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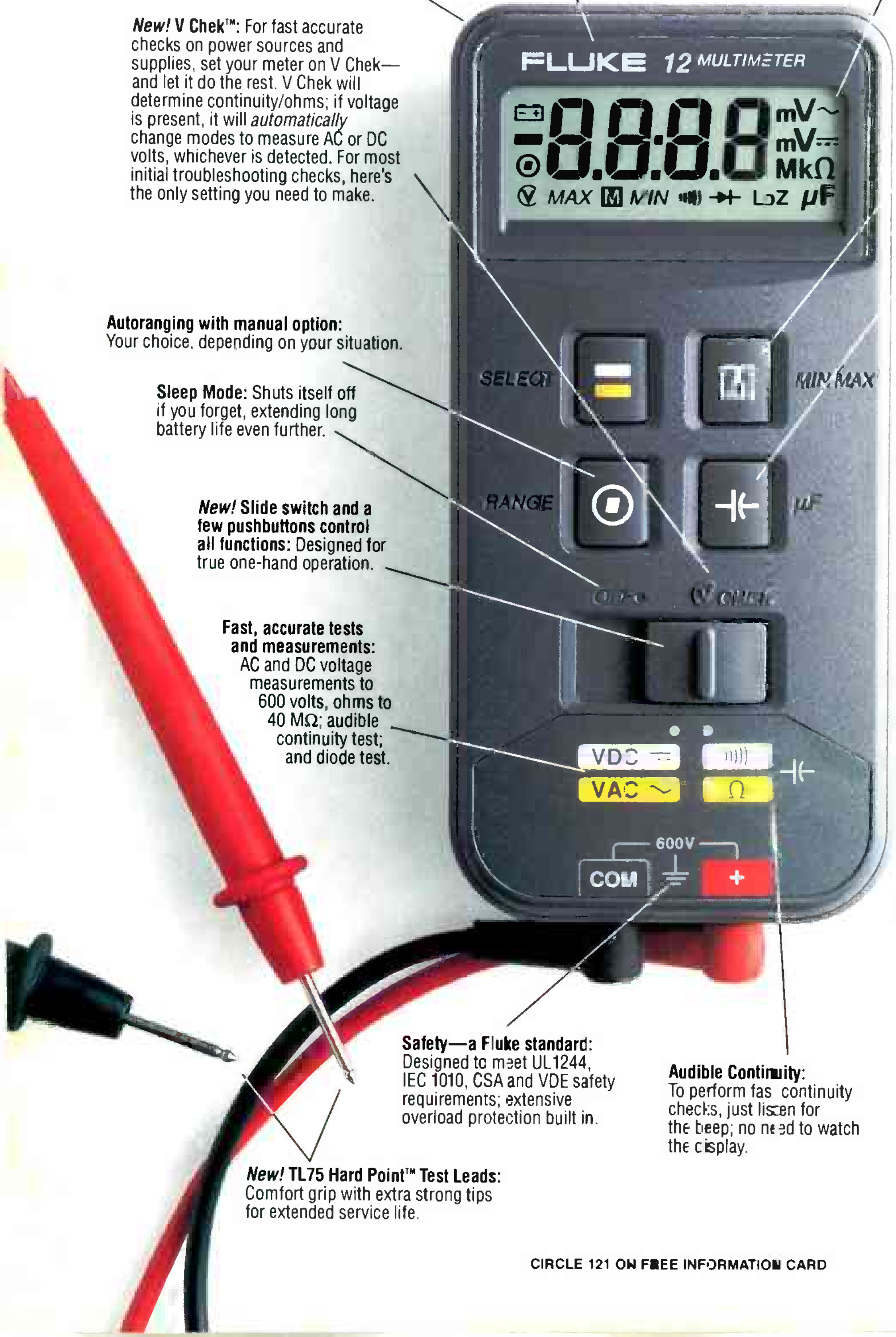

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Vol. 63 No. 5

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DEPARTMENTS

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AND MORE

ON THE COVER

The digital multimeter is the backbone of the modern test bench, and today's DMM's provide better performance and more features than ever. How do you go about selecting the instrument that best suits your testing needs? Your first step should be to read our Buyer's Guide from start to finish. You'll learn how DMM's work, and how to put them to work for you. Read about the latest models from the major manufacturers. Once you know how they differ—and what those differences mean to your work and to your wallet—you'll be ready to make an informed decision. Turn to page 31 for the details.

