original dc-to-dc power converter with an ac-line-operated power supply and incorporates a stereo line-level "preamplifier" that allows any audio signal source—such as a tape deck, tuner, CD player or preamplifier/control center—to drive it to full output with as little as 0.5-volt input.

How it Works

A conventional analog audio power amplifier, through successive stages of gain, simply enlarges a low-level signal applied to its input to produce an output with sufficient current to drive a speaker load. Theoretically, with no input signal applied to its input, no power is delivered to the speaker load. In practice, though, some small amount of power appears at the speaker load as a result of leakages, thermal noise, etc.

In a digital power amplifier like the one to be described, things are a bit different. Such an amplifier sends a constant-voltage, 50-percent duty-cycle, 250-kHz square wave to a filter choke and speaker even when no input signal is present. At such a high frequency, the inductive reactance of the filter choke in the amplifier's output reduces the 250-kHz signal energy to a very small amount. Whatever residual power remains is handled by the speaker's reactance. Thus, with no audio input signal to the amplifier, no audio output is heard.

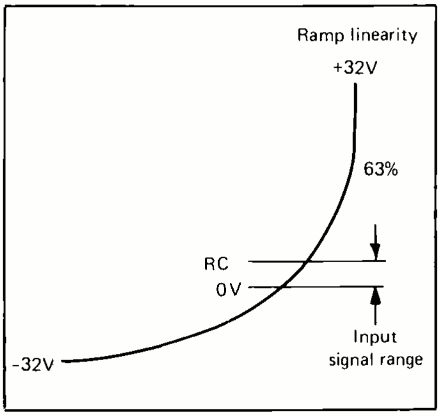


Fig. 1. To assure linearity, only a very small, linear portion of the charging ramp is used. Only 10 mV (0.00016 of the 64-volt power-supply range available) charges the timing capacitor.

When an audio signal is applied to the digital amplifier's input, it off-balances the square-wave signal in proportion to the level of the signal at an audio rate that does get through to the speaker. For a positive-going input signal with an amplitude equivalent to 10 percent of the input range, the square wave would have a duty cycle of 60 percent high and 40 percent low to yield a net positive output signal.

If the square-wave signal were to be sent sent directly to a speaker at a frequency in the audio range, it would develop an audio power level of 180 watts! The digital amplifier, averages the 250-kHz power to less than 1 watt of *inaudible* sound.

The duty cycle of the square wave is modulated by an extremely linear triangle wave produced by the switching-frequency signal across a timing capacitor. The linearity of this ramping waveform is the result of a very-high-value timing resistor that sources current for the timing capacitor. Also contributing to the modulator's linearity is the only 10-millivolt amplitude of the triangle wave. This combines with a large time constant that keeps the amp on such a small portion of the RC timing curve that the ramp is very linear. (For a detailed description, see "100-Watt/Channel Distortionless *Digital* Audio Amplifier Booster," *Modern Electronics*, December 1986.)

Whenever an audio input signal is present, the triangle wave, which relates directly to the square wave output signal, is compared to this signal. When the audio input goes in a positive direction, the amplifier's output stays high for an increasingly longer percentage of the overall time available for that switching cycle. To keep the average voltage of the output to within 10 millivolts of the input, the comparator must change states. This forces the output voltage to be error corrected to within 10 millivolts during every 2-microsecond switching cycle. Clipping occurs just as it does in a conventional linear amplifier when the output can no longer be corrected to match the input signal's amplitude.

The complete schematic diagram of the digital power amplifier is too large to fit on a single page or even two pages side by side. Therefore, it is presented here in four parts: Fig. 2—input preamplifier; Fig. 3—pulse-width modulation circuit; Fig. 4—driver/power amplifier; and Fig. 5—ac-operated power supply. Figures 3 and 4 are similar to those used in the car booster amplifier previously published in these pages. However, a number of changes have been made to that basic circuit.

As shown in Fig. 2, the preamplifier is built around the popular LM381 preamp chip (*U4*) that provides enough voltage gain to drive the am-

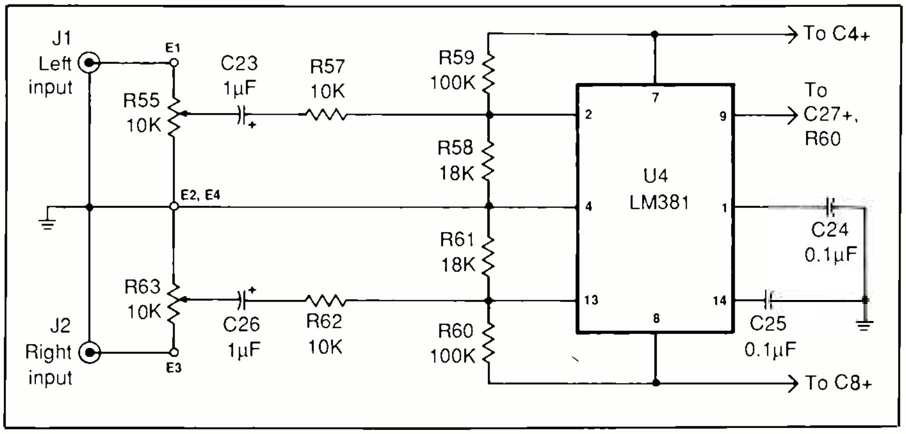


Fig. 2. The preamplifier section shown here can drive the power amplifier to full output with as little as a 0.5-volt input signal from a line-level source.

plifier to full output power with a line-level audio input. An input signal level of as little as 0.5 volt can drive the amplifier to its full 100-watt or more per channel output.

The pulse-width modulator requires approximately 5 volts input to reach full output. Pulse width modulation is accomplished with voltage comparators *U1* and *U3* in Fig. 3 for the left and right channels. When power is first applied to the circuit and timing capacitors *C11* and *C14* have no charge on them, *U3* and *U1*, respectively, have no outputs. Since *U1* and *U3* are open-collector devices, their outputs can swing high at a very rapid rate. These high outputs are sent to phase splitters *Q13/Q14* and *Q16/Q17* in Fig. 4 where the signals in each channel are divided so that positive-going ones are routed to positive level shifters *Q11/Q12* and *Q7/Q8* and negative-going signals are routed to negative shifters *Q9/Q10* and *Q5/Q6*. As each shifter is turned on, it drives the remaining stages of its signal half in its channel.

When the pulse-width modulator causes a high positive voltage to be on one end of timing resistors *R43* and *R25*, *C14* and *C11* begin charging. At 10 millivolts, the outputs of *U1* and *U3* switch state and the process reverses. Charging and discharging occurs at a 250-kHz rate.

So far we have discussed how the switching frequency is developed. Now let us add an audio signal to the input of the amplifier. The input signal goes to a network that provides resistive decoupling between the timing ramp waveforms on *C14* and *C11* and the input signals. A small amount of preemphasis is added by the *R42/C13* and *R48/C12* RC networks to provide high boost to minimize the high-frequency rolloff that results from *L5* and *L6*.

A time-delay circuit mutes the amplifier's output during the first few seconds after power is applied to remove the pops and thumps sometimes associated with high-power audio systems. The delay time is generated by *U2*, whose output is held high by *C5*. This high output keeps *Q15* and *Q18* saturated so that outputs are silenced. When *C5* charges to two-thirds of the 12 volts on the dc supply line, *U2*'s output goes low, cutting off *Q15* and *Q18* and allowing the amplifier to oscillate and amplify.

Because this digital amplifier is designed for home use, it has a 117-volt ac-line-driven power supply, shown schematically in Fig. 5. This power supply uses either a toroid-wound or standard laminated-core power transformer that outputs 50 volts ac center-tapped. The secondary feeds into the bridge rectifier made up of discrete power diodes *CR20* through *CR23*, which provide the pulsating dc that is filtered by hefty 10,000-microfarad capacitors *C20* and *C21* to provide the +32 and −32 volts dc required to power the amplifier stages. The +32-volt supply is also regulated down to +12 volts to power timer *U2* in Fig. 3.

Because of the high-frequency switching signal used in the amplifier, an emi filter at the ac input to the power supply is required to prevent r-f from feeding back into the ac line.

Construction

Because of the large number of discrete components used in this project and the fact that a radio-frequency signal is involved, printed-circuit construction is highly recommended. You can fabricate your own pc board using the actual-size etching-and-drilling guide shown in Fig. 6, or you can purchase a ready-to-wire board from the source given in the Note at the end of the Parts List. If you make your own board, drill a ⅛-inch hole midway between filter capacitors *C20* and *C21* near but not touching the outer ground trace on the bottom of the board. Wire the board exactly as shown in Fig. 5.

If you use sockets for the ICs, start populating the board with these. Otherwise, save installation of the ICs until after the resistors, capacitors and diodes are in place. Make sure that the electrolytic capacitors and all diodes are properly oriented as you install them. The locations for *CR1* through *CR4* on the wiring guide show a heavy black line along one side of the outlines to indicate where the tabs on the transistor-like cases of the devices supplied with the kit go. If you use axial-lead diodes, the cathode leads go to the right for *CR1* and *CR3* and to the left for *CR2* and *CR4*.

Separate the small transistors into piles of 2N2907A and 2N2222A de-

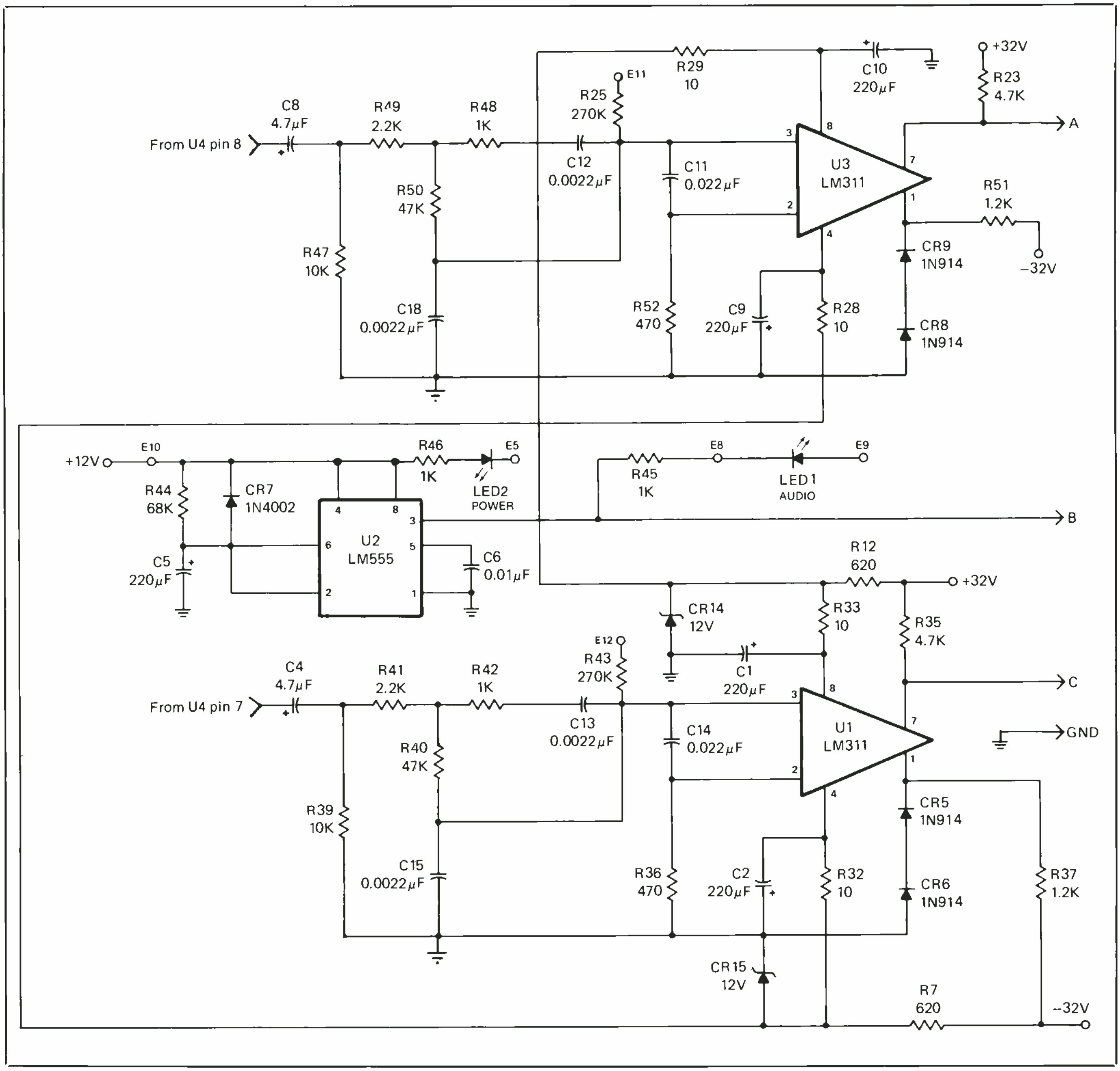


Fig. 3. In this pulse-width modulation circuit, the timing signal is generated by U2, while modulation is provided for each channel separately by U1 and U3.

vices to avoid confusion. Install the 2N2907As in the Q5, Q8, Q9, Q12, Q13 and Q16 locations and the 2N2222As in the Q6, Q7, Q10, Q11, Q14, Q15, Q17 and Q18 locations at least ¼ inch above the board's surface. Make sure you properly base each transistor as you install it. Also make sure that the cases of the transistors do not touch each other. Any small mistake in the placement of the semiconductors can cause instant—and expensive—component failure when power is first applied to the amplifier.

Next, install the jumper wires in the locations identified with "J" numbers. Use 16-gauge or larger solid bare wire links for J1 and J2 and standard solid insulated hookup wire for the other jumpers.

Power MOSFETs *Q1* through *Q4* mount on a heat sink that bolts to the end of the board. Push the "necks" of four shoulder fiber washer into the four ¼-inch transistor mounting holes and follow with a 6-32 ×

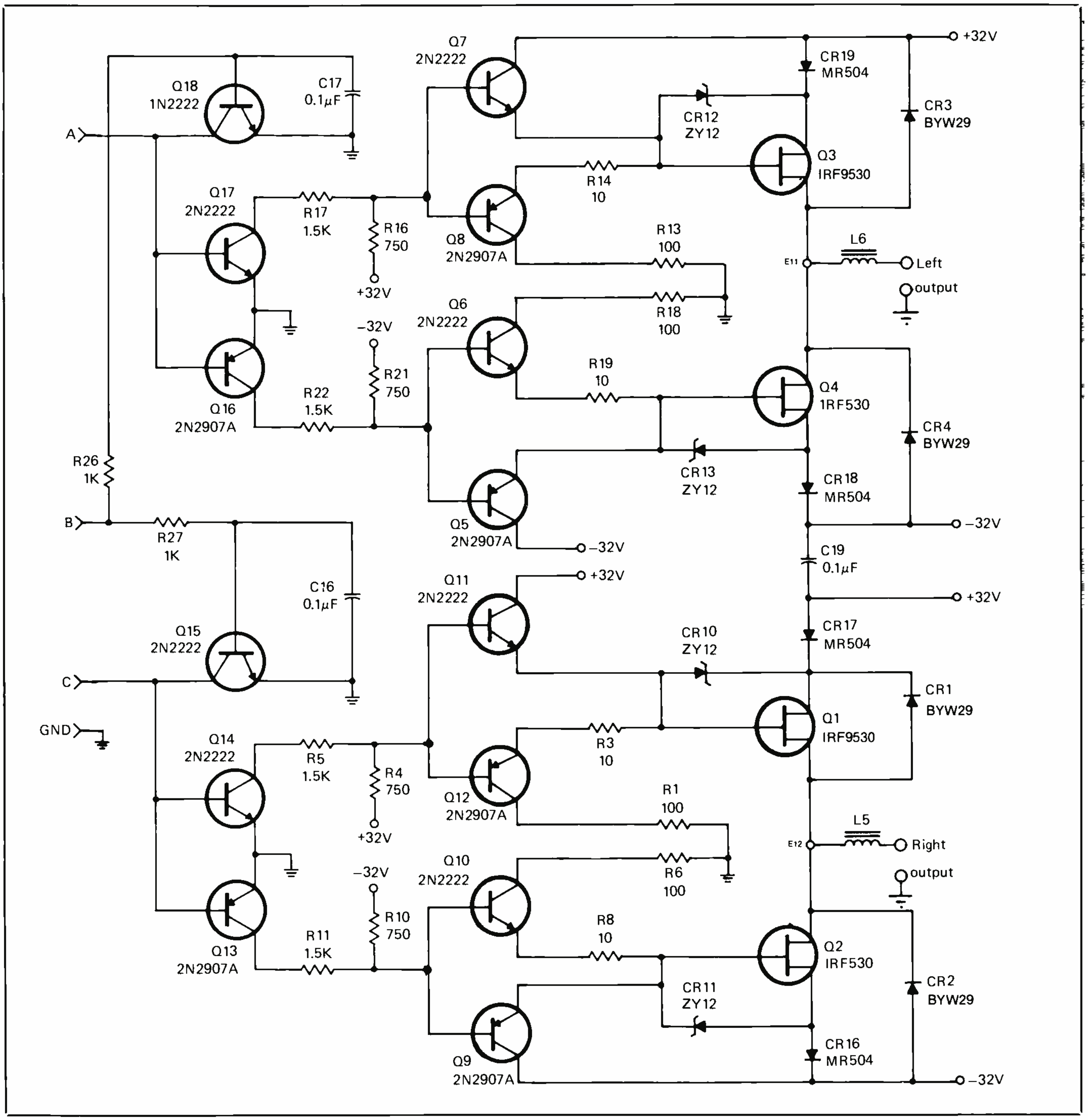


Fig. 4. The schematic diagram of the driver and power amplifier stages.

¾-inch machine screw in all four washers. Place another fiber washer on each screw, necks facing away from the heat sink. Lower the circuit-board assembly, solder side down, onto the heat sink so that the free ends of the screws go into the ¼-inch holes in the board and the washer necks engage the board holes. Thread a No. 6 machine nut onto the screws for *Q1* and *Q3*, making them only finger-tight to hold the assembly together as you mount the other two power MOSFETs.

Liberally coat both sides of two TO-220 mica transistor insulators with heat sink compound and place them over the ends of the screws that have no nuts on them. Observe anti-static precautions when handling and installing the power MOSFETs,

PARTS LIST

Semiconductors

CR1 thru CR4—BYW29-100 ultra-fast diode
CR5,CR6,CR8,CR9—1N4148 small-signal diode
CR7—1N4004 or other 1-ampere, 400-volt rectifier diode
CR10 thru CR13,CR15—1N4742 or other 12-volt, 1-watt zener diode
CR14—Not assigned
CR16 thru CR23—MR504 or other 3-ampere, 400-volt rectifier diode
CR24—1N5351 or other 14.2-volt, 1-watt zener diode
LED1—T-1¾ green light-emitting diode
LED2—T-1¾ red light-emitting diode
Q1,Q3—MTP8P10 or IRF9530 p-channel power FET
Q2,Q4—IFR530 n-channel power MOSFET
Q5,Q8,Q9,Q12,Q13,Q16—2N2907A pnp transistor
Q6,Q7,Q10,Q11,Q14,Q15,Q17,Q18—2N2222A npn transistor
U1,U3—LM311 comparator
U2—555 timer
U4—LM381 dual preamplifier

Capacitors

C1,C2,C5,C9,C10,C22,C27—220-μF, 25-volt electrolytic
C3—Not assigned
C4—4.7-μF, 50-volt electrolytic
C6—0.01-μF, 50-volt ceramic
C7—Not assigned
C8—47-μF, 25-volt electrolytic
C11,C14—0.022-μF, 50-volt stacked-film
C12,C13,C15,C18—0.0022-μF,50-volt stacked-film
C16,C17—0.01-μF, 50-volt ceramic
C19—0.1-μF, 50-volt polyester
C20,C21—10,000-μF, 35-volt upright electrolytic
C23,C26—10-μF, 25-volt electrolytic
C24,C25—0.1-μF, 50-volt ceramic

Resistors (¼-watt, 5% tolerance)

R1,R6,R13,R18—100 ohms
R2—Not assigned
R3,R8,R14,R19,R28,R29,R32,R33, R64—10 ohms
R4,R10,R16,R21—750 ohms
R5,R11,R17,R22—1,500 ohms
R9,R15,R20—Not assigned
R24—Not assigned
R25,R43—270,000 ohms
R26,R27,R42,R45,R46,R48—1,000 ohms
R30,R31,R34—Not assigned
R36,R52—470 ohms
R37,R51—1,200 ohms
R38—Not assigned
R39,R44,R47,R57,R62—10,000 ohms
R40,R50—47,000 ohms
R41,R49—2,200 ohms
R54—220 ohms
R58,R61—18,000 ohms
R59,R60—100,000 ohms
R7,R12—600 ohms (each consists of two 1,200-ohm, ½-watt resistors in parallel)
R23,R35—4,700 ohms (½-watt)
R53,R56—75 ohms (5 watts)
R55,R63—100,000-ohms pc-type trimmer potentiometer

Miscellaneous

L1 thru L5—Not assigned
L6,L7—60-μH output inductor (see text)
S1—Spst power switch (125 V ac at 10 amperes)
T1—50-volt center-tapped, 3-ampere power transformer (see text)
Printed-circuit board; suitable enclosure; heat sink; emi filter/ac receptacle and matching three-conductor computer-type chassis-mount ac receptacle (see text); two chassis-mount phono jacks; speaker output connectors (see text); pc board shield; four sets mica TO- 220 insulators for power FETs; 4- or 5-lug solder-type terminal strip; 4 self-stick rubber feet; heat-shrinkable tubing; machine hardware; hookup wire; solder; etc.

Note: The following are available from NRG Electronics, P.O. Box 24415, Ft. Lauderdale, FL 33307: Complete kit of parts, including enclosure and line cord, $149. Available separately: ready-to-wire pc board, $19.95; all electronic components, $89; toroidal power transformer, $29; enclosure, receptacles, jacks and hardware, $39. Include 5% for P&H; Florida residents, please add state sales tax. A complete parts list that includes prices for individual components can be obtained by sending a SASE to the above address. Telephone orders/information, call: 305-971-3823 after 6:00 p.m. EST.

as they can be damaged by static electricity almost as easily as CMOS ICs can. Bend the leads of the MTP8P10 or IRF530 p-channel power MOSFETs toward the rear (metal tab side) to form right angles at the points where they widen.

Install the transistors via the screws without nuts on them and push their leads into the appropriate holes in the board. Follow with a No. 6 lockwasher and machine nut in both cases, tightening the nuts only enough to avoid distorting the transistor tabs or crushing the fiber washers. Solder the transistor leads to the pc board's copper pads. Remove the nuts from the other screws and repeat the above procedure for mounting the IRF9530 n-channel power MOSFETs in the Q1 and Q3 locations.

Exceptional care must be exercised to insulate the power MOSFETs from the heat sink, to prevent the high radio-frequency difference in potential between the metal parts from causing partial or full short circuits. Use an ohmmeter set to its lowest-resistance range to check for short circuits between the heat sink and metal tab on each transistor and between the pc board's foil pattern and nearby screw heads. When you're finished installing all components on the board, trim all leads as close as possible to the solder on the printed circuit foil.

Wind chokes *L6* and *L7* on 1.57-inch outer-diameter by 0.95-inch inner-diameter by 0.57-inch high MPP ferrite cores with a 125 permeability, using No. 16 enameled wire. Wind both cores in the *same* direction to avoid possible signal coupling when the amplifier is operating. Leave 6-inch or so lead length at both ends of both coils. Carefully scrape ½ inch of enamel insulation from both ends of each lead. Plug one lead of the coils into the E11 and E12 holes and solder into place.

Remove 1 inch of outer plastic jacket from two 12-inch shielded

Lab & Listening Tests

I knew that I'd have problems trying to test this amplifier using conventional test methods and test instruments. The whole concept of a pulse-width-modulation amplifier depends upon an integrating network to change the varying width of constant-amplitude pulses into a recognizable audio waveform. Most loudspeakers represent such a suitable network. A 4-ohm or an 8-ohm pure resistance does not! What to do?

Part of the problem of bench testing was foreseen by the designers of this clever amplifier. They put a small inductor in series with the output terminals, and the combination of that inductor in series with a fixed pure resistance does a bit of integration, but not enough to produce a clearly identifiable waveform.

All I could see on my oscilloscope when I connected the amp to some high-wattage pure-resistance noninductive load resistors (either 8 ohms or 4 ohms) was a picture of the constant 250-kHz pulse train that this amplifier produces. The amplitude of this pulse train was over 30 volts rms, even after the slight smoothing effect of the small inductor in series with my external loads. Obviously, even if a clear audio waveform were developed and superimposed upon the pulse train, at 100 watts per channel across an 8-ohm load the amplitude of that waveform would be only 28.3 volts or so—less than the amplitude of the steady-state 250-kHz pulses.

The solution, of course, was to hook the amplifier to the kind of load it really needs to look into—a *real* loudspeaker. The moment I did so, everything changed. The amplitude of the pulse train was reduced to just a couple of volts. Now when I applied an input test signal, it was replicated at the output terminals with perfect clarity and with no visible distortion. There remained only one problem: how to measure maximum power output without blowing out my speakers and, more importantly, without deafening me and everyone within a block or so of my lab.

With ear protectors applied to my ears, I decided to take a chance on a pair of speakers that I was prepared to sacrifice in the name of science, if need be. As it turned out, the speakers and my ears both survived the tests. Frequency response was plotted at an output level of approximately 10 watts per channel. The preemphasis built into the amplifier no doubt varies according to the speaker load applied. In any event, ordinary tone controls on your preamplifier should be able to restore audibly flat response. What I saw was probably a worst-case condition, with relative dB measurements starting out a few dB down at 20 Hz, rising gradually to flat around 90 Hz, and then increasing steadily to a peak of 15 dB.

I was able to drive the amplifier to its rated output, briefly (in the interest of my neighbors) with about 0.5 volt applied to the input terminals of the amplifier. Output across a 4-ohm equivalent impedance speaker measured just over 21 volts before clipping, which translates to a power level of just over 110 watts per channel, with both channels driven. A slight roll-off at the base end was probably attributable to the input capacitor. Were that to be increased from its present value of 1 microfarad to around 3 microfarads, response ought to be flat right down to 20 Hz and perhaps even a bit lower. Similarly, the decibel level at mid and high frequencies can be reduced by using smaller preemphasis circuit capacitors. [The designers subsequently changed the capacitors to 10 microfarads to flatten the bass end and 0.001 microfarad (from 0.0022 microfarad) to flatten the high end—Ed.]

There is no easy way to measure either harmonic or IM distortion for this amplifier. Even with a true speaker load applied, the amount of r-f (250-kHz pulses) superimposed upon the output audio waveform was around 10 percent of the total amplitude when the amplifier was delivering its full rated output power. (That is one of the reasons why the author of this project warns against direct connection to certain types of tweeter elements and requires shielded speaker wire.) Thus, an ordinary distortion analyzer would read a harmonic distortion-plus-noise level of 10 percent, when in fact we know that the 10-percent reading is neither harmonic distortion nor audible

speaker cables. Trim off the shield at one end of both cables. Tightly twist together the fine wires that make up the shields at the other end of the cables and lightly tin with solder. Strip ¼ inch of insulation from the inner conductors at both ends of both cables, twist together the fine wires in each and tin with solder. If there are two inner conductors, bundle the fine wires of both at each end and tin with solder. Connect and solder the inner conductors of the cables at the ends that have no shields to the free leads of the output chokes. Slip over the connections 2-inch lengths of heat-shrinkable tubing so that they completely cover all exposed wire and shrink them snugly into place. Then use a two-part "putty-type" epoxy cement to mount the chokes on the top of the heat sink.

If the ICs are not soldered directly to the board, plug them into their respective sockets now. Make sure they are properly oriented and that no pins overhang the sockets or fold under between IC and socket.

Trim a single-sided printed-circuit board blank to 5.75 × 4 inches to use as a shield for the circuit-board assembly. If you use a toroidal power transformer for *T1*, trim another single-sided printed-circuit board blank to 4.5 inches square on which to mount it. (A standard laminated-core transformer does not need an insulated mounting platform.) Use a fast-set epoxy cement to secure the toroidal transformer to the unclad side of the mounting plate. Offset the transformer toward one corner noise. This being the case, I had to resort to what is still the best "test instrument" for measuring the performance of an amplifier: a pair of human ears, in this case my own.

Listening Tests

All of the high-amplitude pulses that had been so disturbing to me during my attempts to measure the performance of the amplifier were of no consequence once I hooked up the amplifier to a pair of good loudspeakers and began to listen to musical-program material instead of sine-wave tones. Highs were crisp and bright, but did not seem to need tonal correction with the speakers I used, despite the preemphasis measured earlier. There was virtually no audible background noise when inputs to the amplifier were shorted, indicating a signal-to-noise ratio of at least 80 or 90 dB, or possibly even higher, referred to rated output. For critical listening, a CD player equipped with an output level control was connected directly to the inputs of the amplifier, thereby avoiding the need for a separate preamplifier. Sound was quite accurate and what can best be described as transparent.

It seems inevitable that, with the whole world "going digital," sooner or later both preamplifiers and power amplifiers will be configured somewhat like this NRG model. Pulse-width modulation, rather than pulse-code modulation (PCM), seems like a preferable method of designing a "digital" power amplifier since the varying pulse widths are so easily integrated by the complex network impedance of a loudspeaker. I just hope that test-equipment manufacturers come up with practical means to measure the performance of such amplifiers before test labs of the world deafen their technicians by connecting such high-powered amplifiers directly to loudspeakers for evaluation purposes.—*Len Feldman*

Editor's Note. For an alternative evaluation of this new-technology audio amplifier, we brought NRG's digital power amp to a high-end audio dealer, Performance Audio/Video, Merrick, LI, NY, where Harold Minto cooperated in allowing us to use his facilities to listen to the amplifier with top-notch equipment and a variety of compact-disc program material. Audio salesman Ivan Mitrani lent his more youthful ears for our listening tests.

Equipment used to test the NRG stereo amp consisted of a Conrad-Johnson preamplifier, DCM Time Frame speaker systems, Kinergetics compact-disc player, and Discrete Technology's speaker cable wire. The listening room was a large, nicely appointed area.

A residual hum was immediately apparent when the equipment was turned on with no signal applied. Since it was not evident in any previous listening sessions, we assume that some sort of ground loop was introduced or that a grounding strap under the amp's pc board was shaken loose due to compounded rough handling during a series of shipping moves. Shielded speaker cable was not available, but r-f radiation was not a consideration here. The hum largely disappeared when source material was played.

Our music choices were eclectic: small-group jazz, solo piano, vocal, symphonic, rock and pop. The preamp's volume control was hardly turned up to produce full volume in the large audition room. It was quickly evident that the digital stereo amp produced exceptionally crisp, transparent sound. Transients were superb; sound depth was exceptionally splendid; and the stereo image was rock solid, we all agreed. Sitting in the optimum stereo location, one could not even pinpoint the loudspeaker that was generating the audio. We also concurred that there was a touch of "graininess" in the high-mid and very high frequencies. This was not necessarily dislikable, just a bit different. Discussing this with the designers of the amp, they concluded that this was due to the preemphasis circuit which, in combination with the speakers used, required two capacitors to be changed in order to reduce the high-frequency level.

Given the high power and generally favorable performance attributes of the digital amp, my professional co-listener felt that the amp was a great buy for the money. We will be making the suggested circuit changes and run through the listening tests again to confirm the effect on the amp.

so that it aligns with two adjoining sides of the plate.

Select an enclosure that is large enough to accommodate the power transformer chosen and the amplifier circuit-board assembly. Machine the front panel of the enclosure for mounting the the POWER switch and AUDIO and POWER LEDs and the rear panel for mounting the pair of phono jack inputs, speaker-output connectors and the chassis-mount ac receptacle/emi filter. Also, drill a hole to mount a grounding connector on the rear panel. Only three holes are needed in the floor of the enclosure for mounting a solder-lug-type terminal strip and the hardware for the amplifier circuit-board assembly. If you use a laminated-type transformer, you also have to drill mounting holes for it.

Liberally coat the copper-clad side of the toroidal transformer's mounting plate with a fast-set epoxy cement or silicone adhesive and press the assembly into place in the rear-left corner of the enclosure. (This mounting plate prevents the transformer's windings from shorting out against the metal of the enclosure should the enamel insulation wear away as a result of normal physical oscillation during operation.) Then mount the five-lug terminal strip, sandwiching two No. 6 or 8 solder lugs between the mounting tab and machine nut.

