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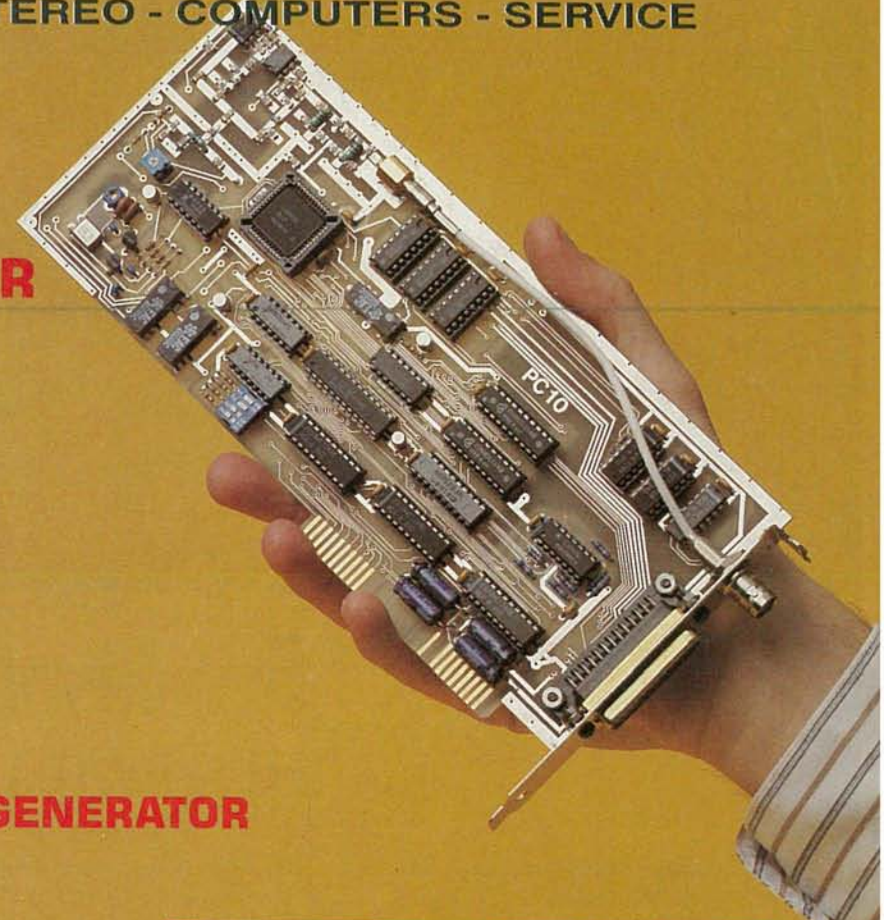

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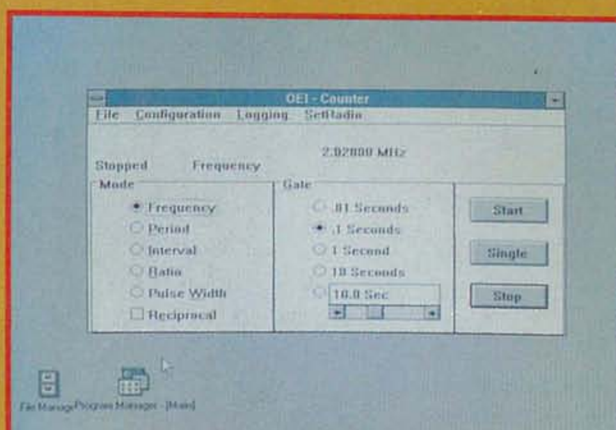

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FLUKE®

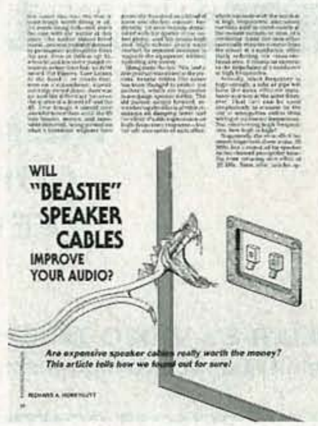
February 1991 Radio-Electronics®

Vol. 62 No. 2

BUILD THIS

PAGE 43

TECHNOLOGY



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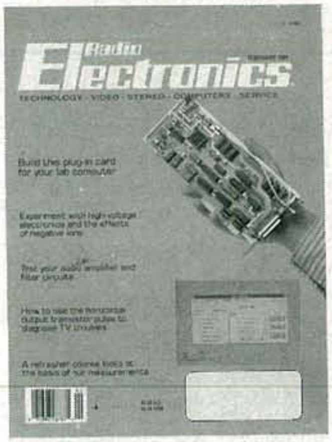
DEPARTMENTS

AND MORE

ON THE COVER



PC's have become an essential part of any electronics test bench. Until recently, however, PC-based instrumentation was considered to be little more than toys with their limited use and features. That's not true any longer. Take, for example, our PC10 frequency counter. It's a card that fits in an expansion slot in your PC and operates in a Windows environment. It can perform direct counts over 200 MHz, it has a 10-digit display, and a 2.4-GHz range. Because it operates in a computer, additional features such as data logging are available. Turn to page 37 for details.

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An in-depth look at solid-state microwave devices.

SEMICONDUCTOR MEMORIES
Take a look at the advantages and disadvantages of CMOS, TTL, and EEPROM's.

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CIRCLE 184 ON FREE INFORMATION CARD

WHAT'S NEWS

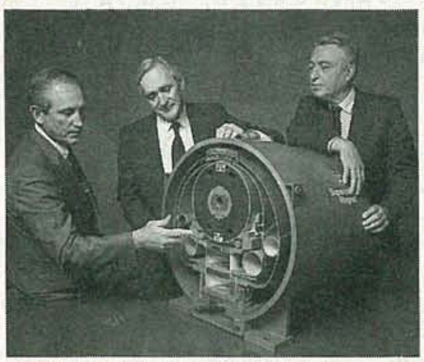
A review of the latest happenings in electronics.

Telephone-Booth Replacement?

Advanced Cordless Technologies (Montville, NJ) began public testing of its CT-2 technology in New York City last fall. Based on two pieces of equipment—a pocket-sized portable phone and a "telepoint," low-powered radio transmitter—the technology offers an alternative to public telephone booths.

The cordless phones use very little power, getting 20 hours or more from the rechargeable or disposable batteries, and are more private and less expensive than cellular phones. The CT-2 phones must be used within 100 yards of a telepoint.

Each telepoint, which is about the size of the Manhattan phone book, connects callers to the land-line telephone network. From there, calls are forwarded to any location worldwide, and are recorded for billing purposes.



A SCALE MODEL SECTION of the superconducting super collider (SSC), the world's largest and most powerful particle accelerator that is planned for operation in Texas in 1998, is examined by executives from Westinghouse Electric Corporation. Westinghouse is competing for the contract to manufacture and test more than 8000 16.5-ton superconducting magnets that will guide thin beams of protons around the SSC's 54-mile underground tunnel at close to the speed of light. The corporation, a leader in producing superconducting magnets, developed the niobium-titanium alloy wire that will be used in the magnets. Pictured from left to right are Bruce Boswell, general manager of the collider dipole magnet division; Chairman and Chief Executive Officer Paul Lego; and Dr. John Hulm, chief scientist emeritus and director of superconductivity technology.

An experimental license granted by the FCC provides two channels, one of them for transmitting calls from handsets and the other for paging the handsets, allowing two-way communications.

Approximately 150 test telepoints are planned for public areas in Manhattan. Each telepoint is capable of handling up to eight calls simultaneously, reducing the usual wait for public phones. In addition, 50 private branch exchanges will be placed in offices participating in the trial, where the CT-2 will function as a cordless extension phone. The private telepoints will be equipped with adapters that automatically transmit calls to each extension on the exchange, so that, with paging, workers will be able to be reached anywhere in the building.

Advanced Cordless Technologies hopes the CT-2 system eventually will change the way public phone calls are made, eliminating the need for coins, and reducing the long waits and incidence of damaged equipment that plague phone booths in urban areas. The trial was the first step in the company's long-term plan to offer the CT-2 telepoint service on a national scale.

Long-life power source

A patented power-source technology developed by the E.F. Johnson Company, a division of Diversified Energies, Inc. (Minneapolis, MN), couples a unique light-emitting polymer with solar-type cells to generate continuous, low-power electrical energy for more than 25 years. Because the power is not generated by a chemical process, it is not adversely affected by extremely cold temperatures. It has been successfully tested at temperatures ranging from −196°C (the temperature of liquid nitrogen) to +100°C (the boiling point of water).

Electricity is generated when a photovoltaic cell is optically coupled to a light-emitting polymer. The light, generated when a phosphor molecule is closely coupled to a hydrogen isotope (H-3 or tritium) within the polymer. Tritium is a radioactive material that is currently used in a gaseous form as the basis of light sources in watches and exit lights in theaters, and that will require licensing by the Nuclear Regulatory Commission. In the new power source, the tritium is chemically bound into a solid plastic matrix.

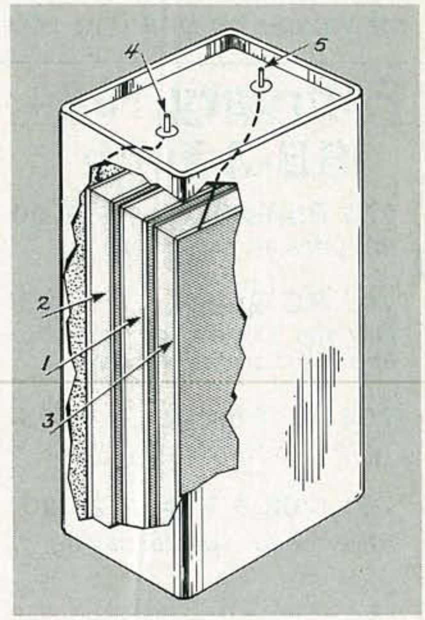


FIG. 1—E.F. JOHNSON COMPANY'S long-life, low-power electrical-energy source is created by combining a light-emitting polymer material (1) and a photovoltaic cell (2, 3) that has a light-collecting surface and a pair of electrical contacts (4, 5). When the polymer and the photovoltaic cell are coupled, an open-circuit voltage is generated between the two electrical contacts.

E.F. Johnson has achieved power outputs in the microwatt range—enough to power a pocket calculator or watch, or to charge a capacitor that would supply periodic surge requirements and then recharge—and expects to significantly increase the power output. While no end products have been created, and commercial usage is several years away, potential future applications for the long-life, low-temperature power source could be in medical implants, space, computers, and superconductivity. **R-E**

VIDEO NEWS

What's new in the fast-changing video industry.

DAVID LACHENBRUCH

• European HDTV setback. Europe's plan for an orderly transition to HDTV suffered a severe blow with the announcement that two British direct-satellite broadcasters planned to merge. Sky Channel has been broadcasting in standard PAL, while British Satellite Broadcasting was beaming a signal in the expanded-definition MAC (multiple analog component) system, which separates the chrominance and luminance signals to provide a better picture. Under the merger agreement, the combined satellite system will transmit in PAL only, after a transitional period.

BSB's MAC transmissions were part of a plan to create a new standard for direct-satellite transmission, which would eventually lead to a "compatible" HDTV system—compatible with MAC transmissions, that is. MAC and PAL are incompatible. MAC has already lost favor in Germany, where broadcasters are using Luxembourg's Astra satellite and transmitting in PAL. At this time, only France is still committed to MAC. Under the European Eureka project, the new all-European HDTV service, HD-MAC, was to be phased in about 1992. Now everything is up in the air, so to speak.

• Japan's HDTV receivers. While the European HDTV system was to have some measure of compatibility (even if only to MAC transmissions), Japan's Hi-Vision HDTV is compatible with nothing, and will require all-new TV sets, VCR's, videodisc players, and so forth. Hi-Vision is being broadcast by NHK, the government-chartered broadcaster, by satellites. Japanese TV set makers have now introduced the first consumer model Hi-Vision receivers, priced generally in the $17,000–$35,000 range, promising prices could be cut in half in about a year.

Newspaper and magazine reports bemoan how far "behind" the United States is as compared to Europe and Japan in instituting HDTV broadcasting, but they neglect to mention that the American project is far more ambitious than the others. The U.S. plans to integrate HDTV broadcasting with conventional transmissions, broadcasting from terrestrial TV stations rather than instituting a completely new incompatible satellite-transmitted service. Official testing of proposed American HDTV systems is scheduled to start in March.

• Multimedia. That's one of today's magic words, and no one knows how it's going to affect the future of television, video, or computing. At least three systems designed to combine video motion, audio, and interactivity are scheduled for major introductions this year. CDTV, which stands for "Commodore Dynamic Total Vision," is scheduled for introduction early this year, as an extension of the Amiga computer system in an attachment for TV sets, with such programs as encyclopedias, cookbooks, atlases, and sophisticated video games. The hardware is scheduled to cost less than $1,000 to start, with CD-ROM programs at $25 to $100 each. CDTV has half-screen full-motion or full-screen half-motion (15 frames per second). The competing CD-I (Compact Disc Interactive), backed by Philips and Sony, will debut in the second half of this year, probably without full motion, but a full-motion adapter will be added later.

Meanwhile, Intel introduced a two-chip set to bring its Digital Video Interactive (DVI) system to personal computers at a premium of less than $1,000 at the start. The DVI chips permit interaction with full-motion video, as well as storage of digital video on PC's. Thus it seems that the TV set moves closer to the computer, and the computer closer to the TV set.

• Digital VHS sound. You can't buy it now, but perhaps in a few months there will be another feature for VHS video recorders. At the recent Japan Audio Fair, both JVC and Hitachi demonstrated VCR's with digital audio, and Matsushita (Panasonic) has a similar system. The new digital sound is for Super VHS recorders, whose expanded video bandwidth provides enough additional space for its 16-bit PCM system. The 8mm format already has PCM audio with an 8-bit system. The VHS group is reluctant to commercialize digital audio because of the dispute over digital-audio recorders and copyright protection, but there is anticipation that it will be offered starting this spring. The PCM audio system, standardized for S-VHS recorders, uses a 48-kHz sampling frequency, and depth-multiplex recording to place the video and audio signals on different layers of the tape's magnetic coating. The two other soundtracks (linear and helical FM) of the VHS recording standard will be unchanged to maintain compatibility. **R-E**

COMMODORE'S CDTV interactive graphics player is expected to cost less than $1000.

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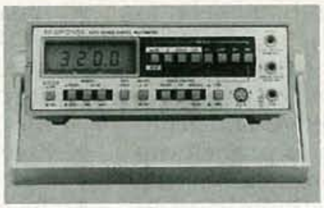

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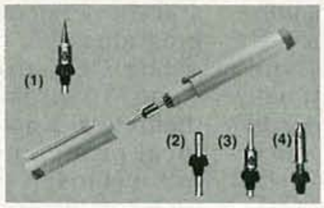

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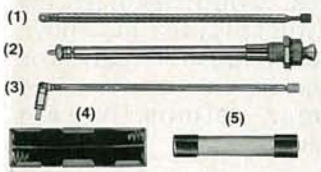
K12	6.0	650	272-1163
K18	7.2	700	272-1164



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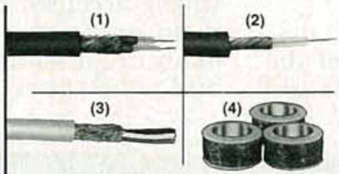

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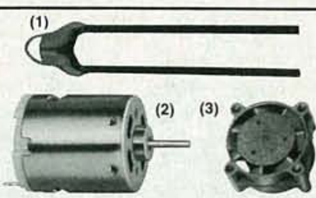

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CIRCLE 78 ON FREE INFORMATION CARD

The country honors its technicians with the celebration of National Electronics Technicians Day.

IN RECOGNITION OF ITS NEARLY 28,000 members, the International Society of Certified Electronics Technicians (ISCET) is lobbying for a joint resolution of Congress to designate March 5, 1991 as National Electronics Technicians Day. Congressmen Martin Frost and Pete Geren (Texas) have whole-heartedly agreed to serve as the original co-sponsors of this bill in the House. Senate approval is also required for this special legislation, and ISCET is seeking an original Senate sponsor for this bill.

ISCET's chairman, Leonard Bowdre, hopes that by officially declaring March 5, 1991 as National Electronics Technicians Day, nationwide recognition will be focused on the high standards of performance and excellence maintained by professional technicians. Most people underestimate our country's need for highly skilled and specially trained electronics technicians, who play a vital role in the electronics manufacturing, testing, and servicing industry.

What is ISCET?

As the proud offspring of the National Electronic Association (NEA), ISCET was founded in 1970 by a committee of Certified Electronics Technicians, whose main purpose was to foster respect and admiration for their profession. By maintaining rigorous standards in its certification program, ISCET is able to separate the highly skilled and knowledgeable technicians from those with less experience. ISCET's main functions include direction and administration of the CET program, the national apprentice and training program, the technical information training and upgrading programs, and the serviceability inspection programs.

The CET program was designed to measure the degree of theoretical knowledge and technical proficiency of practicing technicians. A technician with a CET certificate is thought of in the industry as one who possesses the training and expertise necessary to perform their job with professional competence. Since its inception in 1965, the CET program has become more widely accepted by technicians, manufacturers, and consumers. Many organizations encourage, and sometimes require, their technical employees to be certified by ISCET.

ISCET AWARDED MISSION SPECIALISTS George D. Nelson and James D. Van Hoften titles of Honorary Certified Electronics Technicians for servicing and repairing the Solar Max satellite. Their 305-mile high 5-day service call cost $45 million, but saved the cost of replacing the 5,000 pound, $300 million satellite.

The CET exam

To become certified by ISCET, one must pass both a 75-question Associate-level CET test, and a 75-question Journeyman-level test. Each multiple-choice exam must be passed with a grade of 75% or better. An electronics technician or student with less than four years of experience may apply for the Associate-level exam, covering the following subjects:

- Basic Mathematics
- DC Circuits
- AC Circuits
- Transistors and Semiconductors
- Electronic Components
- Instruments
- Test and Measurements
- Troubleshooting and Network Analysis

A fully certified technician must also pass one or more of the several Journeyman options available in specialized fields of electronics. A Journeyman certified technician must also have four or more years of education or experience in electronics. The Journeyman options that are available are:

- **Consumer**—Subjects covered include antennas and transmission lines, digital and linear circuits in consumer products, TV and VCR servicing problems and use of test equipment.
- **Industrial**—Subjects include transducers, switches, power factor, differential amps, closed-loop feedback, basic logic circuits and functions, elements of numeric control, thyratrons, and SCR controls.
- **Communications**—This test covers two-way transceiver theory and servicing, receivers, transmitters, basic communications theory, deviation sensitivity, quieting, and troubleshooting.
- **FCC Legal**—This is a 25-question optional exam covering FCC regulations. Applicants must take the Associate exam, the

Communications option, and the FCC Legal exam to receive a general radio-telephone license.

• **Computer**—This test covers operation of computer systems with basic emphasis on hardware. Subjects covered include basic arithmetic and logic operations, computer organization, input and output equipment, and memory and storage. Some knowledge of software and programming is required, and the ability to explain troubleshooting procedures is required.

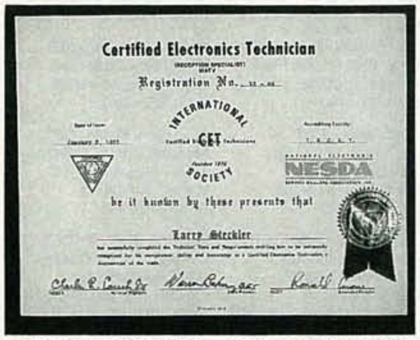
• **Audio**—Products covered in this option include turntables, tape decks, compact discs, and radios. The exam consists of both digital and analog sections, amplifiers and sound quality, system set-up, speaker installation, and troubleshooting audio systems.

• **Medical**—The priorities of this option are electrical safety and accuracy of calibration for electromedical instruments. The technician must be familiar with basic vocabulary of medical instrumentation, telemetry, measurements, differential and operational amplifier applications.

• **Radar**—A general knowledge of both pulse radar and continuous radar is necessary to take this Journeyman option. The test covers transmitters and receivers, CRT display systems and their power supplies, antennas, transmission lines and their characteristics.

• **Video**—The rapidly growing field of video is covered by this exam. The technician needs to know NTSC standards, video basics, test signals, and the operations of both the electronics and mechanical systems in VCR's. Also covered are 8mm video, camcorders, cameras and monitors, and the microprocessors used in video products.

The fee for the CET exam is $25.00, which includes both the Associate exam and any one Journeyman option, if taken in one sitting. If the Journeyman option is taken separately from the Associate exam, each test is $25.00. Each additional Journeyman option is $25.00. If you fail any portion, the first retake is free, after a 60-day waiting period. The fee for any additional retake is $12.50. If you choose to take the FCC Legal exam after you have successfully completed the Communications option, an additional fee of $10.00 is also required.



LARRY STECKLER, editor-in-chief and publisher of Radio-Electronics magazine, received this CET certificate back in 1975.

Don't underestimate the difficulty of the CET exam. Every year over 6,000 exams are taken by hopeful technicians, but only 30% of those taken pass—it's not an easy test. The best way to prepare for this exam is to study diligently. Tab Books, Inc. publishes *The CET Study Guide*, by Sam Wilson, which will help you prepare for both tests. ISCET also has additional study guides available for a nominal fee.

If you're interested in taking the CET exam, you can contact any one of ISCET's volunteer test administrators listed in this article for details. The exams are scheduled to be given the week of March 5, 1991. There are many more test administrators throughout the country than we have provided. Those listed in this article are just the ones who will be giving the exams during the week of March 5. For any additional information you may need, you can contact ISCET at 2708 West Berry St., Forth Worth, TX 76109; phone (817) 921-9101.

Now that we have all of the formalities out of the way, let's take a look at how ISCET honored two technicians who have gone above and beyond their call of duty.

The world's farthest service call

ISCET not only acknowledges those who have successfully completed their certification exam, but those who have exhibited outstanding technical achievement. Such is the case of Mission Specialists George D. Nelson (Phd, Astronomy) and James D. Van Hoften (Phd, Hydraulic Engineering) who were awarded the titles of Honorary Certified Electronics Technicians. Figure 1 shows these astronauts being honored by ISCET.

The astronauts were recognized by the ISCET Board of Governors for their exemplary performance in space during the period of April 8–12, 1984, when the Solar Max satellite was serviced, repaired, and returned to Earth's orbit. They were cited for the extremely difficult and delicate work required to repair the electronics box for the coronagraph-polarimeter, an instrument that was not designed to be repaired in space.

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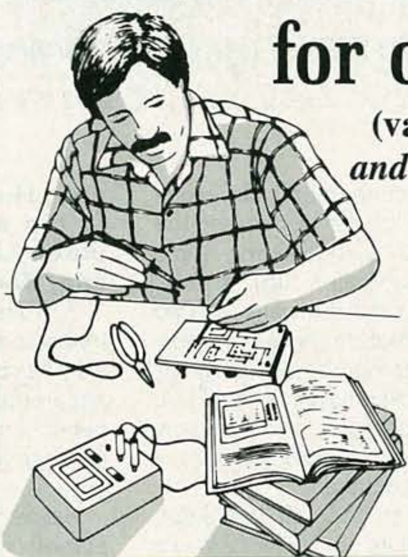

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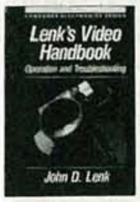

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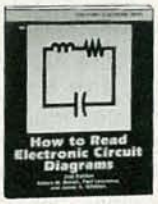

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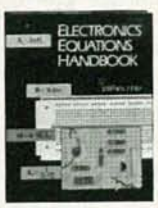

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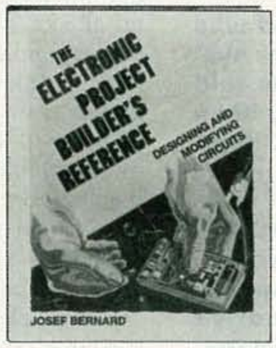

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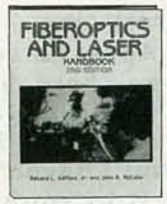

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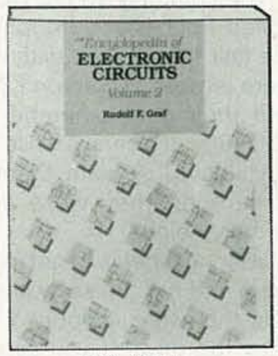

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APPLE DISK

I have an Apple IIe and was recently given a hard-disk system to use with it. I was told that the disk had already been formatted but I haven't been able to get it to work in my computer. Even though I have the interface card plugged into one of the slots, I can't seem to get the hard disk to respond. The manufacturer of the drive is the First Class Company. Can you help me with this problem?—B. Fischer, Indianapolis, IN

The company you're looking for is called First Class Peripherals and, the last time I dealt with them, they were located in Carson City, Nevada and their phone number was 800 538-1307. It's been a while since I had anything to do with them but, as I remember, they were always extremely helpful.

Your best bet is to get in touch with them and get the software and manuals that were supposed to accompany the drive. If you can't do that, check with a local Apple user's group and see if anyone can help you there. The Sider (the name for their drives), was one of the first hard disks available for the Apple II series of computers and I have no doubt that they sold a lot of them.

There are a few things you can try to make sure the drive is still working. You said that you had the card plugged into the computer, but there's a good chance you're not issuing the proper commands to access it. When the Apple is first turned on, it checks the slots to try and find a disk controller card. Each slot has 256 bytes of memory in the main Apple memory map, and each card is designed to work in a slot that has a particular signature that indicates its function. By examining these signature bytes, the Apple is able to identify the cards connected to it.

At powerup, the Apple wants to find a disk controller card and it scans through the slots looking for one. The scan starts at slot #7 (the one nearest the video connector), and winds up at slot #1 (the one nearest the power supply). As soon as the Apple finds a disk controller card, it turns control over to the firmware located on the card. What's important to realize is that the computer will recognize the first controller card it finds. If you have one in slot #6, it won't pay any attention (at bootup) to any others in lower numbered slots.

If you want to boot off the Sider, you have to put its controller card in a higher numbered slot than the one used for the regular disk drives. Since the disk controller is usually located in slot #6, the Sider's controller card should be in slot #7. As an alternative, you can access the Sider by typing PR#X' at the Apple prompt (the "X" is the number of the slot in which you've put the Sider's controller card).

Whichever method you choose, accessing the Sider should turn on its activity light and whatever boot program is on the disk should show up on your screen. Both DOS and ProDOS (the two main operating systems for the Apple series of computers) have to be patched to work with the Sider and the only way to do that is by using the software that was originally supplied with the drive.

VIDEO SYNC

I'm building a video circuit and want to get the sync signals from a standard composite video input. My ultimate goal is to be able to mix video signals together and, even though I have a good design for the mixer and sync generator, I have to be able to identify the sync on the incoming video. Any ideas?—C. Baldwin, Bangcock, Thailand

Fortunately for you, what you're trying to do is fairly common. While it's possible to design your own sync separator, it would be a lot of unnecessary work because there are chips around that can do the job for you.

Remember that stripping sync is something that's done in every TV set on the market and, as a result, semiconductor manufacturers have jumped into the market with single-chip solutions to the problem. Several companies make them, but the one I usually use is the LM1881 made by National Semiconductor. I've found it very easy to put in a circuit and fairly tolerant of variations in sync levels and signal voltages.

The pinouts of the chip are shown in Fig. 1 and I've also drawn in the components needed to make it work. As you can see, all it takes is two capacitors and one resistor. Nothing could be simpler but you still should write to National Semiconductor to get a data sheet for the IC (National Semiconductor Corporation, 2900 Semiconductor Drive, Santa Clara, CA 95052-8090).

When you contact them, you should ask where you can get the part since I don't know what the availability is like in your part of the world. You might find it easier to deal with a supplier in the United States but, no matter what you do, it's not a common IC so you're going to have to do some investigating if you want to buy only one or two of them. Minimum orders can be murder.

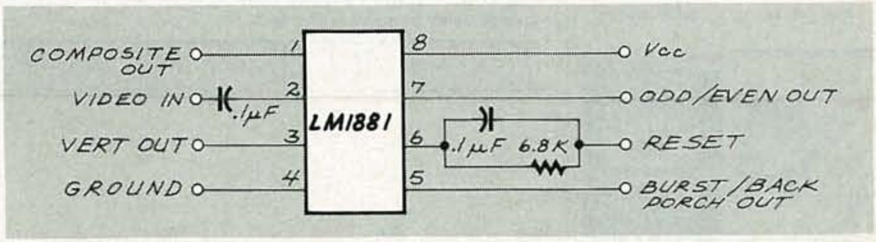

FIG. 1—THE LM1881 SYNC SEPARATOR, made by National Semiconductor, requires very few components to make it work.

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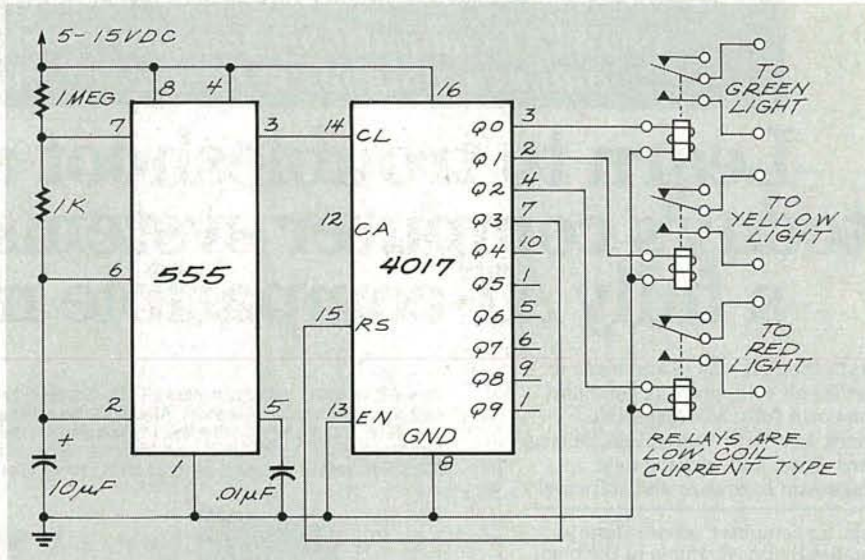

FIG. 2—YOU CAN CONTROL a traffic light, or any other similar device, using this circuit. An AC-powered battery eliminator can be installed right inside the light, along with the circuit itself.

TRAFFIC LIGHT

I have an old traffic light and want to get it working and use it as a yard light in my driveway. What I need is some way to control the AC and make it work like a real traffic light. There must be some simple way to do this.—A. Haycock, Corvallis, MT

Before we get started on your problem, let me tell you that I think it's a great idea. As a matter of fact, if there are any of those lights left, I'd like to find out where I can get one for myself.

I'm not sure how you want the thing to operate and you haven't told me how many lights you have to control. Traffic lights can have one, two, three, or more individual lights. Whatever the case, there are several ways you can get the thing working.

I'm guessing that you want the lights to cycle back and forth and, since I can't imagine that there's that much traffic in your driveway, absolute accuracy in timing isn't really all that critical.

One simple way to control the light is shown in Fig. 2. All you need is a handful of parts and the layout isn't at all critical. You can build the circuit on a piece of perforated construction board and put it inside the light itself. You'll have to put a power supply in there as well but the circuit draws so little power that you can use an AC-powered battery eliminator.

The 555 is set up as a timer with an output frequency of about 10 seconds. That is the rate at which the light will change and, even though it's a bit fast for a real traffic light, it should make for a more interesting display in your driveway.

The clock pulses from the 555 drive a 4017 whose outputs control relays that turn on each of the traffic lights in turn. The reason I'm using a 4017 here is that it can control 10 relays and I don't know how many you have in your traffic light. All you have to do to add more lights is add more relays and move the reset connection on the 4017.

I think your idea is great and I would have done exactly the same thing if I had managed to get my hands on one of those traffic lights.

WORD/HOME PROCESSOR

At a recent garage sale, I purchased a word processor made by an outfit in Sunnyvale, California called Systel. Although the only I/O port is the keyboard connector, I intend to use it as the basis for a home monitor/control system. The system is based around a Z-80A but I don't have any DOS software that will work with it. Do you have any suggestions?—G. Farr Jr., Garden City, KS

I have several suggestions, but they all add up to the same thing, and I'm afraid that none of them are what you're looking for. Trying to build or convert a computer to a home con-

continued on page 80

LETTERS

Write to Letters, Radio-Electronics, 500-B Bi-County Blvd., Farmingdale, NY 11735

STILL MORE ON AM RADIO

I read with interest the letter from Matthew Bailey ("More on AM Radio") that appeared in the December issue of **Radio-Electronics**. He stated that in the beginning many AM stations used standard telephone lines with 5-kHz upper limits for studio-to-transmitter links. I can't comment on that, but his next sentence said that AM radios were built with narrow bandwidth IF filters to minimize interference.

What interference? In the beginning, there were not many commercial power lines or much electrical equipment to generate interference. There certainly weren't enough stations on the air to interfere with each other.

In fact, radios did not have narrow IF's. Many sounded great—once technology produced better speakers, of course. Some units had selectable bandwidth that used a switch labeled "Voice-Music." I believe the main reason for that was to allow for more intelligible speech.

In the sixties, some radio programmer decided that the loudest station in a market would have the most listeners. That started a new trend that caused stations to use greater amounts of audio processing (compression, limiting, and clipping). Before that, most stations used modest amounts of compression (AGC) to counteract operator gain-riding errors. Limiting was used to prevent overmodulation by loud peaks.

When stations used more processing, the average program-material level increased greatly. That caused the occupied bandwidth of stations to increase in density as well. Now there was real interference.

Manufacturers gradually began to reduce the bandwidth of receivers to reduce the interference. The programmers noticed that treble was lacking and began to use pre-emphasis to get the sparkle back in their sound.

The more that receiver bandwidth was cut, the more treble boost was necessary, which caused more interference, which required further bandwidth reductions. That's what happened to the sound of AM radio. Throughout that time, of course, man-made interference was also on the rise.

Many people suspect that the radios in their old cars sounded better—and they did. Today it's hard to find AM radios with decent bandwidth. I possess a few, and have amazed many friends who thought they were listening to FM. The sound of many AM stations is very good, if you can find something suitable on which to listen.

GEORGE THOMAS
Chief Engineer, WJDX/WMSI
Jackson, MS

SATELLITE TV PROGRAMMING

In his article "The Changing Face of Satellite TV" (**Radio-Electronics**, November 1990), Robert Angus did a good job of describing the tip of the iceberg, but he either ignored or was unaware of the most important part—what you cannot see. He also short-changed the existing home reception of satellite retransmitted signals that include network television, cable programming, audio data, narrowcasts, and a variety of excellent educational programming. Existing satellite capacity makes available more than *500*, not 200, channels. Less than 20% of those channels carry "cable programming to viewers."

Mr. Angus and others hype the potential for smaller reflectors. Phased-array panels have been used for years by the military. The size of reflectors and phased arrays that are capable of supplying sufficient signal levels is shrinking because of advances in HEMT technology. Size is also influenced by geographic location, sources of interference, obstacles, weather, equipment used—and, yes, TWT (Traveling Wave Tube) output power. With every reduction in size comes other trade-offs. The problem of non-compatible encryption-decryption technologies, which Mr. Angus so correctly addressed, is a hurdle, not an impasse. VLSI circuits will soon permit multiple digital- and analog-signal-processing and decryption equipment all within the same receiver and/or the television itself. But all of this technical information is just the tip of the iceberg!

The article stated, "Since the same pool of feature films should be available to all the PPV hopefuls, and the majors promise to offer basic programming comparable to current basic cable ..." That's where the rest of the story begins. Most existing "cable" programming is controlled by very few MSO's or Multiple System Operators (giant cable companies), and/or by production companies that either own or are owned by MSO's. Those giants control programming and, more important, the major sources of programming. Since the networks want to be carried on cable in favorable channel spots (2–13), they are not a source of competitive programming.

Without programming, the assertion "Satellite television received on small, flat antenna panels, promises to give cable TV a run for the money" ignores reality. Congress and many of us in the industry have wrestled with program-access problems for more than four years. Without programming, any technology that is not owned or at least controlled by cable interests will wither and die on the vine!

ROBIN ADAIR
Columbia, KY

SPICE VARIETY

I just finished reading T.J. Byers' article about SPICE in the November issue of **Radio-Electronics**, in which he mentioned PSpice and IsSpice. I'd like to mention another product, called Micro-CAP II, which is a student version of the original Micro-CAP. It has all the capabilities of the original except that it is set up for only 25 nodes instead of 150 nodes. The student version has a vast built-in library for such components as op-amps, transformers, NPN and PNP transistors, MOS transistors, diodes, and more. It also includes a schematic editor, netlist, bode plots, time-domain plots, Fourier analysis, and more. The student version costs less than $50.00 and comes with a manual written for the non-professional. I found that to be much better than the sample versions mailed out by PSpice or IsSpice. There is also a student version for digital circuits called Micro-Logic II. It also costs about $50.

I just graduated from an electrical engineering program and I used both of those software packages extensively, with excellent results. Both book/software packages are available from Addison-Wesley Publishing Company (ISBN 0-201-50552-5: Micro-Logic II; ISBN 0-201-50542-8: Micro-CAP II).

DONALD HAROOTUNIAN
Webster, TX

NTSC-TO-RGB CONVERTER

Several incorrect statements appeared in Jim Harrigfeld's article "Build an NTSC-to-RGB Converter" (**Radio-Electronics**, October 1990). The subheading says, "Put a TV in your VGA monitor," and the text says that standard NTSC video rate requirements eliminate "most fixed-frequency (digital) monitors—i.e., most CGA and EGA types."

Both statements are false. As a reference, I cite the *Ask R-E* column on page 12 of the same issue. To display a standard NTSC signal, a 15.75-kHz horizontal scanning rate is required. The table on page 12 shows that VGA does not use that rate, while CGA uses exactly that rate. In fact, CGA video was originally designed so that PC users could use their color TV sets as monitors. Please take care to make your articles technically correct!