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POSTMASTER: Please send address changes to RADIO-ELECTRONICS, Subscription Dept., Box 55115, Boulder, CO 80321-5115.

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Radio-Electronics is indexed in *Applied Science & Technology Index* and *Readers Guide to Periodical Literature*.
Microfilm & Microfiche editions are available. Contact circulation department for details.

Advertising Sales Offices listed on page 94.
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WHAT'S NEWS

A review of the latest happenings in electronics.

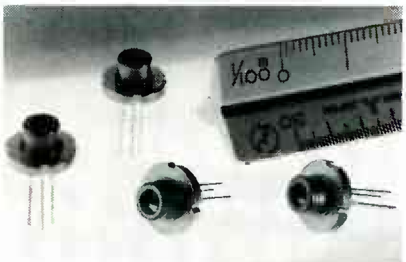
High-power semiconductor laser

A series of reliable, 150-mW laser diodes that oscillate at wavelengths between 800 and 870 nanometers has been developed at Sanyo Electric Company's Semiconductor Research Center in Allendale, NJ. The high-powered lasers are expected to enhance processing speeds in erasable optical-disc memories and image-processing equipment and to be used in satellite communication. In addition, they can be used as pumping sources for blue laser-light generation when they are used with a second harmonic generation (SHG) device.

Blue-spectrum lasers with sufficient power are critical to information-intensive applications as long-playing, high-definition, moving-image video storage as well as for full-color image processing. An SHG device doubles the frequency of an infrared-spectrum laser when the light from the laser passes through a special crystal in the device, halving the wavelength of the beam and moving it from infrared to visible blue on the color spectrum. A blue laser's beam illuminates about 25% of the area on a receptor surface—quadrupling the recording density on a laser disc and significantly improving resolution in laser image-processing applications. The Sanyo development overcomes previous obstacles to blue-laser light generation by providing a high output power to compensate for the power loss inherent in the SHG process. The 860-nm lasing wavelength can be produced for phase-matching conditions at room temperature using a typical SHG device.

The laser diodes are fabricated using a relatively uncomplicated two-step, liquid-phase epitaxy process. Adjustments made to layer thickness, lasing cavity length, and the crystalline active layer insure reliable high-power output and suppress temperature rise, which helps prevent degradation or catastrophic damage. Stable continuous wave operation at 150 mW has been confirmed for more than 5000 hours at room temperature, and for over 2000 hours at 50°C. PIN photodiodes for monitoring light-output are built into the assembly.

Three models operating at 800, 830, and 860 nm will initially be produced, with volume production expected by mid-1992.



OSCILLATING AT WAVELENGTHS between 800 and 870 nm, Sanyo's high-power lasers will have applications in optical-disc memories, satellite communications, and blue-laser light generation.

Safer gold electroplating method

A process allowing intricate gold electroplating on microelectronic devices, developed by Researchers at Sandia National Laboratories (Albuquerque, NM), uses a plating solution that is safer than the conventional cyanide-based solutions.

While gold has many properties that make it attractive for use in manufacturing microelectronics—high corrosion resistance, high conductivity, high melting point, and ability to form good electrical contacts—standard gold-plating solutions can release large amounts of poisonous cyanide gas if the solution becomes too acidic. The cyanide-based solutions are so dangerous that the EPA has classified them as "acutely hazardous;" therefore, they require special safety precautions.

Sandia has applied a gold sulfite solution, which was developed in the 1970's and has been used since then for protective coverings but not for circuitry, to form precise gold patterns for semiconductor devices. The method has been successfully used to plate extremely fine lines on substrates. Sandia researchers have also used the sulfite solution, which contains no cyanide and is not dangerous, to make miniature gold bridges that form crossovers on gallium arsenide substrates. The crossovers allow conductors to cross on the surface of the IC without touching or shorting out adjacent conductors. Tests have shown the plating efficiency to be close to 100% in such applications, and the plated gold's density approached that of pure gold.

Transmission-line impedance measurement

Beckman Industrial has been awarded a patent for developing a time-domain reflectometry (TDR) technique for the accurate measurement of transmission line impedance. The technique has been incorporated in the company's model TMT-1 transmission media tester, which is used to test and certify LAN and telecom physical layer cabling systems.