Mount the ac socket/emi filter, speaker output connectors and phono input jacks in their respective locations on the rear wall of the enclosure. Similarly, mount the POWER

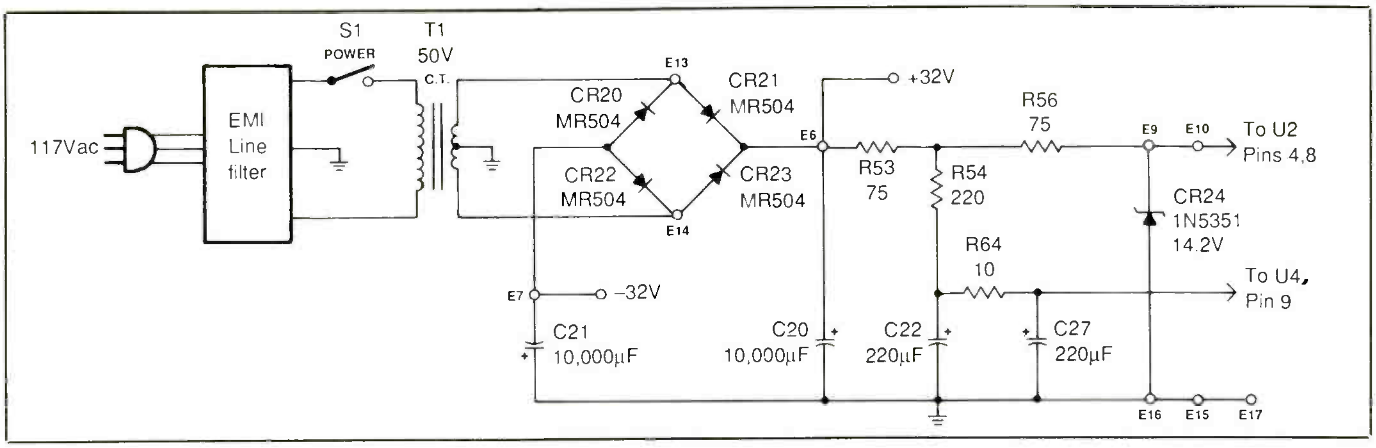


Fig. 5. The ac-line-operated power supply gives the builder a choice of a toroid- wound or a standard laminated-core transformer for T1.

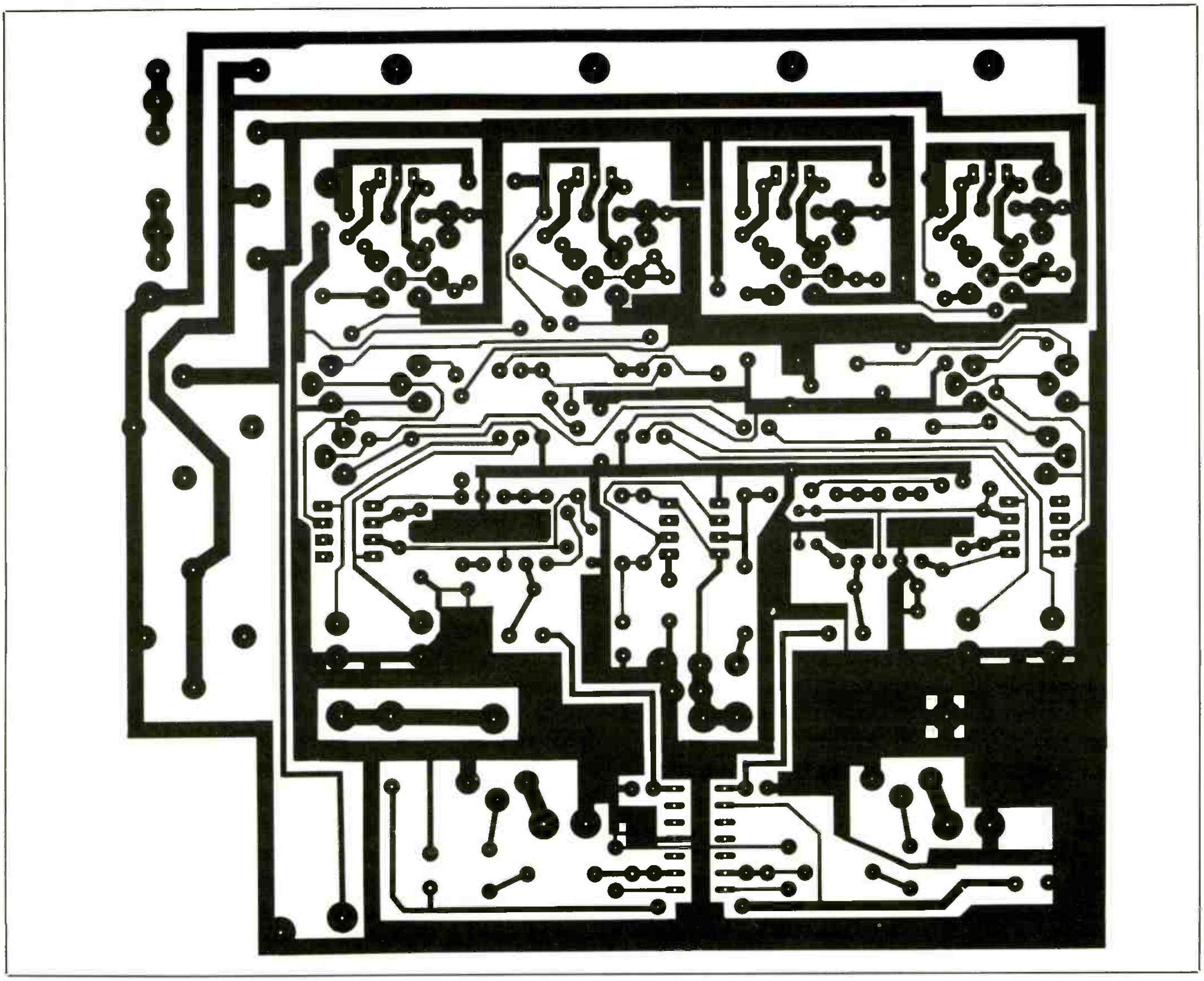


Fig. 6. The actual-size etching-and-drilling guide for the printed-circuit board on which the amplifier circuitry is wired. With just a few wire jumpers (J), the complex circuit wires neatly on a single-sided board.

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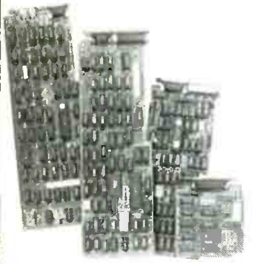

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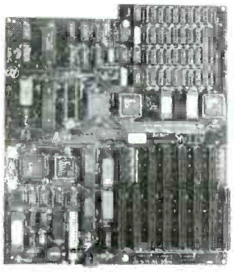

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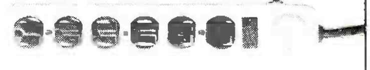

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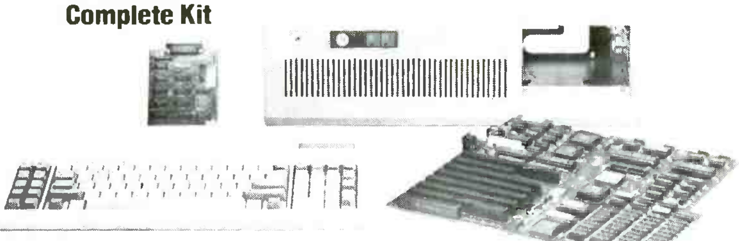

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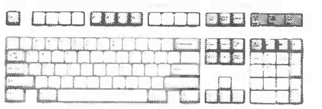

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switch on the front panel.

Referring to the schematic diagrams and pc wiring guide, prepare the wires to interconnect the various elements. Use shielded audio cable to make the connections from the input jacks on the rear panel of the enclosure to the appropriate points on the circuit board. Ground these input cables only at the board end.

Strip ½ inch of insulation from both ends of a 4-inch length of 16-gauge hookup wire. Twist together the wires at both ends and tin with solder. Feed one end of this wire through the hole between *C20* and *C21* and carefully solder it flat against the outer (ground) trace on the other side of the board. Make sure this wire touches *only* the ground trace. If it touches any other nearby trace, it will create a short circuit in the power supply and cause considerable damage to the circuitry on power-up. Connect and solder the other end of this wire to one solder lug under the terminal strip's nut.

Referring to Fig. 5, wire together the power transformer, ac receptacle/emi filter and power switch, using the terminal strip's lugs for intermediate connection points. Keep in mind that *all* ground connections, even those for the inputs and speaker outputs, must go to the *same* grounding point, using the remaining solder lug at the terminal strip, used for the dc power supply ground lead.

Trim the red POWER LED's anode lead and both leads of a 1,000-ohm, ¼-watt resistor to ½ inch long. Solder one resistor lead to the LED's anode lead. Then solder an 8-inch length of hookup wire to the cathode lead and and another 8-inch wire to the free resistor lead. Slide a 1½-inch heat-shrinkable tube over both wires, push them up flush with the bottom

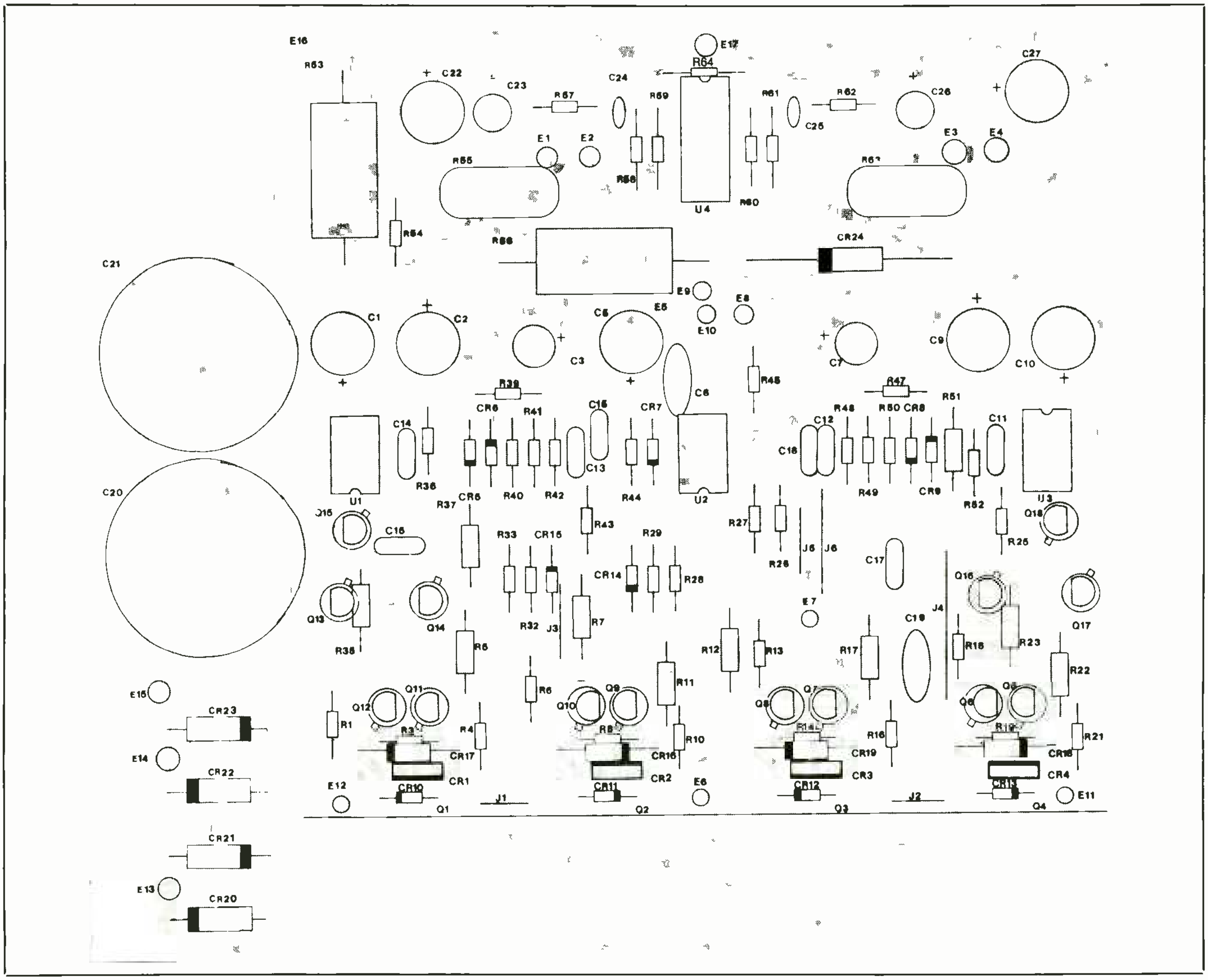


Fig. 7. The wiring guide for the pc board. The leads of power MOSFETs Q1 through Q4 plug into holes in the board but these transistors are physically mounted on a heat sink that is itself mounted on the board.

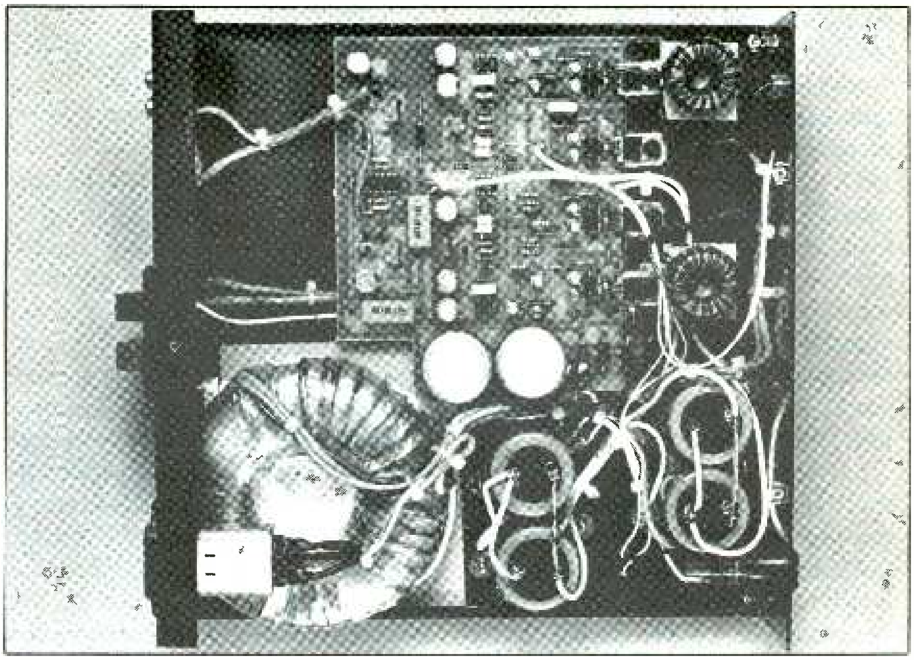
of the LED's case and shrink the tubing into place. Trim both leads of the green AUDIO LED to ½ inch long and solder an 8-inch length of hookup wire to each lead. Insulate each connection with heat-shrinkable tubing as you did for the POWER LED.

Solder the cathode wire of the red POWER LED into hole E5 and the anode wire into hole E10. Similarly, solder the cathode wire of the green AUDIO LED into hole E8 and anode wire into hole E9. Mount the two LEDs via panel clips in their respective retaining clips on the front panel of the enclosure.

Operational Check

Before mounting the amplifier board assembly in the enclosure, run a check to assure proper performance. Be extremely careful to avoid shorting the power supply's outputs together, to circuit ground or any other points in the circuit that they are not supposed to go. Shorting anything on the amplifier board will almost certainly destroy some semiconductors. Therefore, before performing the following tests, place a thick insulator (Masonite, cardboard or even a folded towel) between the amplifier board and the bottom panel of the enclosure.

First check the power supply. Verify with an ohmmeter that there are no shorts between the 117-volt ac input and ground and between either speaker output and ground. If you have a variable transformer (variac), use it to slowly bring up the power to the amplifier as you monitor input current. Ac input current with no speakers connected to the outputs should never exceed 0.1 ampere. You should measure +32 volts to ground at the + side of *C20* and −32 volts to ground at the − side of *C21*. If either or both of these voltages are low or absent, check the phasing of *T1*'s secondary windings. After checking the power supply, turn off the power and bridge the terminals of *C20* and *C21* with a 10-ohm, 5-watt resistor to discharge them.



This interior view of the assembled amplifier shows the toroidal power transformer mounted on an insulating plate (lower-left) and output filter chokes on the power MOSFET heat sink (upper-right). Four large capacitors (left) in this early production prototype were found to be unnecessary and have been eliminated in the latest version of the amplifier.

With the outputs of both channels left open, turn on the amplifier. An ammeter in the input to the power supply should register less than 0.1 ampere on power-up and slightly increase as the output stages turn on and the AUDIO LED lights.

Connect an analog—*not* digital—multimeter across one speaker output. If you measure more than 1 volt dc (positive or negative) with no input to the amplifier, power down and rectify the problem immediately. Continued operation with a short circuit on the amplifier board can quickly destroy components.

Once both amplifier channels are oscillating properly, connect a small 4- or 8-ohm speaker to the output of one channel. You may hear a small amount of hiss with no input to the amplifier and no shield on the bottom of the amplifier board. Set *R55* and *R63* to about the middle of their rotation. Carefully touching with your fingertip pin 3 of *U1* for the right channel or *U3* for the left channel, depending on the channel to which you connected the speaker, should generate a humming sound in the speaker. Repeat the procedure for the other channel to verify that both are working as they should.

Power down the amplifier and connect to it an audio program source (CD player, tuner or tape deck) that delivers audio at a line-level amplitude. If you have two small 4- or 8-ohm speakers, connect one to each of the speaker outputs. If not, check each channel separately. If the signal source has a level control, turn this down all the way to be on the safe side. Then power up both the amplifier and signal source and adjust the level control of the latter upward until you hear the audio from the speaker(s). If everything checks out okay, your amplifier is ready for final assembly.

If you bench test the amplifier, keep all unshielded leads as short as possible and all inputs away from the speaker outputs. You can use any 4-ohm load you wish, though as the inductance of the test load increases so does the r-f across the load. No. 1157 automotive tail lamps connected in parallel serve as a suitable load. This lamp draws about 2.5 amperes at 12 volts, for a load of 30 watts, and can take quite a bit of abuse for a brief period. If you view the amplifier's outputs on an oscilloscope, be prepared to see some unusual waveforms!

Looking at the outputs ahead of the inductors will reveal a 64-volt peak-to-peak square wave. As the input level to the amplifier is increased, you'll notice the square wave's duty cycle changes at the frequency of the input signal. This effect is immediately visible below 10 Hz.

Power down the amplifier, unplug its ac line cord and the signal source, disconnect the speaker(s) and discharge *C20* and *C21* as described above. Turn over the amplifier board and, with a hot iron, "wet" with solder the perimeter *ground* trace of the board at 3-inch or so intervals all around, except along the edge near *C20*, *C21* and *CR20* through *CR23*. Then tack-solder ½- to ¾-inch lengths of solder wick to the ground trace in each location. Keep the solder wick in a continuous piece as you solder it to each wetted area in turn, snipping it to length after the solder has set. When you're finished, carefully check to make sure that the braid and solder touch *only* the ground trace.

Place the pc-blank shield you prepared earlier against the bottom of the circuit-board assembly, unclad side facing the solder side of the amplifier board. Once again, wet with solder the areas on the copper-clad side of the pc blank that line up with the braid. Bend over the braid until it touches the pc blank and tack-solder it into place.

Mount the amplifier board on the floor of the enclosure. Only two sets of machine hardware are needed for this. The heat sink supplies all that's needed for physical support.

Installation

This amplifier generates and uses radio-frequency energy in the form of fast rising and falling square waves that are rich in harmonics. These r-f harmonics can cause interference with received radio signals if careful installation practices are not followed. For the speaker runs, use 14-gauge single-conductor *shielded* cable, with the inner conductor going to the "hot" and the shield going to the "common" speaker output connectors. If you cannot find such heavy speaker cord, tie together the two inner conductors of the two-conductor shielded speaker cable sold by Radio Shack and others and use the shield as a signal ground. Alternatively, you can connect the inner conductors separately to the speaker output connector pair and terminate the shield at the grounding connector on the rear panel of the amplifier but do *not* connect the shield at the speaker end; in fact, cut off the shield at the speaker ends of the cables if they are not used as one side of the speaker lines.

If you use piezo-type tweeters, install a 50-ohm, 2-watt resistor in series with each to remove any residual r-f from the amplified signal. The very-capacitive nature of the piezo tweeter can drastically affect performance of your amplifier. Any r-f not removed by the amplifier's filter inductor is averaged into dc power by any conventional PM speaker.

After installing the amplifier into your sound system, power up the equipment and listen for sound levels from your speakers at various settings of the volume control on your preamplifier/control center. If you notice that the preamp's control has insufficient range to drive the amplifier/speaker combination to loud enough levels, you may have to readjust *R55* and *R63* for more amplifier input "sensitivity." On the other hand, if you find that the amplifier is driven to maximum power at low settings of the preamp's volume control, you have to back off on *R55* and *R63*. What you want is for the preamp's volume control to give you a reasonably wide range of volume settings, with full power available near the control's maximum setting.

As you listen to music, should you notice excessive high-frequency preemphasis, evidenced by a slight harshness in upper frequencies, you can reduce it by substituting smaller-value capacitors for *C12* in the left channel and *C13* in the right channel. The value of these capacitors is specified in the Parts List as 0.0022 microfarad. Substituting 0.001-microfarad capacitors for them would be a good first (and probably final) stab at flattening the preemphasis response with the specific speaker systems you are using.

Matching the lightweight and compact power amplifier (it measures only 10 × 10 × 3 inches) with high-quality stereo components, you can enjoy the exemplary sound that can be produced only by digital means. If your compact disc player has a level control, you can use this amplifier without a preamplifier, too.

Author's Specifications

Output Power: 100 watts/channel rms into 4 ohms, 63.9 watts/channel rms, both channels driven

Power Amplifier Distortion: Voltage-type distortion measurement not possible due to digital waveform; distortion is presumed to be very low because the only sources of distortion are: The ramp, which is very linear (current source to capacitor voltage ratio is 6,400:1 minimum); the filter choke, which has a high-quality frequency alloy core that assures maximum linearity.

Preamplifier Distortion: 0.05% THD at 1 kHz

Channel Separation: 60 dB

Photography: Tracey Trumbull

The State of Op-Amps

What designers have devised during the past year or so to improve in every way the ubiquitous operational amplifier

By Dan Becker

Operational amplifiers were originally built from discrete transistors, capacitors and resistors on printed-circuit boards. These "subassemblies" served as basic building blocks for exotic analog instruments and computers. Built from discrete components, early op amps were expensive, bulky and power hungry. They reigned supreme in their own special nook until the 1960s when advancements in semiconductor processing, in the form of integrated circuits, made possible entire circuits on a single silicon "chip." The introduction of integrated-circuit technology to semiconductor manufacturing suddenly made it practical to mass-produce miniature, low-power op amps. And because IC op amps were low in cost, even back then, applications began to grow at a tremendous pace.

One of the earliest of the successful op-amp designs was the historic 741 device, which quickly became the foundation for many new circuits and projects. So entrenched has the 741 become that it remains in wide use even today, its pinout arrangement a generally accepted industry standard for op-amp devices. But time marches on, and so does technological development. Improved and pin-compatible JFET op amps are now often used in place of the original all-bipolar 741 and similar op-amp versions.

Setting the Stage

Although the schematic symbol for the operational amplifier, shown in Fig. 1, has not changed over the years, performance levels of the newest state-of-the-art devices have dramatically improved. Circuit designers continue to make steady progress toward achieving previously unheard of performance:

- Unity-gain bandwidths of 5 gigahertz
- Input bias currents of 40 femtoamperes
- Slew rates as high as 1,400 volts/microsecond
- Input offsets of 40 microvolts
- Input noise of 1.1 nanovolts/$\sqrt{Hz}$ at 1 kHz

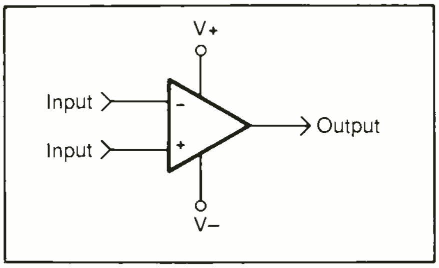


Fig. 1. The commonly accepted schematic symbol for the operational amplifier.

All of these are realizable goals, though not currently all in the same device.

To achieve this kind of performance, op-amp manufacturers devised and combined several new technologies. Some combine special circuit designs with newly developed semiconductor processes, most using their own combinations of new techniques to achieve high-performance products. At the present time, it is impossible to find a single op amp that contains the best of all features. However, with the rapid pace of development in this industry, it may not be long before even this will be possible.

During the past year, many new high-performance IC op amps have become available. Each excels in one or more areas and exhibits outstanding overall specifications. Since some of these hot new op amps are even targeted for consumer products, there is a good chance that not too far in the future they will show up in the experimenter/hobbyist marketplace.

Each of the new generation of op amps generally falls into one of three price/performance categories: JFET-input devices, MOS-input devices and bipolar-input devices. Details of these three different types of devices are illustrated in Fig. 2.

JFET devices generally feature lower input bias and difference currents and lower offset voltages, and they are less affected by changes in temperature than are their MOS and bipolar counterparts. Specifications are often stated in terms of "guaranteed" values.

JFET noise performance in the 1-to-10-Hz range (1/f noise) may be as much as 10 times better than for comparable MOS devices. Prices for these devices range from about $8 to $75 or so in OEM (original equipment manufacturer) quantities of 100 or more pieces.

Latest-generation MOS-input op amps offer cost-effective solutions to many circuit design problems for which heretofore no solutions what-

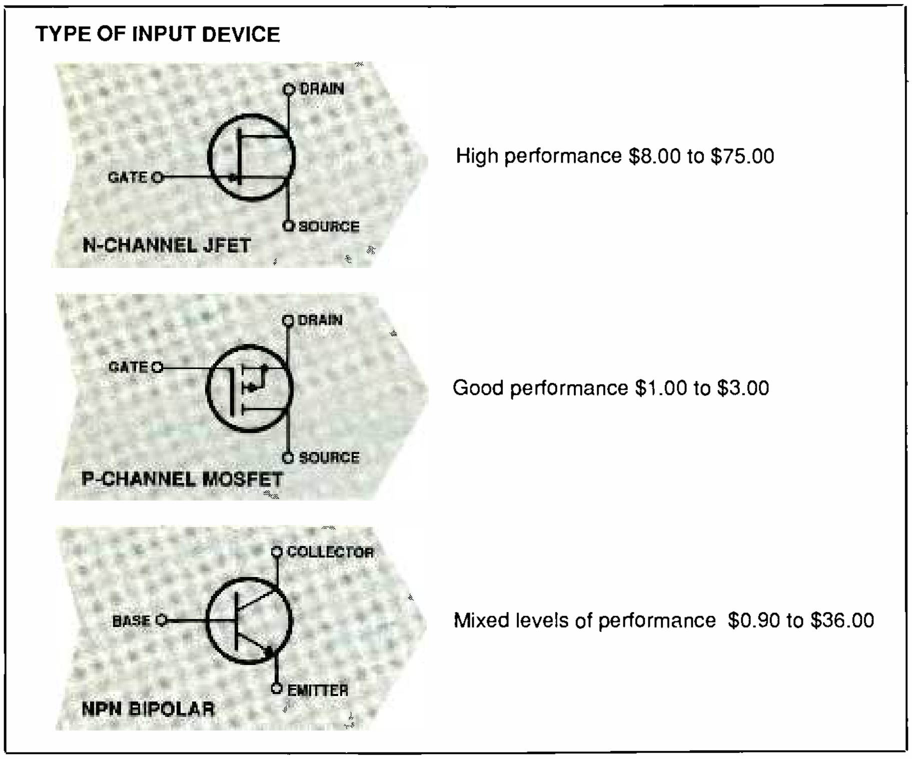


Fig. 2. How the three types of op-amp input devices relate to each other in price/performance.

ever existed. Although their specifications may closely parallel those of JFET devices, values for MOS devices are often given in terms of "typical" (not guaranteed) performance. Prices for these devices range from about $1 to $3 or more in OEM quantities.

Op amps with bipolar input transistors have features that vary over a wide range and offer unparalleled performance in many specific areas. Prices for these devices also vary widely, depending on combinations of features and levels of performance.

User Friendliness

Manufacturers are increasingly aware of the need to make products and devices "user friendly." For op amps, this means simplifying operation over a wide range of supply voltages and temperatures. The present industry trend is toward making op amps that can operate from single-ended power supplies, mainly the 5 volts popularly used in digital and many analog circuits, in addition to more conventional and traditional split supplies. Moreover, because operation from the new 3.3-volt standard is now an important consideration, some op amps can already meet this requirement.

As with input bias current, limiting quiescent power dissipation is of major interest in many applications. Reducing power requirements puts less of a demand on system designers and the power supply components used, making user friendliness a practical reality.

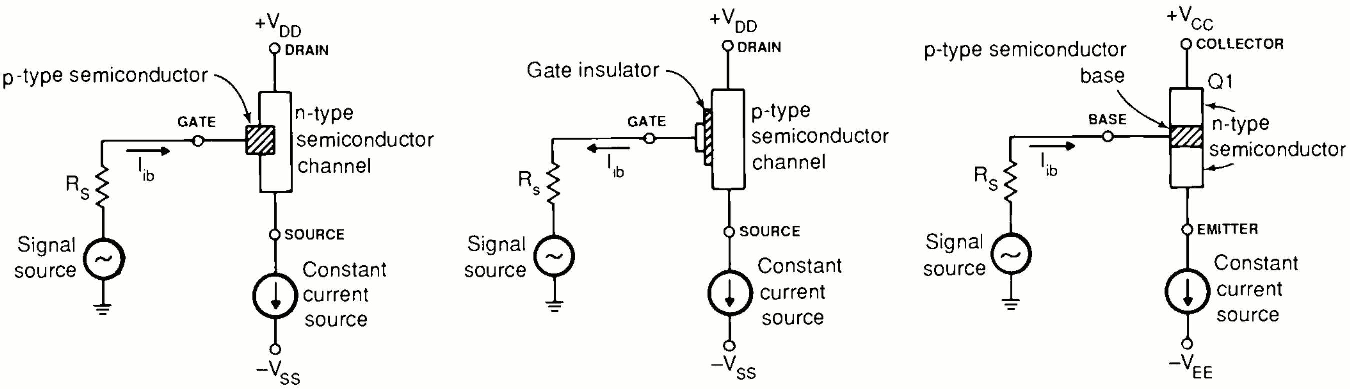
Let us now examine a few of the most important operational amplifier features:

● *Input Noise.* Much of the difference in cost between JFET and MOS op amps lies in the difficulty and length of time required to precisely measure and/or ensure a given IC's performance. For example, if a 1/f noise is an important consideration, op amps with JFET input transistors often come with more complete noise performance information. Generally, JFET data sheets specify both typical spot noise (noise at only one frequency) and typical broadband noise. JFET devices can give as much as 10 times better 1/f noise performance than MOS-input devices. Typical JFET spot noise, measured from 0.1 to 10 Hz, is 4 microvolts peak-to-peak. Typical broadband noise, measured from 10 Hz to 10 kHz, is generally 2.4 microvolts., Spot noise at 10 kHz may also be specified.

You should keep in mind that there are always exceptions to any rule. Linear Technology's LT1028 op amp is a case in point. Designed to amplify signals of a few millivolts or less from low source impedances, this bipolar op amp features input noise figures of 1.9 $nV/\sqrt{Hz}$ at 10 kHz, 1.1 $nV/\sqrt{Hz}$ at 1 kHz and 90 nV p-p over a range of from 0.1 to 10 Hz. These levels are well below those for FET devices. However, as good as they are, input current noise levels for the LT1028 cannot compete with those of certain MOS devices in which noise currents are almost nonexistent.

Noise figures are given as typical values because of the high cost of measuring noise in a production-line environment. When you consider that 1.6 minutes is required to accumulate 10 cycles of 0.1-Hz noise, you can well understand why many manufacturers give typical noise ratings. To give actual (or guaranteed) noise figures would be prohibitively expensive in all but an almost infinitesimally small number of cases. Nevertheless, because input noise is often the limiting factor in voltage measurement resolution, manufacturers continue to strive for product improvements, even if this means added expense.

● *Input Bias Current.* In a similar way, accurate measurement of input bias currents in the femtoampere range is also difficult to perform and



(A) JFET. Dc gate leakage current flows through signal source and across reverse-biased pn junction (gate junction) and into the n-channel. Gate leakage current is an undesirable effect.

(B) MOSFET. Dc gate leakage current flows through gate insulator and signal source and into p-channel. Gate leakage current is an undesirable effect.

(C) Bipolar. Dc base (bias) current flows through signal source and into base-emitter junction, forward biasing Q1. Base current is an essential part of bipolar transistor operation.

Fig. 3. Fundamental sources of input bias current (I_{ib}) for the JFET (A), MOSFET (B) and bipolar (C) transistor.

adds to production-line costs. Guaranteeing input bias currents and input difference currents in the femtoampere range is what separates higher-priced JFET devices from their lower-cost companions whose input bias and difference currents are given only in terms of "typical" performance. Therefore, this and other similar processing technologies offer vast improvements in performance, though at a price that is relative to performance predictability.

To minimize input bias current in both JFET and MOS devices, input stages use field-effect transistors, or FETs, that are often special versions of junction field-effect transistors, or JFETs. They include dielectrically isolated (DI) JFET, the junction-isolated FET, PMOS and silicon-gate CMOS devices. All these special transistors are used because of their extremely low input bias (leakage) current characteristics. Bias currents amounting to as few as 60 electrons per millisecond (1 femtoampere) are achieved. Figure 2 shows details of these transistor devices.

Typical applications requiring low input bias currents include integrators, current-to-voltage converters and log function generators. In addition, many transducers exhibit high internal resistance. These include transducers for measuring pH, photodetectors, accelerometers and numerous piezoelectric devices.

Consider a transducer with a high internal resistance connected to the input of an op amp. Input bias current flows through the transducer (signal source in Fig. 3), which causes a voltage drop across the transducer and is equal to the bias current times the transducer's resistance. This kind of input voltage reduces the accuracy and resolution of a measurement. The low input bias current op amp minimizes this type of error voltage.