I also agree with Mr. Burton ("Throwing Caution to the Wind," *Letters*, October 1990) that cautions about handling CMOS seem overdone. The first CMOS chips were indeed static sensitive, but manufacturers quickly added input-protection diodes.

EARL MORRIS
Midland, MI

Both of the statements in which Mr. Morris finds fault appeared as a result of editing errors. The subhead, of course, should have read "Put a TV in your Multisync Monitor." The text that Mr. Morris quotes is not as clear as it should be. The point we tried to make is that there are two requirements for a monitor: (1) that it accept analog inputs, and (2) that it be capable of scanning at 60 Hz vertical and 15.75 kHz horizontal. Although a CGA monitor scans adequately, it generally has only dig-

ital inputs and thus will not work. An EGA not only scans at the wrong frequency but it also has digital inputs. And a VGA monitor, although it has analog inputs, will not scan at the correct rate. That's the reason for our recommendation for multi-frequency-type monitors.—JIM HARRIGFELD

BRAIN POWER

While I was not surprised that there were objections to Don Lancaster's claim of a four-billion-bit human brain capacity (*Hardware Hacker*, **Radio-Electronics**, January 1990), I was disappointed in the nature of the objections (*Letters*, May and November 1990), given the recent popularity of neural network research. While it is true that the brain compresses data, it is also true that the compression algorithms are part of the brain and (theoretically) could be mimicked by a computer. The real issue is that the "program" of the human brain is not totally contained in its four-billion neurons. It is the ten thousand (rough average) interconnections to each neuron that determine the "program." I'm not sure how much resolution the analog connection strengths have, but I'll guess about 3-bits worth. Therefore, to mimic the brain, you would need and associative memory structure with a capacity of about $(2^3)(4 \times 10^9)(1 \times 10^4) = 3.2 \times 10^{14}$ bits. Keep in mind that many of the brain's functions have been efficiently "hard-wired" over a billion years of evolutions to avoid the waste of connections during trial-and-error programming. We are still a long way from constructing anything with the complexity and power of the human brain.

GEORGE LEGTERS
Melbourne Beach, FL

CONSUMER ELECTRONICS FOR THE BLIND

In response to David Plumlee's letter regarding electronic appliances for the blind (**Radio-Electronics**, November 1990), unless products with such features find widespread acceptance among the sighted, it's not very likely that they'll appear on the market. However, I would think that he could retrofit some appliances himself, or have it done for very little cost. "Dymo" label-making machines include a model that produces Braille-character labels that can be placed over many touch controls. When used over a touch-control panel on a unit that has an audible signal when buttons are pressed, the beep and the Braille might be enough to provide reliable operation by the sightless.

As for a clock radio, perhaps he could use a separate clock that chimes at the hour and each quarter hour. He could interface it with a radio to turn the radio on at the appropriate time. If that didn't work, maybe a talking clock would be easier to use. Mark V Electronics (8019 E. Slauson Ave., Montebello, CA 90640) offers two such models.

One other possible source of information is an organization called Christian Record Braille (P.O. Box 6097, Lincoln, NE 68506). They make audio/visual products for the blind. Most of their products are Christian study and information materials, but they might offer guidance in other areas as well.

ROGER DOERING
Camp Verde, CA 86322 R-E

EQUIPMENT REPORTS

Data Controls Analyst 2 Data Line Monitor

We've all had the experience of trying to troubleshoot a PC's serial data line to establish reliable communications between a PC and external device such as a modem, printer, or serial-to-parallel converter. It's usually a difficult job because you can't see what's going on. Sure, you can use breakout boxes with LED indicators to try to get the lines matched up correctly, but if the communications problem is caused by an incorrect transmission rate, glitches on signal lines, or an unreliable data-communications channel, simple tools just won't do the job. That's when you need a device like the *Analyst 2* data-line monitor and digital test set from Data Controls (2183 Buckingham Road, Suite 217, Richardson, TX 75081).

The *Analyst 2* is a handheld unit, but with a size of about 4¼ × 8¼ × 1¾ inches, you'll probably prefer to leave it on your benchtop. A wall transformer provides power to the bottom of the unit through a detachable cable. The front panel features 8 function keys, a 2-line by 32-character backlit LCD readout, and eight tri-color LED's across the top of the unit.

On power-up the *Analyst 2* performs a self test, after which it's ready to test data lines. The main menu of the unit contains twelve choices for the appropriate mode of operation. Each mode is displayed one at a time, and the list is scrolled through using up or down cursor keys.

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Troubleshoot, test, and analyze data circuits quickly.

Operating modes

In the Data Monitor mode, the *Analyst 2* can capture and display RS-232 serial data streams. Asynchronous, synchronous, or a user-defined bit-oriented protocol are supported, and the display can be in a character-oriented format or in hexadecimal. To aid in troubleshooting, the *Analyst 2* can be triggered to start recording when it sees a specific group of characters. Sub menus let you select the proper signal clocking, data format, how the data is stored in the capture buffer, whether specific signal transitions are captured, and how the display should show the captured data.

The Review Data mode provides a way to examine and manipulate the data stored in the non-volatile capture buffer. As in the monitor mode, various sub menus are used to select data formats.

The Distortion mode is used to detect the deviation of a signal's actual timing parameters from what it should theoretically be. Three types of distortion, gross, isochronous, and bias, can be measured.

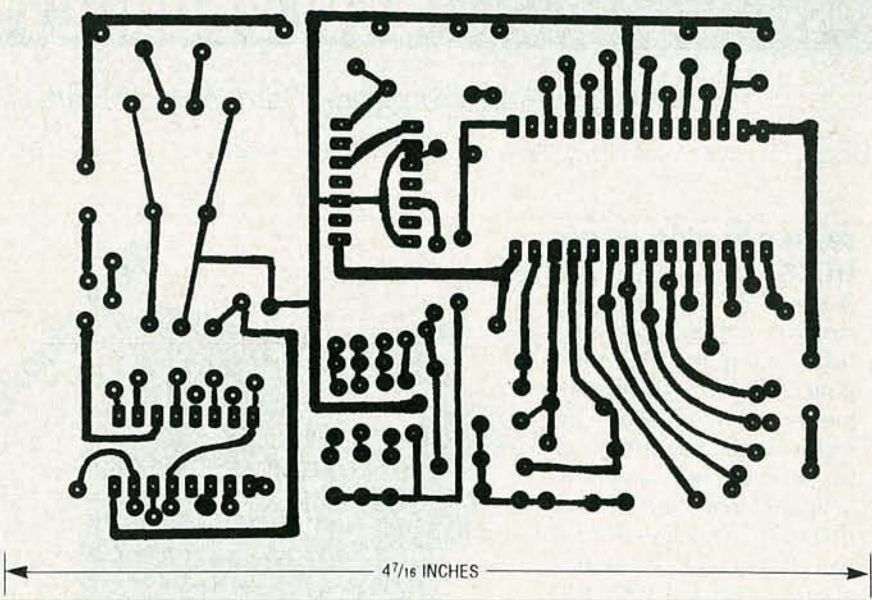
In the Time Delay mode, the *Analyst 2* measures a device's response delay. It sends out control signals, and waits for responses. For example, the length of time between a request-to-send (RTS) and the corresponding clear-to-send (CTS) can be measured.

The *Analyst 2* can also act as a source of data in its Simulate mode, where it outputs data to verify that a data channel is working properly. It can also be used to test printers, modems, terminals, and the like. When requested the unit will output, in either ASCII or EBCDIC coding a QBF or quick-brown-fox message, which contains every letter of the alphabet, the numbers 0 through 9, a carriage return, and a line feed. As you might expect, data-framing and -format modes are selectable.

To simulate a loopback device, the *Analyst 2* can be run in its Echo mode. When running, the unit digitally loops back all data presented on pin 3 (receive data) onto pin 2 (transmit data).

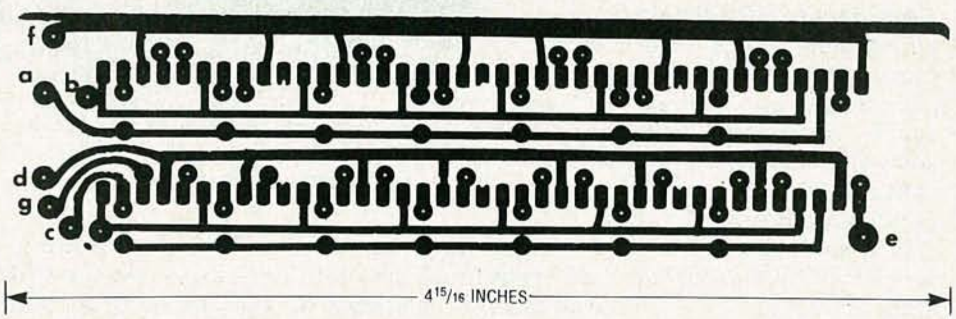
A bit-error rate test or BERT is provided to determine the performance level of a data-communications line, and whether it can support communications with an acceptable number of bit errors. Excessive line noise, crosstalk, and random burst errors on the line can be detected. A block-error rate test or BLERT is similar to a BERT, except that it specifically tests the capability of a data-communications line to handle blocks of messages of specific length. Another test mode—CERT or character-error rate test—is very similar to the BLERT mode, except that the block size is determined by the bits-per-character selection. A final rate-test mode—error seconds test—is used to determine the performance of a data line over time.

We found that putting the *Analyst 2* to work was not too difficult—once we got the hang of it. Unfortunately, the operating manual supplied with the unit was difficult to decipher in many cases. For example, we were at first confused about the proper way to select the right choices from the menu. We did figure it out, but without help from the manual. All things considered, that's a minor complaint. We think that the $965. *Analyst 2 data-line monitor is certainly worth a look from data-communications professionals.* **R-E**



In "Build This Benchtop Frequency Counter," (December 1990) we were unable to provide the PC-board foil patterns. They are reproduced here.

We greatly exaggerated the capabilities of the counter. Because of the components used, the counter cannot perform at frequencies above 25 MHz. We're sorry for any confusion our misstatements caused.



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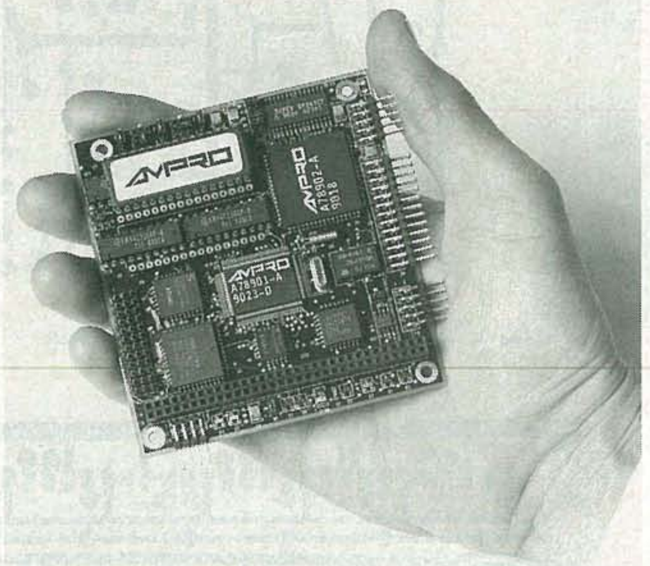

CIRCLE 16 ON FREE INFORMATION CARD

The *CoreModule/XT* is equipped with a CMOS-enhanced 8088-compatible microprocessor that operates at 9.82 MHz, and a full complement of PC-compatible DMA controllers, interrupt controllers, and timers. It comes with two byte-wide sockets for EPROM, flash EPROM, static RAM, or NOVRAM memory that can be used as bootable, DOS-compatible solid-state disk (SSD), eliminating the need for floppy drives. Optional utility programs automatically converts any disk-based PC software to SSD operation.

The *MiniModule* expansion boards, which stack over or under the CoreModule, add configuration flexibility, allowing the addition of CGA, EGA, VGA, LCD, and electroluminescent flat-panel controllers; a 2400-bps modem; a LAN interface; and other capabilities. The *MiniModule/FSS* provides floppy drive, SCSI, and serial port controllers in one extremely compact package.

The *CoreModule/XT* ranges in price (to OEM's) from below $100 in quantities of 10,000 and up to $130 for quantities of 1000. A *CoreModule/XT Development Kit* that includes the *CoreModule/XT*, *MiniModule/FSS*, *MiniModule/VGA*, all cables, mounting hardware, manuals, and DR DOS costs $100 in quantities of 100. The *MiniModule/SSD* costs $90 in 100's.—**Ampro Computers, Inc.**, 990 Almanor Avenue, Sunnyvale, CA 94086; Tel: 408-522-2100; Fax: 408-720-1305.

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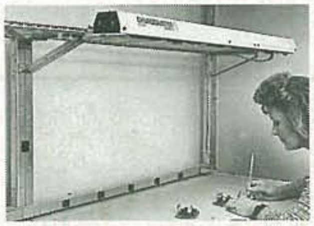
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The *A60420* overhead ionizer costs $630.—**Desco Industries**, Inc., 761 Penarth Avenue, Walnut, CA 91789; Tel: 714-598-2753; Fax: 714-595-7028.

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CIRCLE 18 ON FREE INFORMATION CARD

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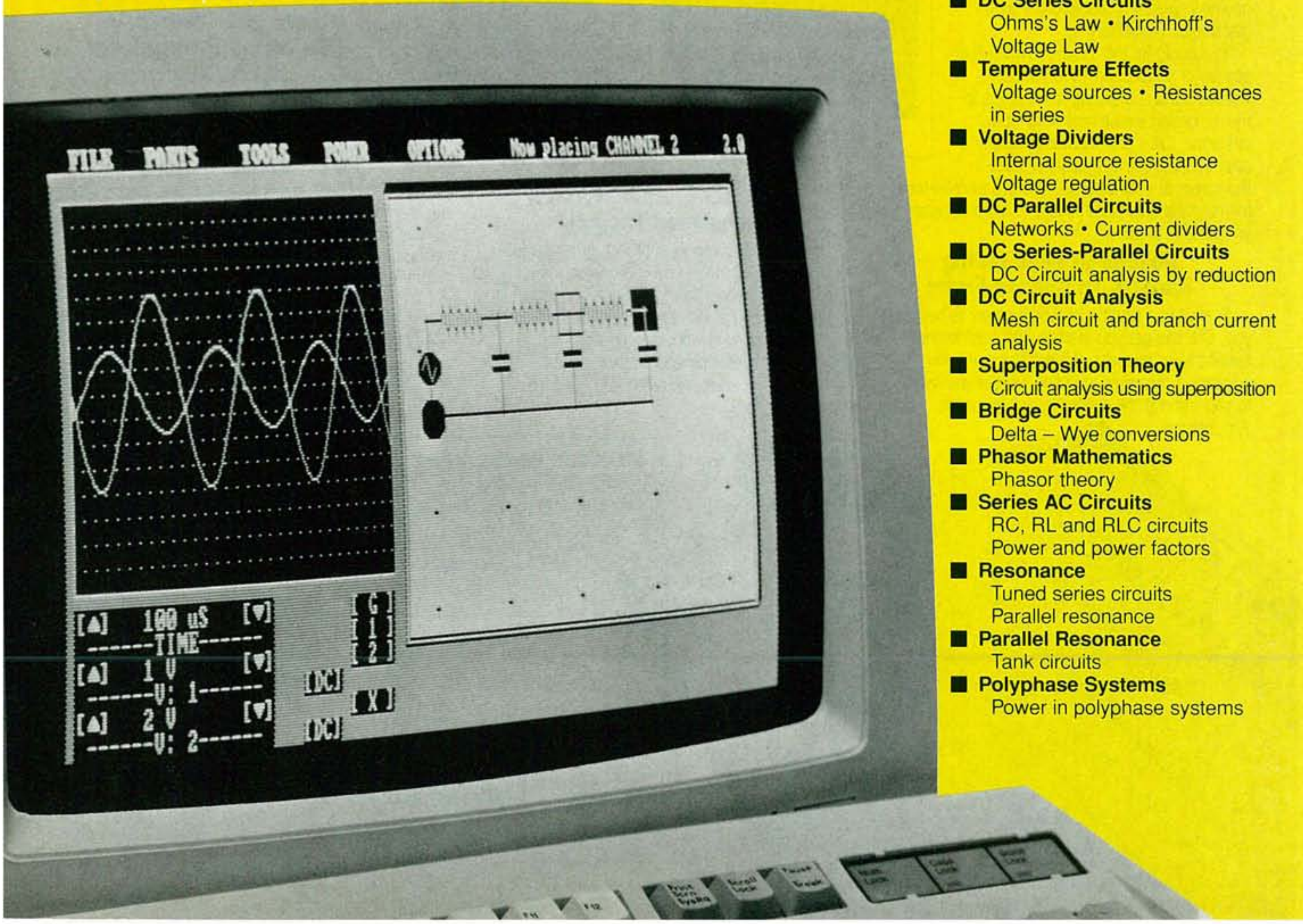

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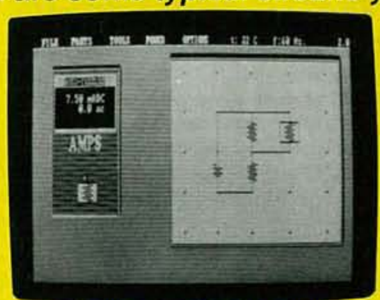
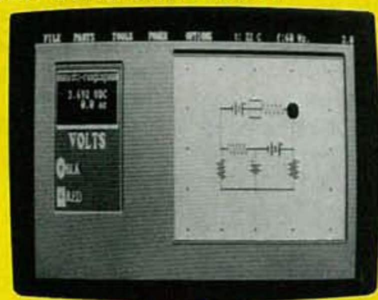
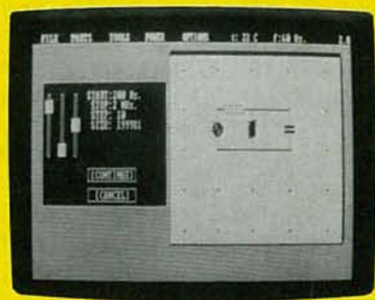


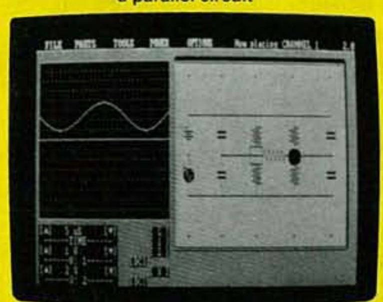
Resistor Series/Parallel Circuit demonstrates current division in a parallel circuit



Thevenin Equivalent Circuit calculating voltage drop and current flow using built-in ammeter/voltmeter



Parallel Resonance LC Tank Circuit using sweep generator to vary voltage across tank, monitoring circuit response



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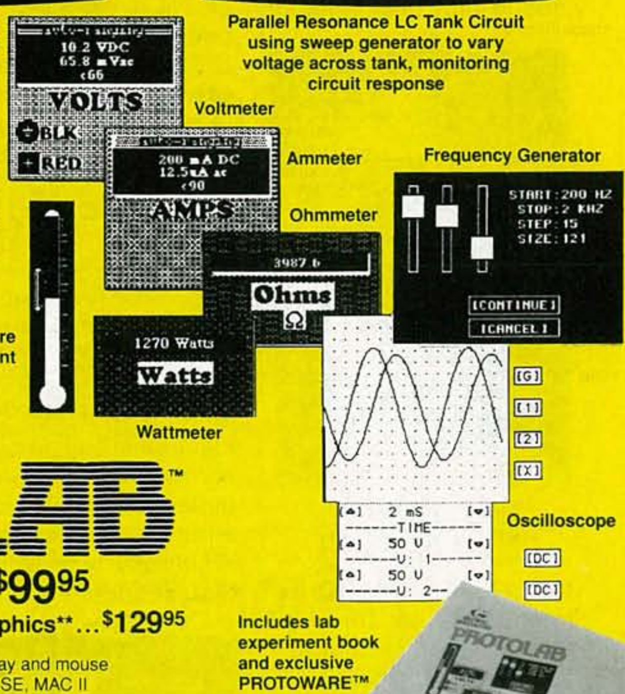

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an antenna tuner without transmitting, or check the SWR of a linear amplifier's input.

The SWR analyzer has a low-distortion RF generator that covers 10–160 meters, an SWR bridge that gives forward and reflected components, and it automatically computes and displays the SWR. A frequency-counter output allows a counter to be connected for precise digital readout. Operation is completely automatic.

The *MFJ-207* HF SWR analyzer costs $99.—**MFJ Enterprises, Inc.**, P.O. Box 494, Mississippi State, MS 39762; Tel: 601-323-5869; Fax: 601-323-6551.

HANDHELD LOGIC ANALYZER. Targeted for use by design engineers and field service technicians, *Trace-Tek's Logic Boy* is a full-featured, 16-channel, 50-MHz logic analyzer. The handheld diagnostic and development

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tool is easy to use, with extensive menus for user prompting and system set-up. All state information, timing data, and menus are displayed on the LCD readout. The *Logic Boy* weighs only 21 ounces with NiCd batteries installed, and is designed to be held and operated with one hand—a convenience when troubleshooting digital circuits at remote locations lacking AC power. It can be coupled with a battery-operated printer to form a complete portable diagnostic and troubleshooting system.

The *Logic Boy* offers 50-MHz operation on all 16 channels, non-volatile system setups and reference memory, a built-in IBM-compatible printer port, and a BNC trigger output terminal that lets the logic analyzer be used as a four-level word recognizer when connected to the external trigger input of most oscilloscopes. The *Logic Boy* is compatible with both TTL and CMOS logic levels, and features 1K×16 capture-and-reference memory, synchronous or asynchronous clocking, a clock qualifier, and programmable trigger delay.

The *Logic Boy*, complete with probes, AC wall adapter, IBM printer-cable adapter, NiCd batteries, and a one-year warranty, costs $1795.—**Trace-Tek Instruments**, 1301 North Denton Drive, Suite 204, Carrollton, TX 75006.

GRAPHIC POWER MONITOR. To help electronics technicians and hobbyists find and solve power problems, the *PowerVisa* power monitor detects all power disturbances that can affect electronic equipment. By simply plugging it into an outlet, a complete power analysis can be made. When any type of power disturbance—including

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sags, surges, impulses, failures, waveshape faults, frequency errors, high-frequency noise, wiring errors, and total harmonic distortion—is detected, an LED lights. A disturbance graph can be printed immediately or, at the users' convenience, a text report of the ten worst events of each disturbance type can be generated. The *PowerVisa* also prints daily and weekly summaries. It monitors true RMS AC voltage, AC current, and temperature. An RS-232 port is included for remote operation. The instrument automatically selects appropriate thresholds depending on the voltage being monitored, or the user can choose to manually set the desired thresholds.

"Help" messages that explain its operation can be printed, and a push of the Advice button generates a printout of the types of disturbances that have been recorded and the times they occurred.

The *PowerVisa* power monitor has a suggested price of $3,295.—**Basic Measuring Instruments**, 355 Lakeside Drive, Foster City, CA 94404; Tel: 415-570-5355; Fax: 415-574-2176.

BI-POLAR POWER SUPPLIES. The *POW* series of single-output, bi-polar power supplies can "sink"—absorb current from external sources—or "source"—supply power to external loads—current. They can be used for applications involving servo systems and precision drives, as variable output power supplies, or as power amplifiers with frequency characteristics ranging from 0 ± 30 kHz. The power supplies are available with three different operating ranges: +35 to −35 VDC at 1A; +35 to −35 VDC at 5A; and +70 to −70 VDC at 2A. Without switching polarity, both gain and positive/negative voltage can be varied continuously by adjusting panel-mounted, 10-turn potentiometers. Constant-current crossover overload protection is provided.

The power supplies are

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available with either a top luggage strap for portability, or a built-in rack-mounting frame.

The *POW* series of single-output, bi-polar power supplies are priced starting at $925.—**Kikusui International Corporation**, 19601 Mariner Avenue, Torrance, CA 90503; Tel: 800-KIK-8784.

SURFACE-MOUNT SOLDER KITS. Two SMT solder cream kits, for evaluation of component soldering using different types of flux systems, each contain 250-grams of stencil-grade solder cream packed in five

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50-gram "Flexpaks." The five different types of mildly activated fluxing systems included are standard, fine pitch, water washable, and two with no-clean residues. The latter leave clear, hard, non-corrosive residues; one is off-fillet residue and the other is on-fillet residue. *Kit 7* provides the flux systems with an Sn62 alloy, while *Kit 8* is supplied with an Sn63 alloy. Each kit comes with a "Vac-Tweezer" set that includes a vacuum pickup and five tips with various sizes of clear pads.

Surface-mount solder *Kit 7* and *Kit 8* are priced at $89 each.—**ESP Solder Plus**, 14 Blackstone Valley Place, Lincoln, RI 02865; Tel: 800-338-4353.

DIGITAL CLAMP-ON METER. The model *ACD-10* clamp-on meter directly measures AC current, voltage, and resistance.

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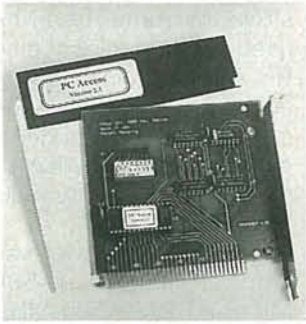
The drop-proof instrument weighs eight ounces and is 6¾ inches long. Its half-inch display provides over-range and low-battery indicators. The autoranging meter provides circuit protection up to 550 volts. The *ACD-10* comes with a wrist strap and a removable belt clip. A 9-volt battery, safety test leads, a carrying case, and instructions are included.

The model *ACD-10* digital volt/amp/ohm meter has a list price of $89.95.—**Amprobe Instrument**, 630 Merrick Road, P.O. Box 329, Lynbrook, NY 11563; Tel: 516-593-5600.

HARD-DRIVE SECURITY SYSTEM. Providing password access security for IBM PC, XT, AT, 386, and compatible computers, *PC Access version 2.1* consists of an easily-installed plug-in card and a diskette of programs.



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Either a valid password or, optionally, a user-ID and a password must be entered each time the computer is booted before DOS will be loaded or executed. One master password and as many as 15 user passwords are allowed. The master password must be used to access the user password list and to select the security system's functions. Version 2.1 features menu-driven selections for establishing the passwords and other security settings, DIP switch selections of the security board's address, and a half-size card with a bracket for easy installation. *PC Access* does not modify COMMAND.COM or any system files, and does not interfere with the operation of any other software.

PC Access version 2.1 has a suggested list price of $79; distributor and quantity discounts are available.—**Renton Products**, P.O. Box 16271, Seattle, WA 98116; Tel: 206-682-7341.

RADIO-FREQUENCY FINDER/COUNTER. The model *1500A* RF finder/counter from *Startek* runs

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on 110 VAC, 12 VDC, or rechargeable NiCd batteries, and is small enough to fit in a shirt pocket. It is housed in a rugged anodized-aluminum case and weighs less than 9 ounces with the batteries installed. The highly sensitive instrument can be used with its telescoping RF antenna to accurately and easily identify and measure transmit frequencies from handheld, mobile, or stationary radio transmitters.

The *1500A* has two overlapping ranges—1–500 MHz and 200–1500 MHz. Two "gate" or "sample" times are switch selectable. A fast gate time of 0.25-seconds yields a 1-kHz resolution, and a slow gate time of 2.5 seconds yields a 100-Hz resolution. A TXCO timebase provides accuracy of ±1 ppm.

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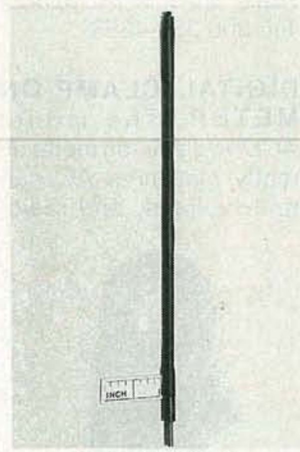
The unit can be operated and charged simultaneously with a 9 ± 12 VDC, AC adaptor. The input signal of the device is coupled via a BNC connector on the top, and various types of probes and antennas can be used to optimize performance for specific uses and frequency ranges.

The model *1500A* radio-frequency finder/counter costs $99.95, the factory installed NiCd batteries cost $20.00, and an AC adapter/battery charger costs $9.00—**Startek International, Inc.**, 398 NE 38th Street, Fort Lauderdale, FL 33334; Tel: 800-638-8050 or 305-561-2211; Fax: 305-561-9133.

ANTENNA STATIC DISCHARGER. Precipitation static and corona discharge noise, which can raise the noise level 20 to 30 dB above ambient, are bled off by the model *AS-1* antenna static discharger,



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which reduces the undesired electrical noise that causes receiver desensitization. The *AS-1* is the same type of device that's used on aircraft and in ground stations to minimize electrostatic interference. It has been modified for use on antennas to prevent any detuning, even if it is element mounted. The antenna static discharger mounts easily to any antenna, boom, or tower and weighs only one ounce. It offers increased range during noisy conditions, minimized receiver desensitization, and lower antenna noise on long wires, dipoles, yagis for HF through UHF, verticals, TV, and TVRO antennas.

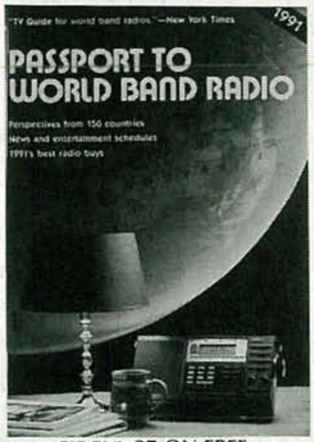
The *AS-1* antenna static discharger costs $12.95. —**Static Buster Inc.**, 3535 Shepherdsville Road, Elizabethtown, KY 42701; Tel: 502-769-2244. **R-E**

NEW LIT

Use The Free Information Card for fast response.

PASSPORT TO WORLD BAND RADIO; from International Broadcasting Services, Ltd., Box 300, Penn's Park, PA 18943; $16.95.

This magazine in book format could be described as the *TV Guide* for radio, *National Geographic*, *Consumer Reports*, and



CIRCLE 27 ON FREE INFORMATION CARD

Time rolled into one. Its 384 pages are filled with articles on topics ranging from music behind the Iron Curtain to how to write to radio stations for free goods, from international politics and current events to how to get started in world-band listening, from Alistair Cooke's long-running *Letter From America* show to the Salt Lake City world-band station that broadcasted rock-n-roll used by American troops in Panama to drive Noriega nuts. In-depth consumer reports provide comparative ratings of portable and table-top radios, as well as a review of a world-band receiver for cars. Comprehensive program guides are listed by time, country, and channel. Newcomers to the hobby will appreciate tips on what features to look for in a world-band receiver, a glossary of terms, and informational articles. Interspersed throughout the book are helpful hints, definitions, and pointers, along with intriguing photographs from around the world and dozens of advertisements for radio stations and equipment.

1991 ELECTRONIC COMPONENTS/COMPUTER PRODUCTS CATALOG; from Jameco, 1355 Shoreway Road, Belmont, CA 94002; Tel: 415-592-8097; Fax: 415-592-2503; free.

Featuring just about everything the electronics enthusiast or computer buff

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could need, the new Jameco catalog offers tools, test equipment, cables, connectors, IC's, motherboards, computer kits, floppy- and hard-disk drives, computer accessories, and more. New to this edition of the catalog are two 386 computer kits, 386 motherboards, a 2400-baud mini external modem, and a 9600-baud fax board. The Jameco catalog features full product descriptions, photographs, and pricing information.

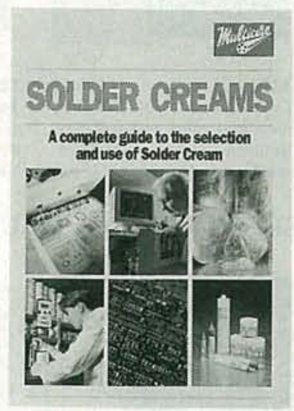
TONER CARTRIDGE RECHARGE: Kits–Supplies–Service; from Chenesko Products Inc., 62 North Coleman Road, Centereach, NY 11720; Tel: 800-221-3516 or 516-736-7977; Fax: 516-732-4650; free.

CIRCLE 29 ON FREE INFORMATION CARD

With the high price of new toner cartridges for laser printers, many people prefer to use cartridges that have been cleaned out, modified, and recharged. This catalog offers toner-cartridge recharge products and services, and explains how to recharge cartridges used with laser printers including the HP LaserJets, Apple LaserWriters, and many others. Six do-it-yourself kits include full instructions for recharging. For those who want to start a recharge business, the catalog offers a complete selection of products—including generic toner, graphic toner, fixing rods, sealing strips, plugs, bags, tools, and vacuums—at bulk prices. For those who aren't handy with toner cartridge recharging, or are short on time, the catalog offers a mail-in recharging service.

SOLDER CREAMS: A COMPLETE GUIDE TO THE SELECTION AND USE OF SOLDER CREAM; from Multicore Solders, Cantiague Rock Road, Westbury, NY 11590; Fax: 516-334-7098; free with request on company letterhead.

This comprehensive 24-page brochure explains and describes the formulation, application methods, and uses of solder creams. It covers the various alloys, fluxes, properties, and rheology of solder creams for surface-mount applications, as well as techniques for deposition, reflow soldering, and cleaning. A chart that illustrates good



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working practices is followed by explanations of how to apply solder creams for various purposes. A three-page glossary of commonly used technical terms is also included in the booklet.

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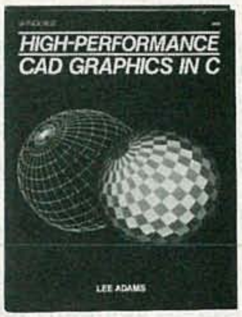

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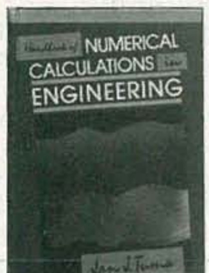

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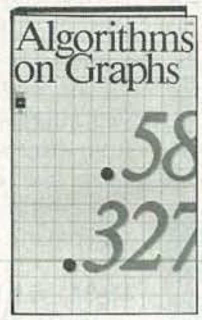

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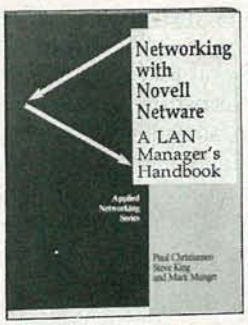

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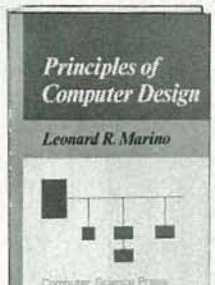

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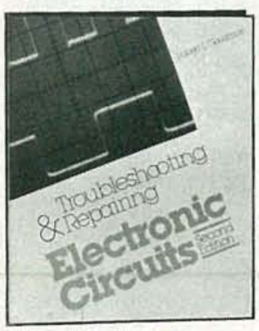

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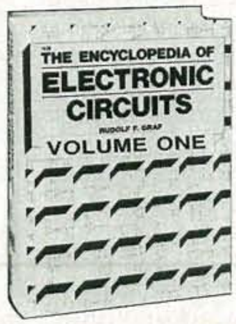

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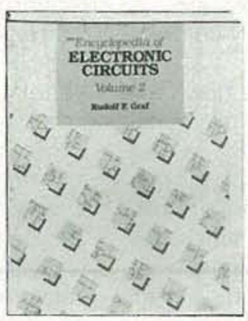

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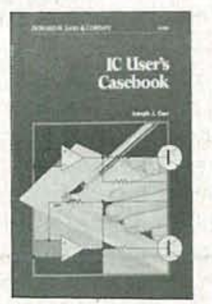

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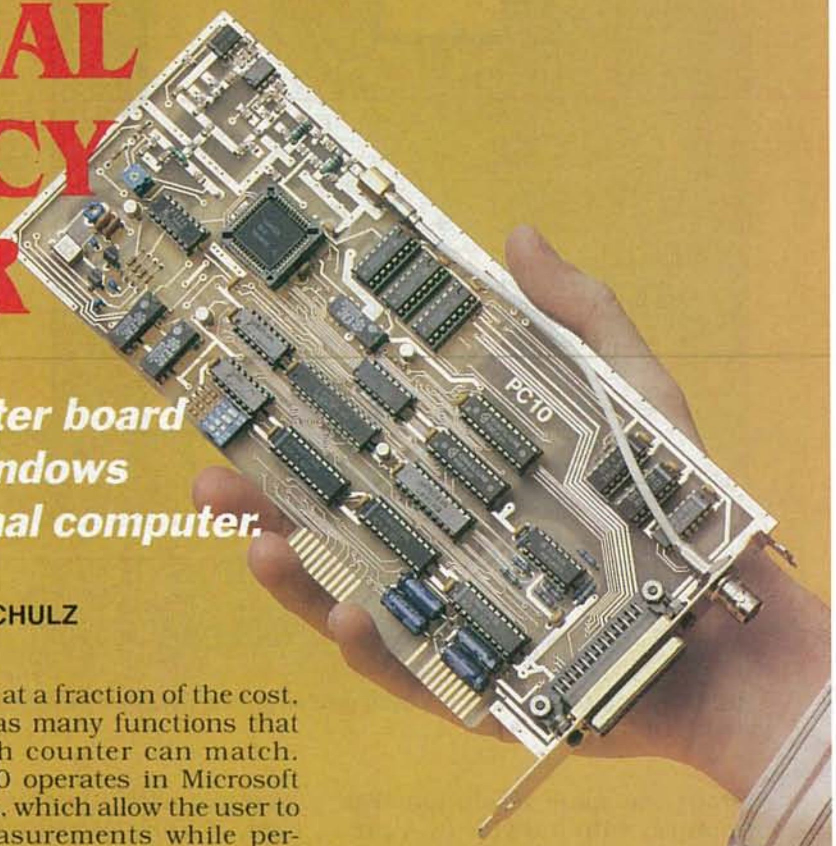
TURN YOUR PC INTO A UNIVERSAL FREQUENCY COUNTER



Build a frequency-counter board that operates in a Windows environment in your personal computer.