TDR could be described as "cable radar"—an electrical pulse is sent along the LAN under test and cable faults (impedance changes) reflect some of the energy back to the TDR where an associated processor plots it in a display or graph as a waveform. Traditional TDR techniques are plagued by "cable dribble-up" or impedance rise, where the fundamental impedance of the cable under test appears to increase along the length of the cable. Beckman's measurement technique correctly measures the impedance along the entire length of cables under test. **R-E**

VIDEO NEWS

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

DAVID LACHENBRUCH

• **Multimedia.** That single word seems to be the hottest topic in both the television and the computer worlds today. With the development of digital video and bandwidth compression, the computer and the TV set are coming increasingly close together, and there are many forecasts that the two will eventually merge. Bets are even being placed as to which will be the survivor.

Of course, that is a ridiculous question, reminiscent of the days when people talked about the computer-controlled home, in which a central computer operated the washing machine, refrigerator, stove, dishwasher, furnace, and everything else. As we all know, that never happened because microprocessors, or mini-computers, became so cheap that they could be incorporated into the appliances themselves.

Since computers and television sets are used in different rooms of the house, the speculation as to which will survive reflects a misunderstanding of the potential of digital technology. We would hope that the computer and the TV set will speak the same language so that their software can be intermixed and combined, but it's ridiculous to think we will attach a keyboard to our TV set of the future to write a nasty letter to the fiber-optic company for overbilling us, while the rest of the family is deprived of watching their favorite sitcom. By the same token, who will want to sit at the 12-inch computer monitor to watch the Olympics? Certainly not anyone who has the option of a 100-inch wall-screen (which, incidentally, has no value in word processing).

• **TV-Computer Compatibility.** Capitalizing on the hope that the TV set and the computer will be able to speak with one another without too much translation is Thomson Consumer Electronics (RCA and GE brands in the United States). Thomson says that all of its efforts in advanced TV will be focused on standardization with computer multimedia. Thomson recently won the contract to supply the digital-compression system and consumer receiving boxes and antennas for Hughes Communications' 100-channel high-power direct-to-home DirecTV satellite system, due to start in 1994. Thomson is also participating in a proposed digital HDTV system with Philips, NBC, Sarnoff Research Center, and Compression Labs. Their HDTV system and Thomson's satellite transmission signal use a standard based on the Motion Picture Experts Group (MPEG) digital-compression formula for full-motion video on a CD-ROM disc. Thomson calls its system "MPEG + +," because it has much higher resolution than the current MPEG standard. Actually, the MPEG + + system is one of 32 different proposals for a movie-quality digital-compression system being considered for the title of MPEG 2" standard.

Thomson notes that it expects the MPEG + + system DirecTV to be directly compatible with multimedia systems, computers, video recording systems of the future, and all other encoded digital-compression media. They don't say what will happen if MPEG doesn't choose MPEG + + for MPEG 2.

• **How Far Off?** Although we're hearing optimistic forecasts that the multimedia age is upon us, one major Japanese manufacturer doesn't see it that way. Toshiba, which, with C. Itoh and Company, paid $1 billion for part of Time Warner's TV-related business, says its preparing for the multimedia age, but doesn't agree that it's just around the corner. Rather than go off chasing a nonexistent standard, they prefer to wait for the industry to set a standard. Says Kojo Hase, senior manager of Toshiba Media and Communications Group, " Our dream is a five-inch disc with 120 minutes recording and playback time, erasable and with high-definition quality. A higher density disc and the next MPEG standard for full-motion [movie quality] video will provide this. But the standards negotiations are only beginning, and there are 32 contenders. There cannot be a standard until 1995."

Asked about CD-I, now on the market and hailed by its principle sponsor, Philips, as a success, Hase said, "We do not think that CD-I is fully interactive. The fact that there are only around 50 titles suggests that the tooling is wrong, that the platform is not sufficiently flexible. We are studying very carefully and asking what is the right material. Certainly not encyclopedias. We need something sparkling that makes people say I must have it'."

• **Small Camcorders Dominate.** Last year, 60% of all camcorders sold in the U.S. were "compacts"—that is, 8mm or VHS-C. That is an increase from just over half in 1990 and only 37% in 1989. The figures are supplied by the Electronic Industries Association (EIA), which doesn't break down the compacts by format, but a good estimate is that 8mm won by a large margin, comprising 63% of all compacts and 43% of total camcorder sales, compared to 32% full-size VHS and 25% VHS-C.