● *Offset Voltage*. Examining data sheets on these new op amps makes it apparent that offset voltages are down significantly from where they were just a short time ago and that JFET devices often exhibit better performance in this area than other devices. In some cases, lasers are used to trim the minute semiconductor components of the JFET's input stage to "tweak" the offset voltage to within guaranteed values. Because this is an added manufacturing expense, it inevitably shows up as an increase in the cost of the device to OEM users and, ultimately, end purchasers of any product in which these devices are used.

● *Temperature Effects*. Input bias current, input difference current and input offset voltage all drift (change) with changes in temperature, which accounts for one of the major sources of error in most precision applications. Therefore, it is important to minimize these factors at all temperatures. As one example of temperature's influence on device performance, for every 10-degree celsius increase, input bias current will approximately double. Hence, manufacturers usually state a maximum bias current at 70 degrees celsius (125 degrees celsius for military versions) for op amps with JFET inputs. Alternatively, some op amps feature bootstrapped inputs and external pins that permit nulling the bias current and/or offset voltage.

● *Static-Discharge Protection*. Unfortunately, diodes must be connected across the inputs to protect the sensitive gates of the FETs used in op-amp input stages from damaging static discharges. These diodes

Performance Specifications for Some New High-Performance Integrated-Circuit Operational Amplifiers

Manufacturer	Device	Single/Split Supply Voltage	Supply Current	Input Type	FP*/UG** Bandwidth	Input Bias	Input Offset	Slew Rate (Vμs)	100-pc. Price Ea.
Advanced Linear Devices 1030 W. Maude Ave. Suite 501 Sunnyvale, CA 94086	ALD1701	2 ~ 12/ ±1-±6	250 μA	MOS	NA/700 kHz	1 pA	1 mV	0.7	$1.83
Anadigics Inc. 35 Technology Dr. Warren, NJ 07060	AOP3510	NA	NA	Bipolar	70 MHz/ 350 MHz	NA	NA	1,200	$32.75
Analog Devices Inc. Semiconductor Div. 804 Woburn St. Wilmington, MA 01887	AD549L	NA/±15	200 μA	JFET	NA/700 kHz	60 fA	500 μV	2	$15.45
Burr-Brown Corp. P.O. Box 11400 Tucson, AZ 85734	OPA-128L	NA/±15	NA	JFET	NA/500 kHz	75 fA	500 μV	1	$23.95
	OPA-128K	NA/±15	NA	JFET	NA/500 kHz	150 fA	500 μV	1	$18.95
	OPA-128J	NA/±15	NA	JFET	NA/500 kHz	300 fA	1 mV	1	$12.50
	OPA-600	NA/±15	NA	FET	NA/5 GHz	20 pA	NA	NA	$75.00
GE RCA Solid State Route 202 Sommerville, NJ 08876	CA5422	2 ~ 10/ ±1 ~ ±10	400 μA	MOS	NA/160 kHz	160 fA	1.8 mV	0.25	$1.95
Harris Corp. Semiconductor Sector P.O. Box 883 Melbourne, FL 32901	HA-5151	2 ~ 10/ ±1.5 ~ ±15	250 μA max.	Bipolar	80 kHz/NA	70 nA	500 μV	4.5	$5.20
Linear Technology Corp. 1630 McCarthy Blvd. Milpitas, CA 95035	LT1028	NA/±15	12 mA	Bipolar	NA/50 MHz	260 nA	40 μV	11	$4.95
Motorola Inc. Bipolar Analog Integrated Circuits Div. 7402 S. Price Rd. Tempe, AZ 85282	MC33171	NA/±15	180 μA	Bipolar	NA/1.8 MHz	NA	1 mV	2.1	$0.90
National Semiconductor 2900 Semiconductor Dr. Santa Clara, CA 95051	LC66OC	3 ~ 16/ ±1.5 ~ ±8	2.9 mA	MOS	NA/1.5 MHz	40 fA	1 mV	1.7	$1.45
Plessey Semiconductors 9 Parker St. Irvine, CA 92718-2892	SL2541	NA/±15	NA	Bipolar	40 MHz/ 2.5 GHz	NA	NA	1,400	$35.49
Precision Monolithics, Inc. 1500 Space Park Dr. P.O. Box 58020 Santa Clara, CA 95052	OP-80	2.5 ~ 8/±5	NA	MOS	NA/300 kHz	100 fA	1 mV	0.2	$1.40
	OP-90	1.6/±0.8	20 μA	Bipolar	NA/25 kHz	5 nA	NA	0.008	$2.75

*FP = Full-Power. **UG = Unity-Gain.

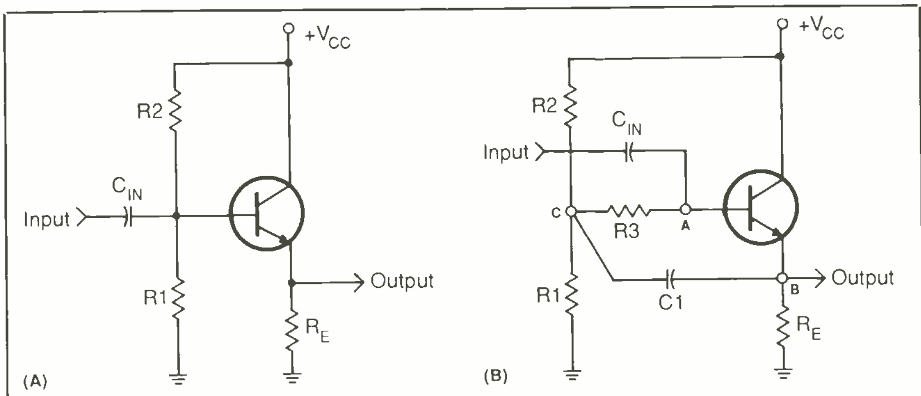
create an additional problem because their shunting action reduces the amplifier's input impedance. To counteract the undesirable effects of the diodes, while ensuring static protection to 1,000 volts or more, several ingenious bootstrapping techniques are employed. Figure 4 illustrates how bootstrapping counteracts the impedance-lowering effect of shunting components.

Mixed Technology

With power-supply potentials in the 2-to-15-volt range, bipolar transistors operate more efficiently than do FET devices when driving low-impedance loads. Therefore, with or without FET input devices, op amps inevitably use an all-bipolar output stage. One example is RCA's line of BiMOS (for bipolar metal-oxide semiconductor) devices (Fig. 5). A high-performance dual op amp like RCA's CA5422 combines MOS devices at the input stage with bipolar transistors in the output stage. These more conventional output transistors produce minimal quiescent power dissipation while providing the capacity to drive a low-impedance load.

There are several important points to consider when deciding on a specific op amp for a given application. Some of these include all of the above (input offset voltage, input bias current, input difference current and temperature stability) as well as bandwidth, quiescent power dissipation, slew rate, output drive current and, frequently just as important a factor as electrical performance, cost.

The new generation of op amps makes selecting an operational amplifier for a particular application an even easier task than it has been in the past. These new op amps open a whole new world of possibilities to the professional and hobbyist alike. As a result, test instruments with higher resolution, greater accuracy and the ability to measure much smaller currents will eventually reach the consumer. In the Table shown elsewhere in this article, we have listed several high-performance op amps from several different manufacturers, along with a number of their most important specifications. If you would like to get a headstart on these devices before they actually become generally available, you can write to the manufacturers to request advance data and applications sheets.



(A) A one-transistor voltage follower without bootstrapping has an input impedance that can be as high as 1 megohm. However, because the power supply (V_{CC}) acts like a short circuit for ac signals, bias resistors *R1* and *R2* are effectively in parallel and shunt the input signal to ground. This lowers the circuit's input impedance to that of the parallel equivalent of *R1* and *R2*. **(B)** Same circuit with dc bias network *R1/R2/R3* bootstrapped. Input impedance is about 1 megohm. Output signal voltage at point B is equal in amplitude and in-phase with input signal voltage at point A. Output signal voltage is connected to point C via *C1* to place equal and in-phase signal voltages at both points A and C and prevent input signal current from flowing through *R3*. Because it is isolated from dc bias network, point A is a high-impedance input. A similar bootstrapping technique is used in op amps to overcome low-impedance shunting effects of static-protection diodes.

Fig. 4. The principles of bootstrapping: a circuit without bootstrapping (A) and the same circuit with bootstrapping (B).

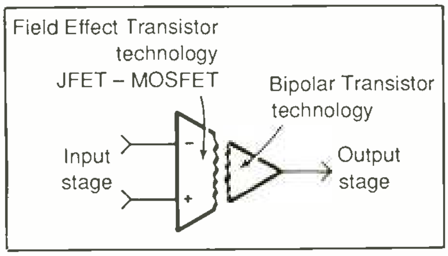


Fig. 5. A depiction of the modern combined-technology op amp.

A Homebrew Analog Computer

The author's reflections on his early-60's computer experiments

By Forrest M. Mims III

In the early 1960s, before the arrival of the integrated circuit and the microprocessor, do-it-yourself computer hobbyists were a rare breed. Some built primitive digital machines using stepping relays and indicator lamps, while others made analog models from potentiometers and meters.

While a student at North Junior High School in Colorado Springs in 1958, I was fascinated by articles about "electronic brains" in *Popular Electronics*, a magazine published for electronics hobbyists. Unable to afford the material to build a digital machine, I experimented with simple analog computers made from potentiometers and meters. I entered two of these machines, which solved simple arithmetic problems, in school science fairs.

Thanks to the inspiration of daydreams brought on by the daily task of memorizing long lists of vocabulary for a 10th grade Latin class, in the spring of 1960 I began designing an analog machine for translating languages. That fall I assembled a working version of the translator.

The translator worked poorly, but it placed third in the math division of a regional science fair. By the time I graduated from high school in the spring of 1962, the translator worked reliably. Its design was more complex, and it could be programmed to translate 20 words of one language into another.

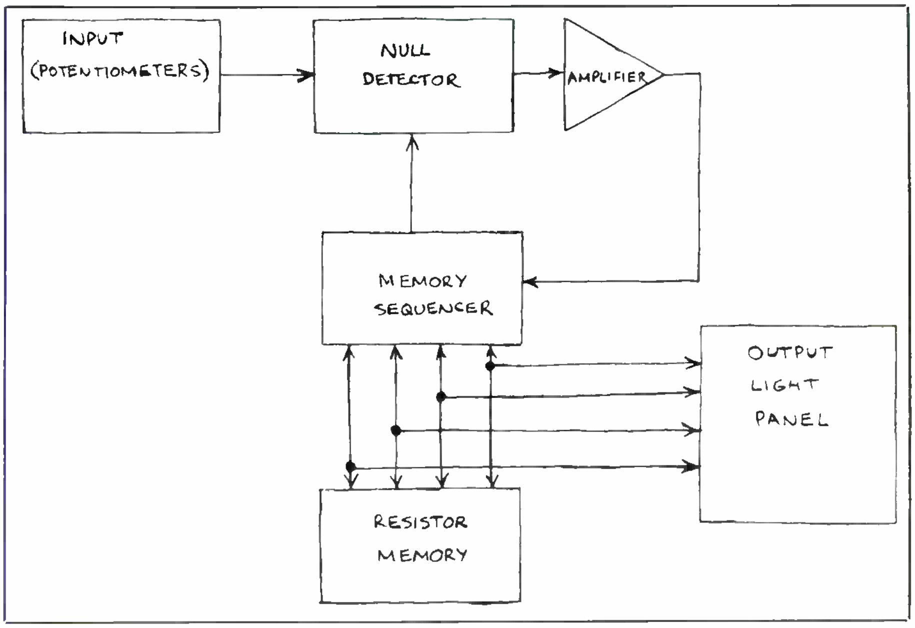


Fig. 1. Block diagram of analog computer language translator.

My translator, which required up to a second to match an input word with a word in its memory, was extremely slow by today's standards. It was also much bigger, heavier and had considerably less vocabulary capacity than a pocket phrase book, but it actually worked.

An Analog Memory

A unique feature of the translator was its use of an array of miniature screwdriver-adjustable trimmer resistors as programmable analog storage elements. Borrowing from today's terminology, the trimmer array could be considered an SPROM (Screwdriver-Programmable Read-Only Memory).

Twenty trimmers were provided, one for each word. Each word was manually set to a resistance corresponding to that of one of the words in the machine's vocabulary.

Figure 1 is a simplified block diagram of the machine. In operation, the first six letters of a word to be translated were dialed into an input panel containing six potentiometers connected in series. Each word provided a different resistance.

The first letter of the word was then dialed into a rotary switch on the machine's main control panel, and then the power was switched on. The machine then automatically compared the input resistance with each of the trimmer resistors in its

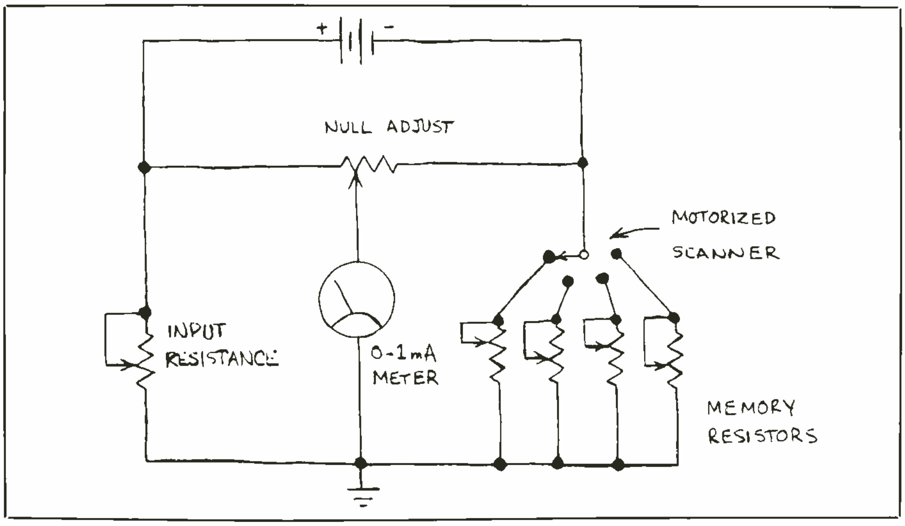


Fig. 2. Wheatstone bridge used in analog language translator.

memory. When a match was found, an indicator lamp corresponding to the translated word was illuminated.

The most complex part of the machine was its automatic memory search mechanism. The memory was organized into five banks of four trimmers each. One bank was selected when the front panel rotary switch was set to the first letter of the word being translated.

Music-Box Memory Scanner

In those days, I couldn't afford a stepping relay. Therefore, I modified a battery-powered music-box mechanism to sequentially scan each of the four trimmer resistors in the preselected bank.

The most difficult part of the design was devising a method to determine when the resistance of the word dialed into the input panel matched that of one of the trimmer resistors in the machine's memory. The obvious solution was to make each resistance one leg in a Wheatstone bridge, as shown in Fig. 2.

A potentiometer connected across the two resistors permitted the bridge to be balanced so that the current flow through each side of the bridge was equal when a match was made. A match was indicated when the pointer of a 0-to-1-mA meter connected across the bridge pointed to 0.

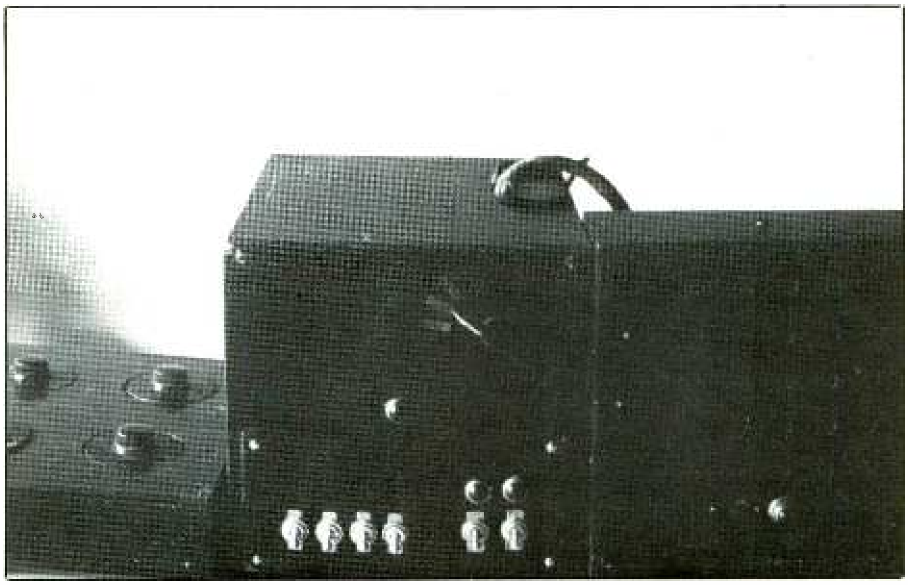
Figure 3 shows how a feedback loop from the meter back to the memory scanning circuit was implemented with the help of a homemade optoelectronic slot switch that detected when the meter pointer was at the 0 position. The slot switch then switched off the music-box motor.

To assemble the slot switch, I first cemented a small silicon solar cell directly over the zero-current position marked on the faceplate of the meter. Then I carefully cemented an aluminum-foil flag to the meter's pointer. Finally, I replaced the meter's glass faceplate with a sheet of black plastic. A slot cut into the opaque cover allowed light from a small lamp to strike the solar cell's sensitive surface when current flowed through the meter.

The solar cell was connected to a single-transistor amplifier whose output struck the cell. The relay's contacts were connected as a switch between the electromechanical memory scanning mechanism and its battery. Therefore, when the meter indicated a current, the solar cell was illuminated and the memory scanner continued to operate.

If the pointer moved to the zero position, thereby indicating a match in the resistance of the input and the sampled memory trimmer, the foil flag shaded the solar cell. This caused the relay contacts to switch off the motor-driven scanner while simultaneously applying power to a panel of incandescent indicator lamps. A single lamp glowed to indicate the translated word.

Though my analog language translator was a bit clumsy, it did work. Recently, I recovered it from



Controller/memory unit.

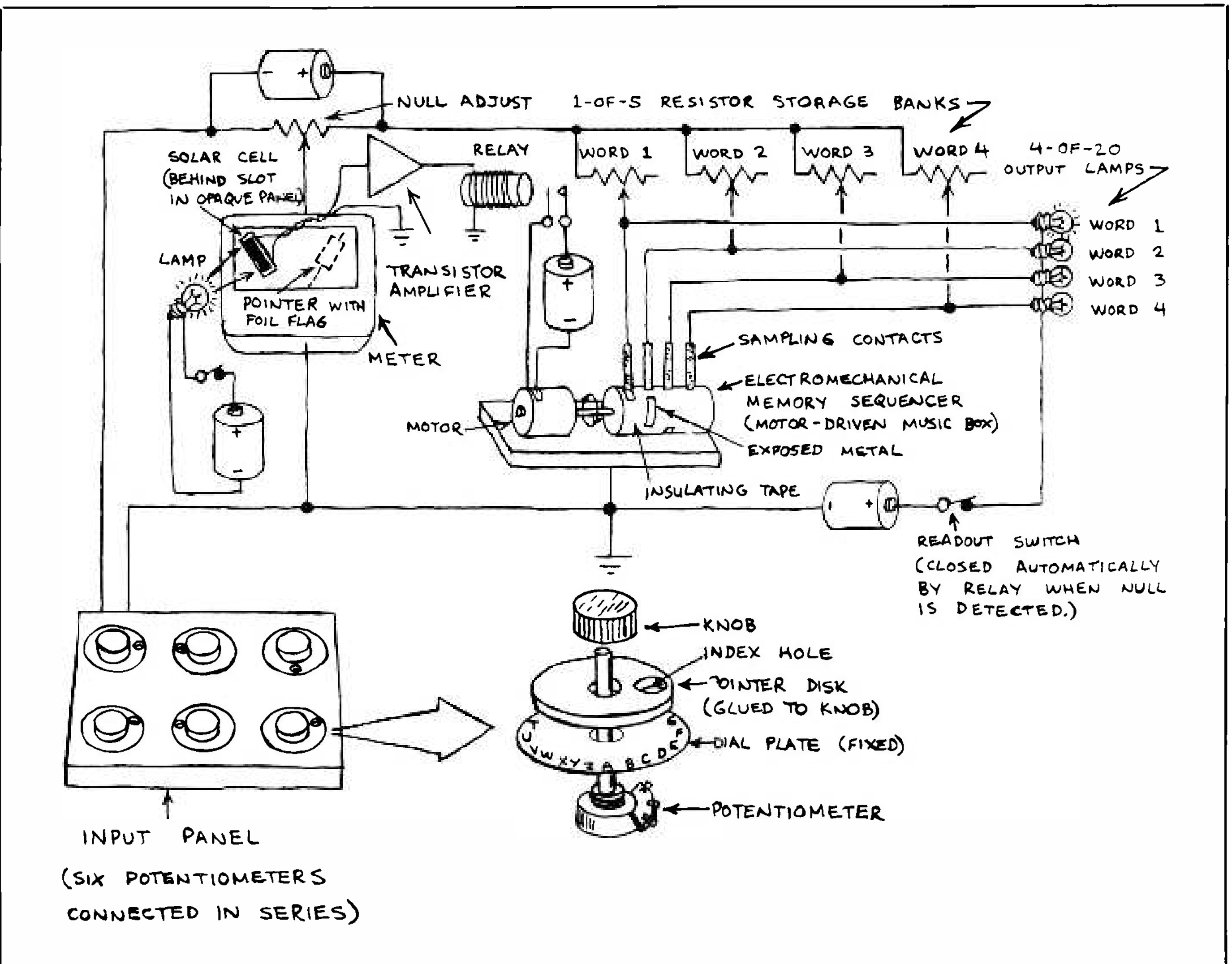


Fig. 3. Circuit and mechanical details of analog computer language translator.

the attic, wiped off the dust and inspected some of its hundreds of solder connections. Only two of the knobs on its input panel were missing. Everything else, from the meter pointer flag and the solar cell to the music-box scanner and trimmer-resistor memory board, is still in place.

Though more than 20 years old, the batteries have not leaked. When time permits, I'll replace them with a new set and find out if the translator still translates.

Lessons From the Past

Tinkering with this antique analog machine has made me acutely aware of the sophistication of today's computers. Nevertheless, I'm still attracted to that primitive but still viable method of using trimmer resistors as storage elements. Assuming a 100-ohm space between settings, a 1,000,000-ohm (1-megohm) trimmer can be "programmed" with a screwdriver to any of 1,000 different resistances. This is nearly the storage capacity of an 11-bit binary register.

Moreover, the music-box mechanism, meter, slot switch and relay of my old translator can now be replaced with several integrated circuits. A solid-state version could be designed around a comparator, some analog switches, a clock circuit and a decoder counter.

However, I wouldn't use an updated version of the translator for translation; that task is handled much more efficiently by digital processors. Instead, I would use it for controller applications that can best exploit the simplicity of a screwdriver-programmable read-only memory.

Imagine a miniature analog-digital machine that operates sequentially, has a programmable memory and responds directly to analog input signals. Perhaps I'll build a breadboard version and see how it works. **ME**

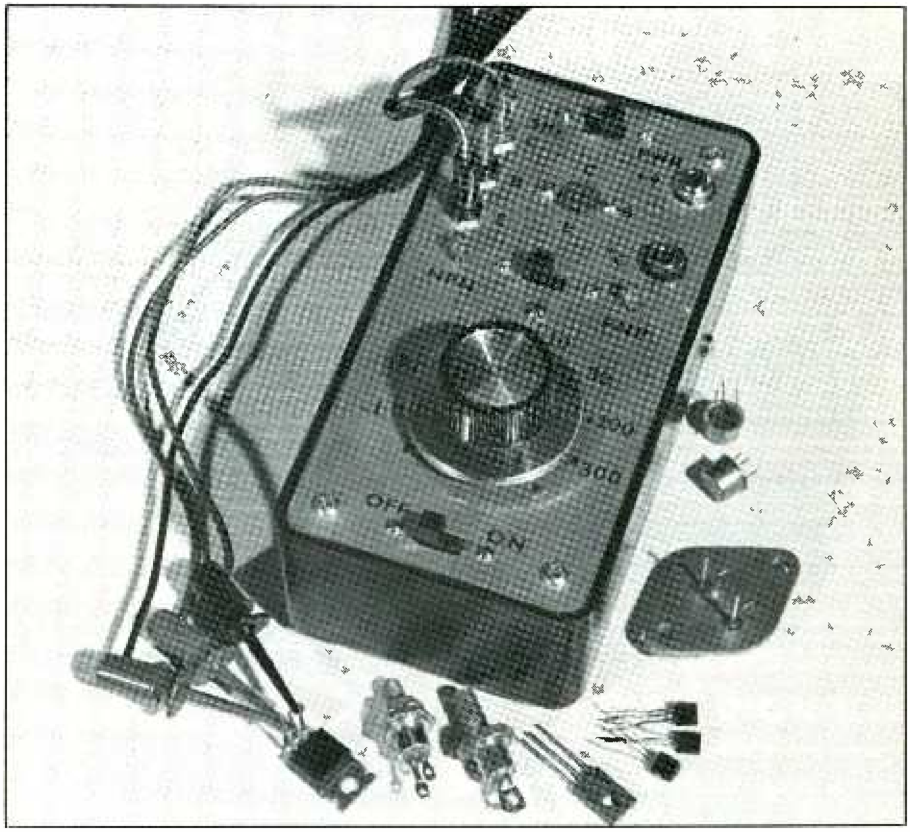
A Transistor/Diode/ SCR Tester

This simple project can be one of the most valuable you have on your testbench alongside your multimeter and oscilloscope

By Adolph A. Mangieri

If you're like most experimenters and professional service technicians, you probably have dozens or even hundreds of untested transistors and other discrete semiconductors. You could do some simple tests on these devices and the circuits in which they're used with an ohmmeter, but the results are often unsatisfactory. Having found yourself in this situation all too often, it's time you had a semiconductor tester like the transistor/diode/SCR tester to be described.

Our tester performs quick and reliable good/bad checks on a wide variety of discrete semiconductors. It provides a low-power signal test mode that virtually eliminates damage to even very-low-power devices. It also has a power mode that checks devices at higher currents. The low-power mode can be performed with either a battery or an ac-line-operated power supply. Because of the high-power demands of the power mode, the power supply here is strictly from the ac line. For maximum versatility, large-signal dc gain of transistors can be measured by plugging a common milliammeter into the tester.



About the Circuit

Shown in Fig. 1 is the complete schematic diagram of the transistor/diode/SCR tester. Socket *SO1* provides the means for connecting low-power (milliwatt) transistors to the tester. Jacks *J3, J4* and *J5* parallel the connections to *SO1* and provide the means for connecting medium-power and high-power transistors to the tester.

The tester is powered by 9-volt transistor battery *B1* or a plug-in ac power supply that outputs 9 volts filtered dc at 300 milliamperes or more. Voltage regulator *IC1* supplies a stable 5 volts dc to the tester circuit.

Switch *S3* applies +5 volts dc to the V_{cc} bus when switched to check npn transistors and reverses the polarity supplied to the bus when switched to check pnp transistors. Jack *J2* permits insertion of a dc milliammeter that can be used to indicate collector current when measuring the dc gain of a transistor. If you wish, you can make the milliammeter a permanent part of the circuit, replacing *J2* with a switch that con-

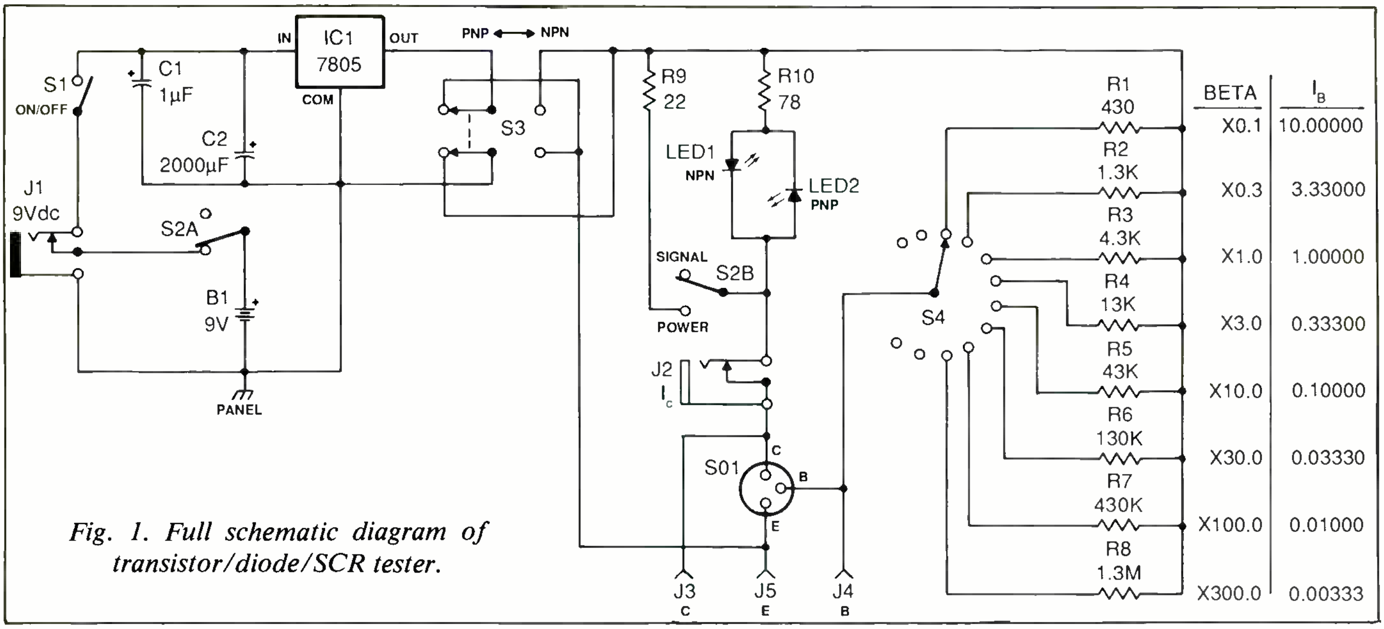


Fig. 1. Full schematic diagram of transistor/diode/SCR tester.

PARTS LIST

Semiconductors
IC1—7805 +5-volt regulator
LED1,LED2—Light-emitting diode
Capacitors
C1—1-µF, 35-volt tantalum electrolytic
C2—2,000-µF, 25-volt electrolytic (see text)
Resistors (½-watt, 5% tolerance)
R1—430 ohms
R2—1,300 ohms
R3—4,300 ohms
R4—13,000 ohms
R5—43,000 ohms
R6—130,000 ohms
R7—430,000 ohms
R8—1.3 megohms
R9—22 ohms (5-watt, 10% tolerance)
R10—78 ohms
Miscellaneous
B1—9-volt transistor battery
J1,J2—Miniature closed-circuit phone jack
J3,J4,J5—Insulated tip jack
S1—Spst slide or toggle switch
S2,S3—Dpdt switch
S4—Single-pole, 12-position nonshorting rotary switch
SO1—Chassis-mount transistor socket
Suitable project box with metal panel; snap connector and holder for B1; control knob for S4; labeling kit; machine hardware; hookup wire; solder; etc.

nects and disconnects the meter as desired.

Switch *S4* provides a means for selecting one of eight base currents ranging from 0.0033 to 10 milliamperes. Each setting of *S4* has a multiplier, as listed along the right side of the schematic in line with the given switch position. The multiplier is used to measure dc current-transfer ratio (beta or h_{FE}). For example, with *S4* set to ×100 and a measured collector current of 0.76 milliampere, gain is 100 × 0.76, or 76 milliamperes. The multipliers are the reciprocals of the base current. For instance, at a ×10 setting, base current is 1/10, or 0.1 milliamperes.

Switch *S2* allows you to select either the signal (SIG) test mode for low-power tests of devices or the power (PWR) mode for higher-current tests of medium- and high-power devices. In the SIG mode, the tester is powered by either battery *B1* or the ac adapter. In the PWR mode, the tester is powered by only the ac adapter plugged into *J1*.

In the SIG mode, the transistor collector-load circuit consists of *R9* connected in series with *LED1* and *LED2*. Only one LED lights; which one depends on the setting of *S3*. Maximum collector current in the SIG mode is about 28 milliamperes. Maximum collector potential in this mode is 5 volts minus the 2-volt drop across the LED, or 3 volts. Maximum power delivered to the transistor under test is about 20 milliwatts, which is well within the handling capabilities of virtually every low-power device now available.

Battery *B1* is deselected when *S2* is set to the PWR mode. Resistor *R9* is in parallel with resistor *R10* and the light-emitting diodes. The LED begins to light when a power semiconductor under test conducts 100 milliamperes or more. With the transistor switched fully on, maximum current is 220 milliamperes. Maximum collector potential is 5 volts with the transistor in cutoff. Maximum power delivered to the transistor is about 275 milliwatts.

Resistor *R9* limits maximum collector current in the SIG mode to 28 milliamperes, which may be a bit too much for a very few r-f/vhf/uhf transistors that have maximum current ratings of only 20 milliamperes. These are not likely to be damaged by the 28-milliampere maximum current with the value of *R9* specified. However, if you want to make certain that you're on the safe side, you can substitute a 150-ohm resistor for *R9* to limit maximum current to 20 milliamperes.

Construction

Assemble the tester on the metal front panel of a small project box, as shown in Fig. 2. Bolt *IC1* directly to the panel. Then mount *R9* and *R10* on a terminal strip and *R1* through *R8* via the lugs of *S4*. Mount the LEDs on the front panel in holes lined with small rubber grommets (friction fit), using fast-set clear epoxy cement or in standard LED panel clips. Insulate *J2* from the metal panel, and use insulated tip jacks for *J3, J4* and *J5*. Install a battery clip inside the project box for *B1*. Then use a dry-transfer lettering kit or a tape labeler to label the front panel (see Fig. 3).