JOEY GRASTY and BILL SCHULZ

FREQUENCY COUNTERS HAVE COME A long way since Hewlett Packard introduced the 524A back in 1952. It was a huge instrument, containing more than 70 vacuum tubes, but it could measure frequencies up to 10 megahertz, and time intervals as small as 100 nanoseconds. In late 1988, a project began to reduce the major parts of a universal frequency counter into a single integrated circuit, which greatly increased the performance and measurement capability of frequency counters built with this new IC. The project culminated with the OE10, an IC that could directly measure frequency up to 240 MHz and measure time intervals with resolution to 0.1 nanoseconds. The OE10 was then incorporated into the PC10, a high-performance universal frequency-counter board for IBM PC/XT/AT and compatibles—and now you can build it yourself.

The combination of a PC and a frequency counter produces a powerful tool useful for a wide range of measurements. Not only does the PC10 contain most of the features of more expensive laboratory benchtop frequency counters at a fraction of the cost, it also has many functions that no bench counter can match. The PC10 operates in Microsoft Windows, which allow the user to take measurements while performing other tasks. The Windows environment also allows data to be shared with other programs. Data logging and automatic software calibration of the timebase are also provided. Finally, the PC10 can directly tune a receiver to the measured frequency using the computer's serial port.

However, before we discuss how the PC10 operates and how you can build one for yourself, let's first talk about how universal frequency counters work.

Frequency measurements

A frequency measurement is defined as a number of cycles of an incoming signal occurring during a given time period. The unit of frequency is Hertz (Hz), or cycles per second (cps). A frequency measurement is performed by counting the number of cycles occurring within a specific gate time, which typically ranges from 0.01–10 seconds, or more. The OE10 has four built-in gates—0.01, 0.1, 1.0 and 10 seconds—as well as programmable gate times than can be set from less than a microsecond to more than 28 seconds. The gate time, along with the timebase oscillator frequency (10.000 MHz), determines the *resolution* of the frequency measurement, or the number of significant digits that can be displayed.

A frequency measurement may also be *prescaled*—that is, before the signal to be measured enters the frequency counter, it is divided by an integer number. Prescaling allows signals to be measured that are higher in frequency than the counter is normally capable of measuring. The OE10 supports three prescaler values: 4, 16, and 64. However, prescaling requires that the gate time must be multiplied by the prescale to

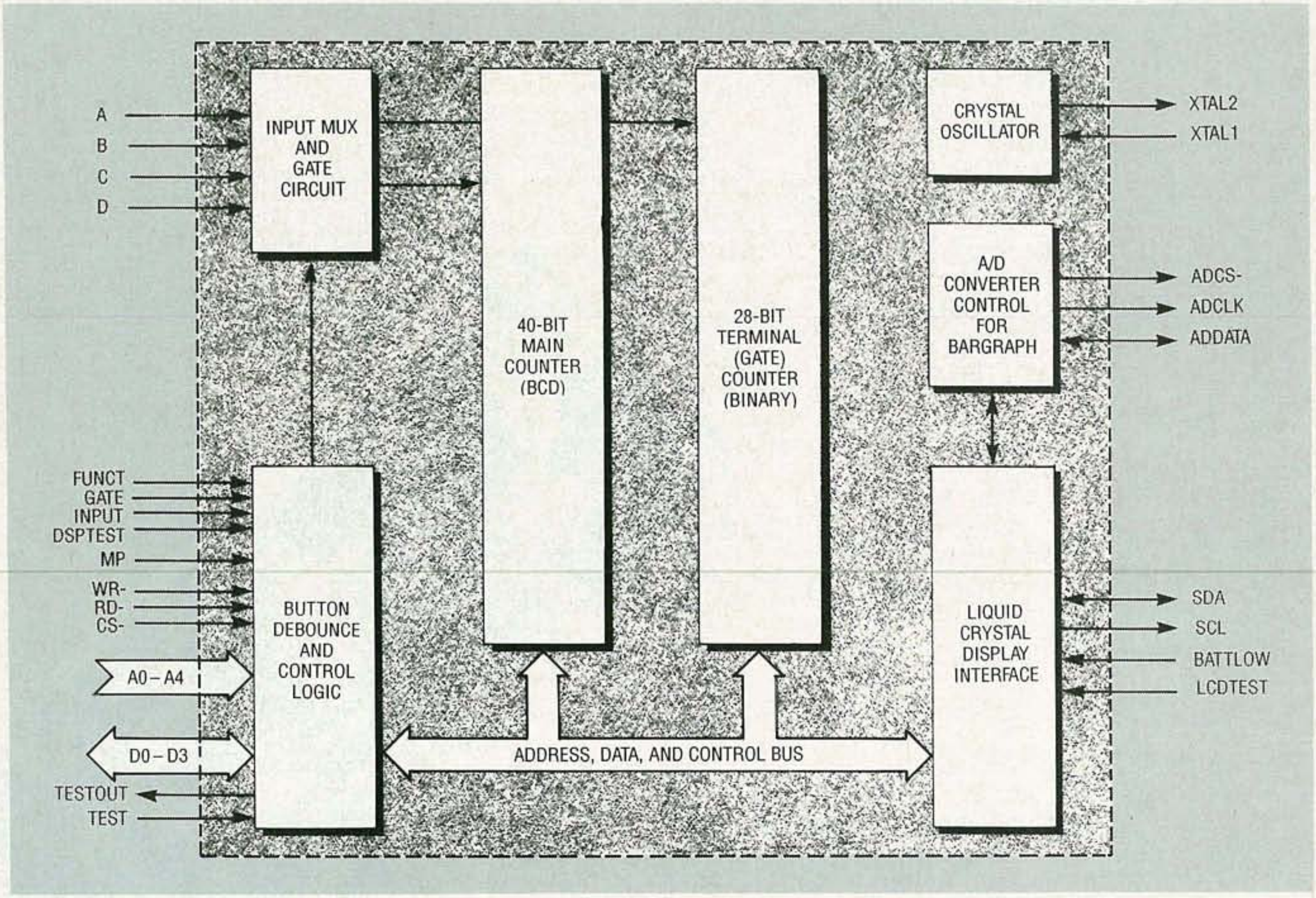


FIG. 1—BLOCK DIAGRAM of the OE10 gate array. The device is packaged in a 44-pin plastic leaded chip carrier.

retain the same resolution. For example, with a divide-by-4 prescaler, the gate times for the same number of significant digits become 0.04, 0.4 and 4 seconds. The final gate time of 40 seconds, is not supported by the OE10. The PC10 board contains two cascaded divide-by-4 prescalers, allowing prescales by 4 and 16. That feature raises the PC10's maximum measurable frequency to 3 GHz.

A period measurement, the inverse of a frequency measurement, is the length of time of one cycle of a signal. A period measurement counts the number of clocks of the time base oscillator between two consecutive rising edges of the input signal. A period average function is also built-in, allowing 10, 100, or 1000 periods to be measured and averaged to give a final value. Programmable averages are also available.

One difficulty with frequency measurements is getting good resolution at low frequencies. For example, with a gate time of 1 second, a 10-Hz signal will be displayed as 0.0000010 MHz, with only one hertz resolution. To counter that problem, the OE10 can be programmed to perform a *reciprocal*, or inverse frequency measurement, which is a period measurement with the measurement converted to frequency. A 10-Hz signal has a period of 0.1 seconds, or 1,000,000 counts with a 10-MHz timebase. That yields a frequency measurement of 10.00000 Hz, with six digits of resolution. Better yet, the reciprocal frequency measurement required only 0.1 seconds to give 6 digits of resolution, compared to the 1-second frequency measurement that gave a paltry 1 digit of resolution! The disadvantage of this measurement technique is that the gate time is no longer fixed; it is the same length as one period of the signal that is being measured.

Short period measurements have the same resolution problem as low-frequency measurements. A signal with a 1-microsecond period, for example, gives a count of 10 with a 10-MHz timebase; a resolution of only 1 digit. If that measurement is performed as a reciprocal period measurement (a frequency measurement), the same signal would be measured as 1.000000 MHz with a 1-second gate, which gives a period measurement of 1.000000 microseconds, or 6 digits of resolution. The main disadvantage of reciprocal period measurements is that the length of the measurement is greatly increased, and single-shot events cannot be measured.

A time-interval measurement determines the time between two events. A time-interval measurement starts when the OE10 detects a rising edge on the A input. The measurement ends when a rising edge is detected on the B input. Any additional edges detected on the A input are ignored until a rising edge is detected on the B input. The number of counts of the time base oscillator

TABLE 1—OE10 REGISTER MAP

Address	D3	D2	D1	D0
00000 MC0	MC0D	MC0C	MC0B	MC0A
00001 MC1	MC1D	MC1C	MC1B	MC1A
00010 MC2	MC2D	MC2C	MC2B	MC2A
00011 MC3	MC3D	MC3C	MC3B	MC3A
00100 MC4	MC4D	MC4C	MC4B	MC4A
00101 MC5	MC5D	MC5C	MC5B	MC5A
00110 MC6	MC6D	MC6C	MC6B	MC6A
00111 MC7	MC7D	MC7C	MC7B	MC7A
01000 MC8	MC8D	MC8C	MC8B	MC8A
01001 MC9	MC9D	MC9C	MC9B	MC9A
01010 TC0	TC0D	TC0C	TC0B	TC0A
01011 TC1	TC1D	TC1C	TC1B	TC1A
01100 TC2	TC2D	TC2C	TC2B	TC2A
01101 TC3	TC3D	TC3C	TC3B	TC2A
01110 TC4	TC4D	TC4C	TC4B	TC4A
01111 TC5	TC5D	TC5C	TC5B	TC5A
10000 TC6	TC6D	TC6C	TC6B	TC6A
10001 CREG 1	GATE1	GATE0	MSEL1	MSEL0
10010 CREG2	EXTGATE	TSOURCE	DT	INSEL
10011 CLRCNT	—	—	—	—

	MSEL1/MSEL0			
GATE1/GATE0	**Frequency (00)**	**Period (01)**	**Interval (10)**	**Ratio (11)**
00	0.01s	1	1	100,000
01	0.1s	10	10	1,000,000
10	1.0s	100	100	10,000,000
11	10.0s	1000	1000	100,000,000
INSEL	**Frequency (00)**	**Period (01)**	**Interval (10)**	**Ratio (11)**
0	A	A	A/B	A/B
1	B	B	C/D	C/D

between the two events is then displayed as the measured value in seconds. A time interval average function is also available, with built-in averages of 10, 100, and 1000 time intervals. Programmable time-interval averages are also present.

A ratio measurement is a frequency measurement with an external signal replacing the time-base oscillator. Therefore, instead of giving a measurement in Hz, the OE10 measures the ratio between the input signal and the reference signal. If the two signals have identical frequency, the display will read 1.000000. Ratio measurements are especially useful for tuning radio receivers and transmitters to a reference frequency. Resolution of a ratio measurement is determined by setting the number of counts that the reference signal must make before displaying the ratio measurement.

Another useful feature is a pulse-width measurement. This measurement is performed by measuring the number of counts of the time-base oscillator between a rising edge and a falling edge (a positive-going pulse) or between a negative edge and a positive edge (a negative-going pulse). The OE10 does not support pulse-width measurements directly, but using a simple external circuit and the time-interval capability, pulse-width measurements are easy to accomplish.

Theory of operation

Figure 1 is a block diagram of the OE10 gate array. The device is packaged in a 44-pin plastic leaded chip carrier. The OE10 typically draws about 25 mA from a 5-volt supply. The OE10 can be configured for two modes of operation by setting the MP pin to logic 0 or logic 1. Logic 0 configures the device for stand-alone operation, used for building handheld or benchtop universal counters (which will not be discussed in this article); logic 1 configures the device for microprocessor-controlled operation, the mode used for this project. When configured in microprocessor-controlled mode, the microprocessor bus interface becomes active and controls all chip operations.

Table 1 shows the internal register map of the OE10. The OE10 has a 5-bit address bus and a 4-bit data bus that allow access to the internal registers. The first ten locations, MC0–MC9, are the 10 BCD digits of the main counter, where the results of the measurement are stored. The most significant digit is MC9. Since the digits are BCD, only binary values 0000 through 1001 are valid. The least significant digit, MC0, can only be read, not written, and any write clears MC0. The 28-bit binary terminal counter occupies the next seven locations, TC0 through TC6. The terminal counter controls the length of the measurement.

The next two locations are control register 1 (CREG1) and control register 2 (CREG2). The MSEL1 and MSEL0 bits control the type of measurement to be performed. The GATE1 and GATE0 bits control the gate times for a frequency measurement, the number of averages for period or time-interval measurements, or the number of counts for ratio measurements. Bit INSEL controls which input (for frequency or period measurements) or input pair (for time interval or ratio measurements) is

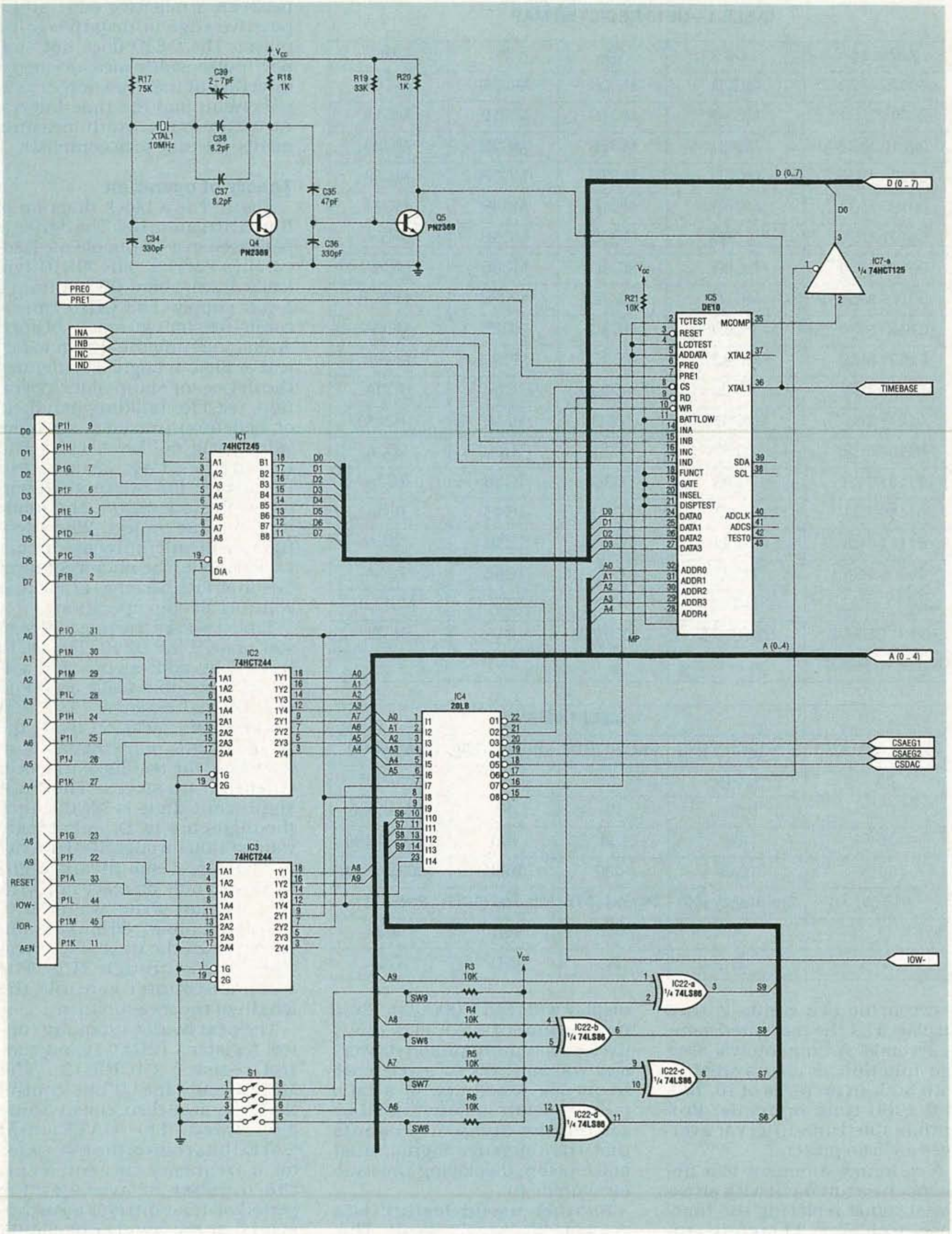


FIG. 2—THE PC10 INTERFACE is an 8-bit industry standard architecture (ISA) bus used in IBM personal computers and compatibles.

used for the measurement. Bit DISPTEST controls the display test, which is not used in the microprocessor mode. Bit TSOURCE determines whether built in or programmable gates are used. Bit EXTGATE is used only for manufacturing test.

Register CLRCNT provides a simple way to clear both the main counter and the terminal counter. A write of any value to this location clears both counters. Likewise, writing any value to location STARTM starts a measurement cycle.

To perform a measurement, clear both counters by writing to location CLRCNT. Next, program CREG1 and CREG2 for the proper type of measurement, gate time, and input source. If programmable gate times are required, program the terminal counter to the required value. Finally, start the measurement by writing to location STARTM. The end of the measurement cycle can be monitored by polling MCOMP, the measurement complete pin.

The OE10 has four signal inputs: A, B, C, and D. A and B can be used for all types of measurements, with the exception that input A is the only input that can be used for prescaled frequency measurements; frequency and period measurements require only one input, and use inputs A and B only. Time-interval and ratio measurements require two inputs, A/B or C/D. Inputs C and D are used only for time-interval and ratio measurements.

The OE10 has two counters, the main counter and the terminal (or gate) counter. The main counter, which is a 36-bit binary-coded decimal (BCD) counter, is used to collect the measurement data. It is driven by a 5-bit Johnson counter that divides the incoming signal by 10. The terminal counter is a 28-bit binary counter that generates gate signals for a frequency or ratio measurement, or provides an average count for period or time interval measurements.

The PC10 interface, shown in Fig. 2, is an 8-bit industry standard architecture (ISA) bus used in IBM personal computers and compatibles (but not PS/2 computers). The PC10 is controlled by the PC through 32 input/output (I/O) ports. Since the PC decodes only the bottom 10 bits of the I/O address, the base address of the board is set by the four DIP switches (S1). The PC10 decode logic consists of a programmable array logic (PAL) device, IC4, a 74LS86 quad XOR gate, IC22, four pull-up resistors R3–R6, and a 4-position DIP switch, S1. The 20L8 PAL decodes the I/O addresses into signals that enable different devices on the PC10 board. The address bus and various control signals from the PC are buffered by two 74LS244 buffers, IC2 and IC3. Data buffering is performed by IC1, a 74LS245 octal transceiver.

Although the OE10 contains a crystal oscillator, much better performance can be obtained by using a temperature-compensated crystal oscillator as the timebase clock. The 10-MHz crystal, XTAL1, controls the frequency of oscillation; the frequency may be set precisely using trim-capacitor C39.

That's all we have room for, so we'll have to finish up this story next month. We will then finish up the discussion on the PC10 circuitry, we'll talk about the optional external amplifier board, the AP10H, and we'll show you what is involved in building both of them. **R-E**

PC10 PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted
R1—2200 ohms
R2—not used
R3–R6, R21—10,000 ohms, ⅛ watt
R7, R10—4990 ohms, 1%
R8, R9—10,000 ohms, 1%
R11–R14—20,000 ohms, 1%
R15, R16, R21—10,000 ohms, ⅛ watt
R17, R30—75,000 ohms, ⅛ watt
R18, R20—1000 ohms, ⅛ watt
R19—33,000 ohms, ⅛ watt
R22, R23—75 ohms, chip resistor
R24—91 ohms, chip resistor
R25–R28—1000 ohms, chip resistor
R29—47 ohms, chip resistor
R31—100,000-ohm potentiometer
Capacitors
C1, C3, C4—10 µF, 25 volts, radial electrolytic
C2—22 µF, 25 volts, radial electrolytic
C5–C33—0.1 µF, 50 volts, monolithic
C34, C36—330 pF, NPO
C35—47 pF, NPO
C37, C38—8.2 pF, NPO
C39—2–7 pF NPO trimmer
C40–C53, C67—0.001 µF, 1206 chip capacitor
C54–C56, C58–C64, C68—0.1 µF, 1206 chip capacitor
C57—330 µF, 16 volts, radial electrolytic
C65—not used
Semiconductors
IC1—74HCT245 octal tristate transceiver
IC2, IC3—74HCT244 octal tristate buffer
IC4—20L8 programmable array logic (PAL)
IC5—OE10 application-specific integrated circuit (ASIC)
IC6, IC8, IC14, Ic15—not used
XXX
IC7—74HCT125 tristate quad buffer
IC9, IC10—74HC374 tristate octal D-type flip-flop
IC11—AD7528 dual 8-bit multiplying digital-to-analog converter (DAC)
IC12—TL074 quad op-amp
IC13—AD580 voltage reference
IC16–IC18—74AC11151 eight-to-one multiplexer
IC19—74HCT74 D-type flip-flop
IC20—74HC00 quad NAND gate
IC21—74HC157 quad two-input multiplexer
IC22—74LS86 quad XOR gate
IC23—74ALS12 triple 3-input NAND gate
IC24—LM339 quad voltage comparator
IC25, IC26, IC29—MAR6 MMIC
IC27—UPB582C high-performance divide-by-four prescaler
IC28—CA3199E general-purpose divide-by-four prescaler
D1, D2—HSMP3800 surface-mount pin diode
Q1–Q3—2N2907 PNP transistor
Q4, Q5—PN2369 NPN transistor
Other components
J1—BNC bulkhead (R141-306)
J2—SMB right-angle PC board connector (R114-665)
RY1–RY3—SPDT DIP reed relay, 5-volt coil, form 1C
L1–L3—100 µH choke
P2—female DB25 connector (ITT DBU-25S-AA)
P3—SMB plug, cable (R114-082)
S1—4-position DIP switch
XTAL1—10-MHz crystal
Miscellaneous: seven 14-pin IC sockets, four 16-pin IC sockets, six 20-pin IC sockets, one 24-pin IC socket (0.3-inches), one PLCC 44-pin IC socket, one G57 modified stamped PC bracket (Globe Mfg.), one lug (Zierick #334), 6-inch 50-ohm coaxial cable RG187 (0.1-inch diameter), PC board, solder, etc.

Note: The following items are available from Optoelectronics Inc., 5821 N.E. 14th Ave., Ft. Lauderdale, FL 33334 (800) 327-5912, in Florida (305) 771-2050, FAX (305) 771-2052: Complete Kit of all parts to build the PC10, including software, $299; OE10 ASIC, $49; PC10 PC board, $59; software, $5; programmed PAL, $19; assembled and tested PC10, $339; complete kit of all parts to build the AP10H, $179; AP10H PC board, $39; machined and painted cabinet, $49; 6-foot 25-conductor straight-through cable, $20; assembled and tested AP10H, $229. Send SASE for priced out parts list. Include 5% shipping and 6% sales tax when shipped to Florida address.

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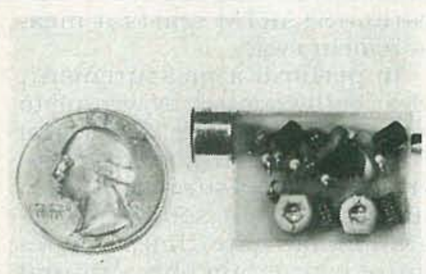

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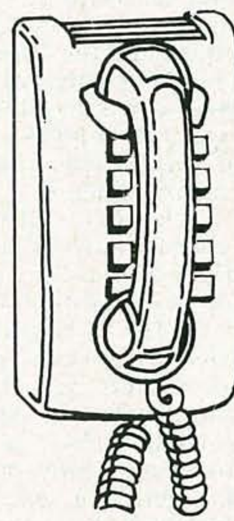
CIRCLE 191 ON FREE INFORMATION CARD



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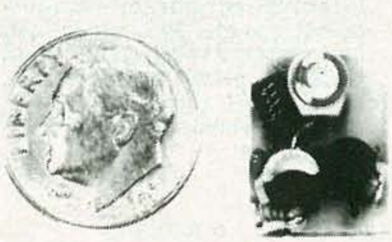

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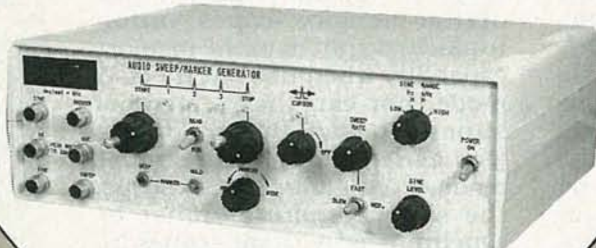
AUDIO SWEEP/MARKER GENERATOR

JOHN WANNAMAKER

Build this sweep/marker generator and discover the audio-range frequency response of your amplifier or filter design.



A PICTURE IS WORTH A THOUSAND words—especially when you're trying to determine the frequency response of an audio amplifier or filter design. Our sweep/marker generator lets you create an oscilloscope display that shows the response of an of an audio system. It can be a useful tool for designing and analyzing amplifier and filter circuits.

With the sweep/generator, the user programs a desired frequency range that is swept into the input of the device under test. The response curve of the frequency sensitive circuit is displayed on the scope screen. When using a conventional storage scope, multiple response curves can be superimposed for a helpful comparison of waveform characteristics.

The sweep/generator can be used to examine the tuning response of an amplifier, check circuit stability or even be used by acoustic engineers. Let's take a closer look into the operation of this versatile unit.

Operating features

The sweep/generator operates in two basic modes: READ or RUN. In the READ mode, the frequency sweep range can be programmed by adjusting the START and STOP multi-turn potentiometers on the front panel. Three user adjustable frequency ranges can be swept into the device under test—3 Hz to 1000 Hz, 35 Hz to 20 kHz, and 3 kHz to 100 kHz. The user adjusts the exact beginning and end of the frequency range to be swept.

While in the RUN mode, each of the frequency ranges may be swept in its entirety, or any portion of the range, as low as 0.4%, may be swept. The upper 100-kHz frequency range may have up to 12% error over the entire band, the amount of error is roughly reduced in proportion to the amount of the band being swept.

There is also a SWEEP RATE potentiometer, which can be adjusted from 50 milliseconds to 30 seconds per ten graticule divisions in each of the three frequency ranges. The SWEEP output provides a sawtooth ramp for the X input to an oscilloscope.

The frequency range that is being swept uses five markers, or brightened spots, equally spaced at 25% intervals along the horizontal graticules. The first and fifth markers are adjusted to the outer most graticule lines. The frequency at each graticule line can then be determined by taking the difference between the start and stop frequencies and dividing by ten. All markers are indicated on the front panel LED's. Figure 1 shows a swept sine output of the sweep/generator displaying such markers at 25% intervals along the horizontal graticule lines.

When you are in the RUN mode, the markers should be turned off when sweeping. A momentary overshoot could occur that is not actually present if the marker switch was on during sweeping. That effect is less likely to happen at higher frequencies.

The amplitude level of the swept sine-wave output may be varied from 10 millivolts to 5 volts peak-to-peak by the SINE LEVEL control. The output impedance is about 700 ohms, and the output level is maintained within 0.5 dB from 10 Hz to 100 kHz. Two on-board trimmer potentiometers allow adjustment of the sine shape to as little as 0.5% total harmonic distortion. The very act of sweeping generates its own type of distortion, which can be minimized by using a long-duration sweep.

Another feature of the READ mode is its capability to move between the five markers and cursor with the SKIP button, and stay at a position with the HOLD button. When held at a particular position, the frequency of that marker or cursor can be read on the front panel display. The initial display is dim, when it brightens after a few seconds you'll have an accurate frequency reading.

The cursor is an additional marker which can be adjusted to a particular point of interest while in the RUN mode. The user can move the cursor marker with the CURSOR potentiometer to any point on the swept frequency. The CURSOR is best used to determine the frequency of a point before going to the memory mode. The cursor frequency is read in the READ mode the same way as the marker frequency is read.

Input and output jacks are located on the front panel for connection to an audio amplifier or

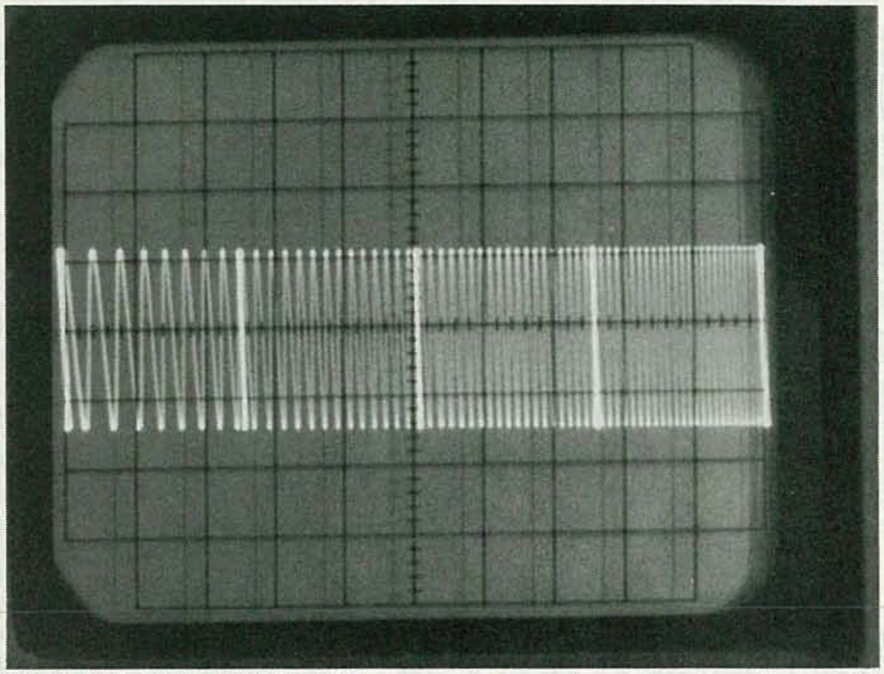


FIG. 1—THE AUDIO OUTPUT SINE wave of the sweep/generator shows five equally spaced markers.

filter device and an oscilloscope. A conventional, digital memory or storage scope may be used with the sweep/generator, however the connections are different. Figure 2 shows a basic connecting diagram that can be used with a conventional scope. The swept sine output connects to the audio input jack, the audio output jack connects to the peak-hold input jack of the sweep/generator. The sweep output and peak-hold outputs of the sweep/generator connect to channels X and Y of the scope, respectively. The scope must be used in the X-Y mode for a proper display.

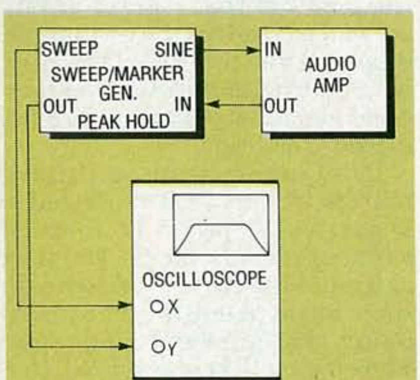


FIG. 2—A CONNECTING diagram shows how the sweep/generator can be used with a conventional scope.

Conventional analog storage scopes are best suited for use with the sweep/generator. When that type of scope is used, the SWEEP output connects to the scope's external trigger. Some digital-memory scopes, unfortunately, do not have the memory capability when used in the X–Y mode, nor can they remember superimposed sweeps of different shapes. To use the storage mode of a digital-memory scope, the sweep/generator must be synchronized with the scope's internal sweep, and the sweep rates must be adjusted for similar times. When a digital-memory scope is used, the SYNC output of the sweep/generator connects to the external trigger of the scope. The dual-trace feature of a digital-memory scope must be used in order to achieve a suitable display. Those various connections are shown in the side bar under Operating Instructions.

A peak-hold circuit is incorporated in the sweep/generator to create a clear base line reference of the frequency response curve. The output signal from the product to be tested may be fed directly into the scope's Y input, but there will be no well-defined base line because of the mirror-image of the audio response. The peak-hold circuit overcomes that problem by momentarily holding the peak value of each positive alternation of the signal, and then quickly reducing to zero. The output from the tested device is connected to the peak-hold input, the peak-hold output is then connected to the scope's Y input. The scope will display a contour line that follows the positive "envelope" of the response curve. That rather nice feature has a nearly flat frequency response from 20 Hz to 20 kHz (within 0.25 dB) and can be used up to 50 kHz.

The input to the peak-hold circuit should not exceed 3.5 volts peak-to-peak. The circuit works adequately with an input as low

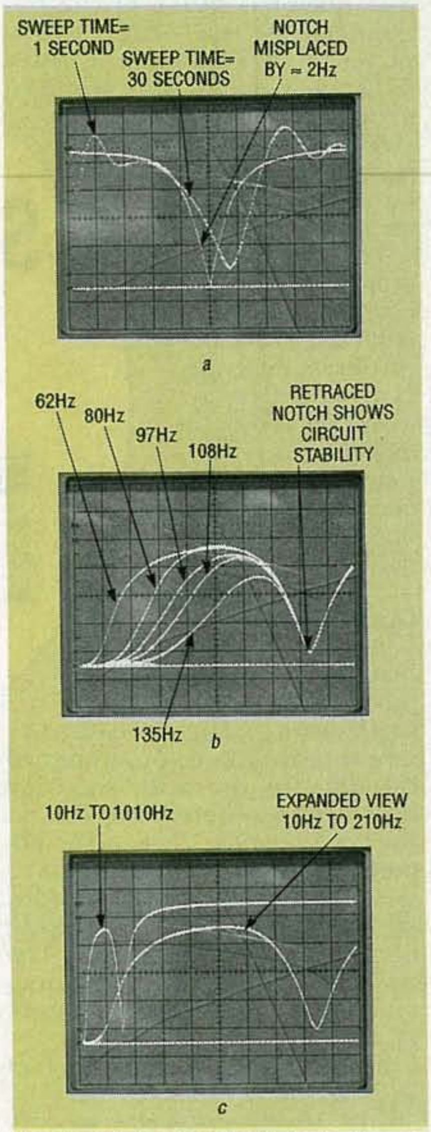
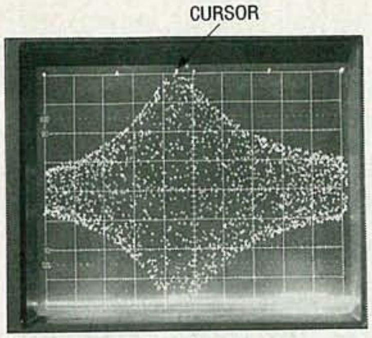
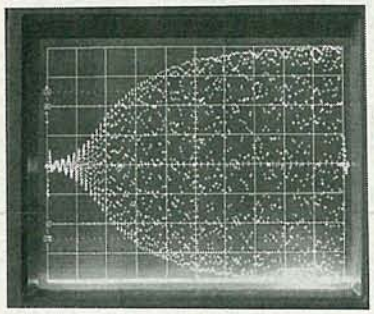


FIG. 3—FILTER RESPONSES: (*a*) shows a 60-Hz notch filter, a smooth response is displayed with a slow sweep of 30 seconds, a faster sweep of 1 second gives overshoots and misplaces the notch by almost 2 Hz; (*b*) shows a 180-Hz notch filter with selectable low-end gains, note the same notch is retraced, indicating circuit stability; and (*c*) shows a low-end response of an amplifier with a 180 Hz notch filter, one trace covers a 10- to 1010-Hz range, the expanded view covers a 10- to 210-Hz range.



a



b

FIG. 4—PEAK-HOLD CIRCUIT not in use, note how the mirror image is displayed: (*a*) shows an L–C tuned circuit, the frequency sweep is 50 kHz at 5 kHz per division, with the CURSOR marker at the curve peak, 52.48 kHz; (*b*) shows an audio amplifier frequency response from 20 Hz to 120 Hz.

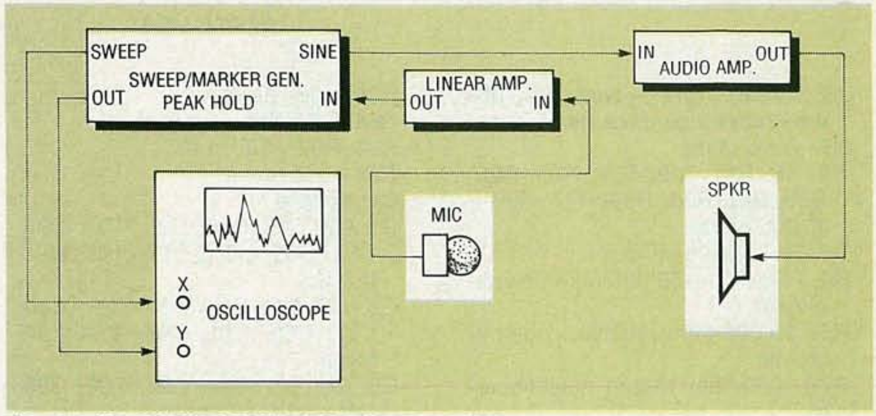


FIG. 5—THE SWEEP/GENERATOR CAN BE USED as a tool in testing the acoustic response of a room. The amplified swept sine wave is projected into a room, and is picked up by a microphone, whose signals are then amplified with a linear amp and fed into the peak-hold circuit.

as 35 millivolts peak-to-peak, but any value below 20 millivolts peak-to-peak will come out as a base-line value of about +5 millivolts peak-to-peak.

Now that we've introduced you to some of the operating features of the sweep/generator, let's examine some of the scope displays it can produce.

Sweep/generator uses

An example of the sweep/generator being used to determine the frequency response of a notch filter is shown in Fig. 3-*a*. The advantage of a slow sweep with its inherent little distortion of the sine wave is seen in the two superimposed sweeps. The smoothest response is at a sweep time of 30 seconds. The faster sweep of 1 second shows overshoots and a displacement of the notch frequency that are not present at the slower sweep rate.