• **Ghostbusting Winner.** As we go to press, the National Association of Broadcasters has declared a winner in its field tests of TV ghost-canceling systems (**Radio-Electronics**, April 1992). It is the system developed by Philips. All five of the proposed systems require that the TV station transmit a pilot signal during the vertical blanking interval, and therefore FCC approval is required. Action on a standard system is expected as early as June. **R-E**

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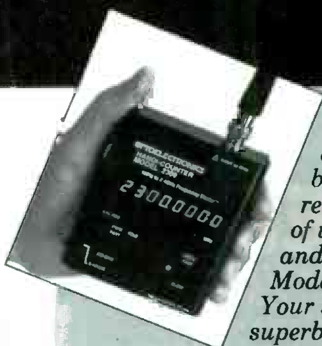

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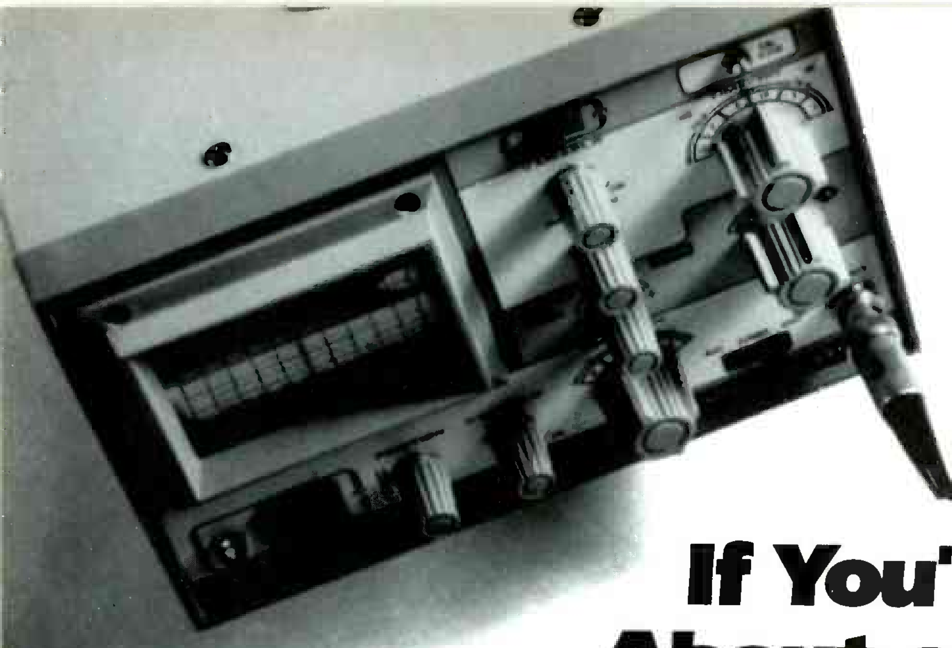