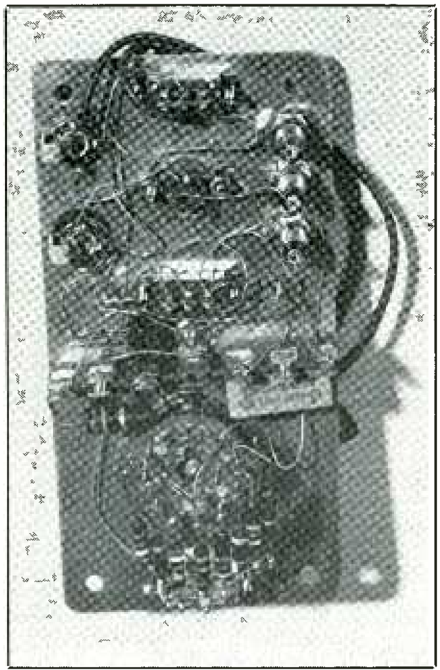


Fig. 2. Tester is assembled on metal panel of small project box.

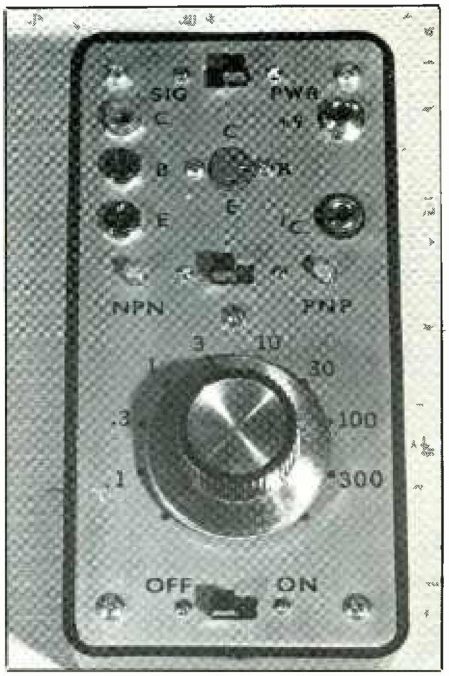


Fig. 3. Suggested front-panel layout, with appropriate panel labeling.

If you use an ac adapter that delivers between 9.5 and 12.5 filtered dc volts at 500 milliamperes, omit *C2* from the circuit. A power supply for a Timex/Sinclair TS1000 computer makes a satisfactory power supply if you have one handy. If you use a power supply rated at 6.5 to 7.5 unfiltered volts dc at 600 milliamperes, install *C2* as shown in Fig. 1.

To check your wiring, set *S2* to SIG and close *S1*. Verify with a dc voltmeter that +5 volts appears at the OUT terminal (pin 3) of *IC1*. Set *S3* to NPN and verify that +5 volts is on the V_{cc} bus (top rail that goes to all resistors in Fig. 1). Connect a jumper wire between *J3* and *J5* and verify that *LED1* lights. Now set *S3* to PNP and verify that *LED2* lights. Connect a milliammeter across *J3* and *J5*; the short-circuit current should be about 28 milliamperes. Connect the 9-volt dc power supply to *J1* and set *S2* to PWR; the short-circuit current should be about 220 milliamperes.

Set *S2* to SIG and *S3* to NPN. Now, using clip leads, connect any general-purpose low-power npn silicon transistor to the tester in the proper basing arrangement and connect a milliammeter in series with the base test lead. Rotate *S4* through each of its positions and verify the nominal base currents listed in Fig. 1. Keep in mind that measured base currents might be on the low side, the result of meter resistance.

Plug the 9-volt dc adapter into *J1*, set *S2* to SIG and *S3* to NPN, and plug a milliammeter into *J2*. Connect a voltmeter to the collector and emitter terminals to measure collector voltage. Set *S4* to an unused position for zero base current. The LED should now be off, collector current should be near zero, and collector potential should be about 3 volts. Advance *S4* in steps from $\times 0.1$ upward while observing LED brightness and meter indications. In several positions of *S4*, the LED will be brightly lit, collector voltage will be very low and collector current will be maximum, all indicating that the transistor is operating in full saturation.

As you further advance the setting of *S4* clockwise, the LED will go to half brightness, collector voltage will rise and collector current will drop, indicating that the transistor is now operating in its linear region where dc gain measurements can be made. Transistor dc gain is equal to collector current in milliamperes multiplied by *S4*'s multiplier.

Set *S2* to PWR for higher current tests and repeat the above procedure. Notice now that the LED may go from full on to full off in one position of *S4*. This is because the LED doesn't begin to conduct until collector current reaches about 100 milliamperes.

Test Procedures

Each of the various semiconductor tests that can be made with the transistor/diode/SCR tester for different types of devices has its own special procedures. The following describes each procedure:

• *Diode Tests.* Test low-power diodes in the SIG mode to automatically limit current flow. Test rectifier diodes in either mode. Figure 4 shows the symbols and polarities of volt-

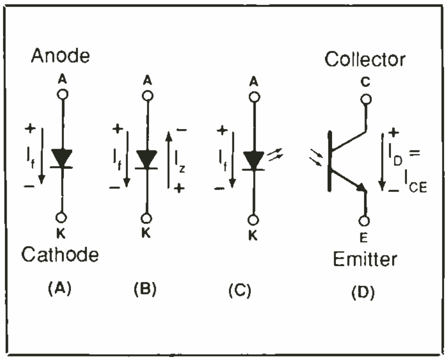


Fig. 4. Symbols and polarities: (A) rectifier diode; (B) zener diode; (C) light-emitting diode; (D) photo-diode.

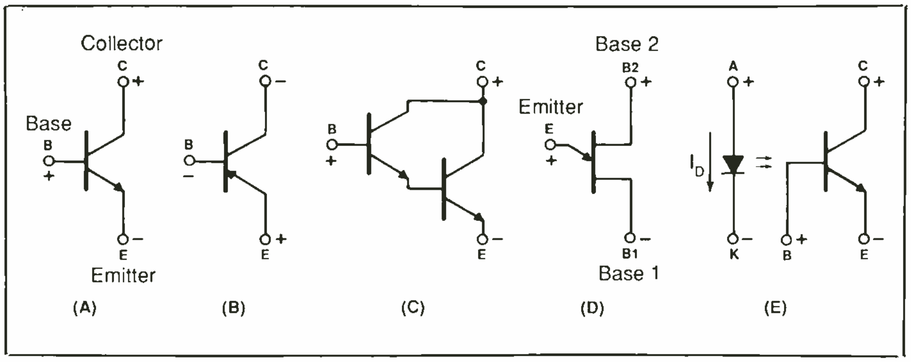


Fig. 5. Transistor symbols and polarities: (A) npn transistor; (B) pnp transistor; (C) npn Darlington transistor; (D) unijunction transistor (UJT); (E) dc-input optoisolator.

ages to use for rectifiers, zener diodes, LEDs and photodiodes.

When performing any diode test, set *S3* to NPN to make collector (C) jack *J3* positive and emitter (E) jack *J5* negative. With anode A connected to *J3* and cathode K connected to *J5*, a diode under test should conduct and *LED1* should light if the device is good. After doing this, reverse the connections and note that *LED1* is off, again assuming a good diode.

The zener diode is a special type of device that conducts like an ordinary diode in the forward direction and blocks the flow of current in the reverse direction until the breakover or "zener" voltage is exceeded. Limit tests on zener diodes to those rated at 6 volts or more and test these devices as you would any other rectifier diode. This tester does not check zener voltage.

To check an npn photodiode, set *S3* to NPN and connect emitter E to *J5* and collector C to *J3*. The device should be off (*LED2* off) with no illumination but should switch on (*LED1* on) when exposed to bright light. Reversing the connections should cause current to be blocked and *LED1* should be off. When subjected to light, a high-speed PIN photodiode may pass insufficient current to light *LED1*. In this case, plug a milliammeter set to its 1-milliampere range into *J2* and observe the magnitude of current flow.

Test light-emitting diodes only in the SIG mode to prevent excess current from burning them out. Set *S3* to NPN. The LED should light with anode A connected to *J3* and cathode K connected to *J5*.

Use the diode test to determine which lead of a diode is the anode and whether the device is a silicon or germanium type. Connect a dc voltmeter across *J3* and *J5*. With the diode conducting, the voltage dropped across a silicon type should be about 0.65 volt, while the voltage dropped across a germanium type should be about 0.35 volt.

• *Transistor Tests.* It is very difficult to zap a semiconductor in the SIG mode of the tester. However, keep in mind device current ratings and use a semiconductor cross-reference manual to keep tabs on device specifications as you use the tester. (General Electric's *Replacement Semiconductor Guide* lists transistors in order of decreasing current ratings. Other guides include those published by Archer and Radio Shack, NTE, Sylvania and RCA.) In the PWR mode, limit LED good/bad tests to devices rated at 200 milliamperes or more.

Shown in Fig. 5 are the symbols and polarities for npn and pnp transistors and for the npn Darlington transistor.

When performing an initial transistor test, use clip leads to connect the collector (C) and emitter (E) leads of the transistor to *J3* and *J5*, respectively and leave the base (B) of the device unconnected. Set *S3* to NPN or PNP, depending on the type of transistor being tested. Set *S4* to ×1 for 1 milliampere of base drive. With the base lead still unconnected, the transistor should be in cutoff and the LED should be off. Connecting the base lead to *J4* should cause the transistor to conduct and the LED to light. Use the PWR mode for low-gain, high-power transistors. Set *S4* to ×0.33 for 33 milliamperes of base drive or to ×0.1 for 10 milliamperes of base drive.

Dc base-transfer ratio, dc beta and h_{FE} variously refer to the large-signal gain of a transistor. Dc gain is the ratio of collector current to base current at a specified collector current and voltage. To measure gain, plug a milliammeter into *J4*. Then, beginning with *S4* set to ×300, rotate the switch counterclockwise and set collector current to any value up to 15 milliamperes in the SIG mode or up to 175 milliamperes in the PWR mode to ensure that the transistor doesn't saturate. Dc gain equals the measured current in milliamperes times *S4*'s multiplier. For low-power transistors in the 20-to-800-milliampere class, a good test current level is 0.5 to 10 milliamperes. For medium- and high-power transistors in the 1-to-30-ampere class, select a test current in the 30-to-150-milliampere range.

Base-emitter drops of silicon and germanium transistors are approximately 0.65 and 0.35 volt, respectively. Thus, the base current applied to a germanium transistor is about 10 percent greater than for a silicon transistor. Therefore, deduct 10 percent from the germanium transistor's dc gain measurement. A Darlington transistor has a base-emitter drop of about 1.2 volts, resulting in about 20 percent less base current; so use the ×300 setting of *S4* and add 20 percent to the gain figure. There is really no need to make these corrections if all you're checking for is nominal gain.

With a milliammeter plugged into *J2* and the base circuit of the transistor under test left open, the meter indicates collector-to-emitter current I_{ceo}, which is very small for silicon transistors but may be several milliamperes for germanium power transistors, enough to light the LED in the SIG mode. I_{ceo} is the result of amplification of internal collector-to-base leakage current I_{cbo}, which can be measured by connecting the collector lead to *J3* and base lead to *J5* and leaving the emitter lead unconnected.

Refer to Fig. 5(D) for the unijunction transistor (UJT) frequently used as a relaxation oscillator and a pulse driver for SCRs. There are two ways to check the UJT. For a UJT with the emitter arrow pointing toward the base as shown, set *S3* to NPN. Connect base 2 to *J3* (+) and base 1 to *J5* (−). Connect emitter E to *J4*. Then set *S4* to any unused position for zero current; *LED1* should be off. Setting *S4* to ×0.1 should cause *LED1* to light moderately.

A light-emitting diode and photosensitive npn transistor in a single DIP package make up the dc-input optoisolator, as shown in Fig. 5(E). To check this device, connect collector C to *J3* and emitter E to *J5*, leaving the base unconnected. Connect cathode K to *J5* and set *S3* to NPN and *S4* to ×1. With the diode's anode not

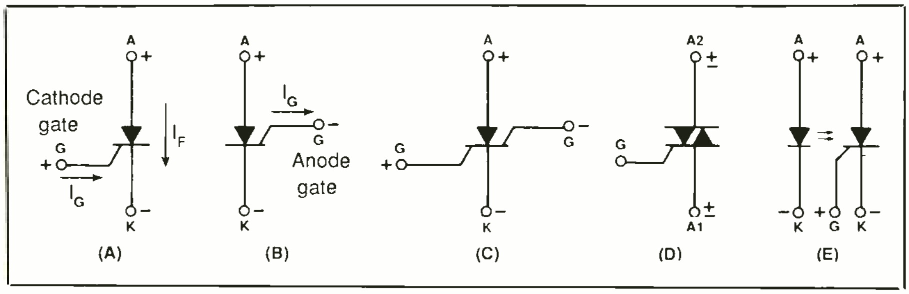


Fig. 6. Silicon controlled rectifier symbols and polarities: (A) silicon controlled rectifier (SCR); complementary SCR (CSCR); (B) silicon controlled switch (SCS); (C) triac; (D) SCR optoisolator.

connected, the transistor and *LED1* should be off.

Connecting the diode's anode to *J4* should cause *LED1* to light. If the LED does not light, set *S4* to ×0.33 or ×0.1. If the LED still doesn't turn on, test the diode and transistor as separate discrete devices.

An ac-input optoisolator has an additional LED connected in parallel but opposition with each other. This allows the input to conduct in both directions.

• *Silicon Controlled Rectifiers.* The SCR is an electronic switch that turns on when a low-level pulse is applied to its gate. Once triggered on, the SCR remains conducting until anode current falls below a relatively small holding current known as I_H.

Shown in Fig. 6 are the symbols for a few members of the SCR family. (A) is the symbol for the unidirectional SCR that turns on by making cathode-gate G positive with respect to cathode K, causing current to flow from anode to cathode. The light-activated SCR, or LASCR, is similar but is switched on by light striking the device. (B) is the symbol for the complementary SCR (CSCR) which has an anode gate and is switched on by making this gate negative with respect to the cathode. The programmable unijunction transistor (PUT) is similar to the CSCR. (C) is the symbol for the silicon controlled switch, or SCS, that has both anode and cathode gates. (D) is the symbol for the bidirectional triac that conducts in both directions and is controlled by a single gate. Finally, (E) is the symbol for the SCR optoisolator that provides electrical isolation between the controlling input and controlled output.

When testing SCR devices rated at less than 200 milliamperes, use the SIG mode. Check higher-current devices preferably in the PWR mode. Set *S3* to NPN to check the SCR. Set *S4* to ×0.1 for a 10-milliampere gate drive. Connect anode A to *J3* and cathode K to *J5*, but leave anode gate G unconnected.

Turning on the tester should not turn on the SCR or LED. If *LED1* is on, the SCR is either shorted or has turned on as a result of the sudden application of voltage and is known as the rate effect. Move *S3* to PNP and then back to NPN to turn off the SCR. With the SCR off, momentarily connect cathode gate G to *J4*, which should cause the SCR to switch on. If it doesn't, momentarily connect the gate to *J3* to turn it on. If a high-current SCR fails to trigger on in the SIG mode, use the PWR mode and momentarily short the cathode gate to the anode for turn-on.

PUT, CSCR and SCS devices are extremely sensitive to low-current devices and can turn on just by touching the gate leads. To check these devices via the anode gate, connect anode A to *J3*, cathode K to *J5* and anode gate G to *J4*. Set *S3* to

NPN. Then set *S4* to ×0.3 to connect a 1,300-ohm resistor from anode to anode gate to reduce the rate effect.

When you turn on the tester, *LED1* should be off. Momentarily jumper the anode gate to the cathode to trigger on the SCR and turn on *LED1*. To complete the test on an SCS via the cathode gate with the device switched off, momentarily jumper cathode gate G to *J4* or *J3* to trigger on the device.

You can obtain an estimate of gate turn-on current sensitivity for an SCR as follows. Set *S4* to ×300 for minimum gate drive and make connections to the SCR. With the SCR initially off, rotate *S4* counterclockwise until it switches on. If the SCR turns on at the ×10 setting, gate turn-on current is less than 0.1 milliampere (reciprocal of dial setting ×10).

Triacs are power devices that passe current in either direction when switched on. To test a triac, connect anode 2 to *J3* and anode 1 to *J5*, but leave gate G unconnected. The triac should not be on in either position of *S3*. However, it should switch on when the gate is momentarily touched to *J3* or *J5*. Depending on device holding current, the LED may go off when the gate is disconnected. If the triac remains on, open *S1* to turn it off and then reclose the switch.

The dc-input SCR optoisolator is analogous to the transistor optical isolator and is tested in a similar manner. Connect SCR anode A to *J3*, both cathodes K to *J5* and leave gate G unconnected. Set *S3* to NPN. The device should be off. Momentarily connecting diode anode A to *J3* should cause the device to turn on.

• *Other Tests.* For in-circuit tests, the project can show that a device is good if it passes the test. However, the device may or may not be bad if it fails the test. This depends on shunt current paths associated with the wired-in device being tested. To check a transistor, connect only the collector and emitter leads. The project's LED should be off or possibly only dimly lit. Connect the base lead and apply increasing base drive by rotating *S4* counterclockwise. The transistor is good if the LED lights in one or more positions.

To check electrolytic capacitors, set *S3* to NPN, connect the capacitor's − lead to *J5* and touch and hold the + lead to *J3*. For capacitors rated at 3 microfarads and larger, the LED should flash brightly at the start but fade in brilliance as the capacitor charges. No light whatever indicates an open capacitor, while a continuous unchanging light indicates a shorted capacitor.

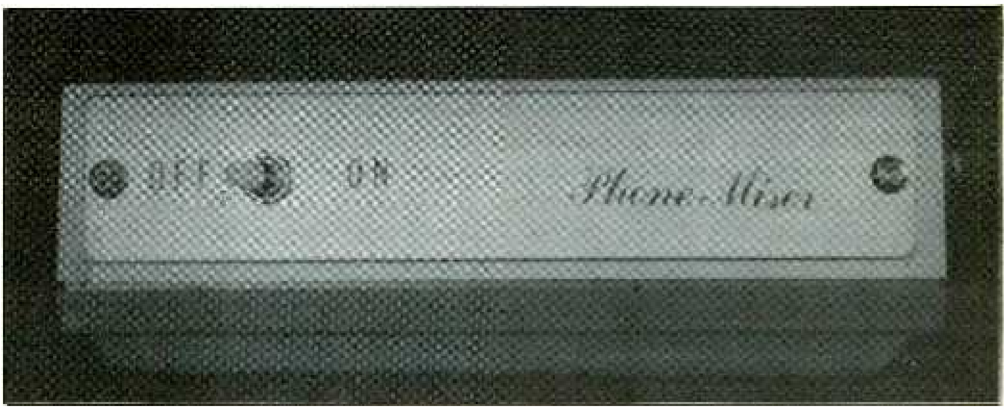
Operating Notes

Unplug the ac line adapter from *J1* whenever you use the SIG mode so that only the project's battery is in the circuit. Battery drain on standby is a modest 5 milliamperes. With the LED brightly lit, current drain can increase up to 25 to 30 milliamperes. Therefore, to prolong battery life, avoid leaving the LED on continuously during testing. Either turn off the tester or make momentary connections to the base of a transistor or terminal of a diode under test. ME

The Phone Miser

A lock-out for unauthorized long-distance telephone calls

By R.F. Sharp



Are your telephone bills sky high because of unauthorized out-of-area calls? If so, the Phone Miser project to be described can put an end to it. Phone Miser remedies this problem by automatically interrupting any attempt to reach a number outside your local calling exchange, whether the caller tries to dial directly or calls upon operator assistance. For those times when a legitimate long-distance call must be made, the project features a disable switch.

Phone Miser can be used with any selected telephone instrument, all instruments on the same line or just a few select instruments. It connects between the incoming telephone line and whatever instrument(s) it is to control. Power for the project is provided by Phone Miser's own low-voltage dc power supply so as not to load down the telephone line. The project automatically locks out any call whose number begins with the numeral 1 and any attempt to dial 0 to get the operator. (Note: If you live in an area that does not require dialing of a 1 before entry of the area code to make an out-of-area call, Phone Miser will *not* prevent the call from getting through, nor will it work with rotary-type dialers.)

Telephone Basics

Before we look at Phone Miser's actual circuitry, let us review the basics of the telephone system. To begin with, two conductors connect your home or business to the telephone system. The telephone company supplies a minimum of 20 milliamperes of direct current over this line to power your equipment. The potential across the line is approximately 48 volts dc with your telephone handset on-hook. Lifting the receiver off-hook causes this voltage to drop. The dc resistance of any device connected to the phone line is expected to be at least 600 ohms when active. (A phone's on-hook resistance is about 10 megohms.)

Ringer voltage, supplied by the telephone company, is a 20-Hz ac signal that can range from 40 to 150 volts, which is sufficient to cause injury. Therefore, always exercise caution when working with exposed telephone circuits. To avoid electrical shock hazard, always be sure to put one telephone receiver off-hook while making attachments to the line to prohibit telephone system equipment from sending a ring signal.

Older rotary-dial telephones are really pulsers that open and close the phone circuit a specific number of times for each digit dialed. They use a mechanical timing scheme to signal each dialed digit. Since Phone Miser expects to "see" an electronic tone pair for each individual digit, this mechanical "pulse" arrangement will not work with the project. If you should install Phone Miser in such a system, it will *not* inhibit long-distance calling or requests for operator assistance, and your phone(s) will work as though the project was never connected into the system.

Modern telephone instruments use all-electronic Touch Tone dialing that transmits audio signals composed of different simultaneous tone pairs for each digit. Tone frequencies range from 679 to 1,477 Hz and are tightly controlled and almost pure. For Phone Miser, our primary concern is with the digits 0 and 1. The tone pair for 0 is 1,336 plus 941 Hz and for 1 is 1,209 plus 697 Hz. This information is purely academic because all filtering and decoding are done inside a single dual-tone multiple-frequency (DTMF) receiver chip that is the heart of Phone Miser. Radio Shack supplies with this chip (see Parts List) a technical data booklet that provides additional information about interfacing with the telephone system, along with a schematic diagram that shows the DTMF chip being used with an SK4515B decoder chip. This is the circuit arrangement used in Phone Miser.

The DTMF chip is an excellent

performer. It exhibits excellent frequency response, low power drain and minimal falsing. A 10-megohm resistor and an inexpensive 3.58-MHz TV colorburst crystal are the only external components required for tone decoding.

About the Circuit

Design goals for Phone Miser included a circuit that: requires no alteration of existing equipment; meets telephone company requirements for attached devices; powers up only when the telephone is in service; and inhibits all long-distance calls. How this criteria was achieved is detailed in Fig. 1. The Current Sensor block is basically a series resistor that causes a voltage to be dropped across it when the phone receiver is off-hook. The Initialization Circuit presets values in the Register.

To prevent long-distance calls from being dialed out, calls prefixed with a "1" must be blocked. Since operator-assisted calls begin with a "0," this type of call must also be inhibited. The trick is to prevent Phone Miser from inhibiting any call not beginning with a 0 or 1 but has these numerals in another part of a legitimate local number. Therefore, the circuit must have memory of one digit, which is accomplished in the Register block in Fig. 1. The Latch is an RS flip-flop that stores information for implementing action based on decisions made by other circuitry.

A detailed block diagram of the Register is shown in Fig. 2. This circuit is made up of two D-type flip-flops from the eight available in a 74LS273. (It was wasteful of the power of the 74LS273 to use it in this application, since only two of its eight stages are used. However, I used it because I had one on hand. You can substitute a less-wasteful dual-D flip-flop, but there will probably be little or no cost advantage in doing so, and the printed-circuit board for the project will have to be modified accordingly.)

The CLR input is used to initialize the Register. A high-low-high transition sets all Q outputs low. Pin 1D is tied high to guarantee a logic 1 will always appear. With the first clock pulse, this high is shifted to 1Q and 2D, where it is stored until the next clock pulse. Pin 2Q remains at logic 0 through the first clock pulse.

The second clock signal shifts the high at 2D into 2Q, creating a unique situation here. Providing the occurrence of each digit signal is timed to coincide with the clock pulse, Register pin 2Q will be at logic 0 for only the first digit dialed. The DTMF chip generates the required timing signal, a strobe for each decoded digit.

How the low proceeds through the circuit is shown in the timing diagram in Fig. 3. This is an ideal representation because we need not be very concerned with inherent component delay. We will use the output of 2Q for comparison when the decision is made to pass or reject a dialed telephone number.

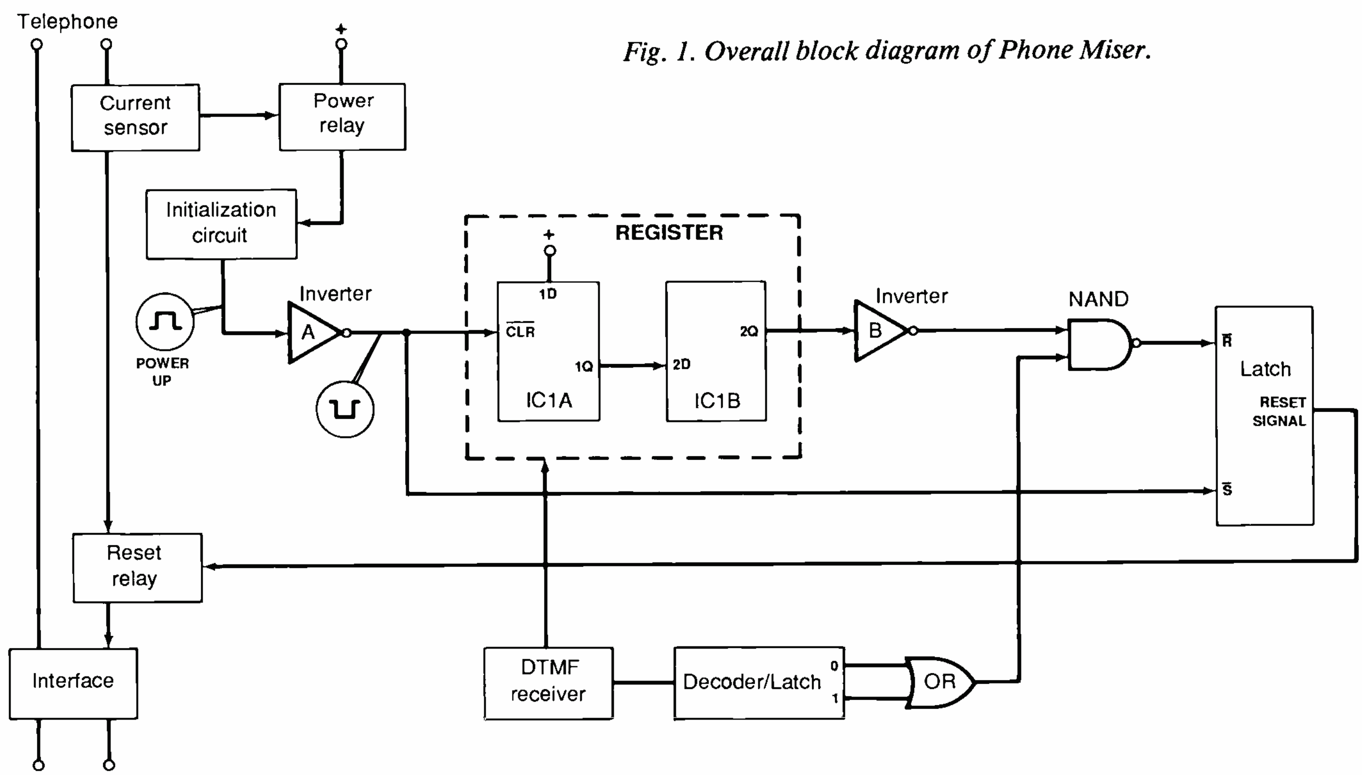


Fig. 1. Overall block diagram of Phone Miser.

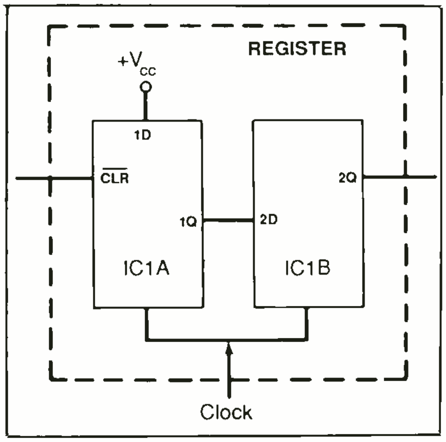


Fig. 2. Details of Register.

A complete schematic diagram of the project is shown in Fig. 4. Phone Miser is turned on and off by *S1*. This switch can be a key-type switch for security or a hidden slide or toggle switch, depending on type of phone installation. If security is a real problem, you might want to hard-wire Phone Miser between your phone and its service line. Also, the power supply used with the project should be made secure because, when unpowered, Phone Miser is transparent to *all* calls.

The power-up reset required by the Register can be provided by the

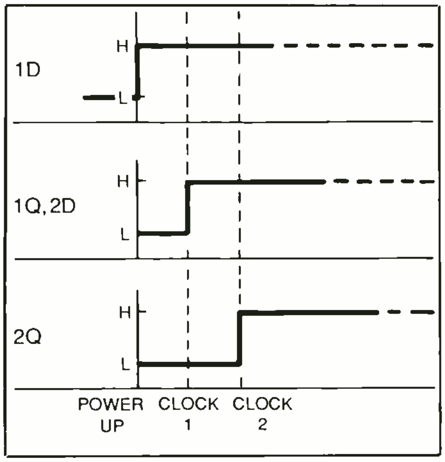


Fig. 3. Register timing diagram shows logic levels vs. time in clock increments for Register stages (neglecting component delay).

phone company, which provides its own power-up signal. However, for convenience, Phone Miser is designed to generate its own pulse, via *IC4*. This 555 timer delivers a pulse at pin 3 when power is applied. Resistor *R3* and capacitor *C2* set pulse duration to approximately 0.5 second (1.1RC). This pulse is inverted by one of the inverters in *IC2*, whose pin 4 output goes to the CLR input of *IC1* at pin 1 to set the register.

Resistor *R1* is a sensing device that provides forward bias for transistor *Q1* when the phone is in service. When *Q1* turns on, *K1* energizes and turns on power to the circuit. Diode *D3* provides a dc voltage to the base of *Q1*. Diodes *D4* and *D5* protect *Q1* by setting a maximum of 1.2 volts at the base.

Transformer *T1* and capacitors *C3* and *C4* isolate DTMF chip *IC5* from the telephone line. Ideally, *T1* should be a 600-ohm 1:1 line transformer. Zener diodes *D6* and *D7* shunt ringer voltage to ground. You may wish to shunt the line side of *T1* and *R1* with a 150-volt surge protector to guard against lightning damage if this is a problem in your area.

A pair of NAND gates inside *IC3* are used to form a latch circuit that changes state when a low is presented to either R or S (see Fig. 1).

When the handset is lifted off-hook, current flows through *R1*, causing *Q1* to turn on and energize *K1*. This powers the circuit and causes *IC4* to generate a pulse that is inverted before it is used to set *IC1*. Simultaneously, a low is sent to S of the latch to assure proper initial setting. When a "legal" first digit (2 through 9) is dialed, *IC5* interprets the tones and sends the result to *IC6*, which converts the hexadecimal to decimal code format, raising high its output corresponding to the dialed digit. Since only the 0 and 1 outputs are connected, no action is taken.

Simultaneous with the decoding process, the strobe signal is generated and clocks a high from 1D to 1Q and 2D (see Fig. 2). Output 2Q remains low, is inverted by an inverter/buffer in *IC2* and is compared with the output from the diode OR circuit made up of *D1*, *D2* and *R4*. This comparison takes place in one of the NAND gates in *IC3*. With both *IC6* outputs low, their OR combination will also be low and will combine with the high from pin 8 of *IC2* to

PARTS LIST

Semiconductors
D1,D2,D4,D5—1N914 switching diode
D3—1N34A diode
D6,D7—3.9-volt, 0.5-watt zener diode
IC1—74LS273 multiple D flip-flop
IC2—7404 hex inverter/buffer
IC3—7400 quad NAND gate
IC4—555 timer
IC5—DTMF receiver (Radio Shack Cat. No. 276-1303)
IC6—SK4514B decoder
IC7—7805 +5-volt regulator
Q1,Q2—2N2222 silicon npn transistor
Capacitors
C1—1,000-μF, 25-volt electrolytic (see text)
C2—1-μF, 10-volt electrolytic
C3—0.01-μF disk
Resistors (¼-watt, 10% tolerance)
R1—100 ohms
R2—4,700 ohms
R3—470,000 ohms
R4,R5—1 megohm
Miscellaneous
K1,K2—6-volt dc, 500-ohm spst relay (Radio Shack Cat. No. 275-004 or similar)
S1—Spst key-operated, slide or toggle switch (see text)
T1—Coupling transformer (Radio Shack Cat. No. 272-1380 or similar; see text)
XTAL—3.579545-MHz colorburst crystal
Printed-circuit board or perforated board and suitable soldering or Wire Wrap hardware (see text); DIP sockets for IC1 through IC6; project enclosure (Radio Shack Cat. No. 270-210 or similar); two ¼-inch inner-diameter rubber grommets; 6- to 18-volt dc plug-in power supply (see text); hookup wire; solder; etc.