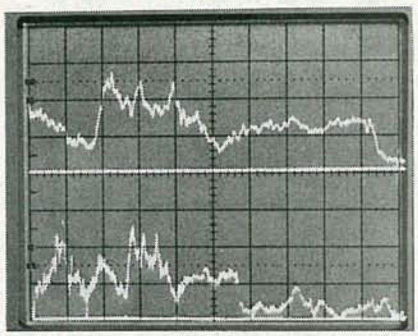
Two interesting displays are shown in Figs. 3-*b* and -*c*. Figure 3-*b* shows five superimposed response curves of a 180-Hz notch filter with variable low-end gains selected at 62 Hz, 80-Hz, 97 Hz, 108 Hz and 135 Hz. The filter's stability is illustrated by retracing the same notch at the various frequencies. Figure 3-*c* shows a low-end response of an amplifier with a 180-Hz notch filter. One trace ranges over a frequency of 10 Hz to 1010 Hz, the other trace is an expanded view with a frequency range of 10 Hz to 210 Hz.

Figure 4-*a* shows the use of a cursor in an L-C circuit. The total frequency sweep is 50 kHz, at 5 kHz per CRT graticule division. The CURSOR marker, at 52.5 kHz, is at the peak of the curve.

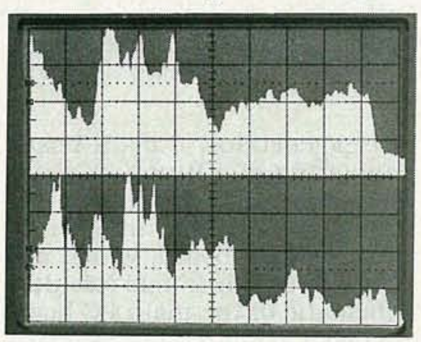
Figure 4-*b* shows an audio amplifier's frequency response from 20 to 120 Hz. The mirror image of the response curve is displayed in both Figs. 4-*a* and -*b* because the peak-hold circuit is not in use.

An unusual application of the sweep/generator is in the field of acoustic engineering. The generator can be used as an aid in acoustic design by amplifying a swept sine wave into a speaker, and projecting that sound into a room, or perhaps an auditorium. The acoustic response of the room is picked up by a microphone, whose signals are fed into a linear amplifier. The output of the linear amplifier is connected into the peak-hold circuit of the sweep/generator. A block diagram showing the connections for an acoustic response arrangement is shown in Fig. 5. A high quality linear amplifier should be used to pick up microphone signals. Also, the frequency response of the audio amplifier and speaker should be known to avoid misinterpretation of the amplifier response with that of the acoustic response of the room.

Figure 6-*a* shows a line contour-display of an acoustic response of a room with the peak-hold circuit in use. The upper display is swept over a frequency range of 1 kHz to 3 kHz (200 Hz per graticule division), while the lower display varies over a 45 Hz to 5045 Hz range (500 Hz per



a



b

FIG. 6—SCOPE DISPLAYS show an acoustic response of a room: (*a*) shows a line-contour display where the top is swept over 1 kHz to 3 kHz, the bottom is swept over 45 Hz to 5045 Hz; (*b*) shows a filled-in display which is achieved by increasing the scope's intensity.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise indicated.
R1—3900 ohms
R2, R5, R15, R19, R24, R25, R26, R39, R41, R58, R59, R77, R99—10,000 ohms
R3, R47—3300 ohms
R4, R28, R31—50,000-ohm potentiometer
R6—10,000-ohm multiturn potentiometer
R7—2000-ohm 10-turn potentiometer
R8—2200 ohms
R9—2000-ohm multiturn potentiometer
R10—6800 ohms
R11—10,000-ohm 10-turn potentiometer
R12, R13—1 megohm, 1%
R14, R17—47,000 ohms, 1%
R16—5000-ohm multiturn potentiometer
R18, R80, R90—100,000 ohms
R20, R79—1000 ohms
R21, R23—10,000-ohm potentiometer
R22—12,000 ohms
R27—500-ohm potentiometer
R29, R32, R33, R36, R49, R54, R56, R67–R71, R92, R102, R103—4700 ohms
R30, R34, R38, R48, R50, R51, R53, R73, R76, R78, R81, R82—47,000 ohms
R35, R40—68,000 ohms
R37—15,000 ohms
R42—1.5 megohms
R43, R83, R87—150 ohms
R44, R46, R91, R100, R101—1500 ohms
R45—50,000-ohm potentiometer with SPST switch
R52—270,000 ohms
R55—4.7 megohms
R60–R66, R94, R95—100 ohms
R72—68 ohms
R74—1 megohm
R75—10 megohms
R85, R86—10 ohms
R84, R87–R89—unused
R93, R97—4.7 ohms
R98—330 ohms

Capacitors
C1, C2, C17, C26, C29, C32, C66, C68, C69—10 μF, 25 volts, electrolytic
C3, C6, C7, C15, C30, C31, C36, C37, C65, C91, C94—0.001 μF, Mylar
C5, C9, C11, C14, C23, C28, C33, C61—0.01 μF, Mylar
C4, C13, C16, C25, C60, C73, C74, C75—0.1 μF, Mylar
C8, C64—22 pF, ceramic disc
C10—470 pF, ceramic disc
C12, C39-C59, C76-C89—unused
C18—100 μF, electrolytic
C19—.0068 μF, Mylar
C20—0.004 μF (four 0.001 μF 1% capacitors in parallel), Mylar
C21—0.8 μF (0.33μF and 0.47μF wired in parallel), Mylar
C22—0.033 μF, Mylar
C24, C27, C35—0.005 μF, Mylar
C34, C38, C62, C67—47 μF, 16 volts, electrolytic
C63, C95—100 pF, ceramic disc
C70—3300 μF, 25 volts, electrolytic
C71, C72—1000 μF, 25 volts, electrolytic
C90—10 μF nonpolar, electrolytic
C92—470 μF, 16 volts, electrolytic
C93—see text
C95—47 pF, ceramic disc
C96—0.05 μF, Mylar
C97—2200 μF, electrolytic

Semiconductors
IC1, IC14, IC15—XRL555 timer
IC2—CD4040, 12-stage binary ripple counter
IC3—DAC1222LCN D/A converter
IC4, IC6, IC7, IC8, IC9, IC23–IC25—CA3140E op-amp
IC5—LM336Z 2.5-volt reference diode
IC10, IC26—CA3130E op-amp
IC11—CD4068 8-input NAND gate
IC12—CD4538BCN/BCP or MM14538BCN dual-precision monostable multivibrator
IC13—CD4017 decade counter/divider
IC16—XR2206 monolithic function generator
IC17, IC18—RDD104 timebase
IC19—74C926 counter
IC20—7812 12-volt positive regulator
IC21—7912 12-volt negative regulator
IC22—7805, 5-volt positive regulator
Q1-Q13—2N4401 transistor
Q14—2N2219 transistor or VN0300M MOSFET (see text)
D1–D7—1N914 diode
D8, D9, D10—1N4001 diode
DSP1—NSB3881, 4-digit, 7-segment LED display
LED1-7—LN28CAL(US) Panasonic high-efficiency light emitting diodes

Other components
S1, S2—momentary contact pushbutton switch, SPST
S3—ON-OFF-ON toggle switch, SPDT
S4—SPST switch mounted on R45
S5—3PDT toggle switch
S6—3-pole, 4-position rotary switch
S7—SPST toggle switch, 1.0 amp, 125 volts AC
T1—120 volts primary, 12.6 volts secondary, 0.6 amps
J1–J6—RCA chassis mount phono jacks
XTAL1—5-MHz crystal
F1—0.5-amp fuse
Miscellaneous: Fuseholder, 3-conductor 18 AWG line cord, Jameco enclosure type H2507, DIP sockets and hardware.

Note: A set of 2 PC boards is available from John Wannamaker, Route 4, Box 550, Orangeburg, S.C. 29115: $43.00, postage paid, S.C. residents add 5% sales tax.

graticule division).

An alternate filled-in display is shown in Fig. 6-*b*. The area under the response curve is filled-in, rather than having only a base line and contour line. A filled-in display can be achieved by increasing the intensity level on the scope. The main disadvantage of that type of display is its inability to display multiple traces.

Theory of operation

Two PC boards are used in the sweep/generator: a main board, consisting of a function generator, counter, and analog-to-digital conversion circuitry, and a power supply board, which also includes the peak-hold circuit. A schematic of the main PC board is shown in Fig. 7. On this board, an XR2206 function generator chip, IC16, is used as a current-controlled oscillator. A low-to-high frequency sweep occurs when current flow from ground into pin 7 varies from near zero to about 3 milliamps. That current change takes place when a digitized ramp, or sweep voltage, is applied to the base of Q1.

The ramp voltage is created by applying pulses from an astable multivibrator, IC1, into a 12-stage binary counter, IC2. The resulting binary-coded outputs are converted into an analog voltage by a 12-bit digital-to-analog converter, IC3. The output of the converter at pin 1 must feed into the virtual ground of op-amp IC4. The output of IC4 has an apparent straight-line voltage rise, but

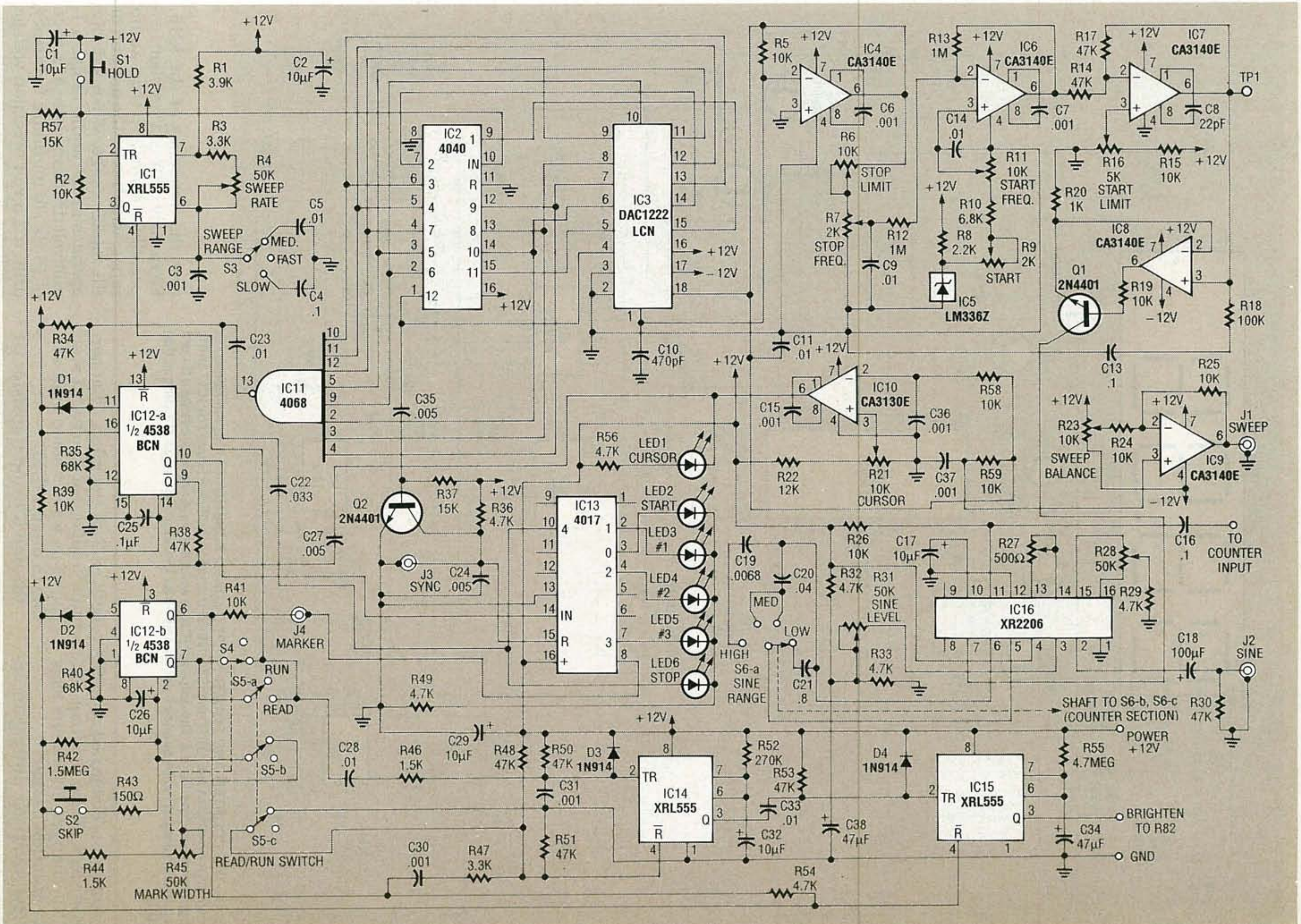


FIG. 7—THE MAIN BOARD SCHEMATIC; IC16 IS USED AS a current-controlled oscillator—a frequency sweep is generated when current flow from ground to pin 7 varies from 0 to 3 milliamps. IC5 is a 2.5-volt precision voltage regulator used to minimize

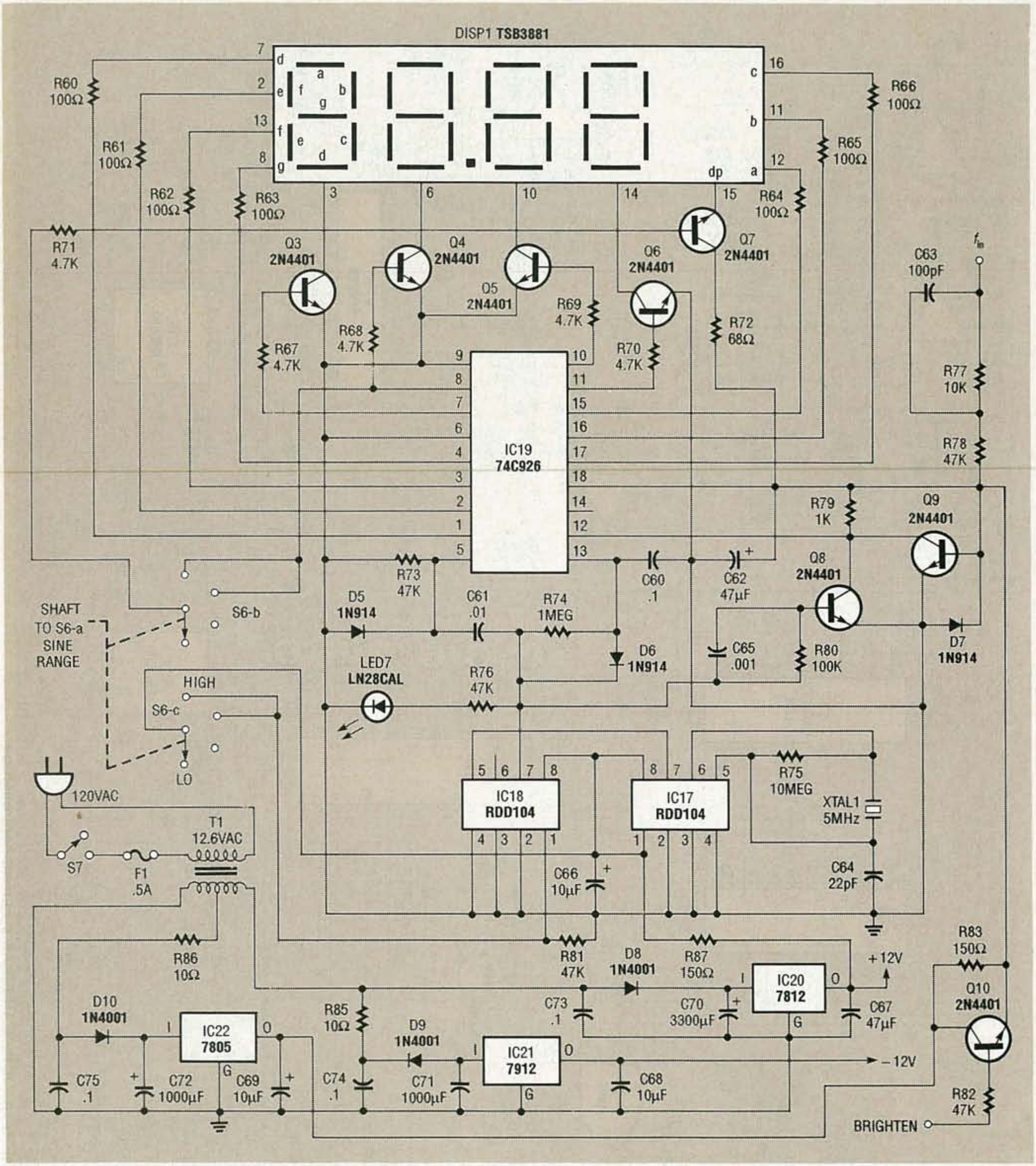


FIG. 8—THE COUNTER AND POWER-SUPPLY BOARD SCHEMATIC; The time-base for the counter originates from IC17 and IC18. A 5-MHz crystal oscillator is used by IC17 and is programmed via pins 1 and 2. The output of IC18 is a square wave which provides a 0.1 or 1 second sampling of the frequency to be measured by the shorting or non-shorting action of Q8.

in reality it is composed of 4,096 small steps. When the frequency of IC1 changes, the ramp's slope and duration change.

Two inverting unity-gain op-amps, IC6 and IC7, provide level-shifting controls for adjusting both ends of the ramp. That permits adjustable start and stop points as well as some limit-setting to protect IC16.

Op-amp IC8 and transistor Q1 act as a voltage-to-current converter for the most linear control over the frequency of the IC16. Frequency drift is a problem, especially within the true audio range, which is at the low end of the middle range. When a device operates in the audio range, a 1-millivolt drift can cause a change of 18 Hz. To minimize frequency drift, a 2.5 volt precision voltage regulator, IC5, is used, and after one hour of warmup time, the drift averages about 5 or 6 Hz per hour.

An 8-input NAND gate, IC11, provides a falling edge output at 25% increments as the ramp is taking shape. That falling voltage triggers IC12-a, a one-shot monostable multivibrator, which then applies a 10-millisecond input pulse to decade counter, IC13, which has one-of-ten decoded outputs. Each of the five counts light separate LED's to indicate which marker is in progress.

The highlighted marker frequency is established by the technique described below. The pin 9 output of IC12-a triggers a one-shot monostable multivibrator, IC12-b. Its pulse width may be either fixed at 15 seconds or variable from 10 to 150 milliseconds depending on whether the unit is in the READ or RUN mode. During the time that the voltage at pin 7 has dropped to zero, astable IC1's $\overline{\text{RESET}}$ pin is held and cannot furnish pulses to the 12-stage counter. The counter holds whatever count exists at that time which ultimately translates into a steady control current at IC16, and a steady frequency out of it. The continuous frequency out of IC16 is the marker frequency. Each time the ramp stops, the sweep applied to the scope's X input holds a steady value. That stops the trace in its tracks and the unmoving electron beam creates a bright spot which is the marker. If there is a signal at the Y input, the marker becomes a brightened vertical line.

The STOP marker is generated on the count of 4,092. After its completion, four more counts return the 12-stage counter to an all-zeros output condition, the ramp returns to its starting point, and a synchronized pulse is generated by transistor Q2. That same pulse resets IC13, the LED markers counter, and the voltage that had previously lit the STOP LED falls to zero. That fall retriggers IC12-a and a new sequence begins.

The built-in counter that displays the marker frequency cannot give a meaningful readout when it is in the RUN mode because the frequency is continually changing. A valid frequency readout can be displayed only in the READ mode, where a one-second sampling of an unchanging frequency can be taken. To keep the user aware of that, the display is dimmed until the readout is valid. An accurate readout may not be available to the user until three seconds after stopping on a marker. A three-second delay is provided for all automatic stops before the display is brightened.

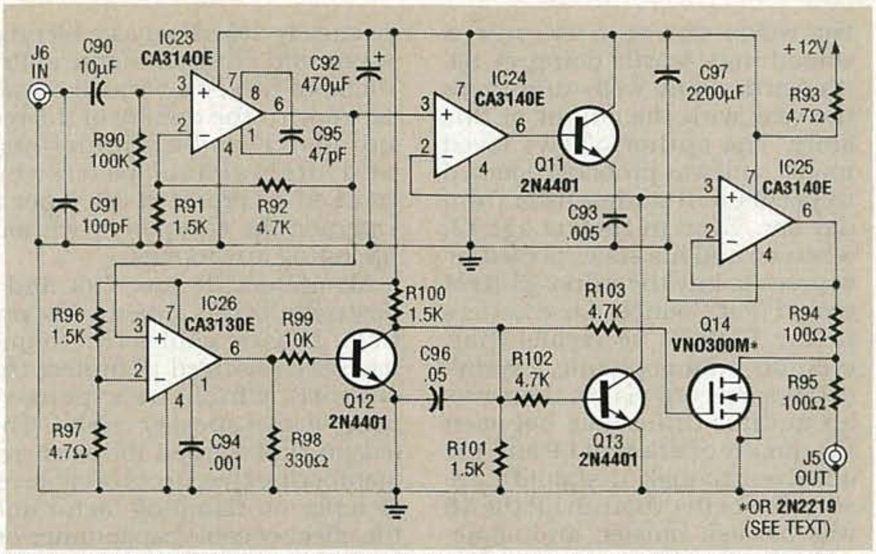


FIG. 9—A SCHEMATIC OF THE PEAK-HOLD CIRCUIT; IC23 AMPLIFIES the signal from the tested device, and reproduces only the positive alternation of the waveform. Transistors Q13 and Q14 act as switches—when open, C93 charges to the peak value of the positive alternation, then holds the peak value. The top portion of that charge is one segment of the positive contour line.

Integrated circuit IC14 is used as the one-shot, three-second delay for the automatic stops. A three-second delay is triggered every time the marker one-shot, IC12-b, is activated. The delayed falling edge out of IC14 at pin 3 triggers another one-shot, IC15, which produces a long duration "brighten" pulse to Q10 in the power supply. Once the brighten one-shot is triggered, it has the capacity to remain on for several minutes, but its time is cut short by IC12-b, which resets after 15 seconds. The HOLD pushbutton can extend this time if held pressed. The HOLD pushbutton also applies a positive voltage to the input of the 12-stage counter and prevents pulses from entering. Timers IC14 and IC15 are type XRL555 made by Exar. Standard 555 IC's do not work in this application.

The CURSOR marker is generated in a totally different manner from all other markers. A single op-amp, IC10, is used as a comparator. A digitized ramp is applied to the inverting input and an adjustable DC voltage from the CURSOR potentiometer is applied to the non-inverting input. When the ramp rises to equal the DC voltage, the op-amp's output falls to zero and actuates IC12-b to provide an added marker. The reason for the complexity of having two one shots to generate markers is that the cursor marker must be counted by all markers, not just by IC13. The CURSOR marker must hold the astable IC1 reset for a period of time.

The MARKER WIDTH control is a variable resistor with an attached switch, S4. When S4 is turned off, there are no markers, but the sweep will cover the same frequencies as if the markers were present.

The frequency sweep for the middle range, or audio spectrum range, presents a problem for a four-digit counter display. Resolution is poor at the low end if the readout is in kHz, and if the readout is in Hz, the most significant digit would be missing on the high end. To overcome that problem, the middle range occupies two positions on the SINE RANGE switch, and the user may select a readout in either hertz or kilohertz.

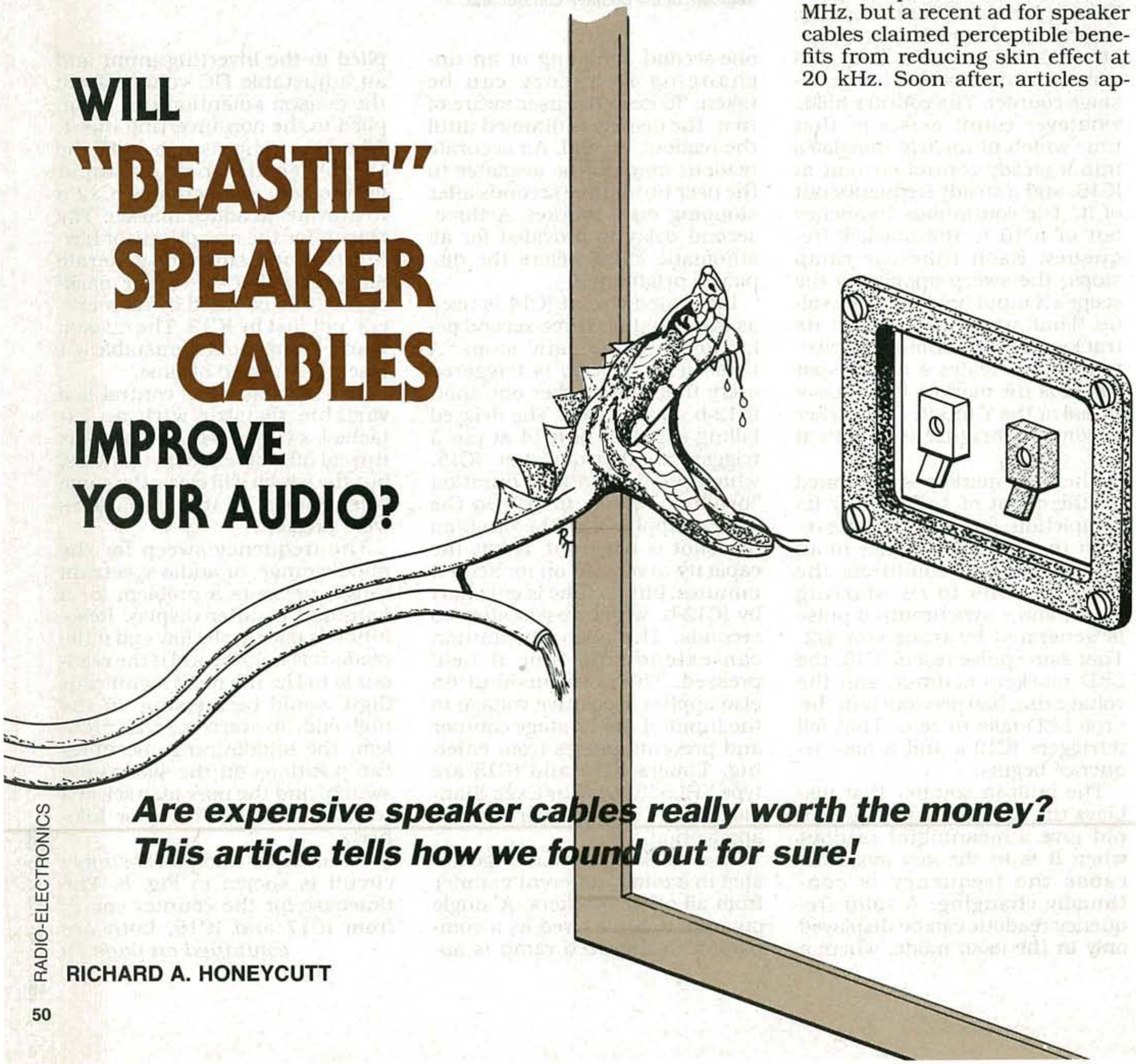
The counter and power-supply circuit is shown in Fig. 8. The timebase for the counter comes from IC17 and IC18, both are

continued on page 70

WILL "BEASTIE" SPEAKER CABLES IMPROVE YOUR AUDIO?

Are expensive speaker cables really worth the money? This article tells how we found out for sure!

RICHARD A. HONEYCUTT



THE PURIST WILL TELL YOU THAT IF something's worth doing at all, it's worth doing well—and that's the case with the author of this story. The author always loved music, and was probably doomed to permanent audiophilia from day one. Even in 1960 at age 12, when he and his sister pooled resources to buy their first 45-RPM record (Pat Boone's "Love Letters in the Sand"), he recalls that, even on a monophonic, crystal-cartridge record player, there was an audible difference between the quality of a decent LP and the 45. Even though it should have sounded better than an LP, the 45 was bassier, noisier, and somewhat distorted, being pressed on what a broadcast engineer later poetically described as a blend of straw and chicken manure. Predictably, he soon became dissatisfied with the quality of the record player, and his junior-high and high-school years were marked by repeated attempts to upgrade the equipment without spending any money.

Along came the late '70's, and a new product was aimed at the purists: beastie cables (the name has been changed to protect the author!), which are expensive heavy-gauge speaker cables. The old purism surged forward, remembering the effects of cable resistance on damping factor and the effect of cable capacitance on high-frequency response—but the ads also spoke of skin effect, which has to do with the fact that at high frequencies, alternating currents tend to travel mainly at the outside surface, or skin, of a conductor. Since the skin effect essentially removes current from the center of a conductor, effectively reducing it's cross-sectional area, it causes an increase in the impedance of a conductor at high frequencies.

Actually, when frequency is high enough, a tube or pipe will have the same effective resistance as a wire of the same diameter. That fact can be used simplistically to account for the use of waveguides rather than wiring at microwave frequencies. But concerning high frequencies, how high is high?

Supposedly, the skin effect becomes important above about 30 MHz, but a recent ad for speaker cables claimed perceptible benefits from reducing skin effect at 20 kHz. Soon after, articles appeared in professional trade journals mentioning the likes of Lucasfilm using the enormous cables, so some real research was in order.

The goal was to find out whether beastie cables did in fact:

- Reduce the amount of power lost in the cable enough to provide a significant improvement in efficiency, or
- Increase the damping factor of the speaker/amplifier system enough to provide audible improvement, or
- Provide any significant benefit in the frequency response of the system.

No other benefits are claimed for these cables, so it is not necessary to look for undiscovered or presently unmeasurable effects.

The problem was attacked both analytically and experimentally. The equivalent circuit of a real loudspeaker driven by a real amplifier through real cables is shown in Fig. 1. Any effects produced by the cables must show up in the cable resistance, capacitance, or inductance. The efficiency and damping-factor questions depend almost exclusively upon the cable resistance, whereas the frequency-response question is mainly a function of the capacitance. Wire inductance is so small compared with the semi-inductive nature of speaker impedance at high frequencies that it can be ignored, as we will see.

The cable resistance is made up of three components: the contact resistance, the ohmic resistance of the wire, and any contribution from skin effect. The ohmic resistance can easily be found from wire tables in most electronics reference books. Table 1 shows the resistance of a representative sampling of copper cables, listed according to gauge. For years, selection of cable gauge has been made according to the criterion of 10% loss. In other words, for a given cable length, what resistance will give no more than 10% (0.46 dB) power loss at the speaker? Figure 2 shows the calculations involved in determining that value. For short cable runs, the resulting gauge is surprisingly small.

About fifteen years ago when the author was an audio consultant, he would specify 18-gauge

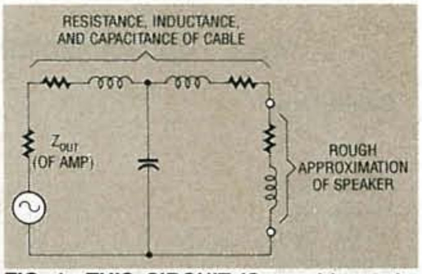


FIG. 1—THIS CIRCUIT IS roughly equivalent to an amplifier, speaker, and length of cable.

cable for amplifiers up to 100 watts feeding impedances of 8 ohms or more with runs of 25 feet or less. For each halving of impedance or doubling of amplifier power or distance, the wire size would increase by two gauges; 16 gauge for 100 watts into 8 ohms at 50 feet or 4 ohms at 25 feet, etc. That rule of thumb includes a safety factor so that the loss will always be less than 10%.

The National Electrical Code specifies cable gauges based upon safety considerations; if a wire carries too much current over a long enough period of time, it can become dangerously hot and start a fire. Going back to the rule of thumb, a speaker with an average impedance of 8 ohms fed by a 100-watt amplifier will draw about 3.5 amperes at full power. However, even running at full tilt, it's unlikely that the average power will be greater than one-third of your amplifier's maximum, so the rule of thumb provides a large safety margin from a fire-prevention standpoint.

The damping factor can be defined as the ratio of a speaker's impedance to the total resistance

TABLE 1
RESISTANCE OF COPPER WIRE

Gauge	Resistance (ohms/foot)
0	0.000098
2	0.000156
4	0.000249
6	0.000395
8	0.000628
10	0.000999
12	0.00159
14	0.00253
16	0.00402
18	0.00639

Note: The wire must make a complete round trip, so there's 20 feet of wire in a 10-foot speaker cable.

in series with the speaker. Since the simple loss calculation in Fig. 2 depends upon the combined resistance of the speaker and the cable, the resistive power loss will be related to the damping factor. Thus we can find a relationship between damping factor and low-frequency loss. In the *Audio Cyclopedia* Howard Tremaine established that there is no value in trying for a damping factor greater than 20[4]. That is based on the fact that the speaker's voice-coil resistance appears in the circuit, and its value—typically 6 to 7.5 ohms for an 8-ohm speaker—sets a practical limit on the benefits of reducing other resistances. The effective damping factor is equal to:

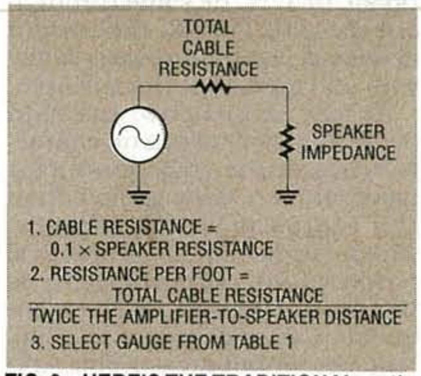


FIG. 2—HERE'S THE TRADITIONAL method normally used to determine speaker-cable gauge by loss.

$$= \frac{Z_{SPEAKER}}{R_{VOICE\ COIL} + R_{AMP} + R_{CABLE}}$$

A stated amplifier damping factor of 20 would represent a total resistance of 8 ohms divided by 20, or 0.4 ohms in series with the amplifier. That would give an effective damping factor of:

$$\frac{8\Omega}{6\Omega + 0.4\Omega} = 1.25$$

assuming a 6-ohm voice-coil resistance. With most amplifiers having output impedances on the order of 0.1 ohm or less, this would mean that the cable resistance could be 0.3 ohms. The loss in dB corresponding to an 8-ohm speaker fed through a 0.3-ohm cable is:

$$= 20\log_{10}\left(\frac{8\Omega}{8\Omega + 0.3\Omega}\right) = -0.32\text{dB}$$

That means that for an optimum effective damping factor, the resistive cable loss should be less than 0.32 dB. Just for comparison purposes, a 1-dB cable loss, which would result from a 0.9-ohm cable resistance, would result in an effective damping factor of 1.14, which is not much lower than 1.25.

As mentioned earlier, skin effect increases the effective impedance of a wire, and can be best explained by looking at Fig. 3. The skin depth of a conductor is the distance into that conductor, measured from the outside surface, at which current density is 1/e times that at the surface. (The symbol e stands for the base of natural logarithms, and equals approximately 2.72.) For a direct current, the current density (amperes per unit cross-sectional area) is the same throughout the wire. For AC, the current density is less at the center of the wire and greater at the surface.

At low frequencies, the skin depth (which depends on characteristics of the bulk conductor material) is usually greater than the radius of the conductor, which means that for all practical purposes the current density is the same throughout the conductor. Larger-diameter conductors can exhibit measurable skin effect at relatively low frequencies, including audio frequencies.

The simplest indicator of skin effect is the ratio R_{AC}/R_{DC}, where R_{AC} is the resistance per unit length of a wire to alternating current of a certain frequency and R_{DC} is the ohmic resistance per unit length. As long as R_{AC}/R_{DC} equals 1, skin effect is negligible. When R_{AC}/R_{DC} rises significantly above 1, skin effect may begin to matter. We say *may*, because it only matters if the total resulting increase in cable resistance causes a perceptible effect in the reproduction. For a frequency of 15 kHz, R_{AC}/R_{DC} equals 1.1 when a 15-gauge solid wire is used. Larger wires will exhibit a greater proportional increase in resistance as frequency increases. Of course, since the resistance of large wires is lower to begin with, the actual change in measured resistance may or may not matter.

Stranded wire is extremely difficult to analyze. Naturally, each strand has a certain surface area, so that all the strands connected in parallel would have a very large surface area. In actuality, though, much of the surfaces of the individual wires are in contact with each other, making the actual effective surface area virtually impossible to determine—unless the individual strands are insulated from each other, as in litz wire. At any rate, we can use solid wire as a worst case to analyze, knowing that we'll really be using stranded wire that has less skin effect.

The actual resistance, capacitance, and inductance of a cable are distributed evenly along its length. Telephone engineers found out long ago that, for analysis purposes, a cable's R, C, and L can be lumped into a single component if certain conditions are met. The conditions depend upon the attenuation constant and length of the cable. The attenuation constant (α) is given by:

$$\alpha = \sqrt{(R^2+\omega^2L^2)(G^2+\omega^2C^2)+RG-\omega^2LC/2}$$

where R, L, C, and G are the cable's resistance, capacitance, inductance, and leakage conductance per unit length, and ω is the angular frequency, or $2\pi f$.

The author does not like to lie awake nights solving equations like that, and tables of attenuation constant versus frequency are not generally available for the kinds of cables used for speaker leads. However, tables for 19-gauge pulp-insulated telephone cable indicate that a 3-kilometer cable section can be analyzed using the lumped-constant

TABLE 2—MEASURED CHARACTERISTICS OF CABLES

Cable Type	C (pF/ft)	L (μH/ft)	R* (ohms/ft)
22-ga. cheap	10.7	0.29	0.0178
18-ga. zip	14.0	0.28	0.007
20-ga. twist	18.0	0.36	0.0107
4-ga. cable	50.8	0.29	0.0007
16-ga. "drop cord"	22.4	0.38	0.006
shielded "guitar cord"	105.8	0.30	0.048
16-ga. zip	12.5	0.23	0.0127

*One-way resistance, not loop resistance; that includes the contact resistance of the terminations.