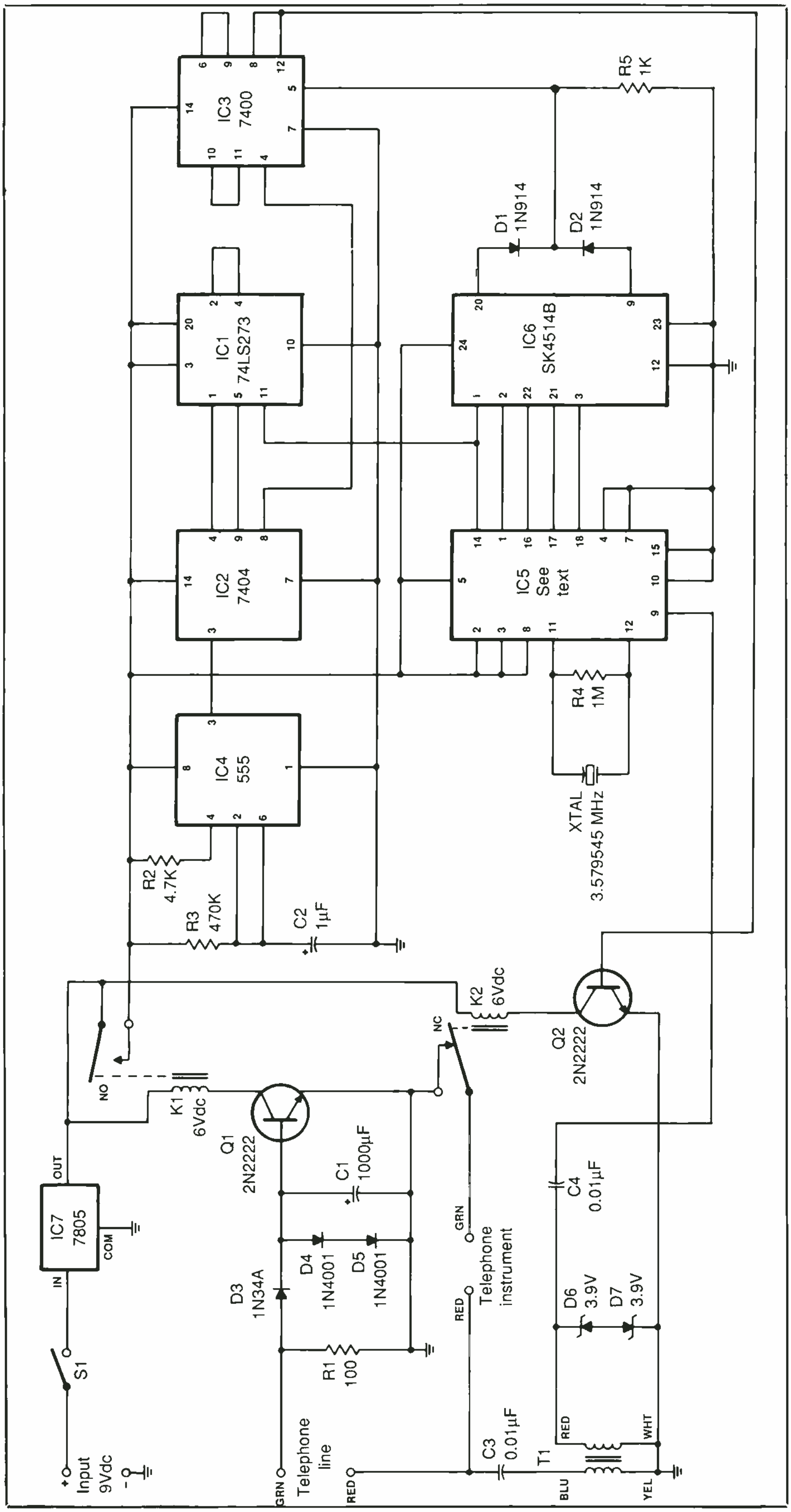


Fig. 4. Complete schematic diagram of Phone Miser.

provide a high at the NAND output, causing no change in the latch.

The next digit dialed may produce either a high or a low at the OR output, depending on whether this digit is a 0, a 1 or any remaining digit. Since the strobe simultaneously clocks a high to 2Q, which will remain high for the remaining sequence of digits, the circuit will ignore all further input. Putting the handset back on-hook causes the voltage dropped across *R1* to drop to zero and shuts off the circuit.

When an attempt is made to place a toll call, power-up occurs just as it did before. If either a 0 or a 1 is the first digit dialed, a high appears at the OR output, where it combines with the high from pin 8 of *IC2* to produce a low at the NAND output. This causes the latch to change states, sending pin 8 of *IC3* high and forward-biasing *Q2*. When *Q2* draws current, *K2* opens the phone-line circuit and aborts the call.

When *K1*'s contacts open, the voltage dropped across *R1* falls; when it goes below the bias requirements of *Q1*, power to the entire circuit, including that to *K2* (which is responsible for aborting the call), is shut off. By holding *Q2* cut off until the charge on *C2* is depleted through the base-emitter resistance of *Q1*, a valid call termination is generated. This sequence will repeat every time a 0 or a 1 is the first digit dialed. A local call can be made without putting the handset on-hook, provided you wait for a dialtone.

Power for the project is supplied from an ordinary plug-in dc power supply that is able to deliver between 6 and 18 volts. The output from the supply is regulated to a stable 5 volts by voltage regulator *IC7*.

Construction

Though it is possible to build the

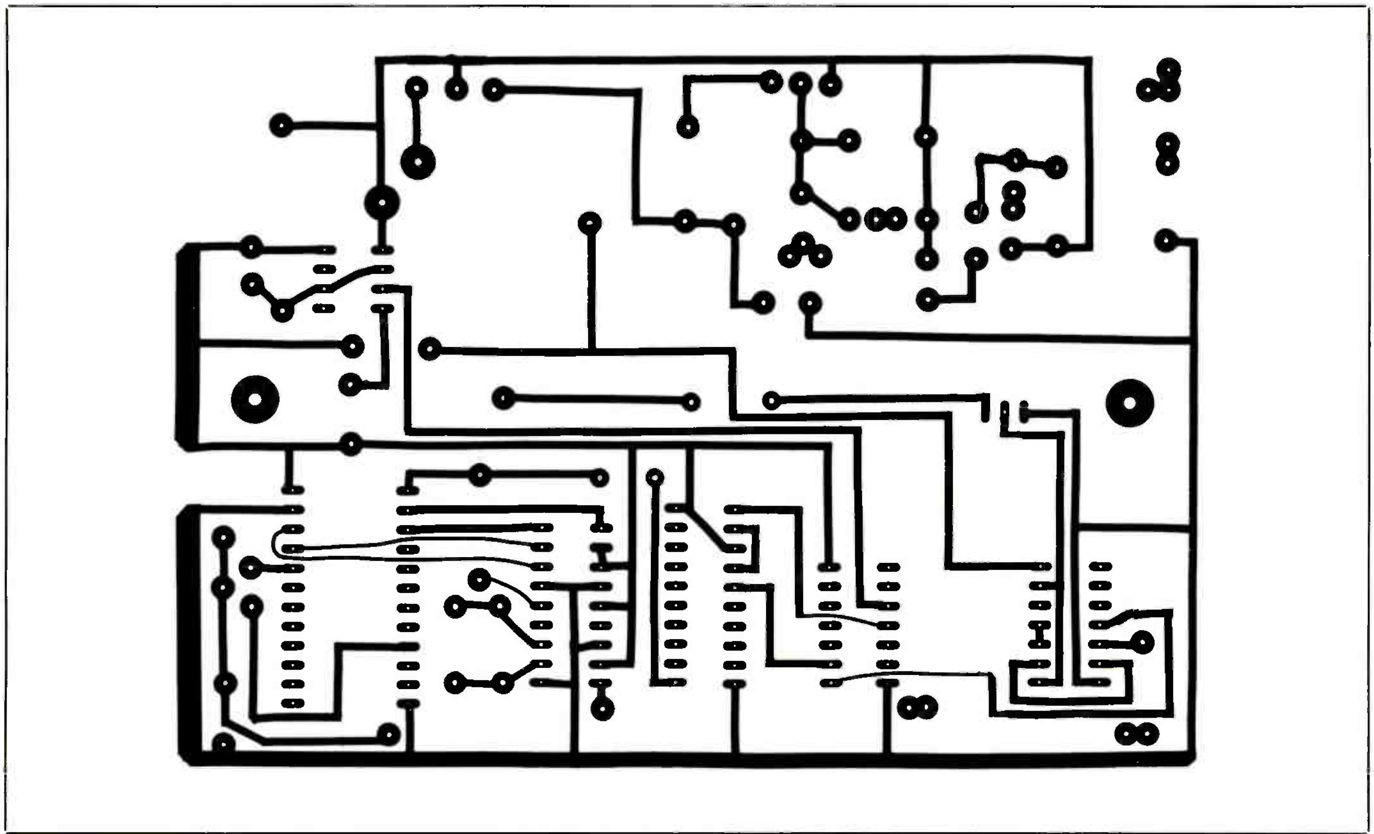


Fig. 5. Actual-size etching-and-drilling guide for printed-circuit board.

Phone Miser by other traditional wiring means, printed-circuit wiring is highly recommended. You can fabricate your own pc board from the actual-size etching-and-drilling guide given in Fig. 5, which is sized to fit inside the Radio Shack enclosure specified in the Parts List. A couple of rubber grommets forced onto the enclosure's studs will hold the wired pc board in place. The enclosure's front panel is also large enough to accommodate a keyswitch, should you choose to use it for *S1*.

If you decide to use perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware instead of a pc board, use the same layout as that for the pc board as a rough guide to component placement and orientation. Though there is nothing critical about component placement (all frequency-sensitive circuitry is contained inside *IC5*), do make sure to locate *R6* and crystal *XTAL* close to *IC5*.

Wire the pc board exactly as shown in Fig. 6. Make sure *C1*, *C2* and all diodes are properly polarized and the transistors, ICs and transformer are properly oriented before soldering their leads to the copper pads on the board. Do not install the ICs directly on the board. Instead, use a socket for each. Also, do *not* install the ICs in their respective sockets until after the preliminary voltage checks have been performed.

Note in Fig. 6 that *C1*, all diodes and all resistors except *R1* mount upright—not flat on the board. Also, use insulated solid hookup wire for the seven jumpers noted.

Do *not* use a jack-and-plug arrangement to route power from the plug-in dc power supply into the project case. Instead, cut the plug (if there is one) from the cord of the power supply you use and route it through a hole in the enclosure and solder it directly into the circuit. If you use a pluggable arrangement and someone accidentally (or purposely) unplugs it, you will lose the security Phone Miser is supposed to give you.

As a further security measure, devise a means for getting ac power to the plug-in dc power supply that cannot be easily interrupted simply by pulling the supply's housing from the wall outlet. If security is a real problem, consider replacing the plug-in supply with a 6-volt lantern battery. Do not use an ordinary 9-volt transistor battery, which would have to be replaced frequently (unless you redesign the circuit around CMOS devices instead of the TTL devices shown). More security can be provided if you *supplement* the plug-in power supply with a battery/relay arrangement that will normally power the circuit from the plug-in supply when it is plugged into an ac outlet but will automatically switch over to

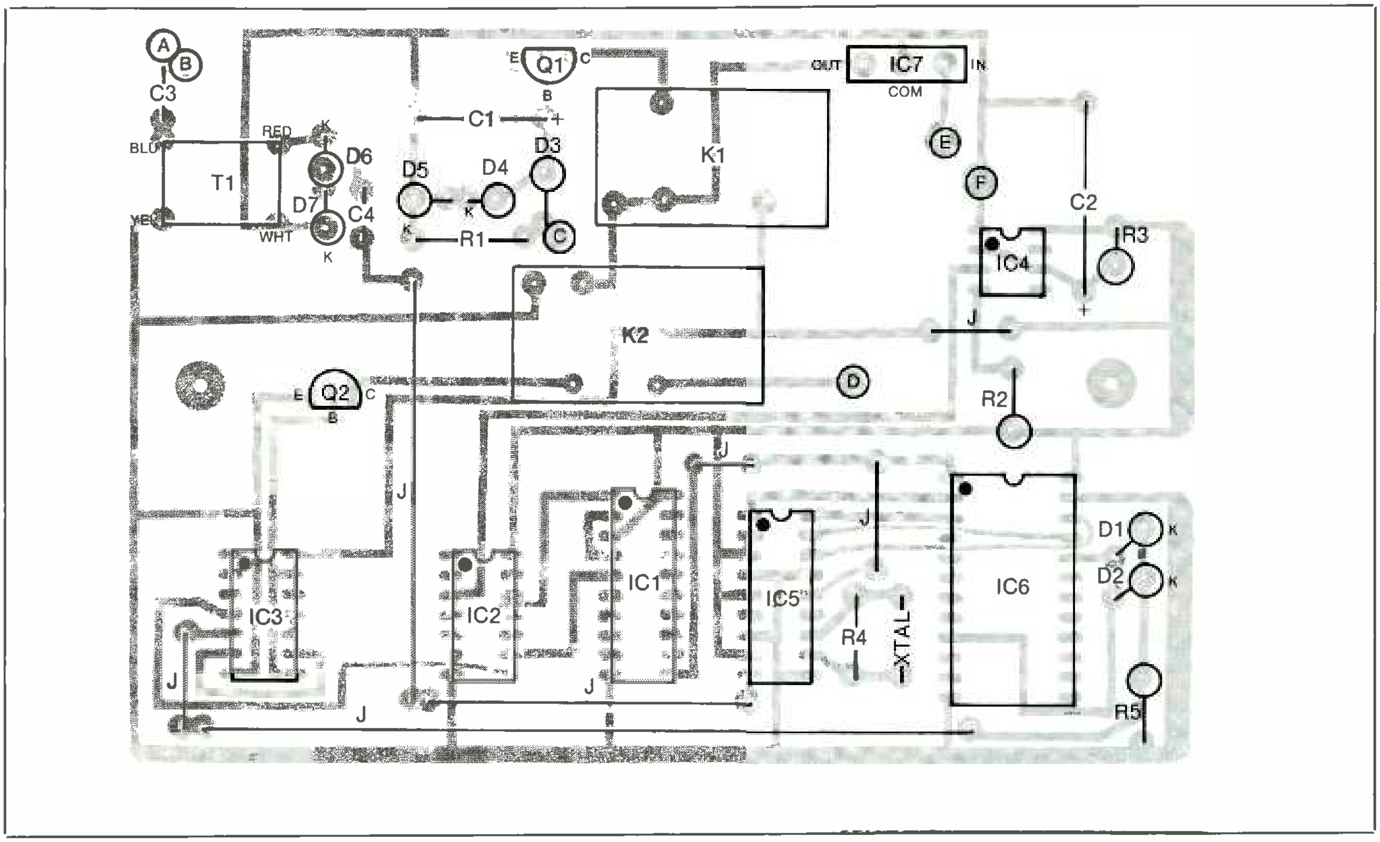


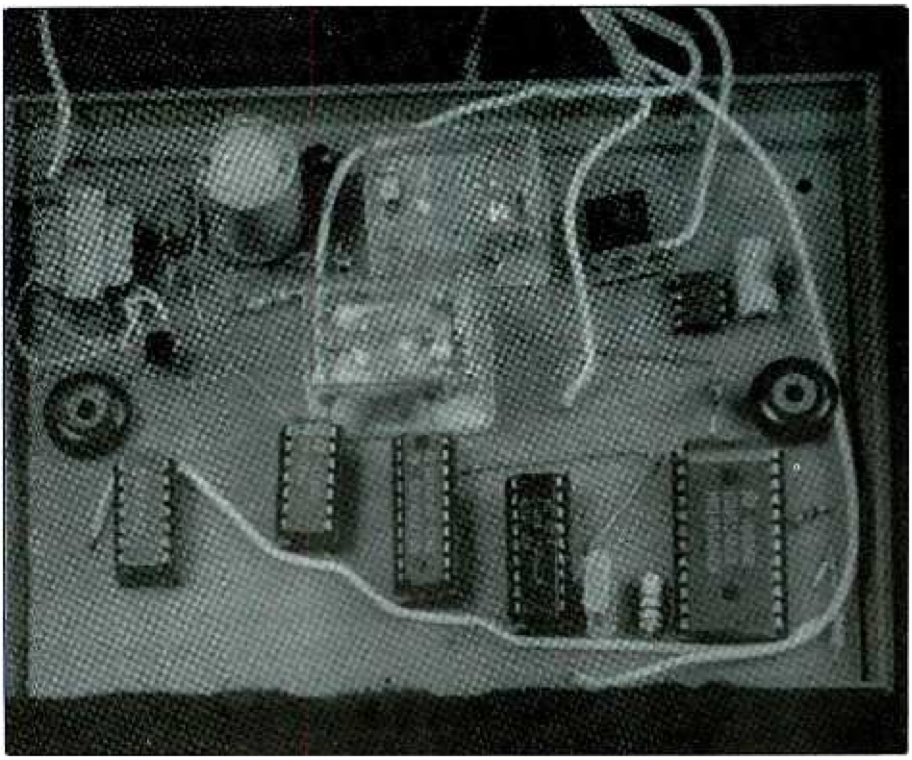
Fig. 6. Wiring diagram for pc board. Use this layout for perforated-board construction as well.

the battery should the power supply be unplugged from the ac outlet.

Checkout & Installation

After you have checked out all components for proper installation and your wiring for proper soldering, connect Phone Miser between your telephone line and an instrument. Make sure polarization is correct—that is, green line wire to green on the board and red line wire to red on the board. Plug the power supply into a convenient ac outlet.

Turn on power to the project by closing *S1* and lift the telephone's handset off-hook. Connect the negative or common lead of a dc voltmeter or a multimeter set to read dc voltage to circuit ground and touch the meter's positive probe to the OUTPUT pin of *IC7* to read +5 volts on the meter. Now check for the presence of +5 volts at pins 3 and 20 of *IC1*, pin 14 of *IC2* and *IC3*, pin 8



The wired project on a printed-circuit board.

of IC4; pins 2, 3, 5 and 8 of *IC5*; and pin 24 of *IC6*. If all readings are correct, power down the circuit, unplug the power supply from the ac outlet, disconnect the telephone line and replace the phone's receiver on-hook. If you did not obtain the proper voltage reading at any point in the circuit, recheck all wiring and soldering. Check particularly for unsoldered or poorly soldered connections and for solder bridges, especially between the closely spaced IC pads.

Once you are sure the circuit is properly wired and soldered, install the ICs in their respective sockets. Make sure that each is properly oriented and that no pins overhang the sockets or fold under between ICs and sockets.

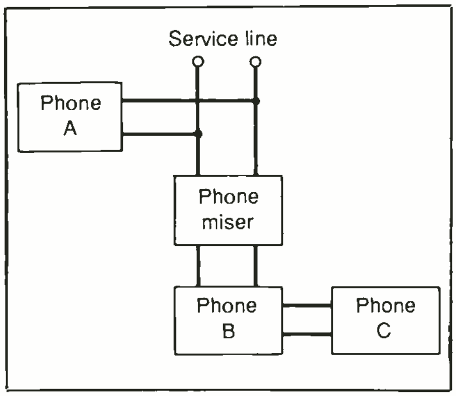


Fig. 7. Typical installation details. This arrangement has two secured (Phones B and C) and one unaffected (Phone A) telephone instruments.

Once again, lift the telephone's handset off-hook and connect the project between the telephone line and your telephone (observe color coding). When you set *S1* to ON, you should hear *K1* click as it energizes. With a voltmeter or logic probe connected to circuit ground and pin 1 of *IC6*, pressing and releasing the key for any digit between 2 and 9 on your telephone's dial pad should register a strobe signal.

Place the receiver back on-hook and then remove it and place it against your ear. You should hear a dialtone. Press and release the 1 button on the dial pad. The dialtone should disappear and *K2* should click. About a second later, the dialtone should be restored. Try pressing the 0 button. You should get the same response as before.

To observe the register counting for an in-area call, monitor pins 2/4 and 5 of *IC1*. Pins 2/4 should change from low to high when the second digit is pressed, while pin 5 should remain high until you hang up.

There is one potential problem with the Phone Miser. That is if *C2* should discharge too quickly when a reset occurs. If this should occur, it might be interpreted by the telephone system as a digit 1 from a rotary-type dial. Should you experience this, simply increase the value of *C2* to 200 microfarads or more.

If all tests are successful, you are ready to put Phone Miser into service. Before you do this, decide how you want to use the project. If you have only one telephone instrument or you want all instruments secured, simply install the project between the telephone line and the one instrument or between the telephone line and all instruments. Should you wish to secure only one or only selected instruments in a multiple-instrument system, install Phone Miser between the telephone line and the one instrument or between the telephone line and the run to which the secured instruments are connected. If all instruments you want secured are on two or more runs, you will have to redo the wiring to put all of them on the same run. Figure 7 shows how two instruments can be secured and one can be bypassed in a three-instrument system.

When installing the project, put it *between* the telephone line that feeds the instrument to be secured and its modular-jack box. In a system where more than one instrument is to be secured, install Phone Miser between the *first* instrument in the line's modular-jack box and the phone-line run. Finally, if one or more instruments are to be permanently secured, you can dispense with *S1* altogether.

A final note: Be careful with color coding when connecting Phone Miser into the telephone line. Current must flow in the proper direction through *R1* for the project to turn on. If you experience any turn-on difficulties, recheck your wiring. If it looks okay and the problem persists, try reversing the line connections.

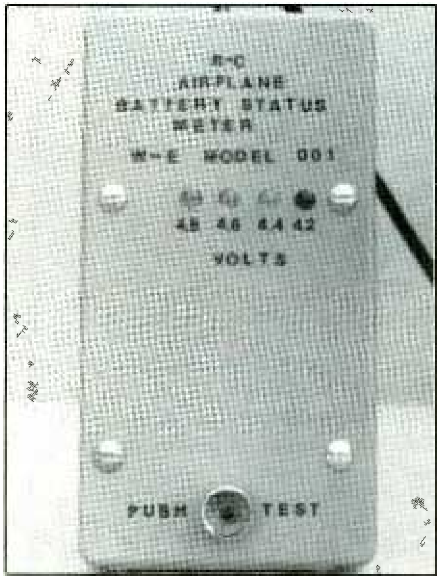
With Phone Miser standing guard, *you* have control over calls made from your telephones. If you had a problem with long-distance calls in the past, you will find that you no longer have one. **ME**

R/C Aircraft Crash Saver

An accurate battery status indicator for on-board radio-control gear ensures availability of sufficient power for takeoff and landing of costly model airplanes

By Harold Wright

More than 100,000 enthusiastic radio-control hobbyists put a lot of money at risk every time they send their models into the wild blue yonder. Some of these models have 6-foot wing spans and took hundreds of hours to build and get into flying condition, aside from the cost of the model and its accompanying radio-control receiver, transmitter and servomechanisms. The whole system depends on a small Ni-Cd battery's power, which has only a 0.6-volt cushion to ensure that it will operate the airborne model's rudder, elevator, ailerons and throttle. If battery voltage drops below this tolerance, the airborne model may not be able to be landed safely.



The accurate (to two decimal places) push-to-test battery status indicator presented here ensures that there is enough power left to make a smooth, controlled landing. Typically, an airborne receiver and servo-system battery pack has four Ni-Cd cells, each delivering 1.2 volts, series connected to provide 4.8 volts when fully charged. It is considered risky to launch an R/C model aircraft if battery output drops to 4.2 volts, so the "pilot" needs to know with considerable accuracy if he might be sending up his plane just once too often. With only 0.6-volt tolerance, the usual expanded-scale analog meter used for this purpose is inadequate.

Out R/C model airplane battery status meter uses a quad comparator, an adjustable voltage-reference chip and a series of four light-emitting diodes in three colors to tell you when your batteries are fully charges, when they are at intermediate levels of charge, and when the charge on them is too low for safe operation. This simple tester, in its raw state, weighs between 1 and 2 ounces and can be built right into a model airplane. If you have more than one model, you can build the project into a hand-held case and use it to monitor the status of the batteries in all of them.

About the Circuit

As shown in Fig. 1, the heart of the battery test meter is 339 quad comparator *IC1*. The principle used to display battery status is similar to that used in such bargraph ICs as the 3914. With this meter, however, each individual step can be calibrated to a high degree of accuracy. All inverting (−) inputs can be tied to LM336Z 2.5-volt reference *IC2*. Calibrated with *R26*, *IC2* holds the reference at 2.50 volts through a wider range of input voltages than is needed for this project meter.

Battery voltage to be monitored connects between the circuit common (negative pole) and the inverting inputs of *IC1A* through *IC1D* (positive pole) through multi-turn trimmer potentiometers *R1*, *R7*, *R13* and *R19*. When it goes high, the output of each comparator turns on its

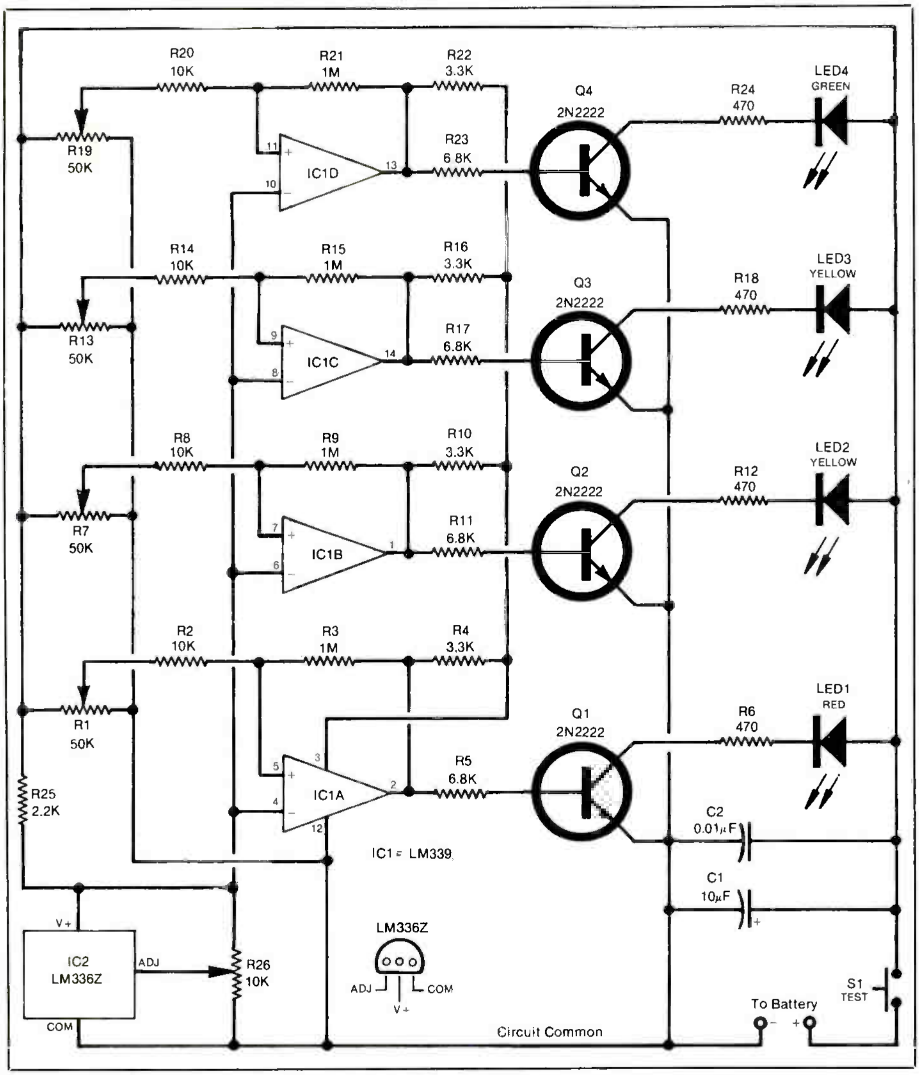


Fig. 1. Complete schematic diagram of battery tester.

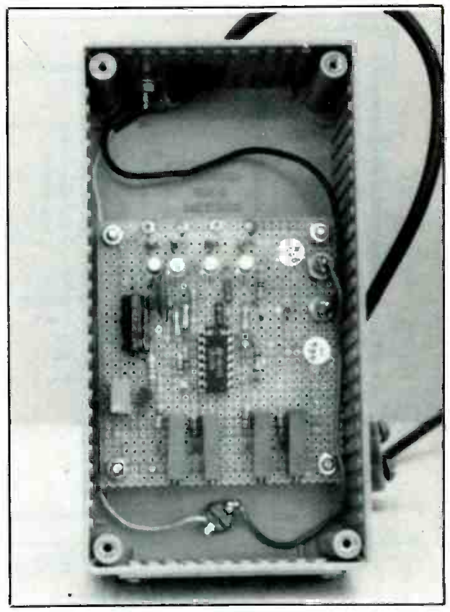


Fig. 2. Interior view of project.

associated transistor and lights the light-emitting diode connected to it.

Calibration is such that with 4.80 volts on the input line, all four LEDs light. If there is a drop of a few hundredths of a volt, green light-emitting diode *LED4* extinguishes. The remaining LEDs extinguish with lower battery voltages: yellow *LED3* just below 4.6 volts and yellow *LED2* just below 4.4 volts. With only red *LED1* on, battery output is 4.2 volts or less.

With slowly changing input voltages, the LM339 has a tendency to oscillate. By giving the comparators a small amount of "snap" action, any tendency toward oscillation is eliminated. Resistors *R3*, *R9*, *R15* and *R21* connected between the non-inverting (+) inputs and the outputs of each comparator provide the needed snap action for *IC1A* through *IC1D*, respectively.

To minimize the drain on the battery under test, *S1* is a momentary-action, normally-open pushbutton switch. To make a battery test, *S1* would be pressed for only as long a time as needed for the display to stabilize.

Construction

Construction is simple and straightforward. It should take only a couple of hours to build the project.

Weighing only an ounce or so, the circuit could be mounted inside the fuselage of the R/C model airplane, with the LEDs visible through a small clear plastic window and the TEST switch (*S1*) where it can be easily reached to press from outside the model. If there is a problem (perhaps because the button interferes with

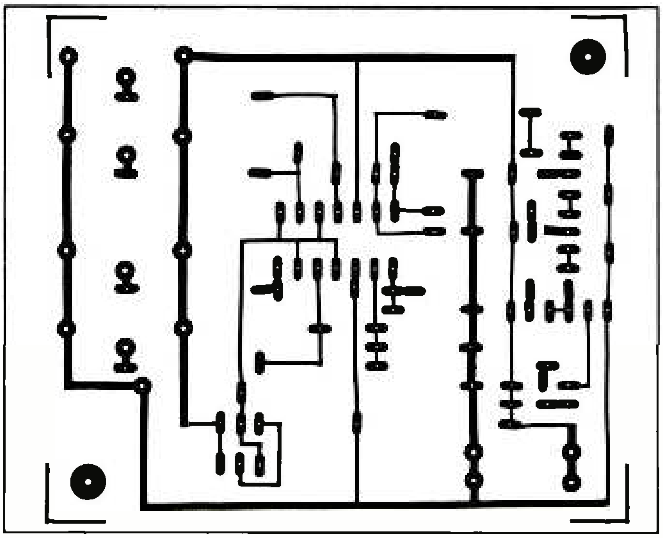


Fig. 3. Actual-size etching-and-drilling guide for fabricating printed-circuit board.

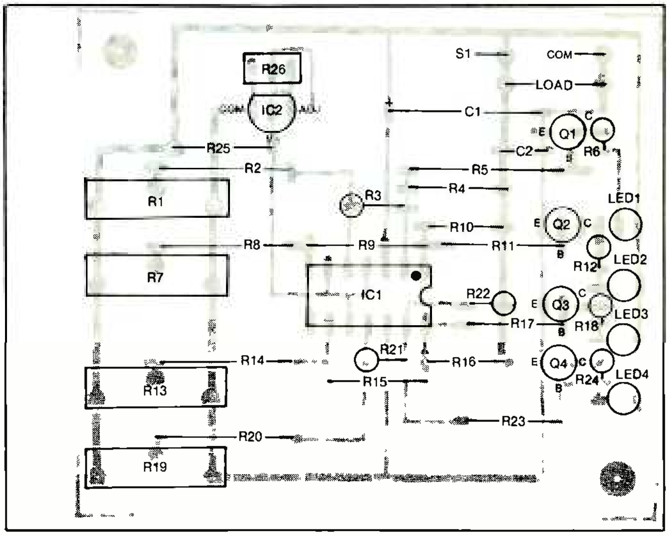


Fig. 4. Wiring guide for pc board.

the plane's streamlining), you can cement a small normally-open reed switch on an inside surface of the model in place of the pushbutton switch and place a magnet near the reed when you want to take a reading.

If you have more than one model, it would be better to build the battery tester into a small hand-held plastic case and equip it with a length of twin-conductor cable terminated with a connector that mates with the one normally used for charging the battery. If you have more than one model, use the same type of connector on all of them for easy, convenient testing. (There does not seem to be a set standard for these connectors among the various manufacturers of batteries.)

Because this is a pure dc circuit, no special component layout is required when wiring the components into place. Therefore, you can use any traditional method of wiring that suits you. Figure 2 is a photo of the prototype assembled on an unclad matrix board with holes on 0.1-inch centers. Wiring here was accomplished with the aid of the stick-on copper pattern and tape system described in "The 'Easy Circuit' Way to Make Circuit Boards (*Modern Electronics*, March 1985). However, you can use appropriate solder-type or Wire Wrap hardware or a home-fabricated printed-circuit board.

If you use the self-stick pattern-and-tape method, make sure you check each soldered joint with a low-range ohmmeter. Joints that look good to the eye can remain open circuits if the end of one tape curls a little where it overlays another tape or pattern.

You can fabricate your own printed-circuit board from the actual-size etching-and-drilling guide shown in Fig. 2. Once you have the board ready, refer to the wiring diagram in Fig. 3 to install a good-quality DIP socket for *IC1*, then install the resistors, capacitors, transistors and *IC2* in that order. Make sure you properly polarize electrolytic capacitor *C1* and have the basings correct

PARTS LIST

Semiconductors
LED1—High-efficiency red light-emitting diode
LED2,LED3—High-efficiency yellow light-emitting diode
LED4—High-efficiency green light-emitting diode
IC1—LM339 quad comparator
IC2—LM336Z 2.5-volt reference
Q1 thru Q4—2N2222 npn transistor

Capacitors
C1—10-μF, 10-volt electrolytic
C2—0.01-μF disc

Resistors (¼-watt, 10% tolerance)
R2,R8,R14,R20—10,000 ohms
R3,R9,R15,R21—1 megohm
R4,R10,R16,R22—3,300 ohms
R5,R11,R17,R23—6,800 ohms
R6,R12,R18,R24—470 ohms
R25—2,200 ohms
R1,R7,R13,R19—50,000-ohm trimmer potentiometer (Bourns No. 3006P-1-503 or equivalent)
R26—10,000-ohm trimmer potentiometer (Bourns No. 3299W-1-103 top-adjust)

Miscellaneous
S1—Spst normally open, momentary-action pushbutton switch
Printed-circuit board or other wiring medium (see text); suitable enclosure (see text); 24-inch two-conductor cable; load resistor (see text); battery connector (see text); lettering kit; machine hardware and spacers; hookup wire; solder; etc.

for the transistors and *IC2*.

A 5$^{13}/_{16}$″ × 3$^{1}/_{8}$″ × 2″ plastic box like that shown in the lead photo makes an almost ideal case in which to house the battery tester for hand-held use. The bottom of the box is used as a front panel, on which to mount the circuit-board assembly and TEST switch and through which the domes of the LEDs protrude. You also need access holes for the trim screws on the trimmer pots and entry for the battery cable.

The length of the spacers used to mount the circuit-board assembly into place is partly related to the mounting of the LEDs. You must drill four holes in the bottom of the box to match the spacing on the circuit board. These holes should be sized to provide a light push fit for the LEDs you use. Mount the LEDs on the *solder* side of the board, making sure you properly polarize them.

To set the height of the LEDs evenly above the board, temporarily bolt two spacers to the solder side of the board and stretch a strong thread between the spacers under the bolt heads to give a line that represents the inside surface of the panel on which the assembly mounts. Line up each LED's base (or its lip if it has one) with the taut thread and solder into place.

Temporarily mount the circuit-board assembly in the box (see Fig. 2) to determine the height from the bottom the four holes for the trimmer potentiometers must be. Accurately mark each hole location. Dismount and set aside the circuit-board assembly. Drill a hole large enough at each marked location to admit a jeweler's screwdriver. Make a strip of stiff plastic, such as Plexiglas, to cover the four holes after calibrating the battery tester. This plastic can be held in place with a pair of short 4-40 machine screws in threaded holes in the plastic. If you leave these holes open, you will find that a few ants or other insects will find their way into the box on a grassy airfield.

Strip ¼ inch of insulation from both conductors at both ends of a two-conductor cable. twist together the fine wires in each conductor and sparingly tin with solder. Solder to one end of this cable a connector that mates with the battery in your model airplane. Pass the free end of this cable through its hole in the box and tie a knot in it about 6 inches from the prepared end inside the box to serve as a strain relief. Solder the conductor that goes to the connector's + terminal to one lug of the TEST switch and the other conductor in the hole labeled S1.

Plug *IC1* into its socket. Note the correct orientation of this IC and make sure no pins overhang the socket or fold under between IC body and socket.

Mount the board inside the box (make sure the LEDs are seated in their holes in the "front" panel) with appropriate length spacers and machine hardware.

Calibration

A stable variable-voltage bench supply that can be adjusted over a 3.0-to-5.0-volt range is needed to calibrate the battery tester. You also need a digital voltmeter that has a resolution of two decimal places. If you do not have this type of equipment, it is almost certain that one of the members in your local flying club has them and will be happy to calibrate your tester for you.

Connect the voltmeter across the bench power supply and set the latter to exactly 4.8 volts on the meter. Then connect the voltmeter between circuit common at the negative (−) side of *C1* and the *R25/IC2* point on the circuit board. Adjust *R26* for a reading of 2.50 volts. Return the voltmeter to the bench supply. If all four LEDs are on, adjust *R9* until green *LED4* just extinguishes. What you want here is a potential on the + inputs to the comparators of about 2.48 or 2.49 volts.

Connect the voltmeter between pin 20 of *IC1* and circuit common. Readjust *R19* until *LED4* turns fully on. You do not want this LED to be off when the battery is at 4.80 volts.

Readjust the bench supply to 4.6 volts and trim *R13* until the potential at pin 9 of *IC1* is at 2.48 or 2.49 volts, at which time *LED3* should extinguish. Change the supply's output to 4.40 volts and adjust *R7* for a reading of 2.48 or 2.49 volts at pin 7 of *IC1* and *LED2* extinguishes. Finally, adjust *R1* until *LED1* just extinguishes and then bring up the adjustment until it comes fully on again.

With calibration complete, slowly adjust downward the output from the bench supply to simulate a dying battery. Note as the voltage decreases the LEDs each go out at the correct voltage levels.

It would be unrealistic and misleading to check a model's battery output without an appropriate load. The battery tester itself draws about 36 milliamperes of current without a load on the battery and with all four LEDs on. This load decreases as the LEDs successively extinguish. To take a proper reading, you need a resistive load across the battery, shown in Fig. 3 as LOAD.

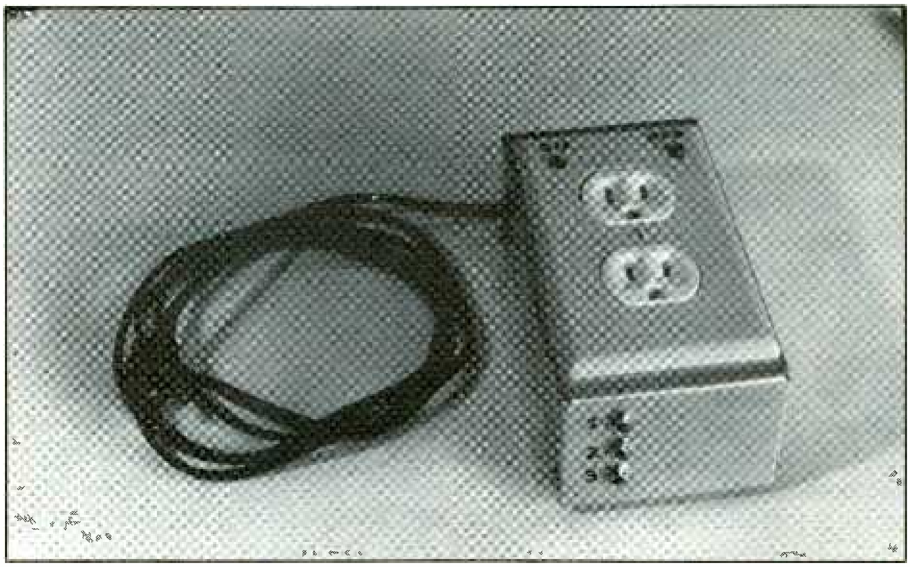
No value is given for this load resistor in the Parts List because the current drawn by the various receivers and servos used in model airplanes varies from model to model. To determine the value of load resistance to use with this project, look up the current drains of your servos and receiver. Multiply the servo drain by the number of servos being used and add to the result the drain of the receiver to get a total figure. Then use Ohms law to calculate the value and wattage needed for the load resistor. For example, if the total load is 74 milliamperes, 64 ohms would be the value of the resistor needed for the load. Since this is not a stock value, you would use a 68-ohm, 1-watt resistor.

Happy landing!

An Automatic Printer Power Controller

Switches on a printer and external printer buffer automatically when you power up any computer sharing them in a multi-computer setup

By Ralph Tenny



When you have one computer and one printer, life is easy. Add a printer buffer so the printer doesn't hog the computer during printing, and life gets better. Add another computer and a way of switching the printer buffer between computers, and things are still okay. However, if you're like most people, each computer you have is controlled by its own power strip, with the printer plugged into the one that's most frequently used. So if you want to use your printer and buffer (if you have one) with computer number two, you have to unplug them from number one's power strip and plug them into number two's if you want automatic power-up when the computer is turned on. Or you can plug the printer and buffer into their own separate wall outlets and manually switch them on and off whenever you need them.

What you need, especially if you have more than two computers that are to be used with the same printer, is a device that will automatically power up/down the printer and buffer whenever *any* computer in your system is turned on. This is what the automatic printer power controller described here does. With this power controller, life with a multiplicity of computers that share the same printer and buffer suddenly becomes almost as easy as it was when you had only one computer.

Our automatic printer power controller connects to each computer with which it is to be used via a cable that taps off the computers' +5-volt and ground lines. Turning on any computer sends 5 volts to the controller, which then powers up the printer and buffer plugged into it. Turning off the computer cuts off the 5 volts and causes the controller to power-down the printer and buffer. The whole operation is automatic. Your only extra step is to switch the printer or buffer to the computer you want to use. Interfacing between the computers and controller is through optical isolators, any number of which can be added as needed for the computers you have.

About the Circuit

Shown in Fig. 1 is the complete schematic diagram of the automatic printer power controller. Power transformer *T1* and rectifier/filter *BR1/C1* power relay *RLY1* to switch power to the printer and printer buffer plugged into the ac power sockets. The same dc voltage used to power the relay circuit is stabilized by zener diode *Z1* to power quad CMOS Schmitt trigger *IC1* to drive the relay via buffer transistor *Q1*.

Since I also have a Tandy Model

100 laptop computer, momentary-action the ON pushbutton switch allows me to activate the printer on rare occasions when I print from this computer. A separate OFF pushbutton switch allows me to turn off the printer when I'm finished working. I could have included another IC to sense when the computers are turned off. However, I didn't feel this was worth the effort or expense.

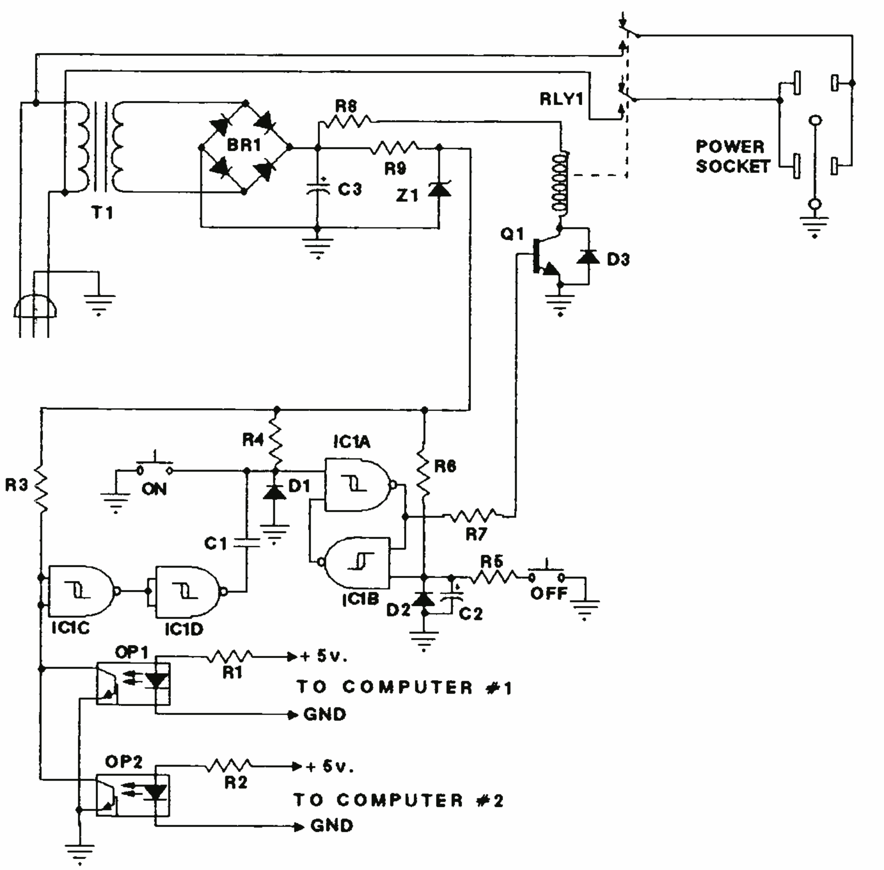
Sections *IC1A* and *IC1B* for this application are connected as a latch that drives *Q1* when the output of *IC1A* goes high. This condition occurs when the ON switch is closed or when either *OP1* or *OP2* detects a computer has been turned on. Note that these optical couplers are powered by the +5-volt supplies in their respective computers only when the computers themselves are turned on. Resistors *R1* and *R2* limit the current from the computer power supplies to a level suitable to turn on *OP1* and *OP2*, respectively.

When either (or both) optocouplers are turned on, current through *R3* pulls *IC1C*'s inputs low. This causes *IC1D* to pulse *IC1A* on via *C1*, which is exactly what occurs when the ON switch is pressed. Resistor *R4* holds the latch input high except when the ON switch or *C1* pulses the input low to set the latch. Diode *D1* protects the input of the latch from negative swings that could be generated when the power supply turns on.

On the other side of the latch, the OFF switch resets the latch by discharging *C2* through *R5*, while *R6* and *D2* protect the input of the latch from negative inputs. Also, *R6* and *C2* hold the input of *IC1B* low when power is applied. This forces the latch to power up in the off state.

Resistor *R7* provides base current for *Q1* whenever the latch is in the ON state. Diode *D3* protects transistor *Q1* from the inductive kickback generated when the relay turns off.

The power supply consists of



PARTS LIST

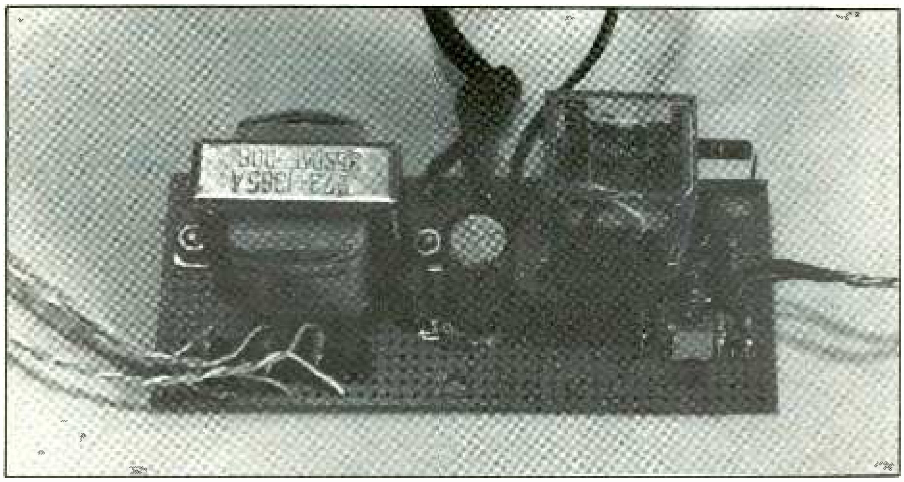
Semiconductors
BR1—50-PIV, 1-ampere bridge-rectifier assembly or individual 1N4001 rectifier diodes
D1,D2—1N4148 switching diode
D3—1N4001 rectifier diode
IC1—CD4093 CMOS Schmitt trigger
OP1,OP2 . . . OPn—General-purpose TTL-level optical isolator (4N25 or similar)—see text
Q1—MPS3904 npn transistor (Radio Shack Cat. No. 276-2016)

Capacitors
C1—0.01-μF, 50-volt film
C2—1-μF, 35-volt tantalum

Resistors (10% tolerance)
R1,R2—1,000 ohms, ¼ watt
R3—22,000 ohms, ¼ watt
R4—100,000 ohms, ¼ watt
R5—1,000 ohms, ¼ watt
R6—220,000 ohms, ¼ watt
R7—4,700 ohms, ¼ watt
R8—82 ohms, ½ watt
R9—330 ohms, ½ watt

Miscellaneous
RLY1—12-volt dc dpdt relay with 5-ampere contacts
T1—12-volt, 300-mA power transformer
Two momentary-action spst pushbutton switches; dual 3-contact ac receptacle assembly; miniature phone jacks for inputs (see text); printed-circuit board or perforated board with holes on 0.1" centers and suitable Wire Wrap or soldering hardware (see text); three-conductor ac line cord with plug; suitable enclosure and wall plate (see text); rubber grommet (to line ac line cord entry hole); lettering kit; spacers; machine hardware; hookup wire; solder; etc.

Fig. 1. Complete schematic diagram of automatic printer power controller.



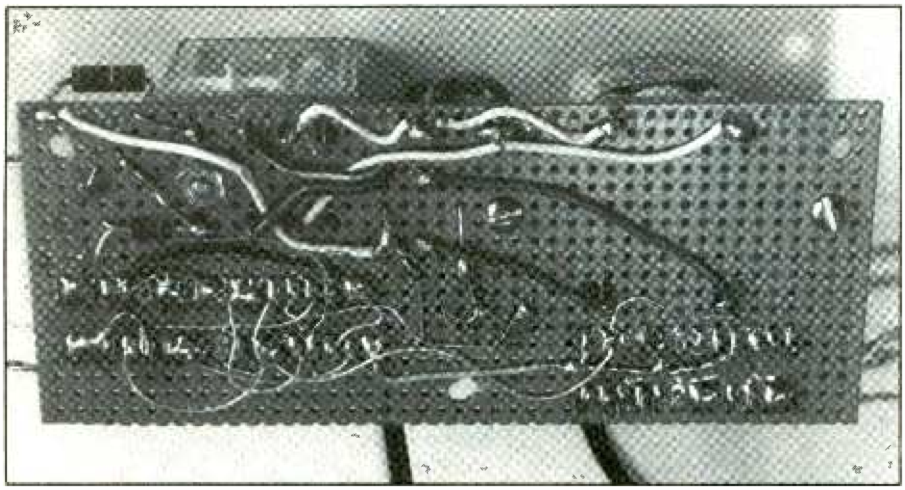


Fig. 2. Prototype of circuit-board assembly wired on perforated board. Upper photo shows top side of board, lower photo shows bottom of board.

transformer *T1*, bridge rectifier *BR1*, filter capacitor *C3*, resistors *R8* and *R9* and zener diode *Z1*. Current limiting for *RLY1* is provided by *R8*. Both *R9* and *Z1* stabilize the voltage for *IC1*. The contacts of *RLY1* switch 117-volt ac line power to both contacts of a standard three-conductor wall outlet. In operation, the printer power cord would be plugged into one socket, while the printer buffer cord would be plugged into the other socket.

Construction

There is nothing critical about circuit layout. Therefore, you can use any traditional wiring technique that suits you, including a printed-circuit board of your own design and a perforated board (with holes on 0.1″ centers) and suitable Wire Wrap or soldering hardware. In either case, it's a good idea to use DIP integrated-circuit sockets for *IC1, OP1* and *OP2*. The prototype shown in Fig. 2 was wired on perforated board. The upper photo shows a top-of-the-board view, while the lower shows the solder side. In this particular case, neither sockets nor other hardware were used.

The only important point to keep foremost in mind with regard to construction is electrical safety. As noted in Fig. 1 and the Parts List, you *must* use a grounded three-conductor line cord and ac sockets, with the green ground wire going to the metal chassis to complete the ground circuit for the printer and buffer.

A common aluminum utility box was used for the prototype of this project (see lead photo), though it did require a respectable amount of chassis work to make the cutout for the power sockets. If you go this route, make sure the project box you choose has enough depth to permit mounting the circuit-board assembly on the floor and the power sockets above, with enough room between the two to prevent interference with each other.

If you prefer, you can use a standard four-outlet electrical box, with the circuit-board assembly mounted in one half of the box and the two sockets in the other half. This will eliminate extensive chassis work, and the box can be covered with a standard two-socket, one-switch wall plate, with the switch slot covered over with electrical tape or a glued-on metal or plastic plate. This type of box lets you avoid any interference whatsoever between the circuit-board assembly and power sockets, though at the expense of a larger enclosure. On the other hand, if you need more room for the additional optical-coupler computer inputs, the double electrical box provides ample room to stack another board on which the extra circuitry can be mounted below the first.

Whichever type of enclosure you choose, drill holes for the ac line cord, the switches and the jacks for the various inputs from the computers to the optical isolators, as well as for mounting the circuit-board assembly (and for mounting the ac receptacles if you use the aluminum utility box). Once you've drilled these holes, deburr all cut and drilled holes to remove sharp edges. Then line the line-cord hole with a rubber

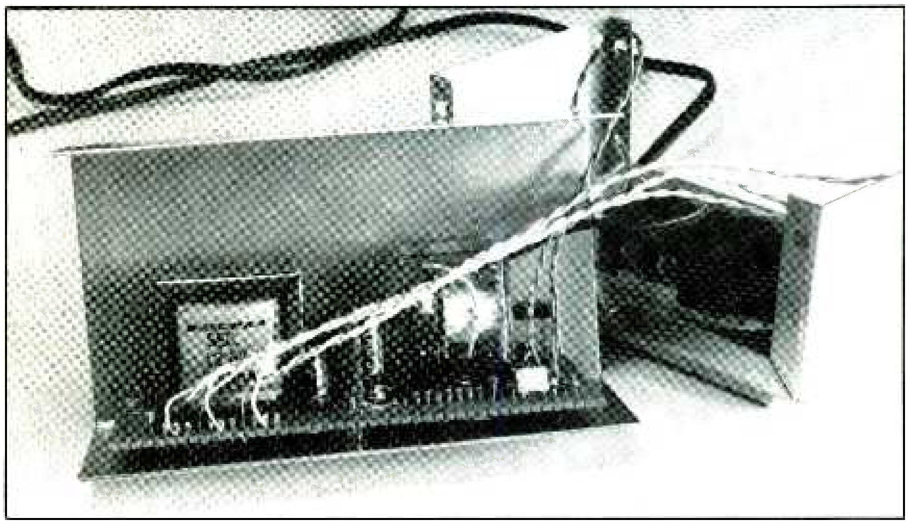


Fig. 3. Circuit-board assembly mounted on floor of aluminum utility box using spacers and machine hardware.

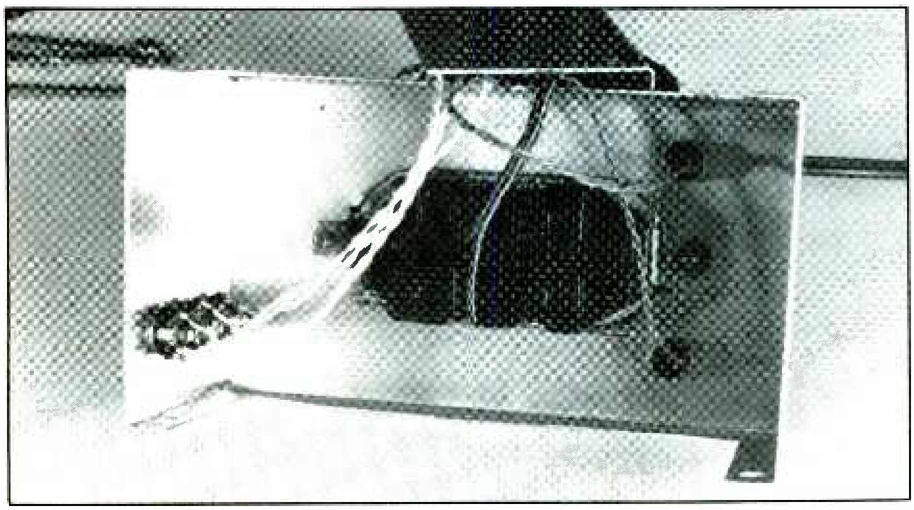
grommet, and mount the switches in their respective locations.

Miniature phone jacks make excellent input connectors for the project. Mount these in their respective holes. Then wire them to the appropriate points in the circuit. Connect and solder heavy-duty hookup wires or at least 18-gauge zip-cord conductors to the contacts of the relay.

Mount the circuit-board assembly in the selected location inside the box, using ½" spacers and 4-40 or 6-32 × ¾" machine screws, nuts and lockwashers (see Fig. 3). Then connect and solder the free ends of the wires last connected to the circuit-board assembly to the ac line cord and power receptacles and wire the switches and jacks into the circuit. Use a voltmeter to trace from the power-cord plug to the socket to make sure you've attached the low side of the line cord to the wide-blade receptacles and the high side to the narrow receptacles of the sockets.

Mount the power sockets, sandwiching the free end of the ac line cord's green (ground) wire between one of the receptacle assembly's mounting tabs and the box to complete the ground circuit. With the project completely assembled, recheck all your wiring against Fig. 1, especially with respect to the integrated circuit and optical isolators. Also, check to make sure the diodes and electrolytic capacitor are properly polarized. Once you're satisfied that your wiring is correct, finish assembling the project.

Plug your printer into one power socket, your printer buffer into the other power socket and the project's line cord into an ac receptacle. You're ready to enjoy the advantages of completely *automatic* printer/buffer switching. **ME**



This interior view shows mounting details for dual ac receptacle and two push-button switches on the front panel and three (you can have as many more as needed) input jacks in one side panel.

A 16-Channel Digital IC Tester

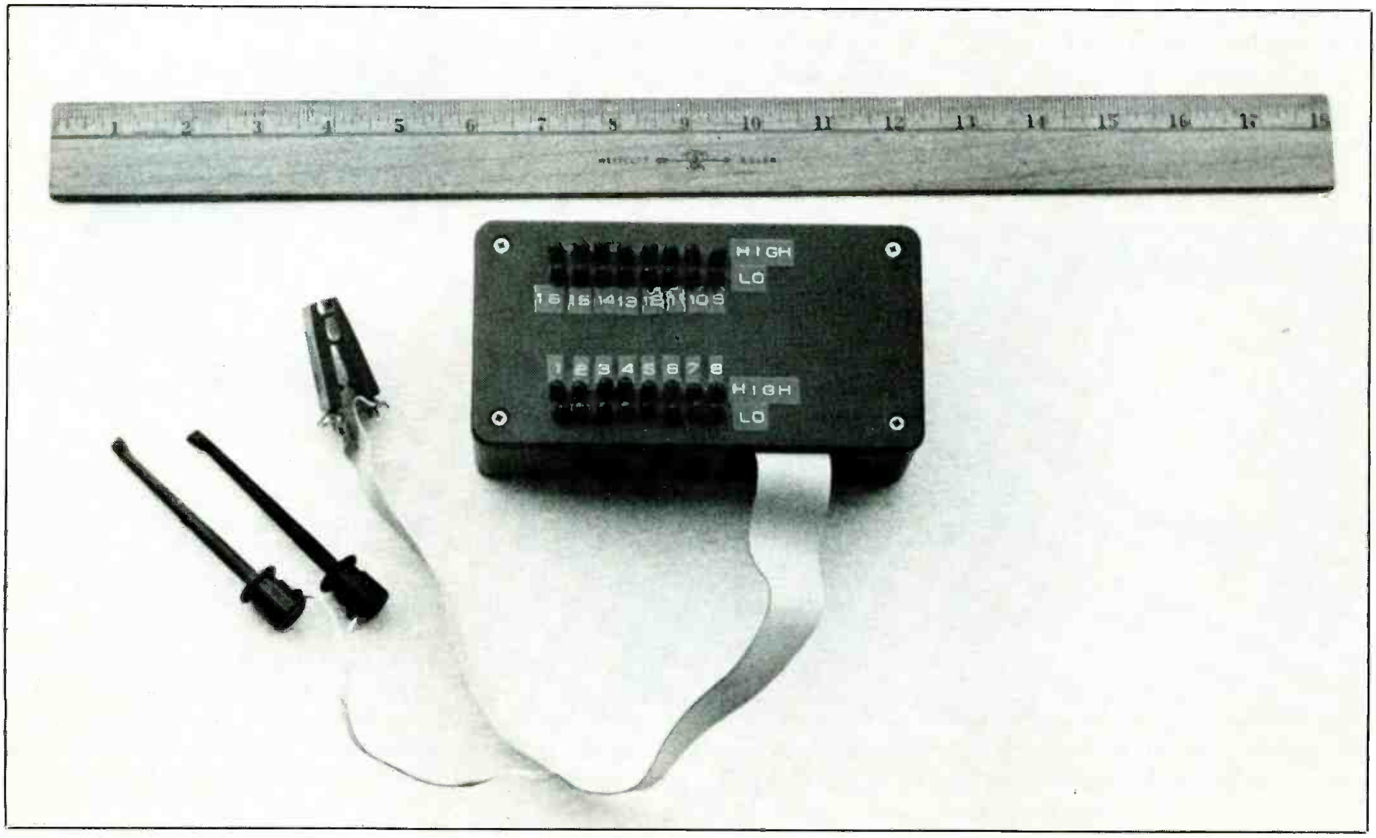
An easy-to-build project that simplifies troubleshooting digital circuits

By David Leithauser

When you build and test a project that uses digital integrated circuits, chances are that the test you perform most frequently is determining whether a given input or output is high or low. If you're like most of us, you use either an oscilloscope or a logic probe to perform this test. While both instruments are good in their own ways, a far more informative instrument is a multi-channel logic analyzer like the 16-channel tester described here. This type of instrument can monitor and report on the status of all 16 pins of a typical digital IC simultaneously. With about two hours at your workbench and an investment of around $15, you can make this instrument. Moreover, it can be expanded for use with 20-, 24- and even 40-pin digital ICs at little extra cost.

About the Circuit

Our 16-channel digital IC tester consists of a series of 16 independent but identical logic probes. Each of these "probes" consists of a simple inverter/buffer, two light-emitting diodes and two resistors with some convenient type of input connector. Because all 16 probes are identical, the circuit



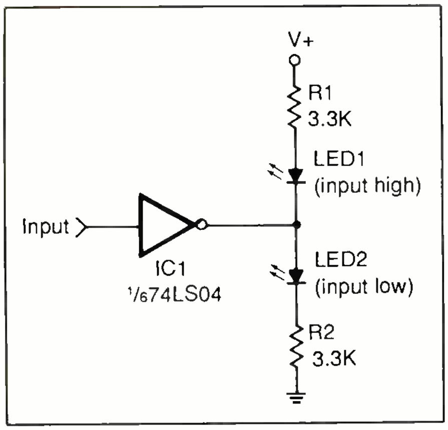


Fig. 1. Schematic diagram of only one of the 16 (or more—see text) logic "probes" that make up the digital IC tester.

PARTS LIST

IC1—74LS04 hex low-power Schottky inverter/buffer
LED1,LED2—Jumbo red light-emitting diodes (two per channel)
R1,R2—3,300-ohm, ¼-watt, 10% tolerance resistors (one for each LED used)
Misc.—One each red and black miniature alligator clips or spring-loaded ball-type hook connectors (see text); IC test clip (16-, 20-, 24- or 40-pin; see text); printed-circuit board or perforated board and suitable soldering or Wire Wrap hardware; sockets for ICs; 24-inch length of multi-conductor ribbon cable (number of conductors depends on number of lines needed for test clip); two small alligator clips or spring-loaded ball-type hook connectors; one each red- and black-insulated 24-inch length of stranded hookup wire or test-lead wire; suitable plastic enclosure; insulating tubing; machine hardware; hookup wire; solder; etc.

Note: The number of ICs, IC sockets, LEDs, dropping resistors, contacts on IC test clip and conductors in ribbon cable depends on how many channels are used. See text for details.

shown in the schematic diagram for one probe is all that's needed to explain project operation.

A basic version of this tester would have 16 channels. Since there are six inverter/buffers in a single 74LS04 IC, you need a minimum of three such ICs, which leaves two extra inverter/buffers that aren't used. If you wanted to build a 20-, 24- or 40-pin tester, you would have to add extra probe channels, each with their own inverter/LED/resistor arrangement. For a 20- or 24-pin tester, you need four 74LS04s (all inverter/buffers used for the latter but four not used for the former); for a 40-pin tester, you need seven 74LS04s (two inverter/buffers not used). Inputs to the buffers would be made through a ribbon cable terminated in a clip-on connector with contacts for all pins of an IC under test. There would also be two extra leads, one terminated in a red alligator clip or ball-type hook connector for the +5-volt power input and the other terminated in a similar black connector for power (and signal since both share the same electrical point) ground.

Not shown in the schematic diagram are the +5-volt and ground connection points in the circuit. These go to pins 14 (+5 volts) and 7 (ground) for all 74LS04 inverter/buffer packages used.

The red and black connectors tie to the +5-volt and ground points of the circuit of the IC to be tested to provide power for the project. With the connector clipped onto the IC to be tested, each conductor of the ribbon cable serves as an input line to each of the inverter/buffers that are active. If an input of any given tester channel is high, the output of the inverter/buffer for that channel will be low, which will turn on *LED1*. Conversely, if the input is low, the output of the inverter buffer will be high and *LED2* will turn on. If there is no output at a given IC pin, the signal will be at neither +5 volts nor near ground potential, which will result in neither LED for that channel lighting.