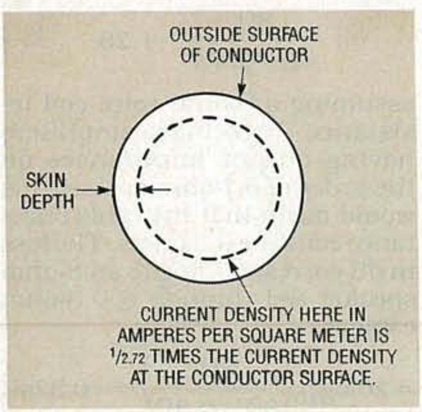


FIG. 3—THE SKIN EFFECT increases the effective resistance of a wire. The skin depth is the distance into the conductor at which the current density is approximately ⅓ of that at the surface.

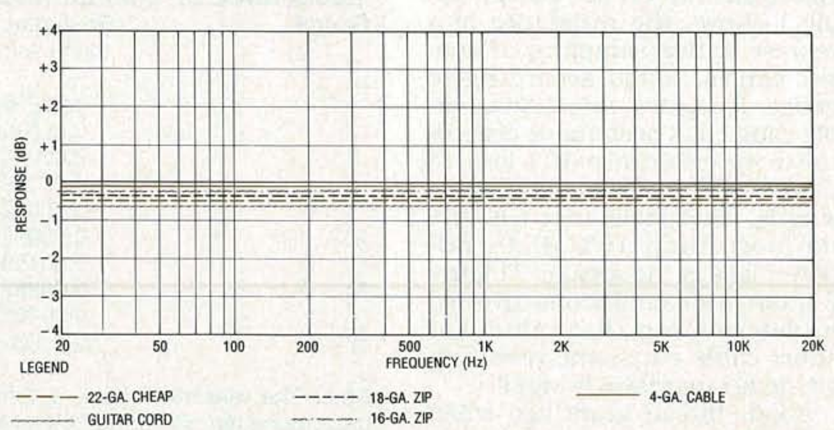


FIG. 4—A COMPUTER SOLUTION, or prediction, of the model in Fig. 1 yielded these results. The worst-case loss is well under 1 dB at 20 kHz.

method at 1 kHz with a total attenuation under 1 dB and a phase accuracy within 5 degrees. Although it may not be immediately obvious to the casual observer, attenuation constant is proportional to the square root of frequency, so that would mean that the same accuracy could be expected at 20 kHz if the length were reduced by

$$\sqrt{20\ \text{kHz}/1\ \text{kHz}}$$

that works out to about 2100 feet. Since we rarely extend speaker cables anywhere near that far, we can safely use the lumped-constant method with no qualms. That's what was assumed in Fig. 1.

Table 2 shows the types of cables chosen for the analysis, along with their measured resistance, capacitance, and inductance. The values were measured using a Hewlett-Packard 4261A LCR meter and a test frequency of 1 kHz. Instead of a speaker, a resistance of 7.9 ohms and an inductance of 6.3 microhenries were used in the calculations. Instead of "real" beastie cables, we used ones that were on hand, including a very large (4-gauge) stranded cable. If those cables showed no measurable detrimental effects on efficiency, damping-factor, or frequency response, then the alleged beastie benefits would turn out to be solutions to a nonexistent problem!

A computer solution of the circuit of Fig. 1 yielded the results plotted in Fig. 4. A 10-foot length was assumed for each cable, and it included the effects of cable capacitance and inductance, but not the skin effect. Notice that the worst-case loss was well under 1 dB at 20 kHz.

Computer solutions without experimental verification are not always trustworthy, so the actual response of the cables was measured on the setup shown in Fig. 5. The impedance characteristic of the test speaker is shown in Fig. 6. Although the amplifier was flat within ±0.2 dB from 20 Hz to 20 kHz, the amplifier's calibration curve was nevertheless subtracted from the measured results in order to provide maximum accuracy. The test results are shown in Fig. 7.

Initial results seem to indicate that virtually anything can be used to connect a speaker to an amplifier and, if the distance is short, no serious detriment to efficiency will result. Damping factor is degraded slightly when cables lighter than 18-gauge are used, as shown by the loss exceeding 0.32 dB. But what will happen if longer cables are used?

From previous measurements, ordinary Romex house-wiring cable is found to have about the highest capacitance per foot of any common wire. With the factors mentioned earlier that control skin effect, it is also clear that small wires will not experience

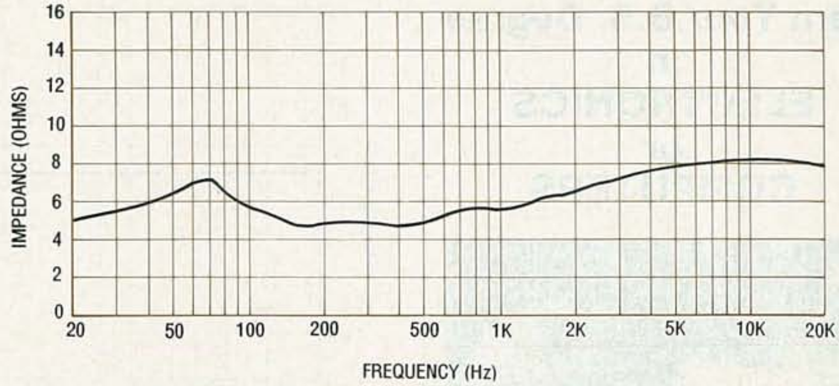


FIG. 6—THE MEASURED IMPEDANCE CHARACTERISTICS of the test speaker.

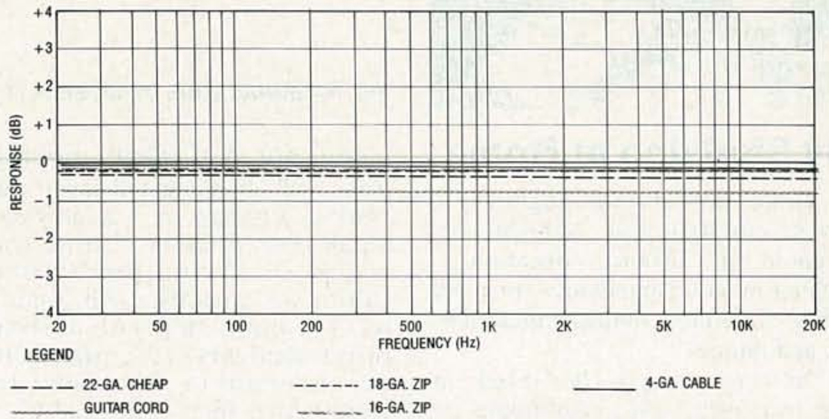


FIG. 7—SEE HOW THE ACTUAL MEASURED CABLE LOSSES compare to the predicted losses of Fig. 4.

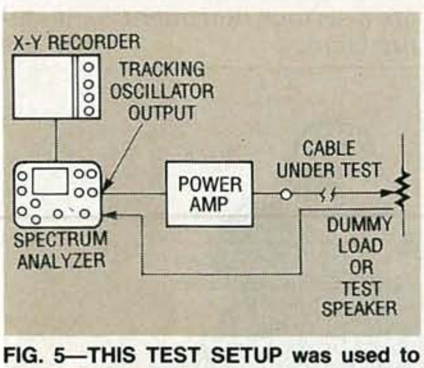


FIG. 5—THIS TEST SETUP was used to measure the effects on an audio signal caused by speaker cables.

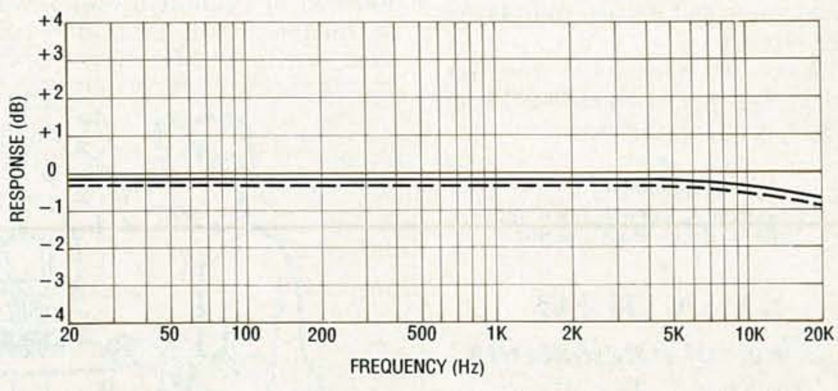


FIG. 8—SIGNAL LOSS OF 40 FEET of 12-gauge Romex cable.

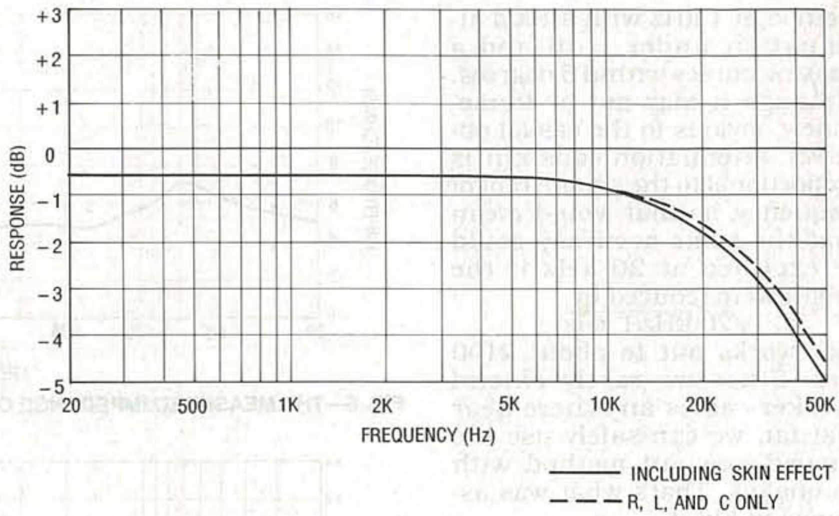


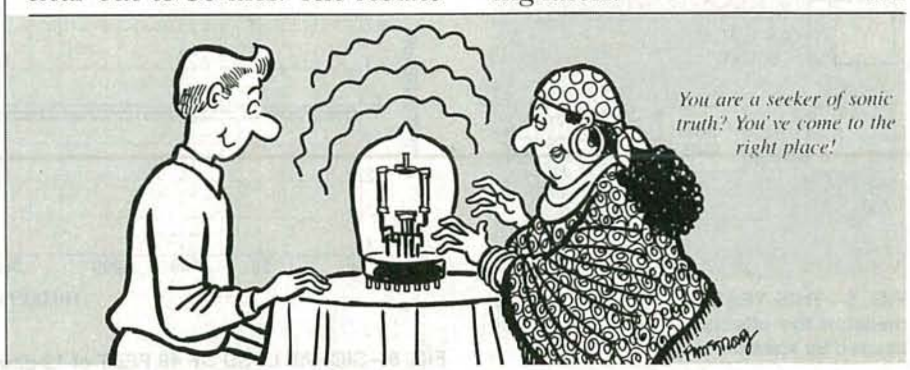
FIG. 9—SIGNAL LOSS OF 100 FEET of 12-Gauge Romex cable.

significant skin effect, and large ones will, but even a large percentage change in a large wire's small resistance is of little consequence. Trying the R_{AC}/R_{DC} values for various cable diameters in conjunction with the computer analysis, 12-gauge solid wire is found to have about the worst skin effect of any cable.

Therefore, if any type of speaker cable could cause frequency-response problems, the high capacitance and the skin effect of 12-gauge Romex should make it the ideal bad example. Another run was made using a 40-foot length of Romex, both into a dummy load and into the test speaker. In the graph of Fig. 8, we see a hefty ½-dB droop at 20 kHz, compared to the response at 20 Hz. The overall signal loss and damping-factor degradation are less than those of the smaller cables that are shown in Figure 8, due to the lower resistance of 12-gauge cable.)

Since that still wasn't significant, a computer simulation of 100 feet of 12-gauge Romex was performed, with response run clear out to 50 kHz. The results are shown in Fig. 9. Here, at last, is something the beastie people can sink their teeth into! Anyone who can hear 50 kHz will find a full 4.5-dB drop resulting from the use of 100 feet of 12-gauge Romex—providing, of course, they're using an amplifier and speaker that can reproduce it. Of course, the skin effect is still only about half a dB, and effective damping is not degraded, so maybe they'd better drop those points from their ads.

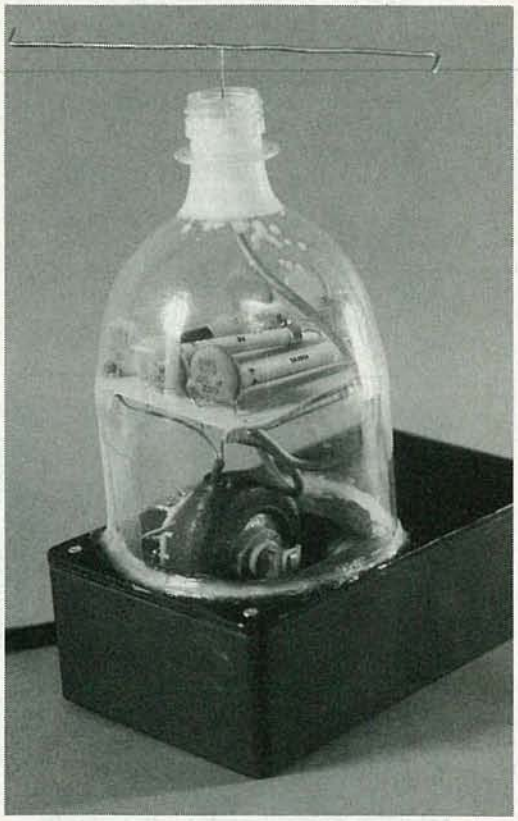
The results of that rather involved bit of research clearly indicate that ordinary speaker cables, including the ones that any knowledgeable audiophile would sneer at, do not significantly degrade frequency response. They vindicate the rule-of-thumb advice (18-gauge for 100 watts, 25 feet, into 8 ohms) except for a slight degradation in damping factor; 1.21 with a 25-foot cable run. For optimum damping factor, that rule should be changed to 18-gauge for 100 watts, 20 feet, into 8 ohms. Also, only 20-gauge, 22-gauge, and guitar-cord cables are a serious detriment to damping factor. **R-E**



BUILD A NEGATIVE ION GENERATOR

Build this negative ion generator and put some charge in your life.

ANTHONY J. CARISTI



LAST MONTH WE STARTED building our negative-ion generator. Let's now finish up the project. We were discussing the flyback transformer and what the various connections are used for.

Pin 7 is used as ground, since it presents the highest resistance between itself and the flyback transformer output lead, which 3x39.4is often quite short to avoid high-voltage breakdown, so be careful how much insulation you remove. The bottom of the voltage-tripler PC board, with D6, D8, and D10, and the attachment points of the ground wire and both high-voltage leads was shown in Fig. 5 in last month's article.

Figure 6-*a* shows the top of the main PC board mounted in the case and held down with RTV, while Fig. 6-*b* shows a drawn exploded rendition, giving the same components with greater clarity and definition, but adding the top of the voltage-tripler PC board, connecting leads, and emitter needle.

The wire shown balanced on top of the emitter needle in Fig. 6-*b* is the rotor for an ion motor discussed later. The foil pattern for the main PC board in the prototype differs from the one shown in this article, primarily due to T1 mentioned in the parts list, which differs from the one used in the prototype.

In the prototype, the resistances between the lower-voltage taps and the flyback transformer output lead were measured, and the tap corresponding to the highest resistance (about 100 ohms) was taken as the ground terminal, since it was electrically furthest from the output lead. The low-voltage taps generally have numbers stamped on the metal bracket surrounding the ferrite core, numbered clockwise. In the prototype, the tap used as ground happened to be pin 7.

Although almost any flyback would work in this project, use one from a small-screen black-and-white TV. It'll usually be smaller and have a better turns ratio, but make sure it's wired for positive output, and has an open ferrite core for the new feedback and bifilar primary windings.

Note the manufacturer, model, and chassis number of the TV you salvage it from, in case you need more information about it later. Either that, or go to any TV service store and buy a new one, but know the specifics about it in advance, including the maximum safe flyback transformer output winding voltage, and the number of turns in the flyback transformer bifilar primary and output windings.

If your flyback transformer has a high-voltage diode attached to its output lead, remove it before adding the new feedback and bifilar primary windings. Then use an ohmmeter to find the transformer taps coming off of the flyback transformer output winding. One tap is the high-voltage common, originally going to the TV chassis; use the highest resistance tap as ground. In the version shown here, which was used in the prototype, pins 1–3 are hidden by the ferrite core, while pins 4–7 are shown.

Figure 7 is a magnified view of the feedback and bifilar primary windings, showing how they're added; use 20–24 gauge enamel wire, for ease of handling and adequate breakdown voltage. Use Mylar tape to insulate both new feedback and bifilar primary windings from the ferrite core. Start with the feedback winding,

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

wrapping a thin layer of tape around a clear part of the core where the feedback winding will go. Use nine inches of magnet wire, five inches for the turns themselves and two inches for each lead, and wind five close turns around the core.

At the end of the fifth turn, form a U-loop about 4 inches long as a center tap, and then wind an additional five turns in the same direction, as shown. Secure the feedback winding with tape, mark the start of the feedback winding with a "1," the U-loop with a "2," and the end with a "3," using masking tape; remember the direction of the feedback winding.

The bifilar primary winding is next. Although you can wind both halves adjacent to one another, as shown in Fig. 7, the performance should improve if you superpose them, actually winding one half on top of the other for optimal coupling. Twist two pieces of magnet wire together, with five turns spread along the entire length as a twisted pair, for close proximity between the two wires during the winding process. At one end of the twisted pair, mark one wire with a "4," and the other with a "5."

Obviously, for the center tap in the feedback winding, if you break the wire segment making the loop at the point where it bends, there's no electrical effect on the feedback winding, provided you route both segments of the loop (now two separate leads) to the same pad on the PC board. Thus, if you prefer, you can break the loop at the point of the bend.

However, in the case of the bifilar primary winding, you really should make an effort to superpose both halves, one on top of the other. However, if you do that, you have to wind both halves in the same direction, and in that case, if you bend the enamel wire into a loop, you'll have to spread both ends after completing the *first* half, in order to retrace it on the *second* half. Thus, it's probably easier in that case to physically break the wire, and wind the second half separately.

Start with those ends, and allowing four inches of lead length, wind six turns of twisted pair through and around the core in the same direction as the feed-

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—1000 ohms, PC-board mounted potentiometer
R2—220 ohms
R3, R4—560 ohms (the former for the astable-flyback transformer combination, the latter optional for the battery-operated version)
R5-R6—200- and 40-megohm series high-voltage focus divider, RCA SK3868/DIV-1, used for an optional high-voltage range extender for a conventional high-impedance (10-megohm) voltmeter (see text)
R7—2.7 megohms

Capacitors
C1—1000 µF, 25 volts, electrolytic
C2—100 µF, 16 volts, electrolytic
C3–C8—0.001 µF, 10 kilovolts, ceramic disc
C9—0.001 µF, 500 volts, ceramic disc, optional for aluminum can/neon bulb experiment (see text)

Semiconductors D1, D2—1N4004 silicon diode
D3, D4—1N4148 silicon diode
D5–D10—RCA SK3067/502 high-voltage diode, 12 kilovolts PIV
LED1—light-emitting diode for the battery-operated version
Q1, Q2—TIP31B NPN transistor
IC1—LM317T adjustable voltage regulator

Other components
F1—0.5-amp slow-blow fuse with holder
NE1—120-volt AC neon-bulb assembly with 47–100K built-in series resistor for the plug-in version (Radio Shack 272-712)
NE2—neon bulb, type NE2 (not the part number), optional for experiment (see text)
S1—SPST toggle switch
S2—SPST toggle switch
T1—18-volt center-tapped transformer (Radio Shack 273-1515)
T2—standard TV flyback transformer (see text)

Miscellaneous: Plastic case (7.5 × 4.25 × 2.25-inches, Radio Shack 270-224), enamel magnet wire, three-wire line cord, emitter needle (made from either straight pin or sewing needle), RTV silicon rubber, heat sinks, four alkaline "D" cells (optional for battery operation), 2-liter plastic soda bottle, and a sewing needle.

Note: The following are available from Anthony J. Caristi, 69 White Pond Road, Waldwick, NJ 07463: Two etched and drilled PC boards (one each for the main and voltage-tripler sections) for $15.95, IC1 for $3.25, Q1 and Q2 for $2.75 each. Please add $2.00 for postage and handling with each order; NJ residents please add 7% sales tax.

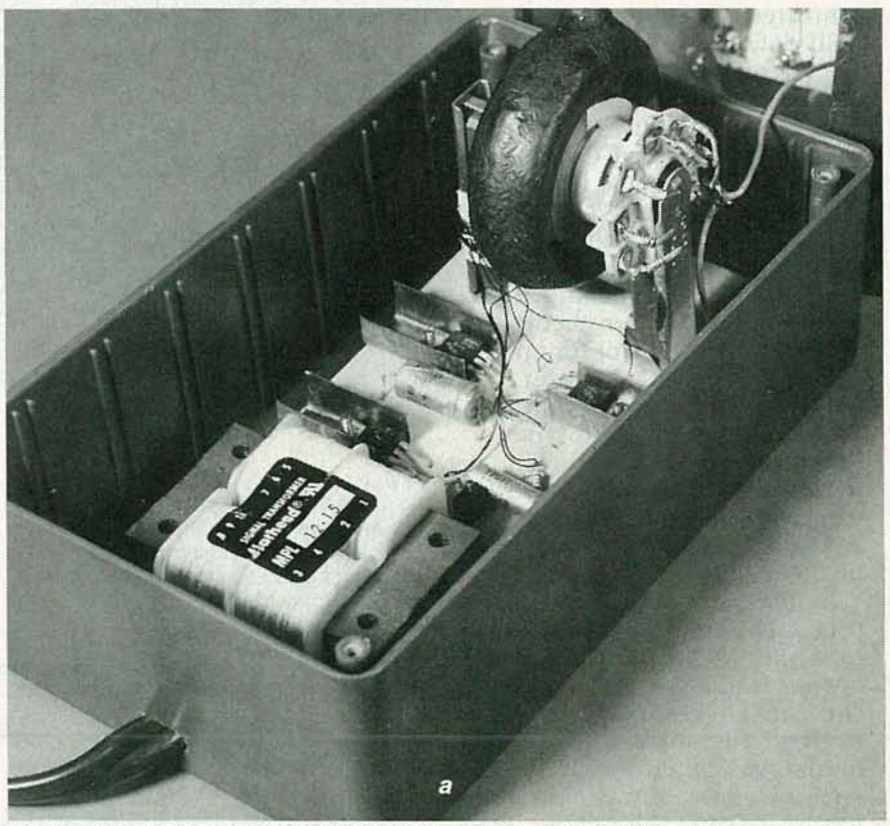


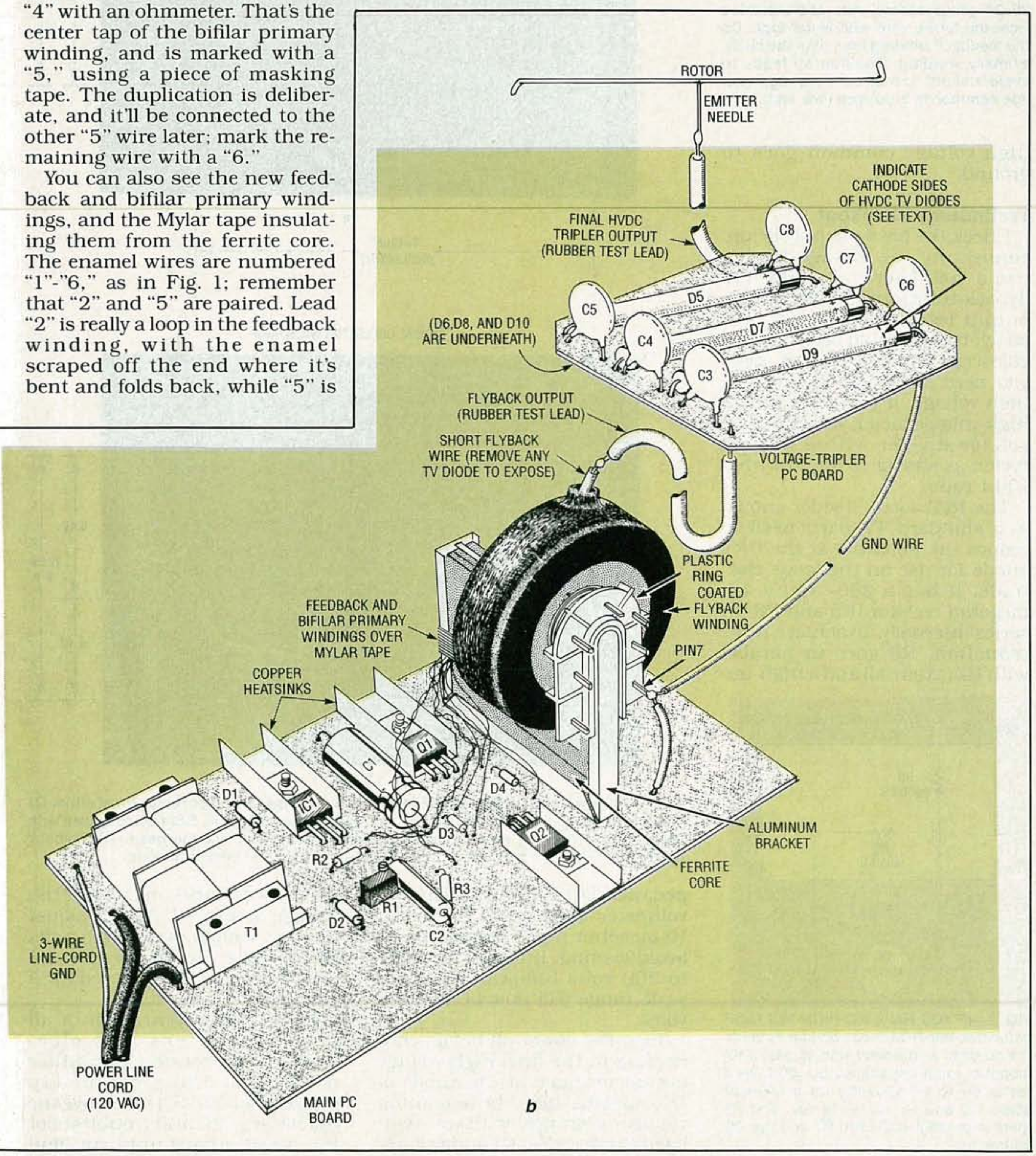
FIG. 6—THE TOP OF THE MAIN PC BOARD, held down with RTV (*a*), and an exploded view (*b*), with D2, D4, and D6 not visible. You can see the new feedback and bifilar primary windings, with Mylar tape insulating them from the ferrite core. The enamel leads are "1"-"6," as in Fig. 1; "2" and "5" are paired.

back winding. The directions of both new feedback and bifilar primary windings must be correct to achieve oscillation. Place the closely wound turns directly over the feedback winding, and secure the bifilar primary winding to the core with plastic tape.

Scrape away ⅜-inch of enamel at the four ends of the bifilar primary winding, and locate the unmarked end connected to wire "4" with an ohmmeter. That's the center tap of the bifilar primary winding, and is marked with a "5," using a piece of masking tape. The duplication is deliberate, and it'll be connected to the other "5" wire later; mark the remaining wire with a "6."

You can also see the new feedback and bifilar primary windings, and the Mylar tape insulating them from the ferrite core. The enamel wires are numbered "1"-"6," as in Fig. 1; remember that "2" and "5" are paired. Lead "2" is really a loop in the feedback winding, with the enamel scraped off the end where it's bent and folds back, while "5" is really two separate wires from the bifilar primary winding. In Fig. 6, on flyback transformer T2, you can clearly see the low-voltage taps. Their corresponding numbers are stamped on the metal frame of the ferrite core, increasing clockwise when facing the taps, so that pin 7, the ground, is at the lower right.

Mount the flyback transformer to the main PC board with suitable hardware. Using Figs. 1, 2, and 7 as a guide, connect the feedback and bifilar primary windings after cutting the leads and scraping the enamel. Remember, there are two leads marked "2" and two marked "5," so don't mix them up. When finished, position the leads to avoid a short, and be sure the



b

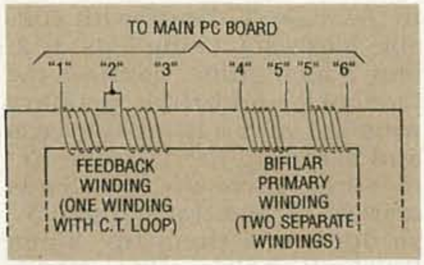


FIG. 7—THE NEW FEEDBACK and bifilar primary windings, wound on the ferrite core of the flyback transformer, using 20–24 gauge enamel wire and insulated from the ferrite core with Mylar tape. Do the feedback winding first, then the bifilar primary winding. Position all leads to avoid a short, and be sure the high-voltage common is grounded (see text).

high-voltage common goes to ground.

Preliminary checkout

Check the power-supply before connecting the voltage tripler. Use a voltmeter to be sure the flyback transformer high-voltage output lead isn't shorted, or a shock hazard could occur; an oscilloscope would be useful. Also, you need some way to measure high voltage; if you don't have a high-voltage meter, you can use a voltage divider with a normal meter, as shown in Fig. 8 with a 100:1 ratio.

The RCA focus divider shown is a standard TV part, used to reduce the potential at the CRT anode for use on the focus electrode. It has a 200- and a 40-megohm resistor (R5 and R6) in series internally. To achieve 100:1 reduction, R6 goes in parallel with R7 (external) and a high-impedance DC voltmeter. The DC voltmeter used needs at least a 10-megohm input impedance to avoid loading. If the meter is set to 200 volts full-scale, it's full-scale range will now be 20 kilovolts.

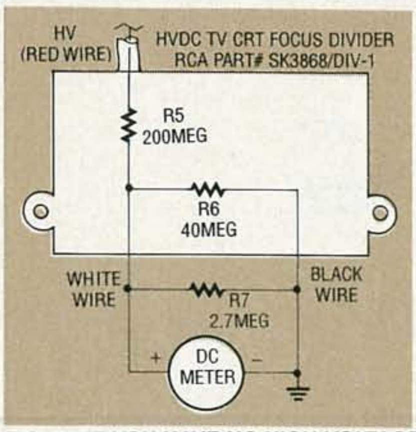


FIG. 8—IF YOU HAVE NO HIGH-VOLTAGE voltmeter, this RCA focus divider extends the range of a voltmeter with at least a 10-megohm input impedance by 100:1, so it reads up to 20 kilovolts on a 200-volt scale. R5 and R6 are in series, and R6 goes in parallel with both R7 and the DC voltmeter.

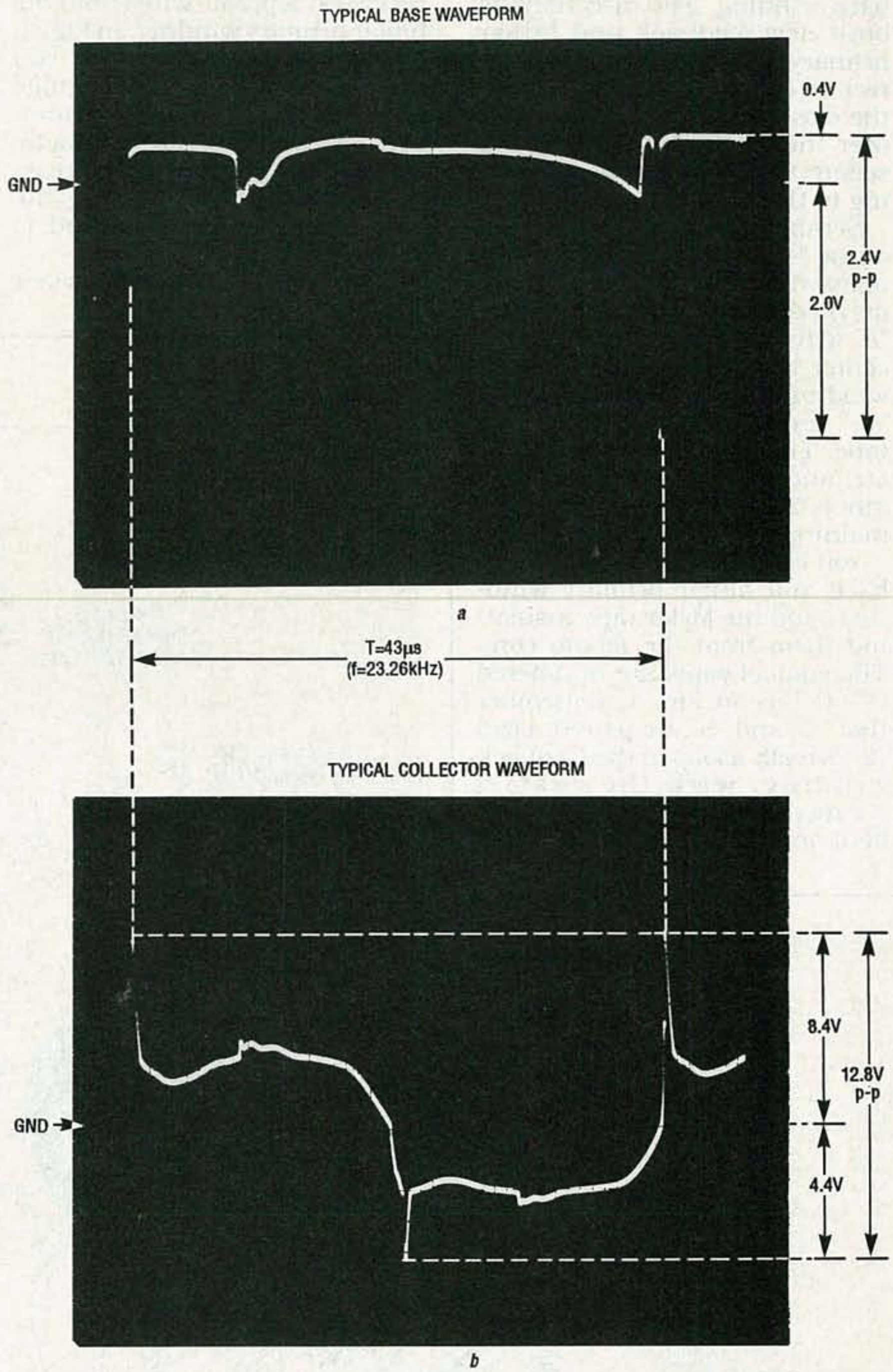
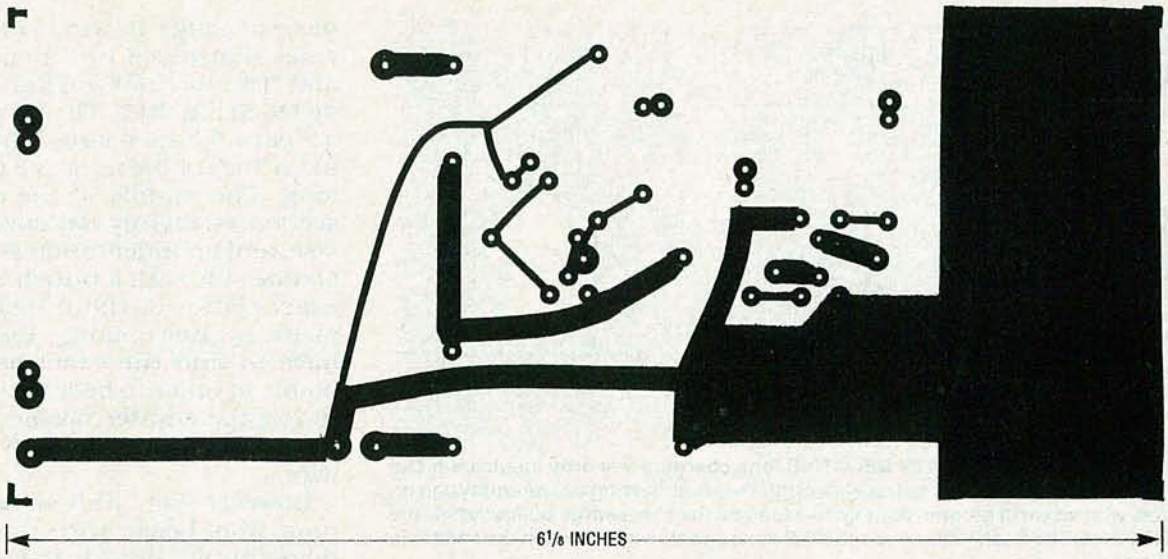


FIG. 9—NORMAL ASTABLE WAVEFORMS from the base (*a*) and collector (*b*) of either Q1 or Q2. With IC1 set to 3–4 volts DC, the fundamental is 23.26 kHz. Both are irregular, with sharp, narrow spikes, upward for the collector, downward for the base. The flyback transformer you use may create different waveforms, so expect variations.

Turn the power off before connecting to the final high-voltage output terminal at the anode of D10, and dissipate the remaining voltage to ground with an insulated clip lead. Set R1 midway, apply power, and measure the voltage across C2. As you adjust R1, you should see 1.25–5 volts DC or more. Set R1 for about 4 volts DC, and don't proceed until you do.

Check the orientation of all semiconductors and electrolytics, disconnect the bifilar primary winding center tap (marked with a "5") to remove the oscillator load, and troubleshoot the power supply until you find



THE FOIL PATTERN OF THE main PC board in the negative ion generator.

the fault. If you use batteries, be certain their terminal potential is at least 6 volts DC.

With IC1 set to 3–4 volts DC, measure the astable fundamental frequency with a scope, if possible; it should be about 20–30 kHz. Figure 9-*a* shows a typical collector waveform of the prototype, for either Q1 or Q2. Its amplitude is 2.4 volts p-p, double the DC voltage obtained from IC1; it goes 400 millivolts above ground, and 2 volts below. Fig. 9-*b* shows the base waveform; its amplitude is 12.8 volts p-p, going 8.4 volts above ground, and 4.4 volts below. Both of the waveforms are quite irregular, with sharp spikes, upward for the collector, downward for the base, generated by the high inductance of the flyback transformer output winding.

Since the inductance, resistance, and number of turns in whatever flyback transformer you use may differ considerably by comparison with the version used in the prototype, as well as the current gains and saturation voltages of both Q1 and Q2, the waveforms shown here may also vary considerably, so expect variations. The waveforms shown here are shown purely to illustrate typical responses, *not* as ironclad guarantees of what you'll see.