Power monitoring is automatically taken care of when the ribbon-cable connector is clipped onto the IC under test and power is applied. Whichever pin has the steady +5 volts applied to it will deliver to the project a constant +5 volts that will cause *LED1* for that channel to light. Conversely, the pin that serves as power and signal ground will be at 0 volt so that *LED2* for that channel will be on continuously.

Because this tester has separate HIGH and LOW LEDs for each channel, brief pulses are easier to spot than with some costly commercial models, which usually have only one LED per channel. If both LEDs in a given channel appear to be on at the same time, this is an indication of rapid high/low transitions. If the LEDs are well-matched, you can even estimate the signal's duty cycle by observing the relative brightnesses of the two LEDs.

Though the schematic diagram and the Parts List both specify 74LS04 inverter/buffers, you can use standard 7404 TTL devices. However, the "LS" (low-power Schottky) devices specified will draw less power from the circuit of the device being tested and, more importantly, will cause less interference with the IC under test.

Construction

Since there's nothing critical about component mounting and layout, you can use any traditional method of wiring for the ICs and resistors that suits you. For example, you can design and fabricate your own printed-circuit board or use perforated board with holes on 0.1-inch centers and suitable soldering or Wire Wrap hardware. In either case,

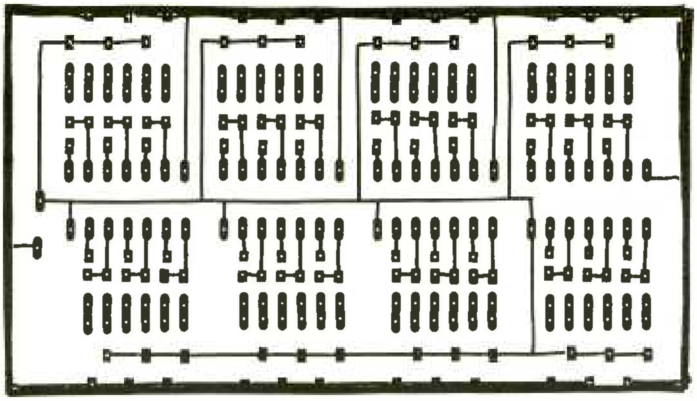


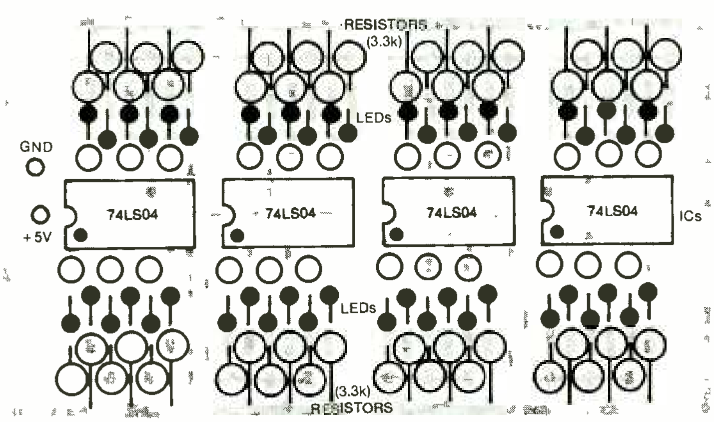
Fig. 2. Actual-size etching-and-drilling guide for up to 24-channel tester. Two boards are needed for a 40-pin device tester.

it's a good idea to use sockets for all integrated circuits.

Note that the Fig. 2 etching-and-drilling guide and Fig. 3 wiring diagram show a layout for up to a 24-pin tester. If you wish to test only 14- and 16-pin ICs, you can leave out one IC and the resistors and LEDs that go with it. For a 24-pin tester, include *all* four IC stages, resistors and LEDs. For a 40-pin tester, you need two of the Fig. 2 boards, one fully populated and the other lacking only one IC and its associated components.

Note, too, in Fig. 3 that all resistors mount upright on the board, with the bodies mounted directly over the circled holes. This is done to conserve space to make as compact a unit as possible.

Wire the boards exactly as shown in Fig. 3, installing and soldering into place first the IC sockets and then the resistors. Trim ¼ inch of insulation from both ends of as many 3-inch lengths of hookup wire as needed to make the connections to the off-the-board LEDs. Use black-insulated wires for the cathodes and red-insulated wires for the anodes. Plug one end of each of the black-insulated wires into the holes labeled K and solder into place. Similarly, plug one end of the red-insulated wires into the LED holes that are not labeled and and solder into place.



Notes: Resistors mount upright at top and bottom of board. LED cathodes go to holes indicated by solid black dots. Inputs from ribbon cable go to circled holes.

Fig. 3. Wiring guide for printed-circuit board.

Next, separate the conductors at one end of a 24- to 36-inch ribbon cable a distance of 1 inch and trim from all conductors ¼ inch of insulation. Separate the conductors at the other end of the cable a distance of 3 inches and trim from each ¼ inch of insulation. Tightly twist together the fine wires of each conductor and sparingly tin with solder. Connect and solder the conductors at the 1-inch separated end to the solder pins of the IC test clip. Then, working with an ohmmeter and referring to Fig. 1, plug into the appropriate holes in the board the conductors at the other end of the cable and solder each into place as you go.

Strip ¼ inch of insulation from both ends of 24-inch-long red- and black-insulated wires. Twist together the fine wires at both ends and tin with solder. Plug one end of these wires into the +5V (red insulation) and GND (black insulation) holes and solder into place.

Mount the LEDs on the lid of the selected enclosure. You have either of two options for LED mounting. One is to drill a single suitably sized hole in which to friction mount each LED from the rear of the panel so that only the LED's domed top protrudes through the front of the panel. The other is to drill two ¹⁄₁₆-inch holes 0.1 inch apart for each LED's leads and plug the leads into the holes so that the entire LED housing is external to the box. A piece of perforated board with holes on 0.1-inch centers serves as a good drilling guide for this. Both approaches are suitable, though with the latter, it's a good idea to apply a very small drop of fast-set clear epoxy between the bottom of each LED and the front panel to secure the LEDs into place.

Arrange your LED layout on the panel to emulate the pin arrangement of the type of IC the project is designed to test. That is, you should have two parallel rows of LED pairs, as shown in the lead photo. As a finishing touch, you might want to paint onto the panel the traditional IC case outline and number each pin location.

Slide a 1-inch length of small-diameter insulating plastic tubing over each of the LED wires on the circuit-board assembly. Then identify the anode leads of all LEDs and trim each to ¾ inch long and form a small hook in each. Identify the wires on the board that are to connect to the anodes of the LEDs and form a small hook in each of these. Connect and solder the free ends of the wires to the anode leads of the LEDS. Make sure you connect each wire to the correct LED anode before soldering the connections. When all anode wires have been connected and soldered to the LED anode leads push the insulating tubing up over the connections until it sits flush against the bottom of the LED or panel. Do the same for the cathode leads and wires.

Notch both halves of the plastic box in which the project is to be housed to provide exits for the ribbon cable and +5-volt and ground wires. Mount the circuit-board assembly in place. Then assemble the box with the ribbon cable and power leads routed through their slots. Finally, terminate the free ends of the power leads in miniature alligator clips or spring-loaded ball-type hook connectors.

Using the Tester

Use of the tester is simple and straightforward. Simply connect the red and black power leads to any +5-volt and ground points, respectively, in the circuit containing the IC to be tested. Then place the IC clip on the IC, observing orientation to make sure the pin arrangement matches the numbering on the project. Finally, turn on the power to the circuit containing the IC to be tested and observe the activity of the project's LEDs. Compare this activity with what would be expected from a good integrated circuit under the conditions that exist in the circuit.

Though the lowest level tester described is for 16-pin digital ICs, the project can be used on DIP (dual in-line package) ICs with fewer pins. To simplify interpreting LED activity, it's a good idea to always align the pin 1 contact of the IC clip with pin 1 of the IC, regardless of the number of pins on the latter. You can, of course, place the clip on the IC anywhere all pins will make contact, since the project is neither pin nor orientation sensitive. Whatever IC clip contacts aren't needed will simply overhang the IC being tested. ME

Experimenting With Shape-Memory Alloy Wire

By Forrest M. Mims III

Shape-memory alloys are metals that possess a crystalline structure that rapidly and dramatically change shape in response to a temperature change. The length of a shape-memory alloy (SMA) that has been drawn into a wire will contract as much as 10 percent when the wire has been heated beyond its transition point. Such a wire can be easily heated simply by passing a current of a few hundred milliamperes through it. After the current is removed, the wire rapidly resumes its normal length as it cools.

It's interesting to recall that metal generally expands when heated and contracts when cooled. This explains the incorporation of expansion joints in metal bridges and structures and the intentional slack of power lines. Over its transition temperature range, an SMA alloy behaves in exactly the opposite fashion.

SMA wire can be used to make various kinds of circuit breakers. Its most interesting application, however, is in the production of many different kinds of simple but effective electromechanical actuators. These actuators are well suited for many kinds of robotic applications. They can also be used to make electrically operated latches, indicators, heat engines, louver and valve controls and pumps.

Later in this column, a new kind of SMA wire, BioMetal™, will be described in detail. Also presented are some simple circuits for use with the wire. First, let's examine some of the basics of shape-memory alloys.

Shape-Memory Alloy Basics

In 1961, William Beuhler and his team of researchers at the Naval Surface Weapons Center, then known as the U.S. Naval Ordinance Laboratory, discovered that a titanium-nickel alloy exhibited the shape-memory effect. This effect had first been discovered in a gold-cadmium alloy a decade earlier by Chang and Read in Europe. Later, the effect was found in an alloy of indium and titanium.

The discovery by Beuhler's team was important since their Ti-Ni alloy was less expensive and lacked the possible health risks of earlier shape-memory alloys. They named the material "nitinol" (after *ni*ckel *ti*tanium *N*aval *O*rdinance *L*aboratory).

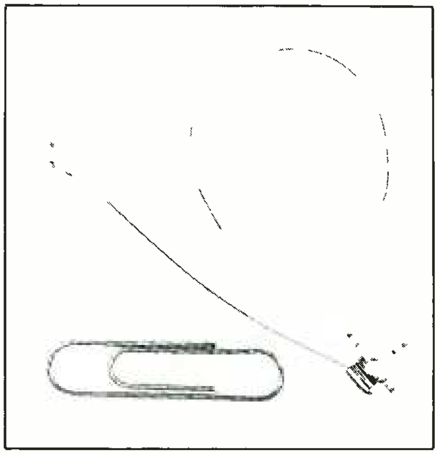


Fig. 1. Terminated and unterminated BioMetal Wire.

In 1985, Japan's Toki Corp. announced that Dr. Dai Homma had discovered an improved version of nitinol. Dr. Homma had accidentally discovered the improved alloy some years earlier, and several years were required before he was able to recreate his original discovery. Toki now manufactures the improved nitinol alloy as a wire under the trade name "BioMetal."

BioMetal wire can be purchased from TokiAmerica Technologies, Inc. (18662 MacArthur Blvd., Suite 200, Irvine, CA 92715). TokiAmerica and Mondo-Tronics (20090 Rodrigues Avenue #1, Cupertino, CA 95014) also sell a variety of economical project kits that demonstrate the characteristics of and applications for BioMetal.

SMA Applications

Many applications have been devised for nitinol. Some have not been commercialized or used in practical applications. For instance, NASA once proposed using nitinol to make lunar antennas that would deploy when heated by the sun or a heater. Many other applications have found commercial acceptance, to be sure. For example, nitinol has been used in eyeglass frames, dental alignment materials, miniature pumps and even an experimental artificial heart.

Another application that has been suc-

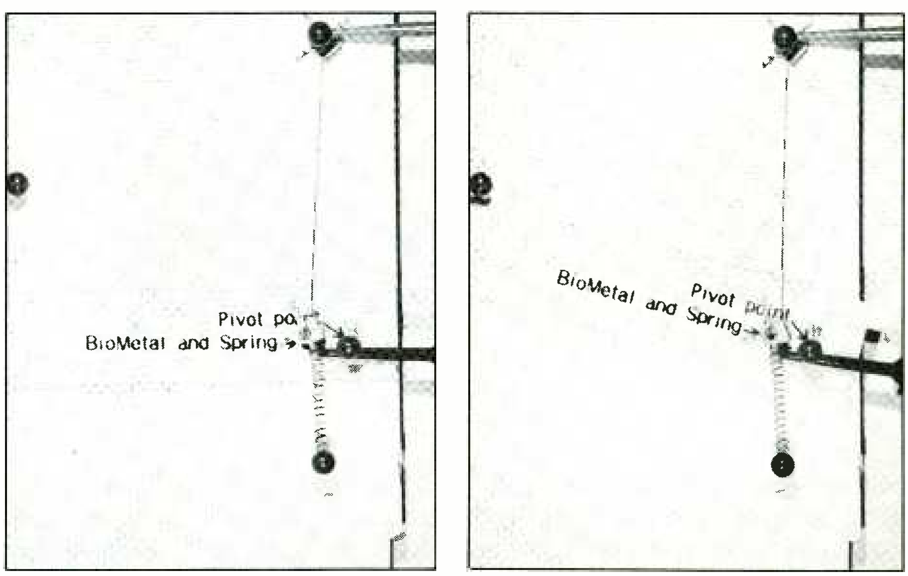


Fig. 2. A BioMetal-controlled lever in its resting (left) and actuated (right) positions.

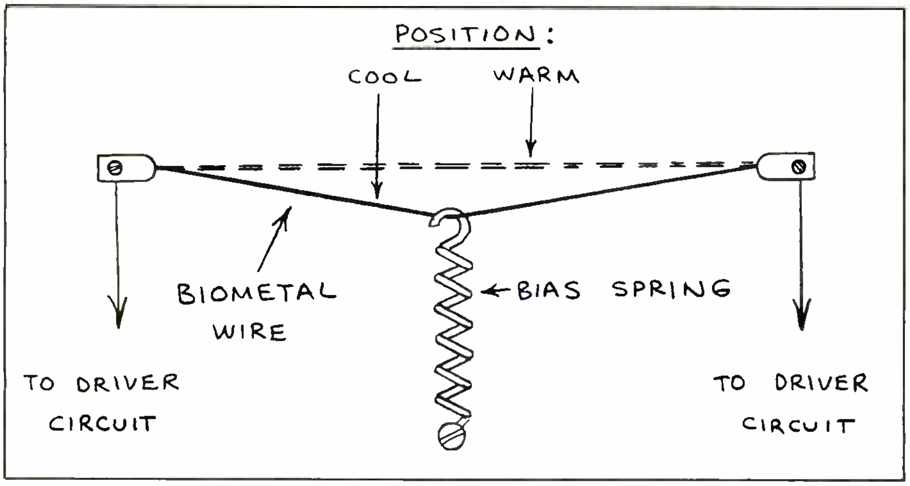


Fig. 3. BioMetal Demonstrator.

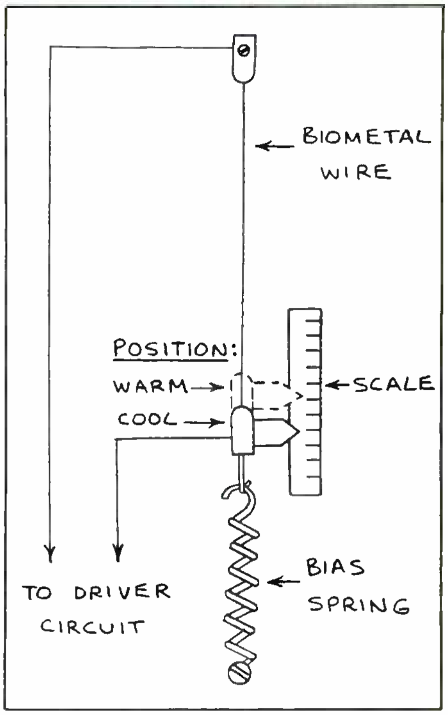


Fig. 4. Arrangement for measuring contraction of BioMetal.

cessfully implemented is nitinol pipe fittings for hydraulic couplers in jet aircraft. The nitinol used in this application has a transition temperature range below the normal ambient. Prior to installation, a nitinol pipe fitting is expanded by cooling it. After the fitting is installed, its temperature is allowed to rise to ambient, at which point, the fitting contracts and firmly secures the union.

Nitinol has many more applications when drawn into wire than when used in bulk or sheet form. This is in part because the resistance of nitinol wire is typically 10 times that of copper. Therefore, it can be easily heated simply by passing an electrical current through it.

BioMetal Wire Characteristics

BioMetal wire from TokiAmerica Technologies is currently supplied in a 6-mil diameter. This wire has a resistance of about 1 ohm per inch. BioMetal wire supplied with the project kits described above is either unterminated or terminated in a pair of maple connectors. Shown in Fig. 1 are both terminated and unterminated BioMetal wire. Compression terminators are generally required because BioMetal wire should not be raised to the heat required for soldering.

When heated, BioMetal wire can pull up to about 11 ounces as much as 10 percent of its length. For a maximum life of as much as a million cycles, the contraction of BioMetal wire should be kept to around 4 percent of its length. Thus, a 3-inch length of BioMetal wire can reliably contract 0.12 inch.

BioMetal wire has a remarkably fast response time. After it is heated to its transition temperature, it responds within a millisecond. When BioMetal wire is immersed in a heat-dissipating liquid, such as silicone oil, and a fast-rising current is applied to it, it can be made to contract and expand within a few tens of milliseconds.

BioMetal is harder than steel. Like stainless steel, it is compatible with body fluids. The 6-mil wire supplied by TokiAmerica has a breaking strength of around 6 pounds.

Nitinol Actuators

Among the most interesting applications for nitinol wire is in the production of simple actuators whose actions resemble that of a solenoid. TokiAmerica Technologies' BioMetal wire can be used to demonstrate many such actuators, all of which can be operated by means of the simple circuits described below.

Fig. 2 shows one of the experiments that can be performed with a Toki BioMetal Project Kit (No. DH-601: "Lines, Angles and Levers"). The experiment shows how a length of BioMetal wire biased by a small spring can move a lever over a substantial distance. In the left photo, no current is applied to the BioMetal wire. The right photo shows what happens when a current is passed through the wire, which contracts and pulls the lever upward.

Many other simple experiments can be performed with a few inches of BioMetal wire, a bias spring and a few other simple components. Figure 3 is a simple demonstrator that consists of a length of BioMetal wire mounted between two fixed supports. A bias spring pulls the center of the wire to one side. When the wire is momentarily heated by a direct current from a single 1.5-volt alkaline cell or by means of a pulse or pulses supplied by one of the circuits to be described, the wire contracts and pulls away from the spring.

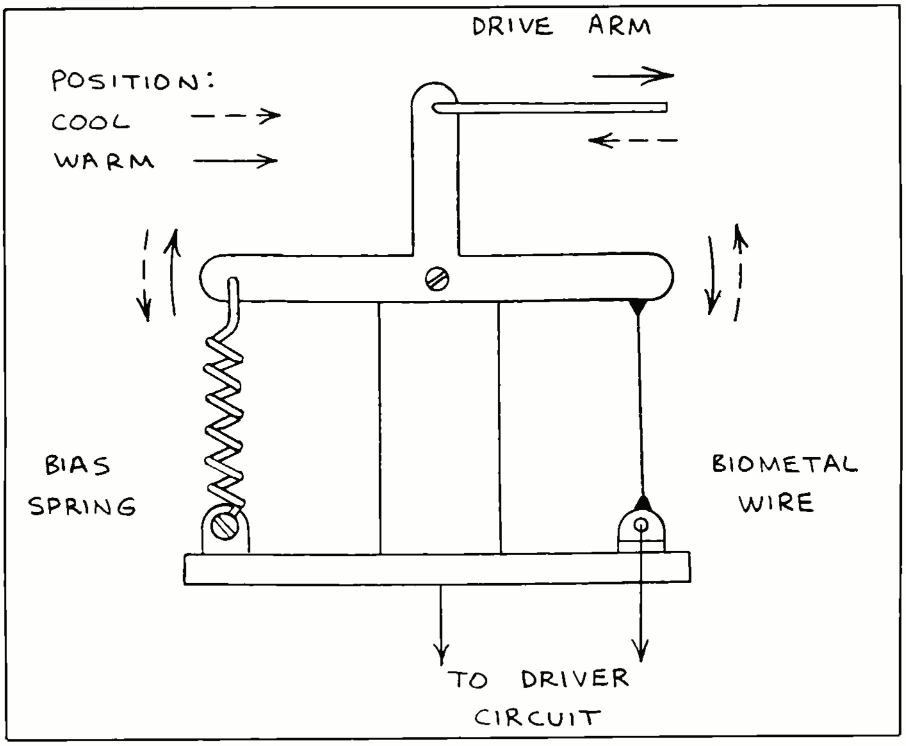


Fig. 5. Linear-motion actuator.

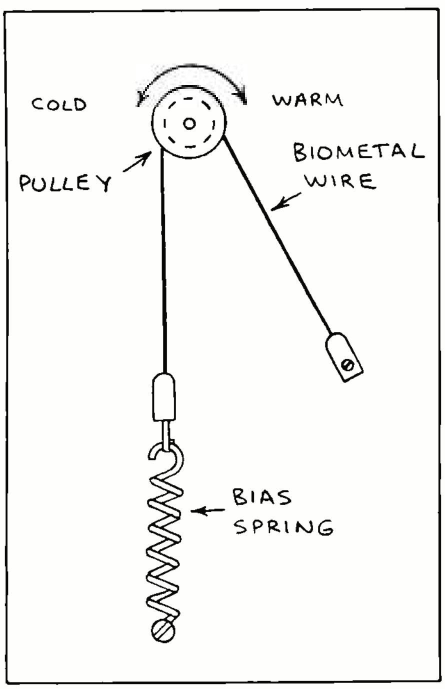


Fig. 6. Rotational actuator.

When current is removed, the wire cools and resumes its normal position.

Figure 4 shows an arrangement for measuring the overall movement of a length of BioMetal wire. Here, the bias spring is attached to one end of the wire and indicates the wire's movement on a scale. This simple arrangement demonstrates that BioMetal wire contracts when heated and resumes normal length after it cools to ambient temperature.

Figure 5 shows a linear-motion actuator whose key components are a length of BioMetal wire and a bias spring. When a current is applied to the BioMetal wire, the latter contracts and pulls the right side of the actuator down. This moves the actuator arm to the right. When the BioMetal wire cools, the actuator returns to its resting position.

How a BioMetal wire and a pulley can cause rotational movement is illustrated in Fig. 6. Once again, note that a bias spring is needed.

Figure 7 shows a compression or piston actuator made by installing a length of BioMetal wire inside a hollow tube. In this application, heating the BioMetal wire with an electrical current causes the inner tube to be pulled part way into the outer tube. A compression spring provides the needed bias force and returns the actuator to its normal position when the BioMetal wire is once again at ambient temperature.

An interesting three-movement flexor that produces remarkably lifelike movements is illustrated in Fig. 8. This device is made by threading a loop of BioMetal wire through two holes in a silicone tube. An ordinary copper wire is then threaded through a third hole in the tube and is wrapped around the loop at the center of the BioMetal wire. Applying a current between the copper wire and one end of the BioMetal wire causes the flexor to move to the left or the right. The flexor moves backward when a current is applied to both ends of the BioMetal wire.

BioMetal Wire Drivers

A BioMetal wire can be caused to contract simply by briefly connecting a 1.5-volt penlight cell across its ends. If power is applied for too long a time, however, the wire will overheat and possibly suffer damage. Therefore, it is best to use some form of regulated driver in BioMetal applications.

Many different methods are available for driving BioMetal wire by electronic means. For example, a power-supply chip whose output is connected across a wire can be gated on and off. Or the switching contacts of an electromechanical relay can be connected between the BioMetal wire and a power source. The relay's coil can then be actuated at any desired interval and duration by means of a simple transistor oscillator.

In the circuits to be described, current is switched through a BioMetal wire by means of a common 2N2222 switching transistor. In each case, the transistor is controlled by an equally common 555 timer IC. The transistor is rated for an

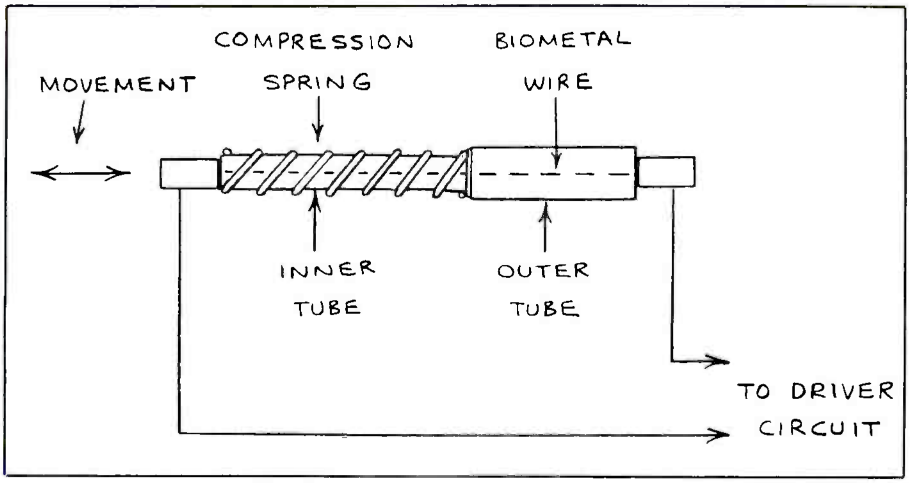


Fig. 7. Compression or piston actuator.

absolute maximum collector current of 800 milliamperes and absolute maximum output power of 400 milliwatts. Therefore, it will work well in each of the following circuits. For driver applications in which the BioMetal wire is heated for longer periods than by the circuits given below, it might be necessary to place a heat sink on the switching transistor or to use a power transistor. However, it's

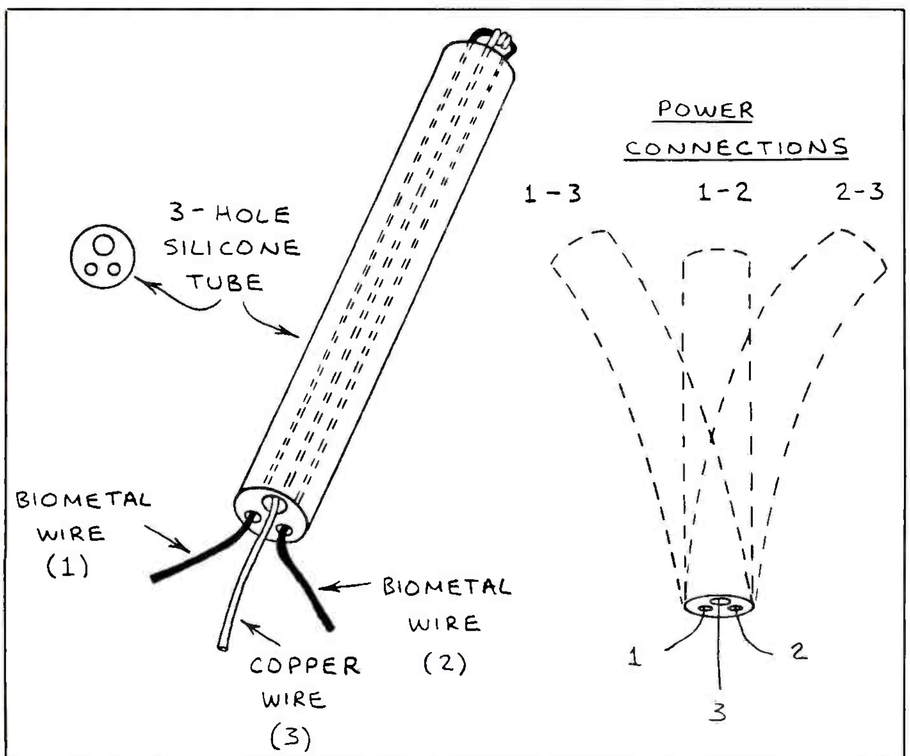


Fig. 8. Three-movement flexor.

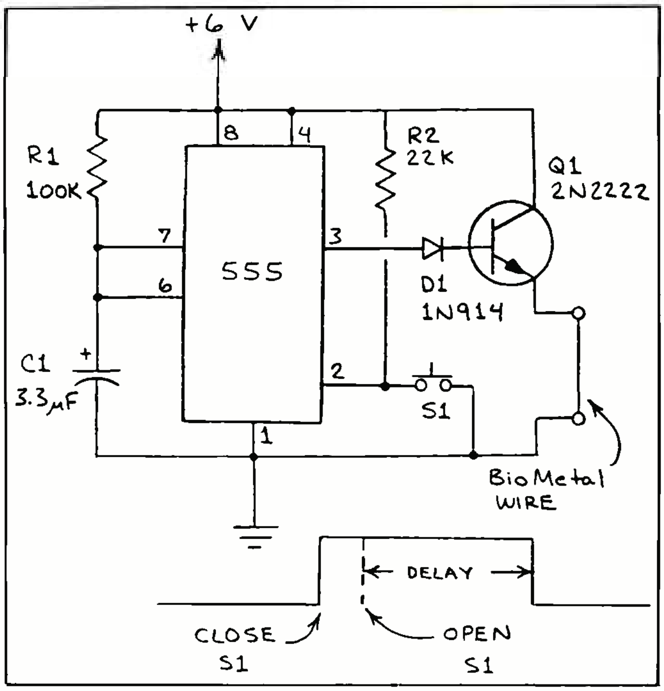
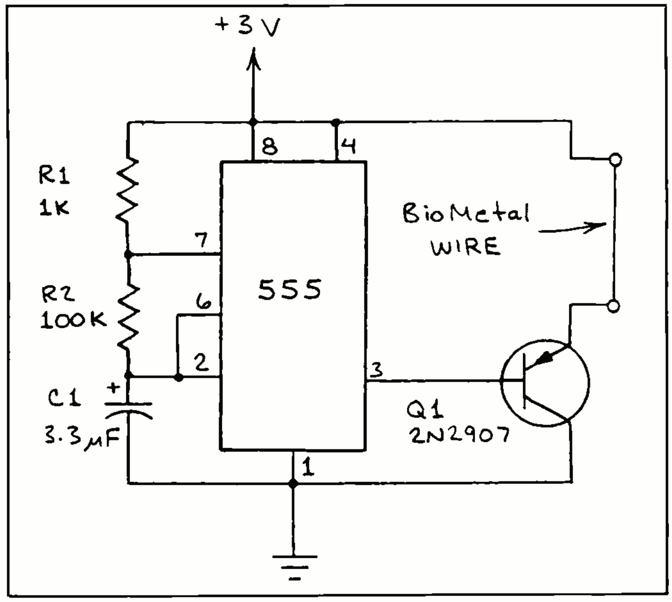


Fig. 9. Single-pulse BioMetal wire driver.

Fig. 10. Oscillating BioMetal wire driver.



likely that the BioMetal wire is being overdriven if the switching transistor becomes too hot.

When experimenting with the following circuits, it's good practice to use the same piece of BioMetal wire with each circuit, to permit the effect of each circuit to be compared with the others. The simplest approach is to install the BioMetal wire and biasing spring on a substrate, as shown in Fig. 4 or Fig. 5. Movements of the wire can then be easily seen.

Single-Pulse Driver

Figure 9 is the schematic diagram for a monostable multivibrator that delivers a single current pulse of fixed duration to a length of BioMetal wire. Ordinarily, the output of a 555 timer is low. In turn, this keeps *Q1* switched off. Closing and then releasing *S1* causes the output of the 555 to go high. This switches on *Q1* and permits current to flow through the BioMetal wire. When the charge on *C1* reaches approximately 4 volts, the output of the 555 goes low and switches off *Q1*.

The length of the output pulse from this circuit is controlled by *R1* and *C1*. With the values shown in Fig. 9, the pulse duration is approximately 100 milliseconds *plus* the length of time *S1* is closed. Therefore, for uniform results, keep *S1* closed for as brief an interval as possible.

The amplitude of the current through the BioMetal wire is approximately 460 milliamperes. Less current will cause less contraction of the wire. Current can be reduced by reducing the power-supply voltage or by inserting a small series resistance between the BioMetal wire and the emitter of *Q1*. For example, inserting a pair of parallel-connected 10-ohm resistors will reduce the current to around 300 milliamperes.

Oscillating Driver

Space Wings, a product of Mondo-Tronics, is a novel device that automatically flaps a pair of Mylar wings up and down approximately seven times a minute. The wings are moved by a short length of BioMetal wire installed across the hinge between them.

Figure 10 is the Space Wings driver circuit's schematic diagram. The circuit switches on and off *Q1* with a duty cycle of about 50 percent. The frequency of the pulses applied to the BioMetal wire can be increased by reducing the value of *R1* or *C1*. However, this will reduce the time for the BioMetal wire to cool between driving pulses. Consequently, the wire may remain warm between pulses and may not move as much as when it is allowed to return to room temperature before another pulse is applied.

Pulse-duration modulation provides an effective means for controlling the temperature of a BioMetal wire. Figure 11 shows a circuit that applies bursts of pulse-duration modulated pulses at a duty cycle of about 50 percent.

Like the circuit shown in Fig. 10, that shown in Fig. 11 will cause a length of BioMetal wire to alternately contract and resume its normal length. Unlike the Fig. 10 circuit, however, the Fig. 11 circuit permits the magnitude of the movement of the wire to be controlled merely by adjusting the width of the current pulses sent through it during each burst.

In operation, one of the timers in a 556

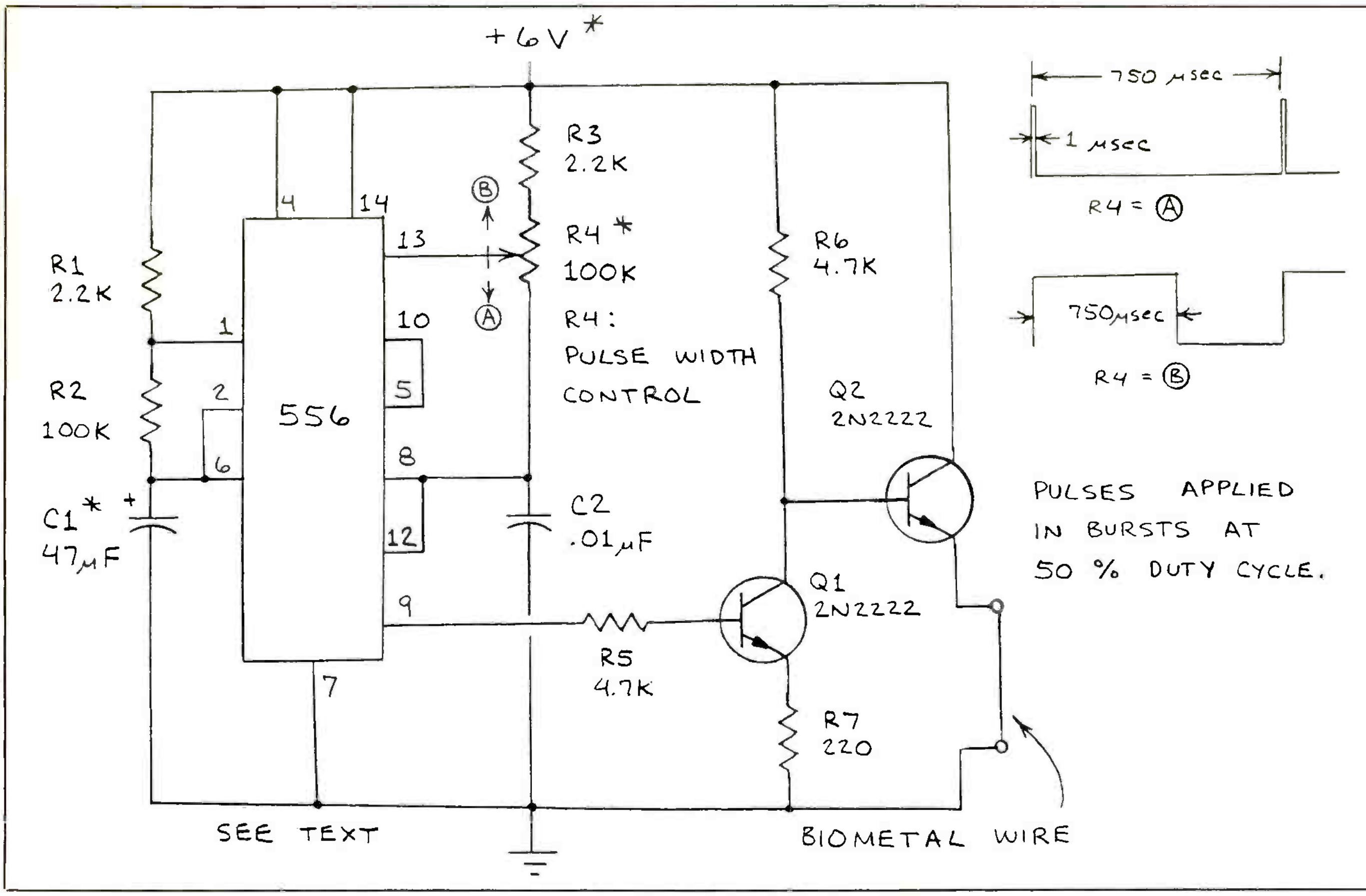


Fig. 11. A pulse-width-modulated BioMetal driver.

is connected as a free-running oscillator whose pulse duration is controlled by the setting of potentiometer *R4*. This timer will be referred to as "timer 2." With the component values given in Fig. 11, the duration of the individual pulses delivered by timer 2 can be varied over a range from 1 to 750 microseconds. The time between the onset of two successive pulses remains approximately 750 microseconds for any setting of *R4*.

The remaining timer in the 556, timer 1, is connected as an oscillator that repeatedly switches on and off timer 2 at a duty cycle of approximately 50 percent. This is accomplished by connecting timer 1's output (pin 5) to timer 2's reset terminal (pin 10). With the values given in Fig. 11, timer 1 switches timer 2 on for about 2 seconds, followed by a similar off period. The off/on time can be increased by making the value of *C1* larger.

The BioMetal wire is connected to the output from timer 2 through *Q1* and *Q2*. Transistor *Q1* inverts the output pulses from timer 2 and then toggles transistor *Q2* at timer 2's oscillating frequency. Transistor *Q2* then delivers current pulses through the BioMetal wire.

Going Further

Applications for shape-memory alloy wire, such as BioMetal wire, are virtually unlimited. It's an area ripe for exploitation by experimenters and garage inventors, as well as industry. Only small quantities of BioMetal wire are required to make functional devices, and many kinds of driver circuits can be designed.

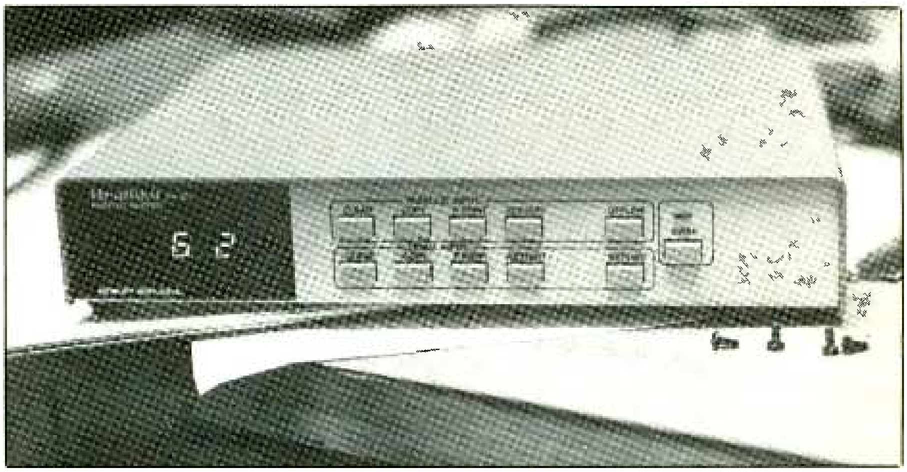
The best way to begin experimenting with BioMetal is to purchase one of the TokiAmerica Technologies kits. For more information about these kits, write to the company at the address given above. Be sure to order the firm's "BioMetal Guidebook" when you do. This excellent manual describes in detail the characteristics of BioMetal wire. It also expands on most of the simple demonstrations and experiments presented here. And it describes some simple robotic devices and applications for BioMetal.

Perhaps some of the applications for BioMetal I am exploring will give you ideas for going further. They include a parachute ejection device for model rockets, a camera shutter tripper, a scanning mirror and a flap actuator for radio-controlled aircraft. ME

Heath's New Printer Buffer Kit

The Heathkit Model SK-203, like other printer buffers, intercepts data fed to a printer by a computer, stores it in its own memory chips, and controls the printer's operation. The buffer's purpose is to quickly relieve a computer from feeding data to a printer at the slow mechanical pace that the printer requires. Given sufficient memory, therefore, the buffer frees up the computer so that the user can continue to input information on the keyboard instead of waiting for the printing operation to be completed.

The kit, which costs $199.95, comes with 64K of storage memory, which is about equivalent to 21 pages of typed material. It's expandable to 512K. An LED display shows the amount of buffer memory remaining as it stores data. The SK-203 has serial and parallel inputs and outputs, with internal DIP switches and jumpers that can be configured to choose either or both. Up to 99 printed copies can be selected by the user. The enclosure measured 9.25"W × 7.5"D × 1.5"H.



A numeric display area at left on front panel shows number of kilobytes of storage available. Two rows of switches, boxed separately for serial and parallel inputs, select various functions and on/off line switching. Single separately boxed switch shown at right permits serial in to parallel out or parallel in to serial out arrangement.

Description

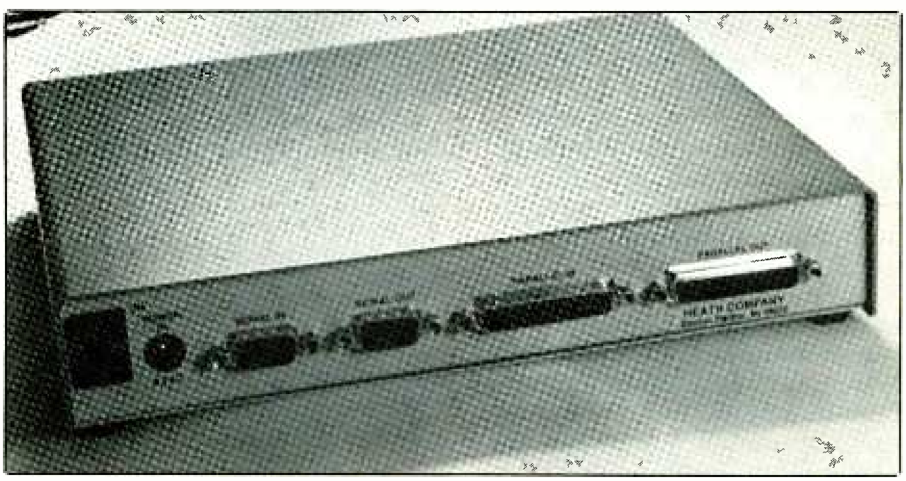
The SK-203 kit comes with a set of eight 6664 64K × 1-bit chips. There are three banks of memory chip sockets that will accept either 64K or 256K ICs. If you fill Bank 2 with 6664 chips, then the total available memory is 128K, but if Bank 2 is filled with 41256-15 chips, then you will have 320K available. Alternatively, you can remove the 6664 chips supplied with the kit and replace them in both banks with 41256-15 chips, for a total memory of 512K.

At turn-on, the SK-203 counts up and displays the total memory available. Since its internal ROM program wants 2K, however, the number quickly decrements 2K. For example, if 64K is installed in the SK-203, the counter increments to "64" at turn-on, but within a few seconds displays "62" (the *available* memory).

Although I installed 256K chips in both banks shortly after building the SK-203, my initial experience was with 64K of memory. I found out that the lack of memory does not cause loss of the end of a print file, but it does delay freeing up the computer. A 35-page file displayed a "FULL" indication on the LED display, and my computer issued a "PRINTER FAULT" message on the screen. After about a minute, however, the SK-203's display shifted to "2" (indicating 2K available), and the computer transmitted the rest of the file and extinguished the screen warning. The computer then left the print routine and allowed me to finish an article.

Another interesting feature of the SK-203 is that you can stack files in sequence. If the next print file becomes available before the file presently being printed is finished, you can check available memory to see that enough is free, and then continue to print the file. When the buffer is finished with the present file, simply press RESTART and the subsequent file will start printing.

The rear panel has the following connectors: SERIAL INPUT, SERIAL OUTPUT, PARALLEL INPUT and PARALLEL OUTPUT. Depending upon how you configure the SK-203 with its internal DIP switches and jumpers, the buffer will allow you to op-



Rear panel contains an input jack for an 8-volt ac plug-in power supply, power switch and D-type serial and parallel input and output connectors.

erate either serial to serial, parallel to parallel, serial to parallel, or parallel to serial. An alternative, however, is to connect *both* serial and parallel inputs to different computers, or the serial and parallel outputs to two different printers, and run both at the same time. Of course, internal memory is divided between the two.

The following modes of operation are allowed: *straight through*, *cross* and *both inputs to one output port*. In the straight-through mode, serial input port data goes to the serial output port, and data to the parallel input port goes to the parallel output port. In the cross mode, data coming in to the parallel port is directed to the serial output port, and data on the serial input port is directed to the parallel output port. Note that this mode allows serial to parallel and parallel to serial data conversions that allow you to mix and match computers and printers. Finally, the last mode allows directing both serial and parallel input ports to either the serial or parallel output port.

The front panel of the buffer has a large three-digit LED numeric readout that provides the number of available kilobytes, as well as displays status information. For example, if the OFFLINE button is pressed, the upper halves of the digits blink to warn the user. The other control buttons on the front panel are SWAP, plus two each of the following (one set for parallel input selections, the other for serial input): CLEAR, COPY, P.PRINT and RESTART. These buttons operate as follows:

CLEAR is basically a "reset" since it clears all files except the one file being received at a particular instant.

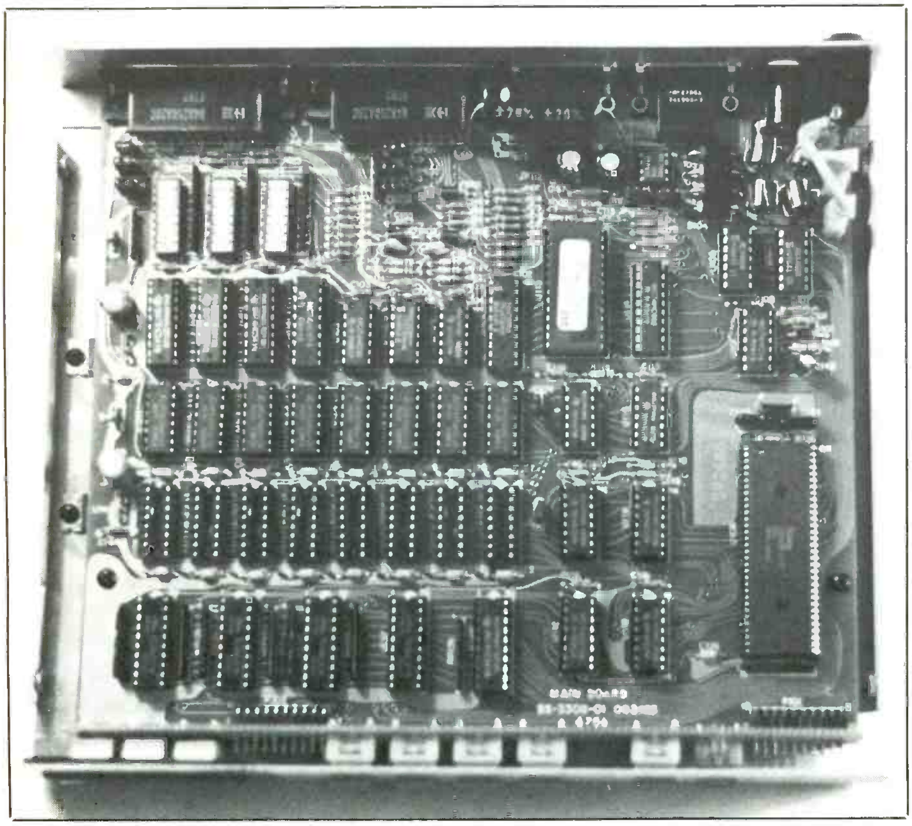
COPY allows you to designate the number of copies that the buffer will make, which appears on the LED display. Every time this control is pressed, the copy counter increments by one, up to a total of 99 copies.

The P.PRINT button causes the buffer to stop printing the stored file and allows you to transmit a new "priority file" to be printed immediately. Then you can go back to printing the original job.

RESTART is used to restart printing at the top of the file. One possible use of this control is to clear a mechanical or paper problem in the printer and then restart the printing operation.

OFFLINE prevents data from being sent to the buffer.

SWAP allows the user to swap data paths.



Interior view of completed buffer kit.

Building the Buffer

I built my SK-203 in one evening. Assembly is easy, requiring no technical skills other than the ability to solder IC sockets to a printed wiring board.

Heath's system of mounting small components on a double row of tape that resembles a belt of machine-gun bullets is an appreciated feature that speeds assembly. This assemblage is designed to be taped to a printed paper template cut out from a supplied pictorial booklet. The template has parts values printed on it, and the components are in the order called for in the assembly instructions. Thus, is you can not tell a 4.7K resistor from a 47K resistor, then not to worry. Just look on the template and remove the next part in order!

By the way, the SK-203 is 100 percent kit—you even have to assemble the assembly manual into its binder.

Conclusions

The only problem I found with this kit is a disagreement between the manual and the configuration decal that the builder places inside the top cover. In the manual, the two memory banks are called "Bank-1" and "Bank-2," while on the decal they are called "Bank-0" and "Bank-1." Although initially confusing, this proved to be no great problem.

Although I tested the SK-203 only with an IBM PC, the buffer should also work with any other computer that has a parallel or an RS-232C serial printer output. The manual contains cable wiring instructions for all Heath/Zenith computers, the IBM PC family of computers, and the Apple II series of computers. **ME**

—Joseph J. Carr

CIRCLE NO. 101 ON FREE INFORMATION CARD

Principles of Digital Audio by Ken C. Pohlmann. (Howard W. Sams & Co. Soft cover. 285 pages. $19.95.)

Digital audio is the latest wave to hit the audio scene. With it comes such *digital* equipment as compact discs, digital amplifiers and (hopefully soon) digital audio tape recording, not to mention such other "digital" devices as music synthesizers and the like. The principles used in the latest-technology equipment now on the market and soon to be so in no way resemble those used in audio gear of yesteryear.

Rather than being a deep mathematical treatise on digital audio theory, this book serves as a primer on the new technology. It traces its beginnings, reports on its current state of development and use and gives the reader an idea of what is in store for audio's future.

Through lucid text and excellent illustrations, the technology story unfolds in an easy-to-digest manner. Early on, the foundation is laid with discussions on the characteristics of sound and analog versus digital techniques. Having dealt with the basics, the book proceeds to the theory of digital audio, discussing such topics as discrete time sampling, aliasing and dither. Digital audio recording and reproduction are then handled in separate chapters.

A later chapter chapter discusses the various digital audio media, including magnetic and optical recording and transmission. Error protection, an important topic, is handled in a chapter of its own, as is the compact disc for audio, video and CD-ROM. The final chapter, titled "A New Beginning," talks about digital audio with respect to music and technology and discusses the battle of digital audio and the state of the art.

This is an important book. Its subject matter is relatively new, and the book itself fills an until now unfilled niche in audio libraries.

Power Control and Solid-State Devices by Irving M. Gottlieb. (Tab Books. Hard cover. 372 pages. $29.95.)

This latest addition to the TAB Professional and Reference series details techniques that range from the traditional to the cutting edge of technology. Though most of the circuits presented are geared toward filling a wide variety of specific needs, a large portion of the book is devoted to the theory involved. Introductory chapters cover basic principles of solid-state power control and fundamentals pertinent to solid-state devices. A chapter on practical aspects of solid-state devices familiarizes the reader with rectifier diodes, switching and power transistors, SCRs and triacs to provide the details needed to select the right device(s) for a given application. This section goes heavy on theory, though without resorting to rigorous mathematical analyses, using instead full text descriptions, characteristics curves, tables and typical circuit configurations.

Fully detailed applications circuits are given for transistors and power ICs, thyristors and newer developments. Power transistor and IC circuits are provided for such diverse items as an automatic automobile headlight beam controller, power IC intercom, several audio power amplifiers, battery chargers, automobile electronic ignition system, switching regulator, solid-state circuit breaker, power inverters and motor controllers. Thyristor circuits include a constant-brightness controller, photoflash slave unit that uses an LASCR, proportional temperature controllers, triac-controlled lamp "chaser," counter for sequentially flashed lights, trigger for high-frequency fluorescent lamp inverter, pulser for injection lasers, optically triggered high-voltage switch, and more. Among the newer developments discussed, some on the cutting edge of power-control technology, are a synchronous bridge rectifier using power MOSFETs, gate turn-off SCRs (GTOs), and interfacing a microcomputer to power-line loads with opto-isolators. A bevy of good schematics and drawings complement the lucidly written text. This book will serve electronics technicians very well as a single reference text and for gleaning lots of interesting circuit ideas in the power control area.

Go Public! by Natalie McClendon. (Wakerobin Communications, 611 N. 26 St., Lincoln, NE 68503. Soft cover. 219 pages. $12.95.)

As its subtitle states, this is a "Traveler's Guide to Non-Commercial Radio." As such, it provides comprehensive listings for just about every public radio station in the continental United States, about 1,100 of them. Programming is incredibly diverse, such as operation by Indian tribes on reservations. The listings are arranged by area (northeast, southeast, east central, etc.), with a total of seven individual areas. Within each area subcategory, the listings are in alphabetical state order for easy look-up.

At the beginning of each state's section is a two-color topographical/radio map for that state. Then comes the individual radio station listings, each arranged in call-sign alphabetical order. Call signs are followed by station frequency, city of origin, output power and estimated range. Where appropriate, notes of program formats and broadcast times are also given.

To get things started, the book begins with a discussion of what public radio is and tells how to use the guide. It closes with a section on understanding public radio and a number of useful appendices: frequencies by state, commercial classical stations, commercial jazz stations and public radio information sources. There is also a bibliography. On the inside front cover is a quick reference state map, while on the inside rear cover is a list of abbreviations used in the book, along with their meanings.

NEW LITERATURE

IC Data Book. A 748-page engineering and selection guide from Sprague fully details and supports with application notes more than 120 IC families. The first of the eight sections into which the book is divided describes available technologies and technical terms and presents cross-references and competitive part-numbering systems. Subsequent sections cover high-voltage, medium-current, high-current, BiMOS (smart power), military CMOS logic, and linear IC families. The final section provides package drawings and surface-mount device availability. Each section includes application notes and quick guides. For a free copy of Integrated Circuit Data Book No. WR-504, write to: Technical Literature Service, Sprague Electric Co., P.O. Box 9102, Mansfield, MA 02048-9102.

Keyboard Enhancements Catalog. Hooleon's "Customize Your Keyboards" catalog lists and fully describes, including prices, the company's complete line of stick-on keytop kits for popular software, keytop expanders, custom printed keytops and more. The 32-page, two-color catalog lists die-cut keytop kits for emulation, word processing, Dvorak conversion, language conversion and accounting/spreadsheeting. It also includes specialty and miscellaneous keytop kits, as well as ordering information for custom imprinted keytops. Among other items listed are keytop expanders, FlexShield keyboard protectors, templates, individual key lock-outs, removable keytop shells and workstation and printer ID labels. For a free copy, write to: Hooleon Corp., Page Springs Rd., P.O. Box 201, Cornville, AZ 86325.

Transformers Catalog. The new 1987-1988 product catalog from Triad-Ultrad gives full specifications for and illustrates all of the company's products. These include audio, power, pc-mount, pulse, interstage and input transformers and voltage regulators, filter reactors and toroidal inductors. The 48-page catalog has tabular listings that provide part number, full technical specifications and dimensions (keyed to accompanying drawings). Handy catalog and "classified" indexes are up front to make it easy for product look-up. For a copy of the Triad-Ultrad Transformers 1987-1988 catalog, write to: Triad-Ultrad, Div. of MagneTek, Inc., 305 N. Brian St., Huntington, IN 46750.

Technical Video Information Notes. A series of application notes titled "Teleproduction Test" designed to augment available technical information in the application of video test equipment can be obtained from Leader Instruments Corp. Basic concepts and routine test procedures are explained, and short cuts to complex VCR and video camera alignment procedures are offered. The first three issues are primers on the use of the waveform monitor. The fourth starts a similar series on the basic aspects of the vectorscope, and the fifth and sixth discuss the basic operation of the vectorscope. For free copies, write to: Leader Instruments Corp., 380 Oser Ave., Dept. ME, Hauppauge, NY 11788.

Books / Hardware / Software Catalog. Group Technology's Fall 1987 catalog contains descriptions of all the company's new and current books and products that are directed to those people who want hands-on experience in interfacing external devices to microcomputers. Among the hardware items listed are a data acquisition/output board for the TRS-80 Color Computer and an optical fiber communications package that provides a comprehensive introduction to the theory and practice of fiber-optics technology. Under software are listed an order entry/inventory/mail list/payroll program that provides separate but integrated programs for operating a small business and a simultaneous equation solver for MS-DOS computers for solving linear and nonlinear algebraic equations. New books on microcomputer interfacing, assembly-language programming and spreadsheet programs supplement older standbys and include special emphasis on artificial intelligence, expert systems and the FORTH language. For a copy, write to: Group Technology, Ltd., 6925 Dogwood Rd., Baltimore, MD 21207-2606.

Industrial Electronics Catalog. Listed, described and illustrated in Joseph Electronics' latest 480-page industrial catalog are test equipment, tools and chemicals, wire/cable/connectors, batteries and chargers, a wide variety of electronic components, computer accessories, and video and sound equipment. A separate section features "value-added services" that stress custom battery assembly to a variety of configurations and featuring Gates rechargeable battery systems. Other services described are custom cable assemblies, custom project kits, prototypes and production runs. For a free copy, write on company letterhead to: Joseph Electronics, Inc., 8830 N. Milwaukee Ave., Dept. ME, Niles, IL 60648.

Battery Catalog. The 24-page, full-color 1987 Communications Catalog from Alexander Manufacturing describes a full line of replacement batteries for use in portable two-way radios and pagers, leather cases for the radios and pagers and radio antennas. It discusses chargers and analyzers for nickel-cadmium radio and pager batteries and information on several new chargers and includes full information on the company's own mercury pager battery. For a copy, write to: Alexander Mfg., 1987 Communication Catalog, P.O. Box 1508, Mason City, IA 50401.

SOFTWARE FOCUS

Chessmaster—A Champion Program

By Art Salsberg

I'm not a chess master or even a player with a ranking. But I have enough experience to know when one's game is good . . . and The Chessmaster 2000 from The Software Toolworks (Sherman Oaks, CA) is that. My brother-in-law, who *is* a ranked chess player, though on the rusty side, agrees wholeheartedly.

The champion program is available in IBM, Apple, Commodore 64/128 and Atari versions for only $39.95; Macintosh, Amiga and Atari ST versions retail for $44.95. The programs are distributed by Electronic Arts (San Mateo, CA).

The IBM version I used requires a machine with at least 256K of RAM, which everyone has, and DOS 2.0 or later, which is commonplace, too. Only one disk drive is needed and it'll load on a hard disk or a 3.5-inch floppy with an optional $10 installation disk. (Apple computer versions need only 64K of user memory.) The chess program is copy protected; a backup is available for $5.

If all that Chessmaster 2000 offered was its fine standard of chess playing, it would be enough to justify its modest price. After all, it is claimed to have the largest opening library among PC chess programs (71,000 moves) and a host of play levels that range from newcomer to grandmaster (60 moves in 5 minutes to 40 moves in 6,000 minutes, respectively). But CM2000 is replete with features that add to its value.

Firstly, there are additional play modes, which includes one called the "Easy Mode," designed to make chess playing simpler for newcomers. Moreover, you can set the game for the computer to always make its best move or mix best and random moves (Normal) or for a more random-move mode called "Coffeehouse." Then there are graphic choices to spice the visual impact: two-dimensional and three-dimensional representations; monochrome and color (with color choices). Sounds aren't neglected either, with a choice of a bell sound, music sound or no sound when a chess piece is moved. The board can be rotated, too.

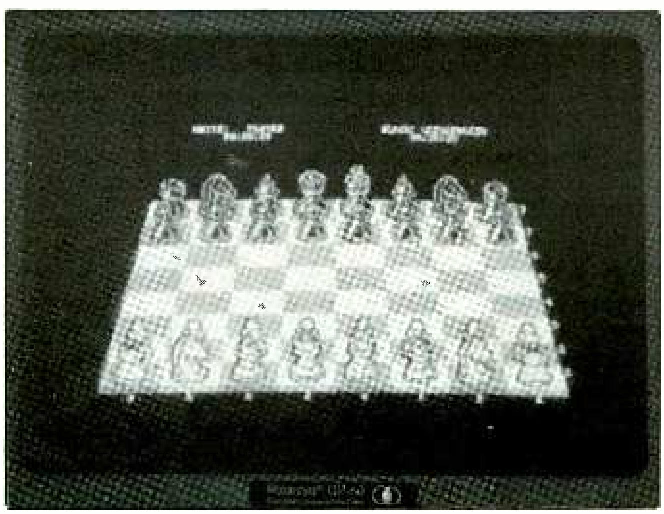
Frills aside, there's a welcome Teaching Mode that illustrates all the possible moves for a selected chess piece, a hint choice that causes the computer to show you what your best move is, and, my favorite, an analysis option that shows the computer's "thinking" process. Here, one can save a game and have the computer demonstrate what it considers to be the best move for either or both sides and give an ongoing overall game score at that time.

Add a clock and move on/off option, algebraic notation or abbreviated notation choice, move listing, printing of moves, solving for mate demonstration, and a provocative "sliding" of pieces instead of jumping, and you get a better idea of the versatility of this remarkable program. You can also select white or black to play, delete moves on both sides and recall them if you wish, force the computer to make its move quickly if you get tired of waiting for it to analyze its possible move ply by ply, learn how many moves or plys the computer used before making its decision, and other goodies that embellish playing and advance your understanding of chess.

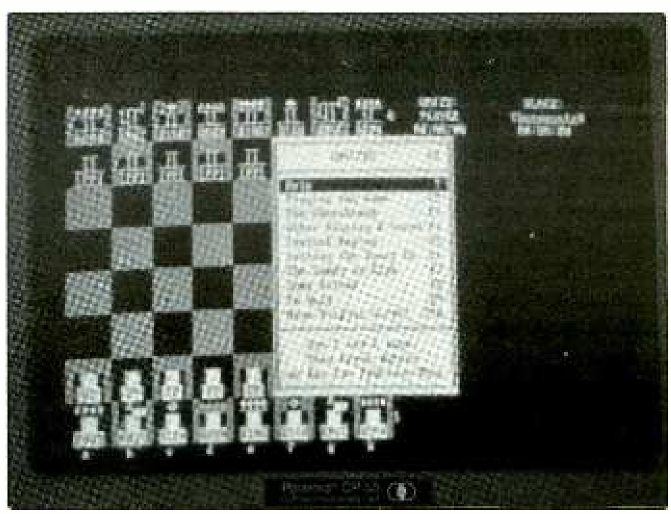
Conclusions

Level 1 consistently provided me with an entertaining and informative game, allowing me to win almost half the games. My more experienced brother-in-law did this at Level 3 (40 moves in 30 minutes vs. Level 1's 60 moves in 5 minutes). The more time the computer has, the more plys (move stages) it can examine, of course. He said that the computer's middle and end game was very good. Furthermore, no bugs showed up after many months of use, which was not the case with the chess program in Borland's Turbo GameWorks, which he said played much weaker, to boot.

In addition to the features previously noted, CM2000 contains a library of 100 classic chess games played by masters in tournaments that can be played and analyzed, as well as a group of famous chess problems that have challenged professionals over the years.



Chess pieces in 3-D can be selected for more realistic look.



Chessmaster with pop-up menu and text-driven chess pieces.

It's difficult to criticize this program since it offers so much power play, learning opportunities, and options. The only flaws I could observe are related to the program's chess-piece graphics. They're fairly good in two-dimensions, but its touted three-D mode, though attractive-looking, is difficult to play with because some pieces obliterate part of another piece. Viewing it in a 2-D plane, which is what the video monitor really is, I found that I had to strain a bit at times to see what square the piece was on. Also, if you don't have a computer with a graphics board—say, the original IBM mono adapter instead of a Hercules-type board—the text mode's representation of chess pieces is poor. In normal 2-D with graphics provisions, it was okay. Aside from this, the program is terrific all around, right down to the easy-to-use help menus that make extensive use of function keys and cursor-bars to make choices . . . and priced right. **ME**

CIRCLE NO. 136 ON FREE INFORMATION CARD

Article Cumulative Index

January 1987 through December 1987

Product Evaluations

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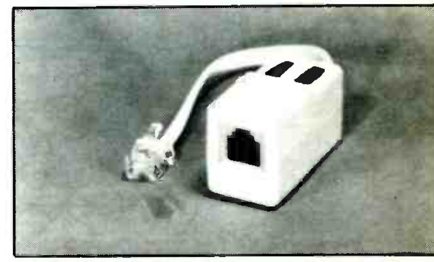
Modem Data Interrupt Eliminator



Data Spec (Chatsworth, CA) has announced a line of "Data Interrupt Eliminators" for modems. These devices are said to prevent accidental loss of data when modems and telephones are used on the same line. Any extension telephone picked up while the modem (or phone) is in use is disabled. One Eliminator is needed for each telephone or modem sharing the same line.

Operating like a switch, the Data Interrupt Eliminator sends signals to other Eliminators to electronically turn off any instrument on the line, except the first one used. In addition to protecting modem data from interruptions, a Data Interrupt Eliminator can be used as a privacy device because when one telephone extension is picked up, all others are disabled.

Four different models are available: Model MP600 ($9.95) is a stand-alone in-line unit; Model MP620 ($10.25) is a standard surface-mounted modular version; Model MP30 ($13.95) replaces the standard telephone modular wallplate; and Model MP640 ($11.95) is for a wall-mounted telephone like those used in kitchens.

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Options. IC-R7000: RC-12 remote control, EX-310 voice synthesizer, CK-70 DC adapter, MB-12 mobile bracket. IC-R71A: RC-11 remote control, EX-310 voice synthesizer, FM module, CK-70 DC adapter, MB-12 mobile bracket, FL-32A 500Hz, FL-63A 250Hz, and FL-44A filters.

See the IC-R7000 and IC-R71A at your local authorized ICOM dealer.

* Specifications of IC-R7000 guaranteed from 25-100MHz and 1260-1300MHz. No coverage from 1000-1025MHz

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