If you don't have a scope, touch a large screwdriver with a plastic handle to the flyback transformer output. If the oscillator isn't running, there'll be no spark, so the phasing is wrong. Try reversing wires "1" and "3," and then check the orientation of Q1, Q2, D3, and D4, and the T2 connections. When you get the astable working, disconnect the power and let C1 and C2 discharge.

Final checkout

Connect the voltage-tripler to the flyback transformer. For the connection from high-voltage winding to transformer and C3, use wire rated to at least 5 kilovolts, preferably 18-gauge rubber-covered test lead. The common of the high-voltage assembly can be made using ordinary hookup wire since it's at ground potential. Don't forget the transformer and voltage tripler common connections.

With the circuit fully assembled and power off, connect the high-voltage voltmeter adapter or a high-voltage DC voltmeter to the emitter needle and common with suitable clip leads. Don't go near the high-voltage output, and position the clip leads to avoid arcing. Apply power, and note the meter, adjusting R1 for −9 to −14 kilovolts. Any more, and you'll generate ozone, an undesirable byproduct, which has a peculiar odor. Correct any arcing or corona by insulating the connection with RTV.

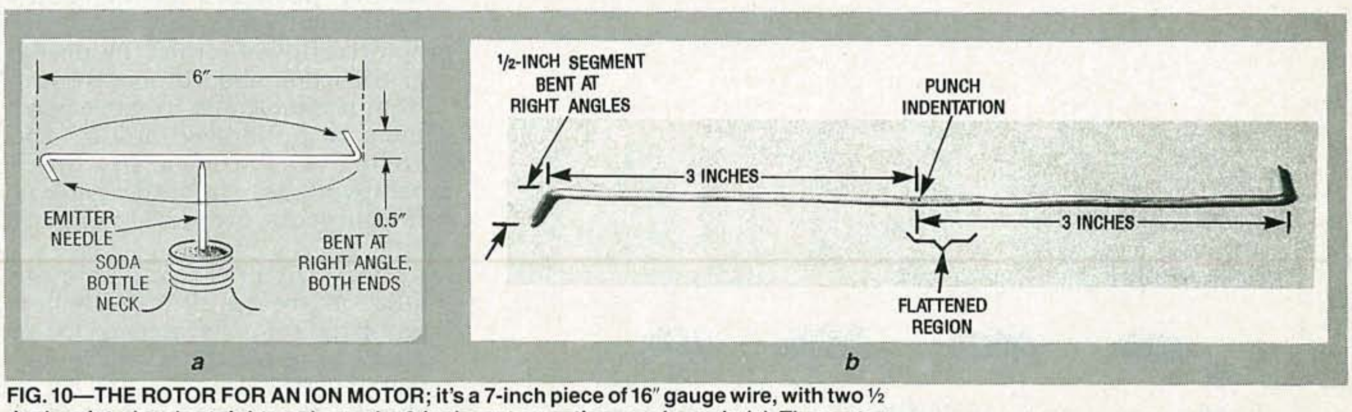


FIG. 10—THE ROTOR FOR AN ION MOTOR; it's a 7-inch piece of 16″ gauge wire, with two ½-inch pointed ends at right angles to the 6-inch center section, as shown in (*a*). The center is flattened, with an indentation made in the middle with a punch (*b*).

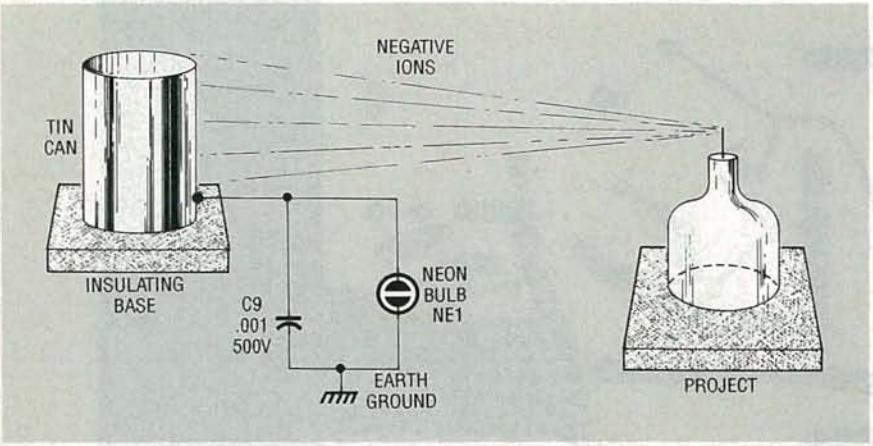


FIG. 11—AN EXPERIMENT TO SHOW NEGATIVE ions charging a nearby insulated metal object to high voltage. Negative ions travel through the air, collecting on the empty can on a rubber mat, with an earth ground. As negative ions hit the can, charge builds; at 90–100 volts DC, NE2 fires. The flash rate increases as distance decreases, or when the emitter is aimed at the can.

Don't arc the high voltage to ground with power on to observe a spark, or you'll damage the high voltage rectifiers. You should do so when power is off, when no shock hazard exists. Unplug the line cord and touch the ground prong to the emitter needle; otherwise you can use an insulated clip lead connected to ground on battery-operated versions.

Using the ion generator

You can use the negative ion generator as an air purifier, to clear a room of smoke, dust, or pollen. As the negative ions are generated, they'll attach themselves to any particles, and fall to the floor or a nearby grounded object. Other phenomena can also demonstrate that it really does emit negative ions. The "ion motor" is quite dramatic, and proves the existence of negative ions and that they can perform work. Ion propulsion is a viable means of space travel, since escaping ions at high velocity can produce speeds approaching the speed of light in free space. The ion-motor experiment demonstrates the principles that are involved with Newtonian action and reaction.

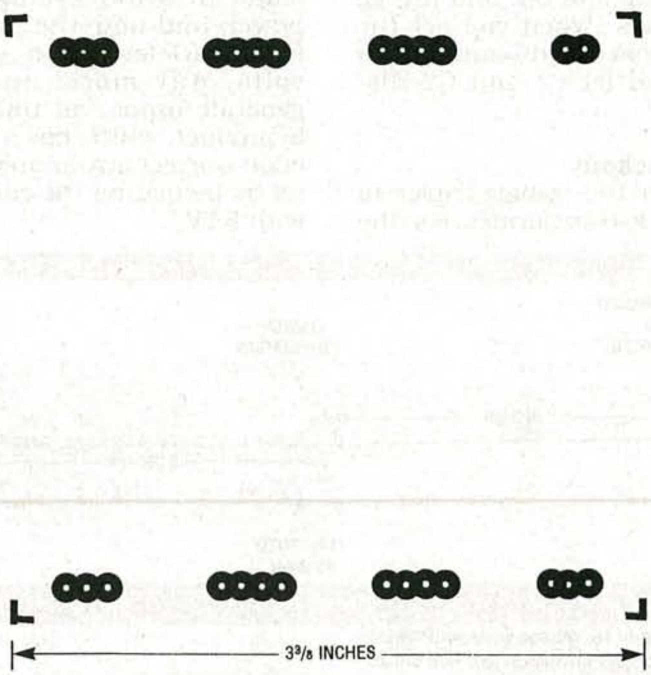
An ion motor can be built as shown in Fig. 10; it's just a 7-inch piece of gauge 16 wire with both ends sharpened to fine points, and bent at right angles, as depicted in Fig. 10-*a*. The bent ends are each 0.5 inch long, while the main body of the rotor is 6 inches long. The middle of the center section is slightly flattened in a vise, and an indentation is made on one side with a punch, in the *exact* center of the 6-inch segment, as shown in Fig. 10-*b*. You have to find the exact balance point, in order to balance the rotor on the emitter needle at the indentation point of the 16 gauge wire.

However, Fig. 10-*b* shows the rotor from below, with the right tip pointing upward, and the left pointing downward. Thus, the rotor shown rotates clockwise when viewed from below, and counterclockwise when viewed from above. When the indentation is on the bottom (the right tip pointing downward and the left pointing upward), the reverse is true. In Fig. 10-*a*, the rotor shown rotates clockwise when viewed from above, since the tips are reversed in orientation to those of Fig. 10-*b*. You can obviously make the rotor turn in either direction as long as both rotor tips face in opposite directions.

The emitter needle won't work with its point covered. Instead, the ends of the rotor now become the emitters. Since negative ions are emitted in opposite directions from each end, it spins like an aircraft propeller, reaching high angular speed in just a few seconds.

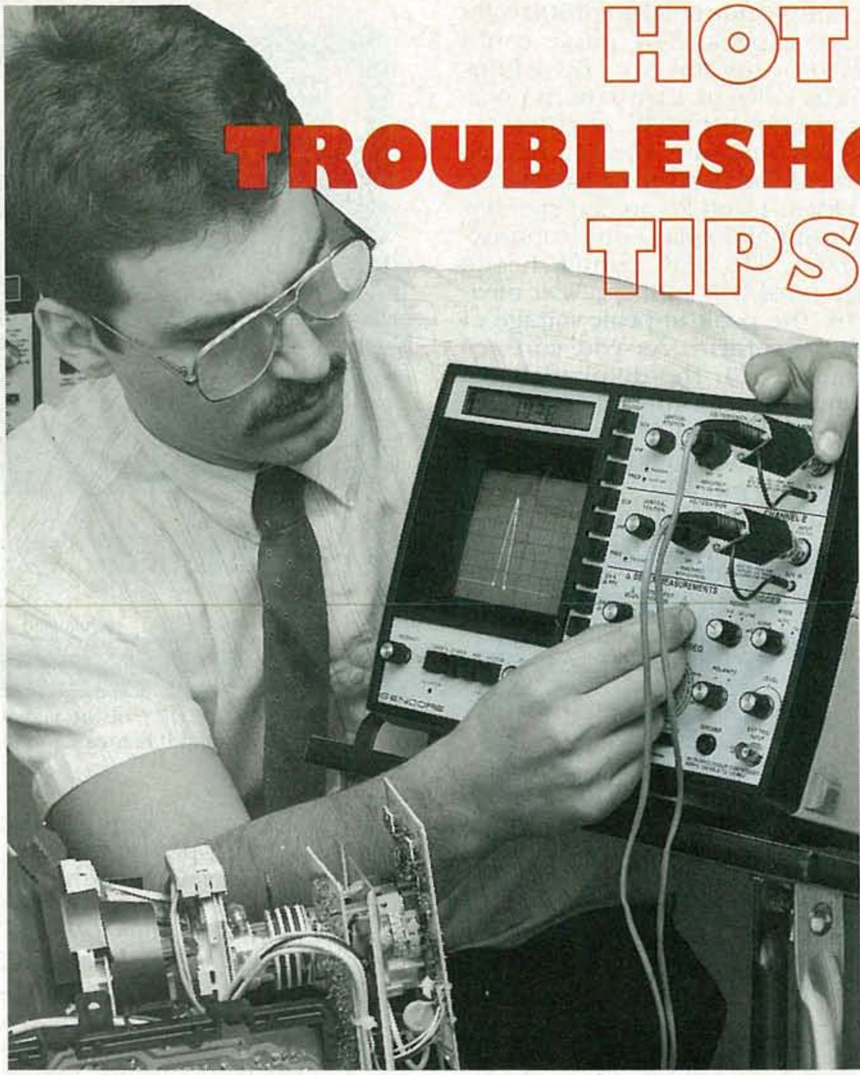
Actually, the word "emitted" is a misnomer, since neither the needle nor the rotor actually absorb or generate ions, per se. Rather, polarized air molecules collide with the surface of the pointed tips of either the needle or the rotor, absorbing electrons from the molecules, or releasing them to un-ionized atoms. The absorption process produces positive ions, the latter generation process produces negative ions.

Since the effective discharge surface area is doubled when using the rotor, as opposed to the needle, the negative ion density emitted from each rotor tip is about half of that emitted from *continued on page 70*



THE FOIL PATTERN OF THE voltage-tripler PC board in the negative ion generator.

HOT TROUBLESHOOTING TIPS



The horizontal output transistor is a critical component in any TV set. Let's examine some of the procedures involved in measuring its output.

BRIAN PHELPS

FOR ANYONE WHO HAS EVER TRIED TO repair a television with defective signals throughout, or changed a horizontal output transistor only to have it fail once more, we have a technique that can save hours of work and needless replacement of parts. All you have to do is check the "HOT pulse," or the signal at the collector of the horizontal output transistor. Let's see why this waveform is so important, and some key procedures for measuring the signal.

The HOT pulse is important because it performs many functions other than just sweeping the CRT beam horizontally. Some of the key functions of the horizontal output waveform are:

- It generates 0.7 amps of horizontal deflection current every 63.5 microseconds.
- It generates a 700–1,500 volts peak-to-peak retrace pulse every 63.5 microseconds.
- It generates 15,000–30,000 volts DC for the picture tube.
- It generates 3,000–8,000 volts DC for the focus circuit.
- It delivers "trace-derived" high-current DC power from 16 to 30 volts to operate most circuits.
- It delivers "retrace-derived" low-current DC power of 185 to 220 volts.
- It provides 6.3 volts for the pulse current of CRT filaments.
- It is a critical safety feature.
- It provides accurate pulse voltages for the tuner's frequency-synthesis power source.

What to look for

The horizontal output pulse supplies operating voltages for the entire TV. It is therefore the most important waveform to check on every TV before and after changing parts. **Note:** In order to make any of the following measurements, your scope must be capable of measuring, and have input protection up to 2 kilovolts or more. Also, a digital-readout oscilloscope, although not essential to troubleshooting, will make it easier to make the measurements.

The first thing to check when analyzing the horizontal output pulse is the wave shape; it should look like the one shown in Fig. 1, and be symmetrical in shape during the retrace time. A wide peak at the top of the retrace, or deep saddle conditions, can be caused by an off frequency or glitch in the horizontal transistor base-drive signal. Such problems are often caused by a change in the value of the output-transistor timing capacitors, or by an excessive load on a B+ supply.

Any excessive ringing or noise is a clear indication of deflection-system problems, such as a cracked integrated high voltage

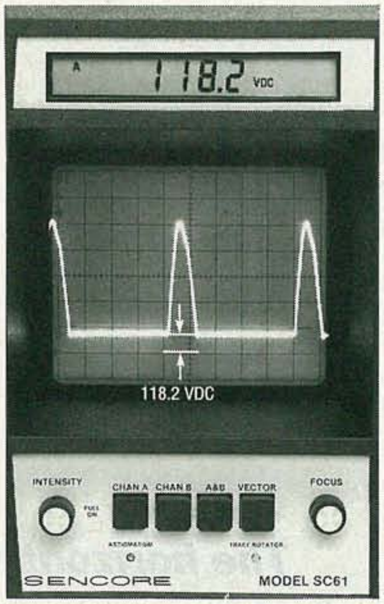


FIG. 1—THE WAVE SHAPE should be symmetrical during the pulse retrace time.

transformer (IHVT) core, or open or shorted IHVT windings. Figure 2 shows an example of a faulty horizontal output. Make sure the waveform looks good before you proceed.

Check to see if there are any noise pulses during the trace time. Many of the noise pulses may not be detected when viewing the low-level horizontal waveforms, but they become very noticeable at the collector with

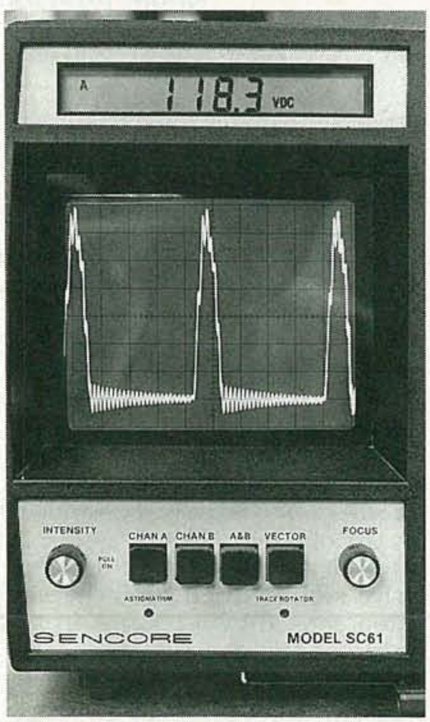


FIG. 2—HERE'S AN EXAMPLE of a faulty horizontal output. Make sure the waveform looks good before you check anything else.

an amplitude reaching 1500 volts peak-to-peak. The noise could cause symptoms from drive lines in the video picture to faint noise throughout the TV's circuits.

First measure the DC voltage level of the horizontal waveform. In Figs. 1 and 2 you can see that the digital display shows approximately 118 VDC, which is the regulated B+ voltage. Next measure the peak-to-peak voltage of the waveform. As you can see from Fig. 3, the display shows 905 volts peak-to-peak.

The frequency of the waveform must also be measured. That's as simple as pushing a button on a digital scope. Figure 4 shows the

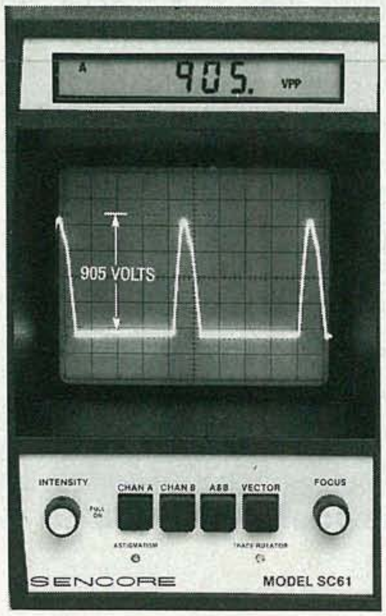


FIG. 3—THE PEAK-TO-PEAK voltage of the waveform should be between 900 and 1500 volts peak-to-peak. It's shown here as 905 volts peak-to-peak.

frequency to be 15.7343 kHz. If everything checks out so far, you know the condition of the regulated B+ supply, that the TV is not in the shut-down mode, and that the horizontal oscillator is locked to the composite video sync pulse.

The duty cycle of the horizontal transistor output waveform is helpful in troubleshooting. The manufacturer specified that the retrace time should be from 11–14 microseconds, and the trace time should be 49–50 microseconds. Those recommended duty cycles should be observed when troubleshooting.

The time-duration measurement of the retrace pulse should be made between the 10% levels

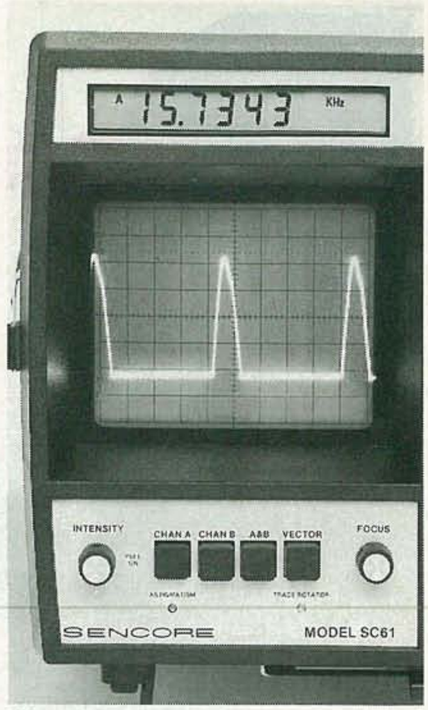


FIG. 4—THE FREQUENCY of the waveform is important; here it is measured to be 15.7343 kHz.

of the waveform. Some digital scopes are equipped to measure portions of a waveform with a delta-time feature. To make that measurement on a digital scope, align the pulse so that the top of it is at the 100% graticule marking and the bottom is at the 0% marking, using the volts/division and calibration knobs. (Make sure your scope will allow accu-

continued on page 70

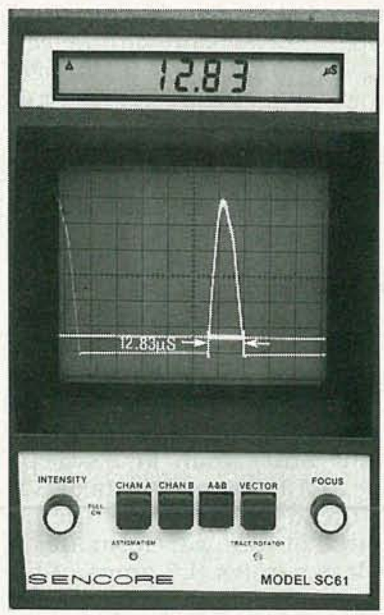


FIG. 5—THE TIME DURATION of the retrace pulse should be between 11 and 14 microseconds; 12.83 microseconds in this case.

MOST PEOPLE INVOLVED IN ELECTRONICS, either as a hobby or a profession, start out by building simple electronic kits. Along the way, they become familiar with electrical terms like voltage, current, resistance, power, and energy, developing a "common-sense" knowledge of them, without fully understanding their meaning.

When asked, "What is a volt?", one might be tempted to respond by quoting Ohm's law; "If 1 amp flows through a 1-ohm resistor, a 1-volt potential is developed across it." That definition, however, isn't much help in defining a volt because one electrical term is used to define another, which leads to vicious-circle reasoning. A proper definition of electrical quantities demands examining length, time, mass, force, charge, and some simple atomic physics.

Here's a refresher course that will help you brush up on standard electric quantities.

1 VOLT=?

DALE NASSAR

Standard units

In any scientific field, accurate and reproducible measurements must be possible. The results of a scientific experiment must be described in well-defined units. Since the metric system will eventually prevail worldwide, all derivations here will be metric, although British units will be mentioned occasionally, as a frame of reference.

We'll now examine length, time, and mass, the basic units from which all other quantities are derived. In some cases, a given letter may have multiple uses as a variable and/or a unit, such as the letter C, which is used as both the variable of capacitance, and the unit of charge. Italic lettering will be used when a label is used as a variable, to avoid confusion. Thus, *C* will denote the variable of capacitance, while C will indicate the coulomb.

The standard variable for length is *l*, although other variables are similarly used, especially d for distance, s for displacement, and x, y, and z, relative to a set of axes. The standard metric unit of length is the meter, abbreviated m, equal to 39.37 inches. The meter is defined as 1,650,763.73 wavelengths of orange-red light emitted by Krypton (Kr)-86 in electrical discharge, a phenomenon that can be remeasured with great precision and comparative ease, given the right equipment.

The standard variables for time are t and T, and the standard unit is the second, s. Normally, t with no subscript is considered to be time as a running, independent variable. By contrast, t with a subscript, like t_0, t_1, and so on, indicates either an initial or specific reference time. The variable T, with or without subscripts, is normally used in electronics to indicate either periods or specific times on waveforms. One second is defined as 9,192,631,770 cycles of radiation from Cesium (Ce)-133. Clocks using Ce-133 from Hewlett-Packard (HP) Corp. are typically accurate to 1 ps.

The standard metric unit of mass is the kilogram, kg, which is 1000 grams, the variable being either m or M. The difference in usage is that m, with or without subscript, normally denotes the mass of an object. While M can also be used this way, it generally refers to very large, celestial bodies, such as the earth, sun, and moon.

Mass is a measure of quantity, not to be confused with weight. Weight is the force due to gravity, which varies slightly over the surface of the earth, due to the change in altitude relative to sea level. The standard kilogram is a platinum-iridium (Pt-Ir) alloy cylinder at the International Bureau of Standards (IBS), in Sevres, France. When an object exactly balances the 1-kg standard on a balance, it's said to be a 1-kg mass, weighing about 2.21 lbs on earth. The British equivalent of the kilogram is the slug, where 1 slug = 14.59 kg.

The first derived quantity is force, F. The metric unit is the Newton, N, named after Sir Isaac Newton. Thus, 1 N is the force (a push or pull) needed to accelerate a 1-kg mass at $1\ m/(s^2)$, written as $1\ N = 1\ kg \times m/(s^2)$; this nomenclature is explained below. Note how this definition uses length, mass, and time. For example, suppose you have a toy car with a mass of 1 kg, and you move it along the surface of a long smooth table. Neglecting friction, no additional force is needed to keep the car moving at its present velocity, the variable for which is v.

However, to accelerate or decelerate an object means to change its velocity, whether in magnitude (speed) or direction. To do so always requires a force, even in space, in the absence of gravity. If the car uniformly accelerates at 1 m/s per second, that means its speed increases by an additional 1 m/s with each passing second. The variable for acceleration is a, while deceleration is a negative acceleration. On or near the earth's surface, the acceleration due to gravity is presumed constant for practical purposes, and is denoted by $g = 9.8\ m/(s^2) = 32.2\ ft/(s^2)$. Thus, 1 kg = 9.8 N on earth, and since 1 kg = 2.21 lbs, then 9.8 N = 2.21 lbs, or 1 N = 0.225 lb.

A concept that's very closely related to force is momentum (p), also known as impulse and is the product of mass times velocity. Momentum is defined by $p = m \times v = F \times t$. Momentum, like velocity, acceleration, and force, is a vector quantity, in that it has both a magnitude and a direction, whereas energy (whether kinetic or potential) is a scaler, possessing only a magnitude.

Throughout this article, we'll discuss several other derived units, all of which are listed in Table 1.

TABLE 1—LIST OF PRINCIPAL

Quantity	Variable(s) and defining equations	Unit (MKS unless otherwise noted)	Dimensional Equivalents
Length (distance or displacement)	*l*,d,s,x,y,z	meter (m)	m
Time	t,T	second (s)	s
Mass	m,M	kilogram (kg)	kg
Velocity (magnitude is speed)	v	m/s	m/s
Acceleration	a (general)	m/s^2	m/s^2
	g (due to gravity)	MKS: $9.8\ m/s^2$	
		CGS: $32.2\ ft/s^2$	
Force (a push or pull)	$F(= m \times a)$	Newton (N)	$\frac{kg \times m}{s^2}$
Momentum (impulse)	$p(= F \times t)$ $(= m \times v)$	$\frac{kg \times m}{s}$	$\frac{kg \times m}{s}$
Energy (work)	*W*	joule (J)	$\frac{kg \times m^2}{s^2}$
Charge, or electric flux	q, Q, Φ_D	coulomb (coul or C) for charge, or lines for electric flux	6.24×10^{18}e
Electric potential (EMF or voltage)	*V*	volt (V), or J/C	$\frac{kg \times m^2}{C \times s^2}$
Current	i,I	ampere (A)	C/s
Power	P	watt (W), or J/s	$\frac{kg \times m^2}{s^3}$
Power density	*S*	W/m^2	kg/s^2
Electric field strength (or intensity)	E	V/m	$\frac{kg \times m}{C \times s^2}$
Electric flux density	$D = \Phi_D/A$	$1C/m^2 = 1A \times s/m^2$	$1C/m^2$
Magnetic field strength (or intensity)	*H*	A/m	$\frac{C}{m \times s}$

The discovery of electric charge

Electric charge was first recorded in 550 B.C. by Thales of Miletus (Greece, c. 640–546 B.C.). He noted that if amber were rubbed with fur, it attracted small objects, such as bits of cork. The Greek word for amber is "elekton," the origin of "electricity." He also found that other objects reacted similarly if rubbed with a suitable material. Such objects, after rubbing in this fashion, possess a net electric charge, or become electrified. A glass rod will become electrified when rubbed with silk, and a lucite or hard rubber rod will become electrified when rubbed with fur.

Both rods contain different kinds of electric charge, shown by the simple experiment in Fig. 1. If the electrified glass rod is suspended at its center by a long thin thread so that it rotates easily, it's repelled by a second similarly charged glass rod nearby, as shown in Fig. 1-*a*. If the charged lucite rod is brought near the charged glass rod, attraction occurs, as shown in Figure 1-*b*. That simple experiment illustrates the basic principle where it can be observed that two similarly charged objects repel, while two oppositely charged objects attract.

One very important property of charge is *conservation*. In any closed circuit involving capacitors, if a charge of $-Q$ appears on one plate, an opposite charge of $+Q$ must correspondingly appear on the other plate. In a circuit that's off, the total initial displaced charge must be zero. For charge to be conserved, that must also apply when the circuit is on. Thus, in any closed circuit, the net displaced charge must be zero, which is something that becomes very important when discussing capacitance.

The atom

To thoroughly understand elec-

AND DERIVED QUANTITIES

Quantity	Variable(s) and defining equations	Unit (MKS unless otherwise noted)	Dimensional Equivalents
Magnetic flux	$\Phi_B = B \times A$	CGS: maxwell	$\frac{g \times cm^2}{C \times s}$
		MKS: 1 Wb = 1 V×s = 10^8 maxwell	$\frac{kg \times m^2}{C \times s}$
Magnetic flux density	$B = \mu \times H$	CGS: 1 gauss (G) = 1 maxwell/cm²	$\frac{g}{C \times s}$
		MKS: 1 tesla (T) = 1 Wb/m² = 1 V×s/m² = 1 N/(A×m) = 10^4 G	$\frac{kg}{C \times s}$
Current density	$J = I/A$, $= \Sigma \times E$	$\frac{C}{m^2 \times s}$	$\frac{C}{m^2 \times s}$
Resistance	$R = V/I = \frac{\rho \times l}{A}$	Ω, V/A	$\frac{kg \times m^2}{s \times C^2}$
Conductance	$G = 1/R$	siemen (S), A/V [formerly the mho (℧)]	$\frac{s \times C^2}{kg \times m^2}$
Resistivity	$\rho = \frac{R \times A}{l}$	Ω×m	$\frac{kg \times m^3}{s \times C^2}$
Conductivity	$\Sigma = 1/\rho$	S/m	$\frac{s \times C^2}{kg \times m^3}$
Permitivity	ϵ	F/m	$\frac{C^2 \times s^2}{kg \times m^3}$
Permeability	μ	H/m	$\frac{kg \times m}{C^2}$
Capacitance	$C = q/V$, $= \tau/R$, $= \epsilon \times A)/d$	farad (F), C/V or S×s	$\frac{C^2 \times s^2}{kg \times m^2}$
Inductance	$L = \tau \times R$, $= \frac{\mu \times N^2 \times A}{l}$	henry (H), Ω×s	$\frac{kg \times m^2}{C^2}$

tricity requires understanding matter. All matter is composed of one or more elements that can't be chemically decomposed any further, like gold (Au), aluminum (Al), and silicon (Si). The smallest complete subdivision of an element is the atom, as shown in Fig. 2, with an extremely dense central nucleus, containing one or more positively charged protons, and neutral particles called neutrons, and one or more negatively charged electrons, equal to the number of protons.

The atom in Fig. 2 is lithium (Li), the third simplest atom. Normally, Li has three electrons orbiting a nucleus with three protons and three neutrons. The electrons are much lighter than the protons and neutrons, and orbit the nucleus at very high speed. If electron orbits were drawn to scale relative to the nucleus, they'd go way off the page.

All electric charge is quantized, or composed of packets of charge. The magnitude of charge depends on the number of electrons extra or absent. A single electron is the smallest unit of charge, usually denoted "e", and the magnitudes of all other charges are then integer multiples of e.

The charge on an electron is defined as negative, while that on a proton is positive. However, the charges are identical in magnitude.

Normally, unionized atoms have as many electrons as they do protons. The opposite charges cancel, leaving no net charge. Electrons have particular orbits about a nucleus; the closer their orbit is to a nucleus, the tighter they're held. The outer electrons are easily removed by friction or light, leaving the atom with a net positive charge, since it would then contain more protons than electrons. An atom may also gain extra electrons, leaving it with a net negative charge; that's why rubbing an object produces net surface charge.

When lucite is rubbed with fur, electrons are transferred from the fur to the rod since they're more loosely bound to the fur than the rod, leaving the rod with excess electrons and a net negative charge (the fur becomes positively charged). When glass is rubbed with silk, electrons are transferred from the glass to the silk (they're more loosely bound to the glass than the silk), leaving the glass with a net positive charge.

Electric field and Coulomb's law

Electric energy, which acts in a space surrounding an electric charge or charged body is called "lines of force." Figures 3-*a* and 3-*b* show the lines of force of isolated positive and negative charges, respectively. Figures 3-*c* and 3-*d* show the force field produced by two like charges and two unlike charges, respectively. The arrows in the diagrams rep-

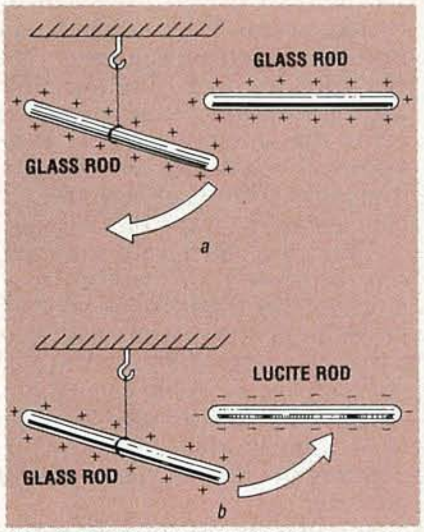


FIG. 1—THIS EXPERIMENT illustrates the acquisition of electrostatic charge. The glass rods in (*a*) are both positively charged. If one is suspended at its center by a long thin thread so it rotates easily, it will be repelled by a second one brought nearby. If a negatively charged lucite rod is brought near the positive glass rod, attraction occurs, as shown in (*b*).

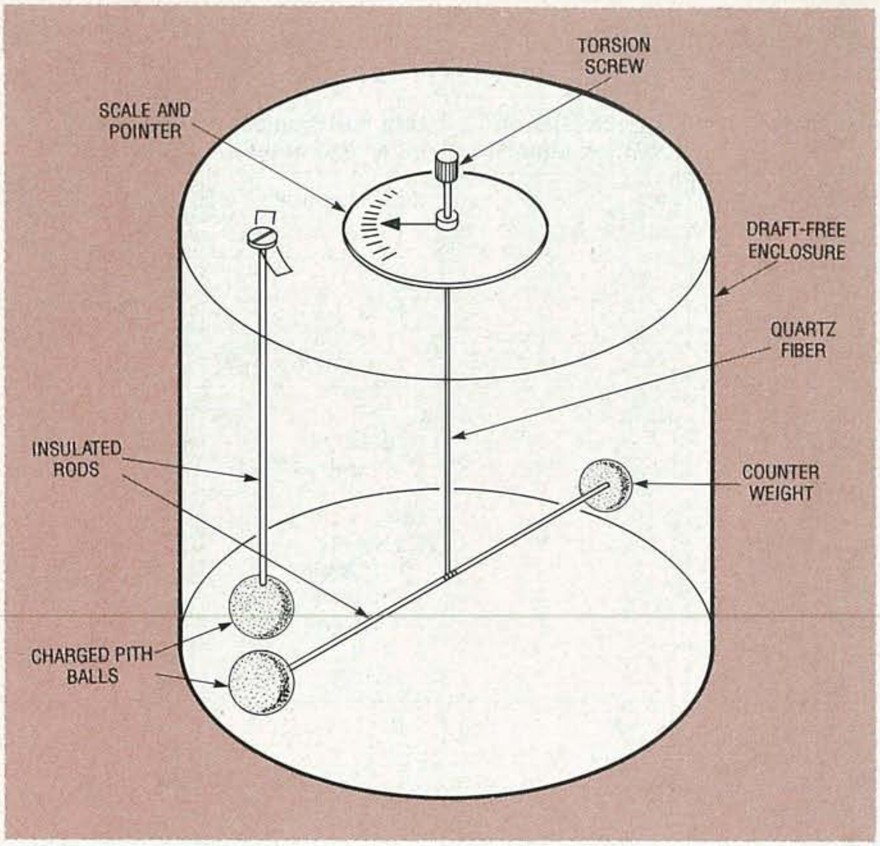


FIG. 3—THESE ARE "LINES OF FORCE" DIAGRAMS, (*a*) and (*b*) are isolated positive and negative charges, (*c*) and (*d*) are two like charges and two unlike charges, respectively.

resent the direction of force on a positive charge, and the field lines emanate from the charge in all directions. The relative density of the field lines is proportional to the field strength.

In 1785, Charles Augustin Coulomb (France, c. 1736–1806) used a torsion balance to perform delicate experiments to learn about electric forces between pairs of charged objects; a basic version is shown in Fig. 4. The force between the charged balls is determined from the torsion (twist) in the quartz fiber.

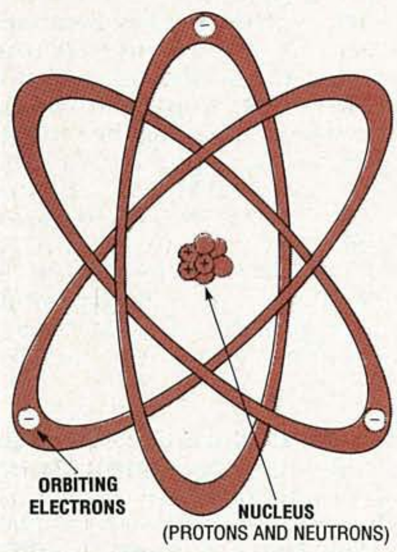


FIG. 2—THE SMALLEST complete subdivision of an element is the atom, as shown here for lithium (Li). The electrons are much lighter than the protons and neutrons, and orbit the nucleus at high speed. If electron orbits were drawn to scale relative to the nucleus, they'd go way off the page.

Coulomb found that the force, F, between charges Q_1 and Q_2 is directly proportional to their product, and inversely proportional to the square of their separation, R. That relationship is known as Coulomb's law, and is expressed as $F=k(Q_1 \times Q_2)/(R^2)$, where k is the Coulomb proportionality constant, which depends on the medium. Coulomb's Law is only valid for R much greater than the radii of Q_1 and Q_2. The units of F are in Newtons, N, while R is in meters, m. The signs of Q_1 and Q_2 depend on the type of net charge, whether + or −

The unit of charge is the coulomb, C. In a vacuum, $k=9\times10^9$ $(N\times m^2)/C^2$; the value in air is slightly higher. If $Q_1=Q_2=1$ C, and R=1 m, then $F=9\times10^9$ N. Thus, 1 C is the charge, that when in vacuum 1 m from a similar charge of identical or opposite sign, yields either a repulsion or attraction, respectively, of 9×10^9 N.

The magnitude of the electron charge e was first measured in 1909 by Robert Andrews Millikan (USA, c. 1868–1953). Measuring the charges on charged droplets of oil suspended against gravity in an electric field, he found that all charges are integer multiples of 1.6×10^{-19} C/electron, or 6.25×10^{18} electrons/C.

As stated above, a charged particle in an electric field is subject to a force. If electrons aren't tightly bound, as in the outer orbits of metal atoms, they actually move; such materials are conductors. Materials where essentially no charges are free to move are nonconductors, or insulators. Different types of materials have different degrees of conductivity. The unit of conductivity is the Siemen (σ), which is the reciprocal of resistance, which we will discuss shortly.

Electric current and the ampere

Since conductors contain relatively mobile electrons, many are always in motion even in the absence of electric field due to random thermal vibration. Such

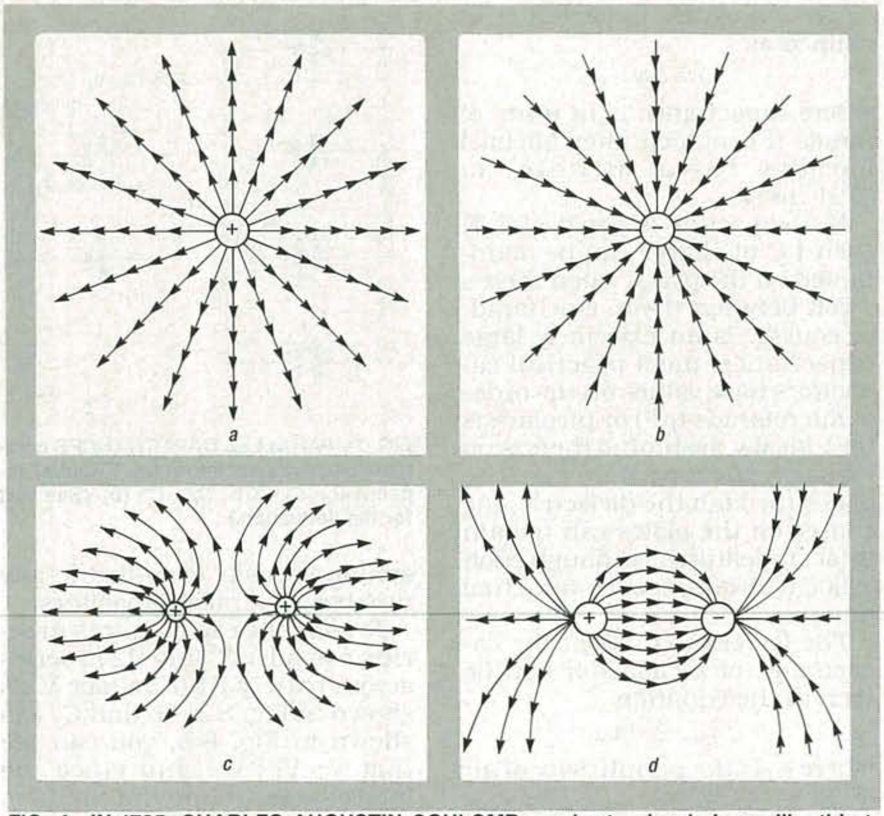


FIG. 4—IN 1785, CHARLES AUGUSTIN COULOMB used a torsion balance like this to measure electrostatic forces between pairs of charged objects by measuring the torque (twist) in the quartz fiber, to determine the proportionality constant. The force F between them is directly proportional to their product of their charges, and inversely proportional to the square of their separation R.

motion is fairly rapid, with an instantaneous velocity of about 10^5 m/s. Electrons undergoing such motion in the absence of an electric field follow an erratic zig-zag path, remaining in the same localized region, as shown in Fig. 5-*a*.

When an electric field is applied to a conductor, the erratically moving electrons drift due to the force generated by the field, causing an electric current, as shown in Fig. 5-*b*. Drift velocity is much lower than instantaneous velocity; about 1mm/s compared to 10^5 m/s for the instantaneous velocity when no electric field is present.

The variable for current is either i or I, for AC and DC current, respectively. The unit of current is the ampere, abbreviated either amp or A, after Andre Marie Ampere (France, c. 1775–1836). By definition 1 A = 1 C/s, independent of conductor area; the symbol A is used for the amp, as distinguished from *A* for area. If 1 A flows in a wire, then 6.25×10^{18} electrons pass through a cross-section of it every second.

Many people incorrectly assume that electric current flows at an extremely high speed, when it literally moves at a snails pace! It is the electric field that moves down the conductor at very high speeds. It can be mathematically shown that if several amps of current (either AC or DC) flows through standard household copper wire, the drift velocity of the electrons move only a fraction of a millimeter per second, but those slowly creeping electrons produce considerable heat due to friction, in the wire.

A volt by any other name...

The definition of potential, or electromotive force (EMF) involves the concepts of work and energy. Energy is the ability to do work. Work results in motion of an object, and is defined as the product of the force applied to an object and the distance through which it travels. The unit of work is therefore the Newton-meter (N-m). The unit of work, or one Newton-meter, is called a joule, abbreviated J, after James Prescott Joule (England, c. 1814–1889). For example, if a force of 5 Newtons is required to push an object, and that object moves a distance of 3 meters in the direction of the applied force, then 15 joules of work is performed. Whatever pushed the object obviously had to have the initial energy to do so.

The concept of work and potential difference can be illustrated by examining the basic operation of a battery. Two terminals of a battery consist of two unlike charges (+ and −) that maintain a constant potential difference by chemical means. Because of the difference in charge, an electric field must exist between them. That electric field has the ability to do work on an electric charge. For instance, if you wanted to move a positive charge from the negative battery terminal to the positive, you would have to work against the electric field between the terminals. A greater potential difference between battery terminals creates a higher electric field, and therefore, it stands to reason that greater work must be done in order to move a charge against it.

We have now come to the unit of potential difference, which is defined as the number of joules per coulomb (J/C), or work per charge. This unit is called, as you might have guessed, the volt (V), and was named after Alessandro Guiseppe Antonio Anastasio Volta (Italy, c. 1745–1827). For example, in a 12-volt battery, 12 J of energy are needed to move 1 C from one terminal to the other; and 24 J would be needed to move 2 C, since 24 J/2 C = 12 volts. The terms voltage, potential difference, and EMF are equivalent, and are very often used interchangeably.

Resistance and Ohm's law

When current flows in a con-

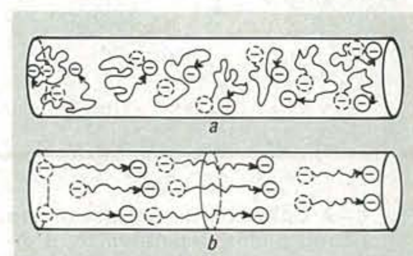


FIG. 5—A DEPICTION OF random thermal motion in (*a*), versus a nonzero drift velocity in (*b*).

ductor due to an electric field, electrons gain energy because of their motion, called kinetic energy. As they move, they collide with atoms of the conductor, dissipating kinetic energy as heat. The conductor can be said to have a degree of resistance to the flow of electric current.

Georg Simon Ohm (Germany, c. 1787–1854), for whom the unit of resistance, the ohm (Ω) is named, showed that current flowing in a conductor is directly proportional to the voltage across it. That concept may be apparent to you since we know that a higher voltage produces a stronger electric field, and therefore exerts a greater electric force on the charges of the conductor. That relationship is known as Ohm's law, and can be written as $V = IR$, where V is the voltage across the conductor, I is the current in amperes through the conductor, and R is the proportionality constant, which is a direct measure of the electrical resistance of the conductor. If the equation is solved for R, we get $R = V/I$. The unit R, therefore, is in volt/amps and is called an ohm (Ω). Ohm's law states that if a current of one ampere flows through a conductor when a potential of one volt is placed across it, the conductor is said to have a resistance of one ohm.

Capacitors and capacitance

A capacitor is basically two conducting surfaces separated by a dielectric, or insulator, as shown in Fig. 6. The capacitance of an element is its ability to store electric charge on its plates. The larger the capacitance (*C*), the more charge (Q) will be stored on its plates for the same voltage (V)

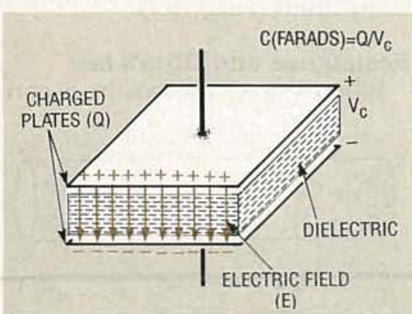


FIG. 6—A CAPACITOR consists of two conducting plates separated by a dielectric, or insulating material. When the plates are charged, an electric field is established between them. Capacitance (F) = Q/V.

across its plates. Capacitance is defined as

$$C = Q/V$$

where capacitance is in units of farads (F), named after Michael Faraday (Great Britain, c. 1791–1867).

If a capacitor is rated at 1 F, then 1 C of charge can be maintained on the plates when there's 1 volt between them. One farad, of course, is an extremely large capacitance; most practical capacitors have values on the order of microfarads (μF) or picofarads (pF). Ideally, assuming there is no leakage current between the plates through the dielectric, the charge on the plates can remain intact indefinitely, although such leakage always occurs in actual practice.

The factors that affect the capacitance of a capacitor can be seen in the equation

$$C = \epsilon_0 \times \epsilon_r \times A/d$$

where ϵ_0 is the permittivity of air (8.85×10^{-12} F/m), ϵ_r is the relative permittivity, *A* is the area of each plate in square meters and d is the distance between the plates in meters.

The preceding equation reveals that capacitance will increase with a larger plate area, or when the distance between the plates decreases. The permittivity factor ϵ is a measure of how well a given dielectric allows electric field lines to be established between the plates. When an insulator is used between the plates, the capacitance will increase by a factor of ϵ_r. The ϵ_r factor equals ϵ/ϵ_0, which is better known as the dielectric constant, k. As a point of interest, the relative permittivity ϵ_r of air is 1.0006, rubber is 3.0 and that of water is 80.0.

You're probably aware that capacitances in parallel add. To show this, consider C1 and C2 in parallel across battery B1 of voltage V, as shown in Fig. 7-*a*. The total capacitance C_T, as shown in Fig. 7-*b*, can be found by the following analysis. If Q_1 and Q_2 are the charges on C1 and C2, then $Q_T = Q_1 + Q_2$. Since the voltage across both C1 and C2 is V, then $Q_1 = C1 \times V$, $Q_2 = C2 \times V$. Therefore, $Q_T = (C1 \times V) + (C2 \times V) = (C1 + C2) \times V$. Dividing by V gives us $Q_T/V = C1 + C2$, but $C_T = Q_T/V$, so $C_T = C1 + C2$. The same reasoning is easily extended to any number of parallel capacitors.

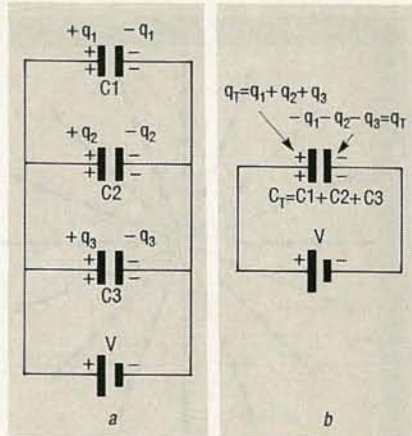


FIG. 7—PARALLEL CAPACITANCES combine like series resistors (*a*). The total capacitance $C_T = C1 + C2 + C3$ (*b*). (See text for the derivation.)

To combine capacitances in series, consider C1 and C2 in series across battery B1 of voltage V, as shown in Fig. 8-*a*. To find C_T, as shown in Fig. 8-*b*, you can see that $V = V_1 + V_2$, and since the total charge around the circuit is zero, $Q_1 = Q_2 = Q$. Therefore, $Q/C_T = (Q_1/C1) + (Q_2/C2) = (Q/C1) + (Q/C2)$. Canceling Q gives $1/C_T = (1/C1) + (1/C2)$.

Inductors and inductance

The inductor consists of a length of wire wound into a solenoidal or toroidal shape, with or without a center core as shown in Fig. 9. When current passes through the coil, magnetic flux lines are established, as shown in Fig. 10. Inductance (L) of a coil is its ability to store energy in the

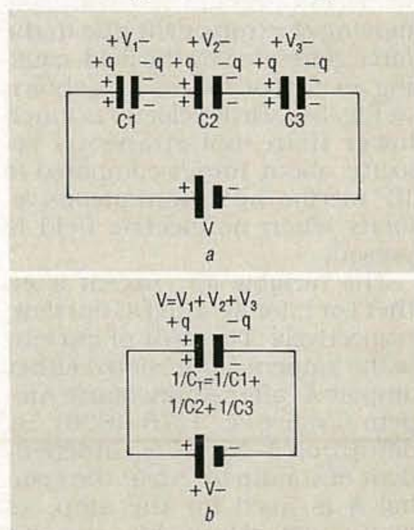


FIG. 8—SERIES CAPACITANCES combine like parallel resistors (*a*). The reciprocal of the total capacitance $1/C_T = 1/C1 + 1/C2 + 1/C3$ (*b*). (See text for the derivation.)

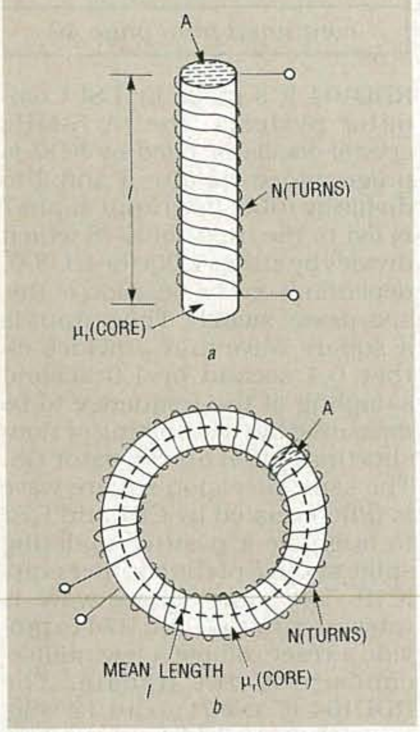


FIG. 9—TWO TYPICAL COIL constructions are the solenoid (*a*) and the toroid (*b*). Inductance in henrys (L) is defined as $L = N^2 \times \mu A/l$.

form of a magnetic field. The unit of inductance is the henry. One henry is the amount of inductance necessary to produce 1 volt across a coil with a current that changes at a rate of 1 ampere per second, and is expressed mathematically as

$$L = E/(dI/dt)$$

where E is the induced voltage and dI/dt is the rate of current change in amperes per second.

For most applications, 1 henry is a very large unit of inductance. Inductance is usually specified in units of millihenrys (mH), microhenrys (μH) or nanohenrys (nH).

Inductance can also be expressed by the equation

$$L = N^2 \times \mu A/l$$

where N is the number of turns of wire, *A* is the core area in square meters, *l* is the core length in meters, and parameter μ is the permeability of the material. The permeability of a material is a measure of its magnetic properties, and is determined by the equation

$$\mu = \mu_r \times \mu_0$$

where μ_0 is the permeability of air ($4 \times \pi \times 10^{-7}$ H/m) and μ_r is the relative permeability of the material compared to air. As the magnetic properties of a material increase, so does its relative permeability. Some materials, such as steel and iron, have permeabilities that are hundreds or thousands of times higher than air, or $\mu_r \geq 100$. A coil with no core has a permeability factor of $\mu_r = 1$. The inductance can be increased by placing a core with a high permeability, such as a ferromagnetic material, within the coil.

Our discussion now leads us to series and parallel inductors. The total inductance for inductors in series can be determined the same way as series resistors; $L_T = L_1 + L_2 + L_3 + \ldots + L_n$. For inductors in parallel, the total inductance can be found the same way as for parallel resistors; $1/L_T = 1/L_1 + 1/L_2 + 1/L_3 + \ldots + 1/L_N$.

Power and the watt

Power is a measure of the time rate of either expenditure or storage of energy, whether electrical, thermal, or any other form. Power, therefore has units of work per time, and is measured in J/s, called a watt (W), named after James Watt (Scotland, c. 1736–1819). To derive the definition of a watt, we must think in terms of the rate at which work is being done on electrical charges. Since 1 A = 1 C/s, and 1 W = 1 J/s, then the proportionality constant must have units of J/C, or voltage. Therefore, $P = E \times I$, and since Ohm's Law gives $E = I \times R$, then $P = I^2 \times R = (E^2)/R$.

Power is directly related to electric and magnetic field quantities mentioned earlier. If you take the product of electric and magnetic field strengths E and *H*, then $(V/m) \times (A/m) = (V \times A)/(m^2) = W/(m^2)$. This is power per unit area, also known as power density, and is generally denoted by *S*.

In electromagnetic waves, the electric field strength E and magnetic field strength *H* vectors are perpendicular to one another. You can't simply take the arithmetic product of the magnitudes of the vectors at a given point to obtain the power density.

For example, the solar constant, or the mean power density reaching the earth *outside* its atmosphere, at normal incidence, and at a mean orbital radius from the sun, is about 0.14 W/cm^2. Of

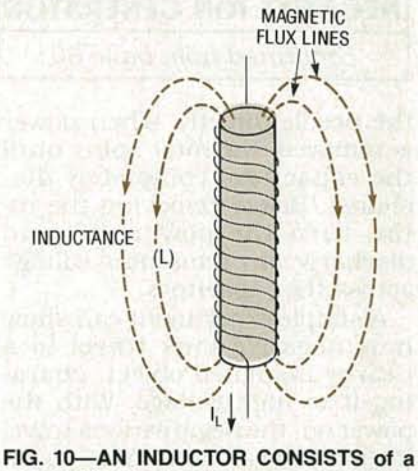


FIG. 10—AN INDUCTOR CONSISTS of a coil of wire wound around a core of air or ferromagnetic material. When current goes through a coil, magnetic flux lines are established.

course, since the atmosphere absorbs a considerable amount of this energy, you never actually feel all that power. Similarly, a 100-W light bulb literally radiates 100 J/s, but becomes dimmer the further you get from it because the power is dissipated over a wider area.

Some additional points

Many interesting and important derivations can be made from the concepts discussed in this article. We'll take a look at a few examples of some commonly used electrical terms.

All timers use time constants, whether capacitive (RC) or inductive (RL). For an RC time constant, the units are $\tau = R \times C = \Omega \cdot F = (V/A) \times (C/V) = C/A = C/(C/s) = s$. Therefore, the units of an RC time constant are in seconds.

A couple of additional, more practical units for both charge and energy are the amp-hour (Ah) and the kilowatt-hour (kWh). A 1-Ah rating is found on many batteries. If a battery is rated at 4 Ah, it can supply 4 A for one hour, or 1 A for 4 hours, or 0.5 A for 8 hours, and so on. Since 1 A = 1 C/s, and 1 hr = 3.6×10^3 s, then 1 Ah = 3.6×10^3 C.

The exact charge obtainable from a battery depends on the current drain, usually decreasing as current drain increases, due to heating. Electric utilities determine bills from the kWh your house consumes every month. Since 1 kW = 10^3 W, 1 hr = 3.6×10^3 s, and 1 *W* = 1 J/s, then 1 kWh = 3.6×10^6 J. **R-E**

NEGATIVE ION GENERATOR

continued from page 60

the needle directly. When power is removed, the rotor spins until the capacitors completely discharge. Before removing the rotor, turn the power off, and discharge any remaining voltage across the capacitors.

A simple experiment can show how negative ions travel to a nearby insulated object, charging it to high voltage. With the power on, the negative ions travel through the air, and in doing so, collect on any metal surface. You can show how that works with an empty can as a collector, as shown in Fig. 11.

Rest the can on an insulated surface, such as a rubber mat, so the charge won't leak off. Use an earth ground for discharging, such as an AC outlet ground screw or a water pipe. As the negative ions hit the can, charge builds until the can is charged to 90–100 volts DC, NE2 fires, and the process repeats as long as the negative ion generator runs. Start with the can 1–2 feet away; you will notice how the flash rate of NE2 increases as the distance between the negative ion generator and the collector decreases, or if the emitter needle points toward the can.

Both experiments can run simultaneously; as the ion motor rotates, dissipating charge into the air, the can collects the negative ions and flashes the neon bulb. Another experiment uses a 40-watt fluorescent tube in a very dark room; be very careful while handling the glass tube in darkness—they're very fragile and you could hurt yourself if one implodes.

Connect a ground wire to a terminal at one end. Hold the tube near the grounded end without touching metal. Bring the other end toward the negative ion generator without touching it. The tube should flash or glow, indicating the presence of negative ions. As you move the tube away, both the flash rate and glow should decrease. When you're finished with the negative ion generator, turn it off, discharge it, and be sure to cover the emitter needle with the cork or other type of insulator. **R-E**

HOT TROUBLESHOOTING

continued from page 62

rate digital readings when it is unscaled.)

Select the dual-channel mode, couple channel B to ground, and align the trace so it lies on the 10% graticule marking. Select the time-measurement mode, and set the "begin" and "end" knobs so that the intensified trace section is as shown in Fig. 5. The digital display should show between 11 and 14 microseconds. (The display in Fig. 5 shows 12.83 microseconds.)

If you measure, say, 9 microseconds, instead of 11–14 microseconds, even though the peak-to-peak value, the DC voltage, the wave shape, and the frequency are correct, the TV will work for awhile, but will more than likely fail at some point. That's because the horizontal output system sees a 35.7% reduction in retrace time—meaning that retrace is faster and generates higher voltage. Therefore, the horizontal output transistor is on longer at full-scan conduction, producing increased heat, increased scan-derived power supply levels, and higher voltages throughout the set. All the circuits are now stressed working at the higher voltages. That, in time, will cause components to fail.

Your scope can also be used to watch for an instantaneous start-up pulse. Simply connect the scope and preset it to view the HOT pulse. Then, watch the CRT as you apply power to the TV's circuitry. If you see a pulse appear and then disappear, your start-up circuitry is operating and the set is in the shut-down mode.

If that happens, service the chassis in a "powered-down" condition by either halving the normal B+ level separately, or reducing the AC input power to 60–90 VAC. Then monitor the collector of the horizontal output transistor with your scope.

Many underlying performance problems can be uncovered by examining specific characteristics of the "HOT pulse." The waveform shape, symmetry, and duty cycle of horizontal output transistor is critical in diagnosing and troubleshooting electrical malfunctions in your TV set. **R-E**

SWEEP/MARKER

continued from page 49

RDD104 IC's made by LSI Computer Systems, Inc. A 5-MHz crystal oscillator used by IC17 is programmed via pins 1 and 2 to divide by 1000. Its output at pin 7 is fed to the input of IC18 which divides by either 1,000 or 10,000, depending on the position of the SINE RANGE switch. The output is a square wave and provides either 0.1 second or 1.0 second sampling of the frequency to be measured by the shorting or non-shorting action of transistor Q8. The same precision square wave is differentiated by C61 and R73 to originate a positive updating spike at pin 5 of the counter chip, IC19. The same square wave is integrated by C60 and R74 to provide a reset voltage a few milliseconds after the update. The RDD104 IC needs about 12 volts to oscillate at 5 MHz, and since the counter IC requires 5 volts, dual-voltage supplies are really necessary.

The schematic of the peak-hold circuit is shown in Fig. 9. In that circuit, op-amp IC23 amplifies the signal from the device under test about four times.

The positive alternation of the waveform is squared and inverted by op-amp IC26. That near-square wave is applied to the bases of transistors Q13 and Q14, both of which act as switches and behave as either open circuits or shorts to ground. If Q14 is a 2N2219 transistor, it shorts to within 5 millivolts with reference to ground. If a VN0300M power MOSFET is used, it shorts to within 1 millivolt to ground.

When Q13 and Q14 act as open circuits, C93 charges to the peak value of the positive alternation, following the rising edge of the alternation and then holding the peak value because there is no discharge path. The flat-top portion of that charge is one segment of the positive contour line. Transistor Q13 discharges C93, and the next time it acts as a short circuit. This varying between charge-time and short-circuit time continues for each cycle.

We're going to have to stop at this point. Next month we'll build and test out the unit. **R-E**

HARDWARE HACKER

This month we'll talk about cheap visible lasers, electric motor resources, induction motor controls, new wavelet math theory, and a dual digital potentiometer.

DON LANCASTER

Let's start off this month's column with a very hackable circuit opportunity that has not quite seen the light of day. At least not yet...

Induction motor speed controls

Why should it be cheap, easy, and trivial to regulate the speed of your electric drill, yet super expensive and next to impossible to control the speed of a compressor or blower motor on an air conditioner? After all, a motor is a motor, isn't it?

Sadly, the answer is no. Those AC induction motors simply were never designed to have their speed changed, and they throw all sorts of really ugly hassles at you when you try to do so. Let's see why that's so.

Just about all electric motors are based on two fundamental electrical principles. The first of those is that like magnetic poles repel and opposite ones attract. The second is known as *Fleming's Rule*, which states that "a current carrying conductor at right angles to a magnetic field will produce a force and attempt to move in a direction at right angles to both the magnetic field and the current."

When using conventional current, that produces the familiar *right-hand generator rule*, wherein your thumb points in the direction of the motion, your index finger towards the south pole of the magnetic field, and your middle finger in the direction of the conventional current.

For a motor, the same rule applies to your left hand. The only theoretical difference between a motor and a generator is that you input motion to get an output current with the generator, while you input current to get a force and hopefully a motion with a motor. In reality, all motors do some generating, and vice versa.

So, your only trick to building a motor is to constantly rearrange your magnetic fields and their strengths so they are either attracting one another or shoving each other away, or use some ongoing combination of *attraction* and *repulsion* together.

A motor usually consists of a stationary part called a *stator* and a moving part known as a *rotor*, or *armature*. If it's necessary to physically transfer current to your rotor, either *brushes* and a *commutator*, or else *slip rings* are used. Slip rings apply continuous power to your rotor, while fixed brushes and a commutator selectively switch in and out chosen windings that happen to be aligned with the brush axis at any particular point in time.

You'll find quite a few different possible motor designs. But by far the two most economically important are the *series DC motor with brushes*, which is sometimes called a *universal motor*, and the *AC induction motor*. Let's take a look at each one.

Figure 1 shows a universal motor and its torque versus speed curve. You'll recognize this one in your electric drill, hot tub blower, vacuum cleaner, blender, sewing machine, or older car starter.

There's a pair of wound stator coils that, when run on DC, will produce a constant stationary magnetic *field*. In series with the stator coil is a pair of brushes with a commutator, which selectively switch rotor windings in and out so that one or more windings is constantly getting attracted to the fixed stator field. As the armature rotates, new windings get switched in by the commutator, so that a more or less continuous attraction, and thus a rotary motion gets produced.

The same universal motor works almost as well with AC, except sometimes you have strong fields and sometimes weak ones as the current alternates. Usually, the mechanical inertia of your load will more or less average all those variations into continuous rotary power.

Even with AC, you still always have opposite poles attracting one another. They just happen to change their polarity 120 times a second. But they always change together. Note that you can reverse your universal motor by placing a DPDT switch between the commutator and the stator coils. But that can cause excessive wear if the motor brushes were not designed for two-way use.

As your universal motor slows down, its torque will increase, which tends to add to the motor *stability*. As you slow down, the available "twist" increases to speed you back up, and vice versa.

Since you have lots of torque at zero speed, your motor self-starts. It may overheat if you stall it permanently, but given half a chance, a universal motor easily gets itself up to speed.

Any motor is simultaneously a generator, and vice versa. A universal motor that is lightly loaded and running at a high speed produces an output voltage and resultant current in *series* with your input current. The voltage that is generated is known as a *back emf*, which *opposes* the input current. When lightly loaded, very little current is drawn from the supply, since the back emf and its resultant current nearly cancels out the input current, which is real handy from a conservation of energy standpoint. If you're doing no useful work, and if your motor isn't getting particularly hot, then you shouldn't need too much input energy just to spin things.

As you add mechanical load, your series machine will become less of a generator and more of a motor. The back emf and its canceling current drops, and the input current goes up. Your new energy needed is mostly

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Thatcher, AZ 85552
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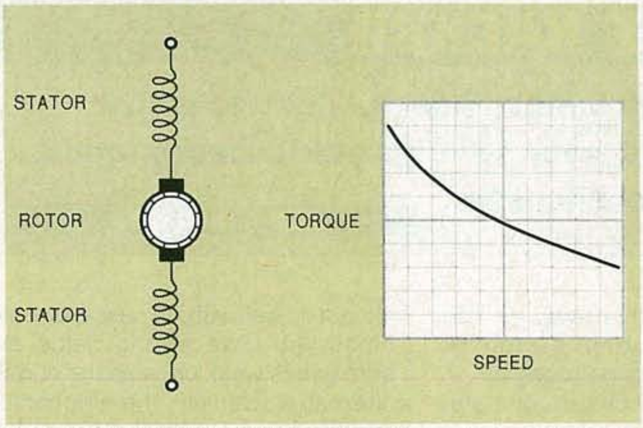

FIG. 1—A UNIVERSAL SERIES motor with brushes used on an electric drill, along with its speed-torque characteristics. The speed of the motors can be easily electronically controlled by using simple circuits.

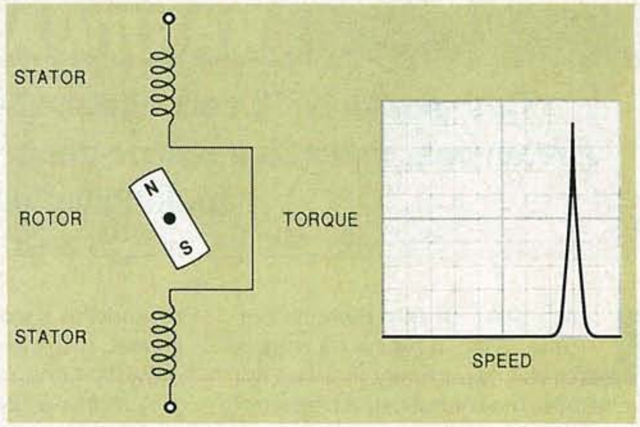

FIG. 2—A SYNCHRONOUS AC MOTOR used on a clock, along with its speed-torque characteristics. The speed is determined by the line frequency. The input current determines how strong a load can be driven.

transferred to your mechanical load. Again by conservation of energy, you're putting more energy in so you can get more energy out.

Neglecting nonlinearities such as air resistance, the speed of a universal motor for a given load is determined only by the input current. You raise your current to go faster; reduce it to slow down. That means you can just throw any old high power resistor in series with your universal motor to control its speed, just like sewing machine motors used to use. Better yet, you can use a far more efficient *triac* style light dimmer for control.

Best of all, you can sense the back emf or otherwise measure the actual motor speed and use electronic feedback with a triac or SCR circuit which is only slightly more complex than a plain old dimmer. That gives you a tightly regulated speed control plus the ability to run real slow with lots of torque.

The bottom line is that it's trivial these days to electronically regulate the speed of a universal motor. We've seen several circuits in past issues and in those *Hardware Hacker II* reprints. *LSI Systems* is a good source for fancy universal motor controller chips, while lots of detailed application notes appear in the usual triac data books from *Motorola, SGS, Texas Instruments*, and several others.

So what's wrong with universal motors? If they are so universal, why aren't they used everywhere? The biggest problem lies in their brushes. Brushes wear out. They are inefficient. They are both acoustically and electrically noisy. They spark and can start fires or explosions. And those problems really get out of hand when you need more horsepower.

Look around, and you'll see that virtually all universal motors in your home only run on an *intermittent* basis. Mostly because the brushes cannot run continuously without grinding themselves into oblivion, or driving you up the wall with noise.

Ideally, we would like to conjure up some scheme to get power onto the rotor without any brushes or other physical contact. And that's where the induction motor comes in.

Figure 2 shows a brushless beastie known as an *AC synchronous motor*. It has a wound stator and a permanent magnet rotor. Assume that we are plugged into the 60-Hz AC line and that the rotor just happens to already be spinning at 3600 RPM.

On a positive line peak, the north magnet pole will get attracted to the upper stator coil. By the time your magnet is pointing straight up, the current will be going through zero and there will be no mutual attraction or repulsion. Soon afterward, the line current swings negative, and that opposite polarity starts repelling the magnet, continuing it on its merry way. The exact opposite happens to the other pole, and the motor will continue to spin.

The *synchronous speed* is set *only* by the number of poles and the line frequency, and is *totally independent* of your input current. The two pole synchronous motor runs at 3600 RPM off the 60-Hz line; a four pole job spins at 1800 RPM, and so on.

We can see that a synchronous motor is real handy for maintaining a constant speed. Important uses are in electric clocks, phonograph motors, timers, chart drives, and other lower power uses where an absolutely constant speed, independent of the load or input current, is essential.

What happens when we apply too much of a load? If your magnet gets 90 mechanical degrees out of phase, there will be no attraction or repulsion, and zero power routed to the load. If it gets further out of phase, it actually tries to stall itself. Therefore, the slower the speed, the less the torque.

You really have a two-speed device here: 3600 RPM and 0 RPM. One consequence here is that any true single-phase synchronous motor will not start by itself. You will have to help it along with a switchable starting winding, a pole shading, an iron hysteresis cup, or a second or third winding driven from a two-phase or three-phase source.

A second consequence is that the speed of a synchronous motor with varying load or current can end up unstable. If it ever breaks out of sync, you almost surely will stall. That happens because a slowdown produces less torque, which in turn produces less speed. Just the same as an auto in too high a gear for the grade.

The load current does decide how large of a load it can drive at synchronous speed. The more input current, the more power you can deliver to the load without having to break your synchronization.

Figure 3 shows a variation on a synchronous machine known as the *AC induction motor*. It is by far the most common motor in use today. You will find AC induction motors in your air conditioners, heater blowers,

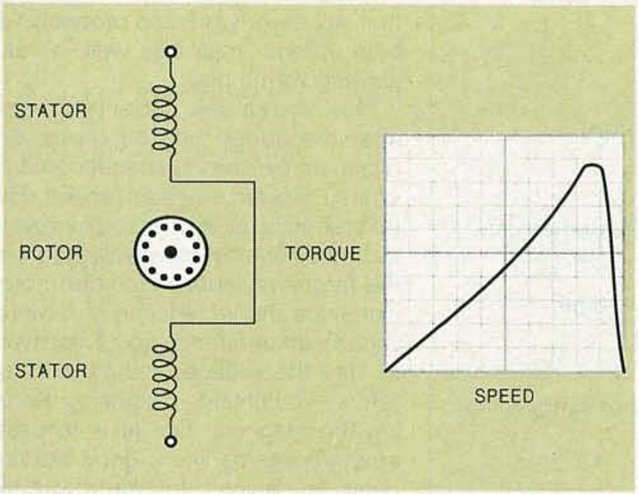

FIG. 3—AN AC INDUCTION MOTOR used on a washing machine, along with its speed-torque characteristics. The current controls the speed over a very narrow range between the optimum slip speed and the synchronous speed. To control the speed of this type of motor over a wider range, you must use a complex cycloconverter circuit that can change both the input frequency and current.

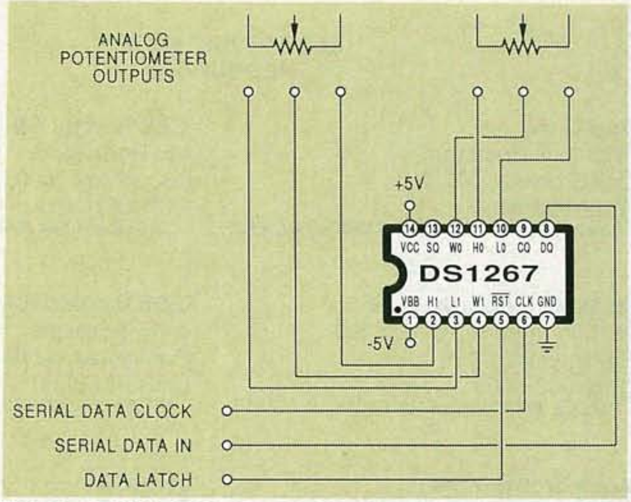

FIG. 4—A DUAL DIGITAL POTENTIOMETER using the Dallas Semiconductor DS1267. A 17-bit serial word determines which of the 256 steps for each potentiometer gets selected. Unlike EEPOT chips, the settings are easily read but forgotten on power-down. A serial output lets you daisy chain your digital commands.

washers, most table saws, dishwashers, dryers, drill presses, water pumps, and many circulation fans.

Motors used in those types of products are also the ones you would most like to be able to inexpensively control the speed of. You would especially like to raise the efficiency of heating and cooling systems.

The concept of the AC induction motor was positively brilliant. Tesla strikes again. Somehow you have to get currents onto the rotor, but we definitely want to avoid any brushes or other mechanical contacts.

Question: What do you get when you have coils and iron driven from AC current? Answer (A) a motor, or (B) a transformer (!).

Instead of brushes or slip rings, you *transformer couple* the rotor current in an induction motor. That's usually done by creating a special low-impedance transformer secondary known as a *squirrel cage*. The purpose of the squirrel cage is to serve both as the transformer secondary and as rotor coils to simulate the rotor magnet of Fig. 3.

But not so fast. Literally. If you're running at synchronous speed, no lines of flux will be cut, and there will be no current induced into the squirrel cage. Which gives you synchronous speed, but zero power. Now, let your speed *slip* just a little bit. There's now a very *low-frequency* AC current induced in the squirrel cage. That creates a changing magnetic field, and you now have more torque than you do at synchronous speed.

If you lower the speed slightly, you create even more torque. But if you slow it down too far, your torque starts dropping radically.

Thus, an AC induction motor has optimum torque at a speed which is only modestly less than synchronous. That's why your "quarter horse" motor is usually rated at 3450 RPM for a two-pole motor and 1734 RPM for a four-pole one.

As you can see, we have a well-behaved torque-speed curve between the synchronous speed and the optimum, but only a slightly slower peak torque speed. Below the peak speed, you'll have the same instability and dropout problems that you'd have with a pure synchronous machine.

Like a synchronous motor, a single-phase induction motor will not start itself. Usually there will be a second starting winding that gets kicked in only when getting the motor up to speed. Other starting variations can include a pole shading or multiple phase windings.

In theory, you could reverse your induction motor by reversing the direction the starting method shoves the rotor. Details vary with the motor type. In some cases, the only way to reverse the motor is to remove the rotor and put it back in pointing the other way.

Another problem with induction motors is that the optimum motor speed is usually far too fast for useful real-world work. You almost always have to use pulleys and belts or some other speed-reduction scheme. Or go to lots and lots of poles, as is done in those fancy ceiling fans.

Thus, any attempt to control the speed of an induction motor with a series resistance or a simple phase control is doomed to failure. Flat out,

ELECTRONIC MOTOR RESOURCES

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Warrendale, PA 15096
(412) 776-4970
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that will never work and probably will burn up your motor as well. It's like plowing with a pig.

Now, you *can* use current control to alter the speed of your motor between its synchronous speed and its slightly slower optimum speed. But that range is usually far too narrow to be useful, unless you're willing to vary the *frequency* applied to your motor. But since the impedance of a motor varies with frequency, you'll also want to vary the voltage or the input current as you change frequency. Keeping the magnetic flux at a constant strength seems like a good starting point, so raising the voltage with the line frequency seems like a good idea. You'll also have to quite accurately sense your motor speed at all times, and feed back all of that information into your controller.

In addition, you do have to guarantee that the starting windings do not kick in at slower speeds. Most starting windings are for *very* intermittent duty only and will rapidly burn up if run continuously.

Circuits which sense motor speed and vary both the frequency and the current are often known as *cycloconverters*. Yes, you can get them. One major supplier is *Asea Brown Bovari*, a Swiss firm with a wide range of induction motor speed controls. But they're not cheap. And cycloconverter-controlled induction motors tend to whine a lot, owing to nonlinear magnetic harmonics in the audio range, unacceptably so for many uses.

But a $19.95 wide range and quiet quarter horse induction motor speed control is not likely to show up in your hardware store in the next few months. Even though we do have lots of better magnetics and new intelligent-power integrated circuits available that should make the task far easier than it once was.

What you're more likely to see are modifications of traditional induction motors which can make them more amenable to electronic speed control. You'll come across such things as dual stators, variable-frequency rotors, and internal speed sensors.

What's the bottom line? A lot of thought and time and effort has gone into induction-motor speed controls for several decades now, and nothing really useful has yet seen the light of day. Despite an incredibly big bag of nickels waiting for the winner.

I strongly urge you to try and hack this one. But don't expect any prompt or easy results. Needless to say, we here at **Radio-Electronics** editorial will be very interested in the first hackable, wide-range, and sanely priced quarter-horse induction-motor speed-control construction project.

Electric-motor resources

To get you started, I've put together some *electric-motor resources* for you in the resource sidebar this month. Here's a quick rundown...

One very good starting point is the $5.00 *Small Motor and Gearmotor* handbook from *Bodine*. *W.W. Grainger*, of course, is by far the leading wholesale distributor of just about any type of small motor. And your best source for electric motor hacking books remains *Lindsay Publications*.

Good surplus motor sources include *C & H Sales*, *Northern*, *JerryCo*, *Herbach and Rademan*, and *Fair Radio Sales*. Two higher-volume suppliers of smaller motors are *Molon* and *Fasco*.

As we've just seen, one international source for AC-induction motor-speed controls is *Asea Brown Bovari*.

Important trade journals involving motors include *Motion*, *PCIM*, *Machine Design*, *Appliance*, *Appliance Manufacturer*, and *Design News*.

Some of the more scholarly stuff comes down in either of the *IEEE Transactions on Energy Conversion* or their *IEEE Transactions on Industrial Applications*. For automotive motor uses, try the publications in the *SAE* library.

Uh, even though this is one of our longer resource listings, I've got a hollow feeling I'm missing several major and obvious motor hacking resources here. Something that you electrical types out there might be able to help us on.

So, for the first of this month's contests, let me know what I've left off the sidebar in the way of motor resources. They'll be all the usual *Incredible Secret Money Machine* book prizes, along with an all expense paid (FOB Thatcher, AZ), *tinaja quest* for two going to the best entry of all.

Or, as a second contest, just add to our ongoing induction motor speed control dialogue in some useful way.

As usual, be sure to send all your written entries directly to me at *Synergetics*, rather than over to **Radio-Electronics** editorial.

Dual digital potentiometer

A ways back (*Hardware Hacker*, January 1989), we looked at a *Xicor X9103* digitally controlled 100-step potentiometer. This dude was a single-channel device, had a permanent memory that remembered even when it was unpowered, and let you increment or decrement the potentiometer setting with a simple interface. But it had no way to sense the present setting, nor any way to jump to any setting without moving through all of the intermediate ones.

Dallas Semiconductor has just introduced a new DS1267 dual digital potentiometer chip that has strengths where the X9103 was weak, and vice versa. As Fig. 4 shows us, this one gives you two 256-step potentiometers in a single package in your choice of 10K, 50K, or 100K total resistance.

Those are *not* memory devices. They return you to a 50% "mid-wiper" position on power up and *must* get rewritten each time. As is becoming common on many new chips these days, there is a three-wire serial control provided, intended to interface with three computer port lines.

To set up your potentiometers, clock in seventeen data bits by using the CLK and DQ lines, while keeping the RST line high. Eight of those bits are for the first potentiometer, eight for the second, with the final bit being used to optionally cascade the potentiometer pair into a single potentiometer with 512 steps of resolution.

Drop the RST line to enter the new settings for the potentiometer pair. There's also a serial OUT that lets you read out the present settings or else cascade chips for such things as multi-band equalizers.

As long as RST remains high, your old setting gets saved. Thus, you can do 17 clocks to read out your existing settings, and 17 more to enter the new ones, without getting any noise or glitches.

The digital end of the chip works off your usual 0 and +5 volts. The analog end can be anywhere from 0 to +5 volts with a grounded VB substrate pin, or can be used over a −5 to +5 volt range with −5 volts on

NAMES AND NUMBERS

Burr-Brown
6730 South Tucson Blvd.
Tucson, AZ 85706
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CIRCLE 321 ON FREE INFORMATION CARD

Circuit Specialists
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Scottsdale, AZ 85271
(800) 528-1417
CIRCLE 322 ON FREE INFORMATION CARD

Dallas Semiconductor
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Dallas, TX 75244
(214) 450-0400
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GEnie
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Rockville, MD 20850
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Canoga Park, CA 91304
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your substrate pin. Thus, you can easily handle bipolar analog signals that go above and below ground.

Your maximum clock frequency is 10 MHz, which means you can upgrade your potentiometer settings as often as 580 kHz or so. Their series wiper resistance is typically 400 ohms, and you're allowed a maximum potentiometer or wiper current of one milliampere. Be sure to see the data sheet for additional specs and timing details.

For our third contest this month, just tell me what you would do with one or more cascaded dual digitally controlled potentiometers.

Making wavelets

There's a brand-new math revolution taking off that appears certain to profoundly change much of what electronics is and what it will be able to do. All the noise is over *wavelet theory*, an incredibly powerful new technique that promises to blow the

A New wave in applied mathematics
B. Cipra, *Science* 24 Aug 1990, pp 858-859.

New wave number crunching
C. Brown *E.E. Times*, 5 Nov 1990, pp 31-34

Video compression using 3D wavelet transforms.
A. Lewis, *Electronic Letters*, vol 26 no 6 pp 396-8.

Non-orthogonal wavelet representations in relaxation networks.
J. Daugman, *New Developments in Neural Computing*, pp 233-50.

A theory for multiresolution signal decomposition.
S. Mallat, *IEEE Transactions on Machine Intelligence*, v11-7 pp 674-93.

Wavelet transformation in signal detection.
F. Tuteur, *8th IFAC/IFORS Symposium*, vol 2 pp 1061-5.

Entropy reduction and decorrelation in visual coding.
J. Daugman, *IEEE Trans. Biomedical Engineering*, vol 36 no 1 pp 107-14.

Wavelet transformation in signal detection.
F. Tuteur, *ICASSP Speech Conference 88*, vol 3 pp 1435-8.

Complete discrete 2-D Gabor transforms.
J. Daugman, *IEEE Trans Acoustics & Speech*, vol 36 no 7 pp 1169-79.

Dispersive noise removal in t-x space.
Beresford-Smith, *Geophysics USA*, vol 53 no 3 pp 346-58.

Adaptive deconvolution by lattice filters.
S. Persoglia, Bulletin of Geophysics Theory, vol 27 no 107 pp 169-83.

A critique of seismic deconvolution methods.
A. Jurkevics, *Geophysics*, vol 49 no 12 pp 2109-16.

Statistical pulse compression.
E. Robinson, *IEEE Proceedings*, vol 72 no 10 pp 1276-89.

FIG. 5—SOME KEY PAPERS on the new wavelet math theory which is now revolutionizing just about everything in electronics.

200-year-old *Fourier* analysis, synthesis, and transforms completely out of the water.

Why worry about some obtuse new math theory? Well, first of all, because it's there. Second, because it's a sure fire winning topic for a school paper. And third, there's a lot of electronic doors about to suddenly get slammed in your face if you do not *quickly* pick up on exactly what wavelet theory is and what it can do for you.

Fourier analysis is, er—better make that *was*, a method of giving you a second way of looking at and dealing with electronic signals. Besides the intuitive or "real-world" *time domain*, Fourier techniques let you create a separate *frequency domain*. Things not at all obvious in the time domain become quite clear when they are in the frequency domain, and vice versa.

For instance, a square wave in the time domain is just a signal that keeps bouncing up and down between two levels. In the frequency domain, that same square wave can be shown to consist of an infinite string of sine waves. Specifically, you can build up a square wave from its fundamental sine wave, one third its third harmonic, one fifth the fifth harmonic, and so on up the line.

A few of the zillions of places that the frequency domain can become important include spectrum analysis, holograms, video-image compression, music synthesis, side-looking radar, picture deblurring, etc.

But the big problem with Fourier analysis is that everything was connected to everything else. Make even the slightest change, and you had to go back to square one and recompute everything. And while Fourier series is a great way to handle *most* of a square wave, it sure has troubles with the suddenly changing leading and trailing edges.

What wavelet theory does is let you selectively mix and match *wavelets* that can both deal *locally* with sudden changes and *globally* with averages and backgrounds. You can thus selectively apply all your math power precisely where it will do you the most good, and do so with speeds and efficiencies that were totally unheard of with traditional Fourier analysis.

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Figure 5 shows a few of the newer key papers involving wavelet theory. Start out with the *Science* and *E.E. Times* overview summary stories before you get into the heavy stuff. Let me know if you want to get into this any deeper.

New tech literature

The prices of bright-red visible laser diodes are starting to drop bunches, with a $45.00-in-singles unit now being offered by *Haltek Electronics*. They are the newer, high-visibility 630-nanometer wavelength, which is same as helium neon. Plan on $5.00 visible lasers within two years or so.

New data books for this month include that *Special Purpose Linear Devices* entry from *National*. Be sure to check out their LMC835 digitally-controlled graphics equalizer you'll find on page 1-227.

Three other new data books are the *Logic Databook* from the *Integrated Device Technology* folks, a new *Optoelectronics and Image Sensors* from *Texas Instruments*, and an *Integrated Circuits Data Book #33B Supplement* from *Burr-Brown*.

Static memory RAM specs cleverly disguised as baseball trading cards are being offered by *SGS* in an unusual promotion. Those are the same folks that previously gave you soup cans full of assorted free integrated circuits and soap boxes full of EPROM's.

Three interesting new surplus catalogs showed up in today's mail. They include *Circuit Specialists*, *International Micro Electronics*, and *H&R Enterprises* publications.

Turning to my own products, for the fundamentals of digital integrated circuits, be sure to check into my classic *TTL* and *CMOS* Cookbooks. And, as you can tell from my nearby *Synergetics* ad, we've now got *Hardware Hacker III* and *Ask the Guru III* reprints available, as well as some new PostScript books.

Also, a reminder that I do have this great new PostScript PSRT roundtable and library up on *GEnie*. You'll also find lots of *Hardware Hacker* and all of the *Midnight Engineering* reprints and other resources here.

Finally, I do have a new and free mailer for you which includes dozens of insider hardware hacking secret resources. Write or call for info. **R-E**

COMPUTER CONNECTIONS

Windows pains (and pleasures)

JEFF HOLTZMAN

Last month, we discussed how and why Windows is going to irrevocably change the PC industry. Now let's look at how to put Windows to use today.

You probably know that Windows can run in three different modes: Real, Standard, and Enhanced. Real mode should have been called Unreal mode, because it is so slow that it's unrealistic to expect anyone to use it. Real mode was created for marketing reasons, not technical ones. Windows will run on an 8088, and older applications will run under it. But you'd have to be crazy to want to. Even on a relatively fast (16-MHz) 386, real mode is *much* slower than the other two modes.

Technically, Enhanced mode is the most sophisticated. It allows you to run regular DOS applications onscreen in graphics mode, in simulated text-mode windows, simultaneously with regular Windows applications. For example, before I got a real Windows communication program (Crosstalk for Windows, discussed below), I used to run ProComm in a window, uploading and downloading files, while I worked in a Windows word processor. Technically, it worked; I was able to send and receive files at 2400 bps without error. However, keyboard response was extremely slow, and screen updates were distracting. If you've ever used Desqview, you know how it feels.

Another example of why enhanced mode is useful: Several years ago I wrote a TSR (terminate and stay resident) program for printing envelopes. On a word processor, I put the cursor on the address block of a letter, load up the LaserJet, press a hotkey, and out comes a nicely formatted envelope. When running in Enhanced mode, I can bring up the word processor (in the graphical simulated-text mode) and the TSR still works.

As for speed, I've seen benchmarks that show Enhanced mode to be about 15% slower than Standard mode (while running Windows, not DOS, programs), but in use it's very hard to notice much difference.

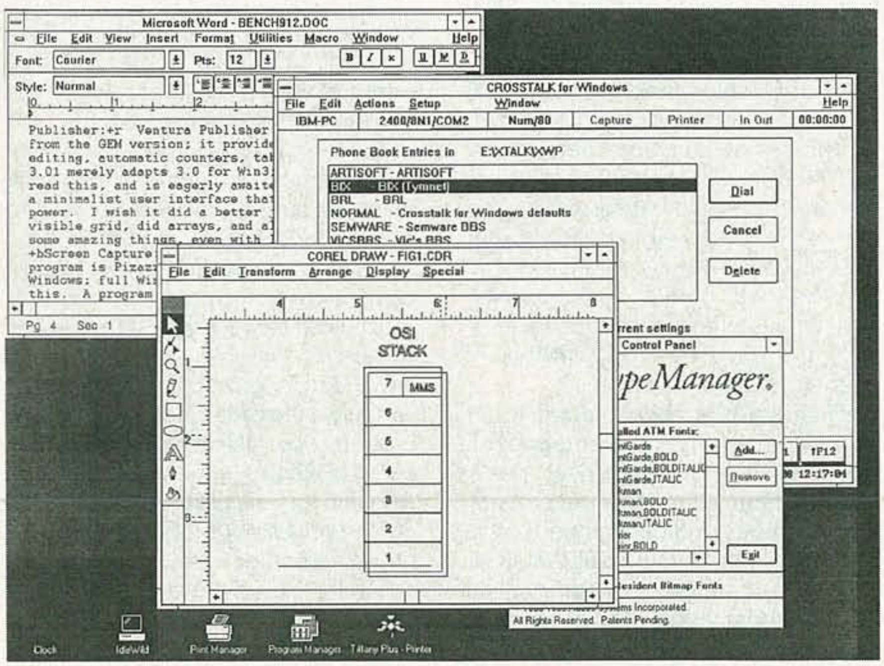

FIG. 1—HERE IS WINDOWS AT WORK, showing a few of the best Windows products.

Enhanced doesn't work for me, however. The problem manifests itself as an occasional keyboard lockup, seemingly without cause. Only the keyboard dies; I can still use a mouse to save files and shut down Windows. Then it's time for a cold boot. Note: The problem happens only in Enhanced mode, not in Standard mode or DOS.

It first happened when I installed a scanner-interface card. In tracking down the problem, I spoke with Microsoft and the PC manufacturer to no avail, and ended up locating the card in another computer. However, after installing a Lantastic network interface card, the problem resurfaced. This time, however, the adapter had to remain in the computer. Trying to resolve the problem, I have spent hours on the phone with Microsoft, the PC manufacturer, and the manufacturers of the interface cards. In the process I've received several BIOS upgrades, hints about keyboard settings in Windows' initialization files, and lots of finger pointing, all to no avail.

The only solution is to operate exclusively in Standard mode. I lose my envelope printer, the ability to multitask DOS apps, and the ability to run them in windows. In standard mode, when you make a DOS app current, Windows clears the screen, swaps some stuff to disk, and then lets the DOS app do its thing. The swapping process is slow and distracting.

On the other hand, standard mode is more than bearable when running only Windows applications. For example, you can start a 2400-bps file transfer and go do something else. I regularly transfer megabytes of data while working undistracted in Word for Windows, Corel, ToolBook, etc.

Font issues

I love my LaserJet II, but sometimes wish I'd never bought it. For the amount of unbillable time I have wasted on soft font problems, I could have bought a PostScript printer. Windows has a mechanism for installing soft fonts, but soft-font installation programs have a habit of really messing up WIN.INI. Several times the file has gotten so badly screwed up that I had to re-install Windows and some apps from scratch. And don't forget about dedicating 10 or 20 *megabytes* of space just to store the common sizes of half dozen fonts.

That said, I've found Bitstream fonts to be the most reliable and of the highest visual quality. They are, however, expensive compared with the fonts sold by some vendors, and they're also limited as to special effects. The best package I've found for generating wild headline fonts and the like is MoreFonts, from MicroLogic Corp.

Flash: a copy of Adobe's ATM (Adobe Type Manager) just arrived. It is the equivalent of putting a PostScript font engine inside Windows itself, and because fonts are scaled as they are needed, disk storage is minimal—about a megabyte for 35 fonts, each of which can be scaled as needed to any reasonable size. Of course what you gain in storage space, you lose in processing speed; file printing and screen updates take longer because fonts must be built as they are needed.

To alleviate that problem, ATM reserves a user-selected amount of memory for a font cache; figure at least 100K; 500K works, and for documents with lots of font changes, a megabyte is better. The basic ATM includes Times, Helvetica, Courier, and Symbol fonts; at about $100 list, it's a steal. **Note:** ATM does its tricks with PostScript printers, LaserJets, and most common dot-matrix devices (Proprinter, Epson, etc.), but only with text; it can't print PostScript graphics. The Plus Pack adds 22 additional fonts, rounding out the typical PostScript complement.

Windows applications

I'd like to be able to operate exclusively in Windows, but cannot do so yet. There are extremely powerful programs in some areas, and a complete dearth in others. What I miss most is a decent file manager—Windows' own file manager is awkward and limited. It doesn't even show the amount of free and used space on a disk drive. What's needed is a Windows version of Magellan, probably the best DOS file manager on the market.

Even so, the basic Windows package is surprisingly powerful. Several of the major applications—Write, Paint, Terminal—are as powerful as decent stand-alone packages of just a few years back. In a way, the Windows apps really are more powerful than the old stand-bys, because they work together, smoothly and efficiently. You can use Terminal to transfer files in the background while working elsewhere. You can create attractive drawings using Paint and paste them directly into write. Both Paint and Write will use whatever fonts you have installed on your system. I can see Windows 3.0 being used by anyone who doesn't need the utmost in power.

The following are my picks for best Windows products.

Word processing: Word for Windows. Allows multi-file editing, multiple views into the same file via (what else) panes; a macro language as powerful as some versions of BASIC; efficient style sheets; the ability to load and save files *directly* in WordStar, WordPerfect, and other formats; outlining; graphics import and printing. Could substitute for desktop publishing in many circumstances, but it is indisputably large and slow.

Telecomm: Crosstalk for Windows. Extremely powerful script language for automated telecomm sessions. Runs beautifully in the background; minimize it to an icon, and it displays percent of transfer complete, beeps when done.

Utilities: hDC's FirstApps. Provides real-time memory-usage display, ability to save complete

ASK RE

continued from page 16

troller is hard enough even when you have all the documentation for the computer. To try doing the same thing with a completely unknown machine that has no supporting paperwork and (so you say) no I/O ports strikes me as an exercise in futility.

How you expect to control lights using a machine with no I/O ports is beyond me. And adding them to a machine for which you have no paperwork, and built by a company you can't get in touch with is a job only Sisyphus would want.

If you've got the urge to build a home controller, you'll be much, much better off spending five hundred bucks or so for a PC clone and using that as the basis for the project. You'll have a known machine with real ports and languages available to write the software.

I don't like to discourage anybody from doing whatever project they set their minds to, but yours is only slightly less difficult than striking a match on a bar of soap. **R-E**

ITEMS DISCUSSED

- Adobe Type Manager ($99), Plus Pack ($198), Adobe Systems Incorporated, 1585 Charleston Road, P.O. Box 7900, Mountain View, CA 94039-7900. (800) 83-FONTS.
CIRCLE 41 ON FREE INFORMATION CARD

- MoreFonts ($149.94), MicroLogic Software, 6400 Hollis Street, Suite 9, Emeryville, CA 94608. (415) 652-5464.
CIRCLE 42 ON FREE INFORMATION CARD

- ToolBook 1.0 ($395), Asymetrix Corp., 110 110th Avenue NE, Suite 717, Bellevue, WA 98004. (800) 624-8999, (206) 462-0501.
CIRCLE 43 ON FREE INFORMATION CARD

- Windows 3.0 ($149), Word for Windows 1.1 ($495), Entertainment Pack ($39.95), Microsoft Corp., 17011 NE 36th Way, Box 97017, Redmond, WA 98073-9717. (206) 882-8080.
CIRCLE 44 ON FREE INFORMATION CARD

- *Windows 3 Companion*, Lori L. Lorenz and R. Michael O'Mara ($27.95), *ToolBook Companion,* Joseph R. Pierce, ($27.95), The Cobb Group/Microsoft Press, One Microsoft Way, Redmond, WA 98052-6399.
CIRCLE 45 ON FREE INFORMATION CARD

- FirstApps ($99.95), hDC Computer Corporation, 6742 185th Avenue NE, Redmond, WA 98052. (206) 885-5550.
CIRCLE 46 ON FREE INFORMATION CARD

- CrossTalk for Windows ($195), DCA, 1000 Alderman Drive, Alpharetta, GA 30202-4199. (404) 442-4000.
CIRCLE 47 ON FREE INFORMATION CARD

- Ventura Publisher Windows Edition ($895), Ventura Software, Inc., 15175 Innovation Drive, San Diego, CA 9212. (800) 822-8221.
CIRCLE 48 ON FREE INFORMATION CARD

- Corel Draw ($XXX), Corel Systems Corporation, 1600 Carling Avenue, Ottowa, Ontario, Canada K1Z 8R7. (613) 728-8200.
CIRCLE 34 ON FREE INFORMATION CARD

- Pizazz Plus ($149), Application Techniques, Inc., 10 Lomar Park Drive, Pepperell, MA 01463. (508) 433-5201.
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Windows environment and reload later. Good alarm clock too. Updates will provide file manager and Lap-Link type communications.

Desktop Publisher: Ventura Publisher 3.0 is pretty much a straight port from the GEM version; it provides excellent table and equation editing, automatic counters, table of contents, indexing. PageMaker 3.01 merely adapts 3.0 for Win3; PM 4 is due out around the time you read this, and is eagerly awaited.

Illustration: Corel Draw has a minimalist user interface that continues to amaze me with its power. I wish it did a better job with small font sizes, displayed a visible grid, did arrays, and allowed symbols.

Screen Capture: My unabashed favorite screen-capture and print program is Pizazz Plus. The current version only partially supports Windows; full Windows support should be out by the time you read this.

Development Environment: ToolBook. For user-interface prototyping, there's nothing like it. Extremely powerful and fun.

Games: I'm not much of a gamester, but I've seen a few Windows games that are attractive. Microsoft has released an Entertainment Pack with a version of Tetris, several card games, a screen blanker, and more. Also, I've collected a few shareware games (Chess, Checkers, a Tetris clone) that I'll post on the R-E BBS.

Books: Microsoft's *Windows User's Guide* is infinitely better than previous versions, but is really a reference guide. The *Windows 3 Companion* provides a view from the user's perspective. For ToolBook programming, the *ToolBook Companion* in the same series is quite useful.

Conclusion

If I complained about Windows, it's only because it's worth complaining about—I see plenty of bad software that isn't worth the magnetic ink it's printed on. In spite of my complaints, I really like Windows. The program is not perfect, but it got a whole lot better with version 3.0. This version is more than just a passing fad because it represents not just a new way of doing things, but a better way. Try it—you really will like it. **R-E**

AUDIO UPDATE

The Boston Sound: Part II

LARRY KLEIN

Last month we traced the intertwined history of some of the important New England-based loudspeaker manufacturers. Without exaggeration, it can be said that those companies established new technical standards for home loudspeakers. In general, their products were smoother, had wider range, and had far less coloration than either previous designs or those of most of their competitors on the West Coast. Although I covered only the most prominent New England companies and designers, I'm sure that there are others who made contributions that also advanced the state of the speaker art.

As discussed in last month's column, one of today's leading manufacturers of high-quality speaker systems is Boston Acoustics. Last fall I had the pleasure of visiting BA's new, highly automated plant and spending the day with the president of the company, Andy Petite. In the course of our conversations, we touched on a number of issues and matters that are of concern to anyone interested in how loudspeakers are designed and manufactured—and particularly what makes them sound good. What follows is a random selection of Andy's views, somewhat condensed and paraphrased.

• As you know, the crossover networks found in today's speakers range from the incredibly complex to the surprisingly simple. We try to design the simplest possible crossover that will do the job in a particular system. Many of the components that you see in complex crossovers are in there to compensate for the deficiencies of the system's drivers. For example, if you design a woofer with a smooth response at the crossover-frequency area and above—which is the right thing to do with respect to overall performance—you can considerably simplify your crossover network. Not only does that save money, but it also minimizes power losses and provides a smoother impedance curve for the amplifier to drive.

• In production, our assembled crossovers are checked against a reference network to a tolerance of ±0.5 dB. Aside from helping ensure the frequency performance of the system as a whole, that procedure eliminates the crossover assembly as the cause if system response is not up to spec in the final checkout. That's important because, while it's easy to replace drivers if necessary, it's a real pain to get to and fix a crossover once it's finally installed in an enclosure.

• We usually prefer to use acoustic-suspension woofers rather than bass-reflex or vented designs for two reasons: The woofer in a vented system is inherently uncontrolled below its low-frequency cutoff. The very low frequencies generated by turntable rumble and tone-arm resonances can cause excessive cone excursions in the infrasonic area and, therefore, intermodulation distortion at audible frequencies. Of course, as LP's fade from the marketplace, the sonic problems produced by the equipment that is used to play them will also disappear.

Another difficulty has to do with the way a woofer ages. Its suspension becomes more compliant over time, which can mistune a critically tuned vented system. In contrast, an acoustic suspension design is relatively immune to bass-response changes through woofer aging. Both of those problems are a lot less severe these days, although we question how well small and/or inexpensive vented systems react to the strong low bass found on many CD's.

FIG. 1—BOSTON ACOUSTICS' SW10 powered subwoofer features a 100-watt internal amplifier with electronic crossover.

• When it's technically and economically feasible to do so, there's a definite advantage in directly powering a woofer or subwoofer. By electronically controlling the characteristics of the signal fed to the woofer you can easily achieve very low frequency crossovers, response curves, and very steep rolloffs that would be quite impractical with passive inductive/capacitive networks. That allowed us to use a vented system for our powered subwoofer—which has the advantage of reduced excursion at low frequencies compared to an acoustic suspension—without running into the infrasonic problems I just mentioned.

You can also avoid many types of acoustic problems with non-powered vented designs by designing them for a good low-bass response. If the cutoff frequency is made low enough, the speaker will be controlled properly down to the lowest musical frequencies.

• There's a common assumption that the larger the woofer in a system, the better the bass. But for a large woofer to be effective it must be installed in a large enough enclosure. For example, if you put a 12-inch woofer in a 1.5-cubic-foot enclosure, the small volume of the enclosed air raises the system resonance, and the bass response decreases. To restore the bass you have to add more mass to the cone, and then use a heavier magnet to maintain efficiency. That is not a very cost-effective process. The only advantage of a large cone

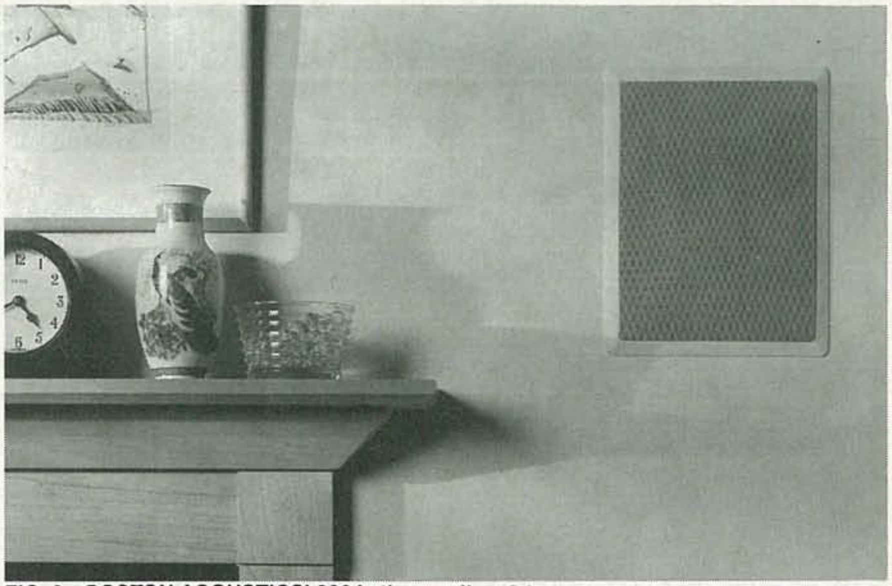


FIG. 2—BOSTON ACOUSTICS' 380 is the smallest 8-inch, two-way, flush-mount speaker system available.

woofer is a somewhat higher maximum output level—assuming that it's installed properly in an adequately sized box. If you can get the loudness levels you want with smaller cones, you are better off using them—in pairs if necessary. Using small cones in pairs has definite advantages.

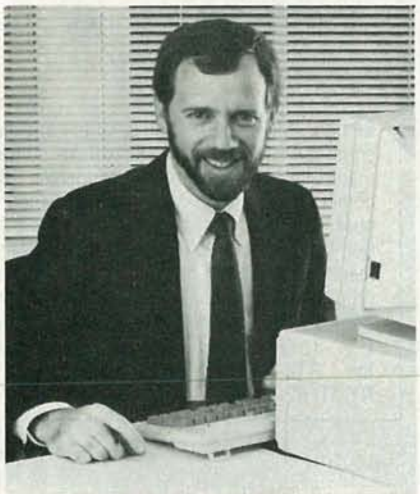
• Some of the basic enclosure ground rules change when you're dealing with car-stereo speakers or speakers meant to be flush mounted in a wall. In both cases, we design the woofers with a fairly stiff-suspension—which makes them more rugged—because their free-air resonance is not shifted upward to any degree by the mounting. In general, there is not a significant variation in the rear loading seen by woofers in most car installations. We get a very good correlation between tests in a car door or rear package shelf and tests done with the woofer mounted on a simulated infinite plane baffle—in other words, a large sheet of plywood.

• Over the years I've observed that there is a real dichotomy between the views of the empirical and the theoretical speaker designers. For example, for years the academic theorists would give loudspeaker-design papers at various Audio Engineering Society conventions. Those were frequently greeted by snickers from the designers in the room, because it was clear that the theoreticians had not tried out their ideas by designing and building systems. A favorite example: One particular professor of acoustics had for years been giving papers on phase-correct crossover networks. At one point he and a grad student decided to build a speaker system based on the professor's theories. It turned out that the system didn't work very well because real-world drivers have a complex impedance, quite unlike the resistors on which the design calculations had been based. The next year his paper was based on his work with real world drivers.

• Except when dealing with audiophiles, speaker designers have always had a tough job satisfying interior decorators, architects, and others who would prefer that speakers be heard but not seen. Electronic woofer control has made possible substantial reductions in cabinet size while still realizing adequate bass. However, the laws of physics put a limit on how loudly a very small woofer can play and how low it can go even with everything optimized. Built-in wall speakers and subwoofer/satellite systems are two variable solutions to make speakers invisible, or at least unobtrusive in the home or workplace.

A final word: Andy Petite's views on speaker design should be particularly interesting to anyone who likes to know the technical thinking and design process behind commercial audio products. As the proof of the pudding is in the eating, so too the test of any design approach is the performance of the product. To my ears, Andy's thinking—and design approach—make an exceptional amount of sense. **R-E**

How to build a high-paying career, even a business of your own, in computer programming.



RICK BRUSH,
NRI PROGRAMMER/ANALYST

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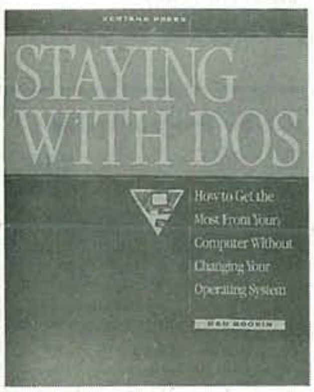
STAYING WITH DOS: GETTING THE MOST FROM YOUR COMPUTER WITHOUT CHANGING YOUR OPERATING SYSTEM; by Dan Gookin. Ventana Press, P.O. Box 2468, Chapel Hill, NC 27515; Tel: 919-942-0220; Fax: 919-942-1140; $22.95.

Even though today's sophisticated computers and applications software are increasingly demanding, there's a good chance that you can get by with DOS, and not have to upgrade to an expensive new operating system. This book can help you decide whether you should stay with DOS as it is, use other products to enhance it, or move on to a new operating system. It emphasizes that DOS can remain a viable alternative to OS/2 or Unix, and explains how users can get more memory, more speed, better graphics capabilities, and even do multi-tasking and networking with their old operating system. A chapter on Windows 3.0 and other graphical user interfaces provides a detailed overview of how to use those to make DOS perform like the newer, more powerful operating systems, without having to invest money and time in buying and learning to use a new operating system. Convenient checklists help readers evaluate their needs, and appendices provide detailed buying information on new products that help boost the speed and power of DOS.



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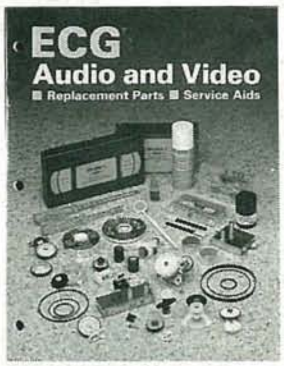

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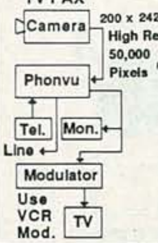

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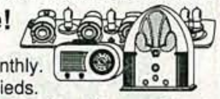

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TA-50C	Multi-Purpose Melody Generator ▲	13.65	18.71
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TA-300	30W Multi-Purpose Single Channel Amp. ▲	20.00	29.00
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TA-377A	Hi-Quality FET Stereo Pre-Amp. ▲▲▲	59.95	75.00
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TA-477	120W Mosfet Power Mono Amp. ▲▲	68.00	85.00
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TA-820A	60W + 60W OCL DC Pre-Main Stereo Amp. ▲▲	40.39	49.37
TA-1000A	100W Dynamic Class "A" Main Power Mono Amp ▲▲	59.69	80.58
TA-1500	100W X 2 Class "A" DC Stereo Pre-Main Amp. ▲▲▲	73.70	95.81
TA-2200	Fet Super Class "A" DC Pre-Amp. ▲▲▲	47.70	58.24
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TA-2500	HQ Pre-Amp w/10 band graphic equalizer ★		68.80
TA-2800	HI-FET IC Pre-Amp w/3 way tone control ▲▲	48.90	63.57
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TY-35	FM Wireless Microphone ▲	11.25	
TY-36	AC/DC Quartz Digital Clock ▲	19.00	26.20
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LG-1924	4"	19"	11½	TA-802, TA-820A, TA-1500,TA120MK 2, TA-800, TA-1000A	32.80
LG-1925	5"	19"	11½	TA-477, TA-800, TA-1500, TA-1000A, TA-3600	35.80
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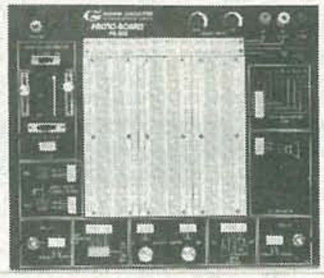

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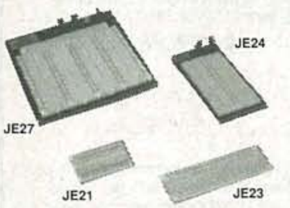

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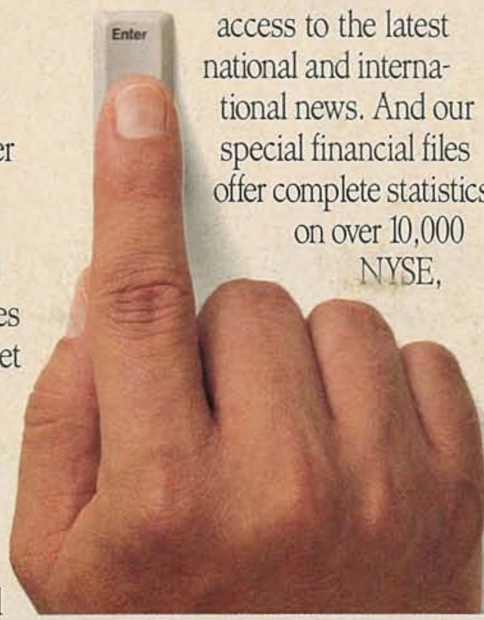

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