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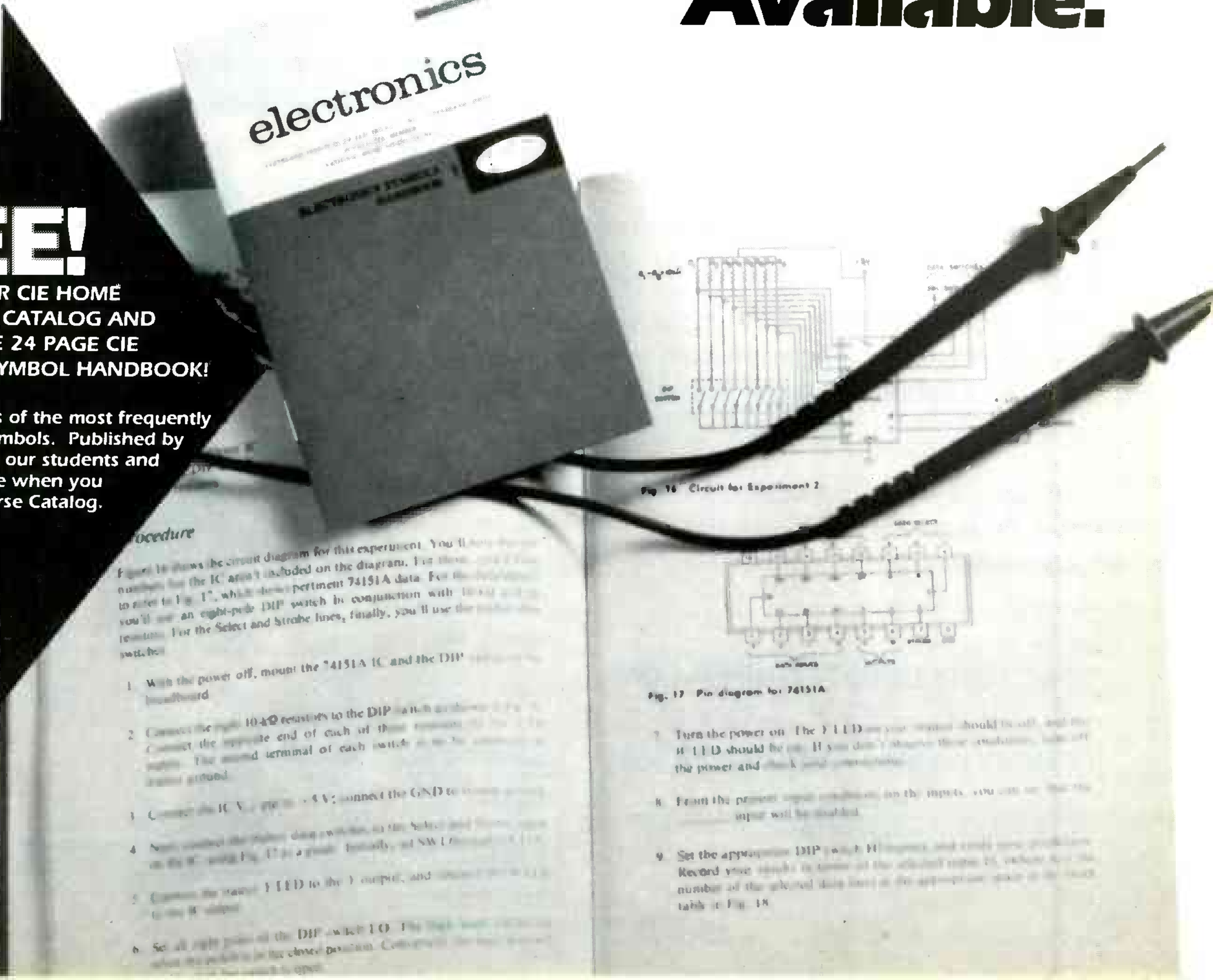

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SIMPLE CHARGER

I've been trying to come up with a battery-charger circuit that can maintain an older alarm system. It has two 12-volt 1.2-AH batteries connected in series. I'd like something that charges them in about two hours and then drops the charging current to a trickle charge. I don't need a lot of bells and whistles, but a having a charge/discharge indicator would be nice. Got any tricks up your sleeves that can help me out?—C. Peterson, Van Nuys, CA

It seems that this sort of request shows up every year. Even though rechargeable batteries, of various chemistries are in common use just about everywhere, there's a real shortage of intelligent charging circuits. I ran across the problem a few years ago and designed the circuit in Fig. 1. It has all the features you asked about and can be adapted for use with a wide range of batteries.

The circuit has two basic parts. The first monitors and controls the charging of the batteries and the second monitors the amount of charge left in the batteries when they are being used to power the circuit.

When you're recharging a battery, the most important choice is the value of the current-limiting resistor. Too large a value will result in no charging action, and too small a value will allow so much current to run through the batteries that they'll either be damaged or, if you're not lucky, be destroyed.

The PNP transistor has its base-emitter junction sitting across the current limiter and, when current flows through it, a voltage drop appears across the resistor. That causes current to flow through the collector-emitter junction of the transistor and lights the LED to show that the battery is charging.

As the battery voltage increases, the battery's impedance increases and the current flow gets less and less. That results in a constantly lowering voltage drop across the resistor, and the LED will get dimmer and dimmer until it finally goes out completely. If the intensity of the LED doesn't change, that's giving you some good information as well. Constant high intensity means the batteries aren't taking a charge, and a low intensity (when you first plug in the charger) means the batteries were already charged.

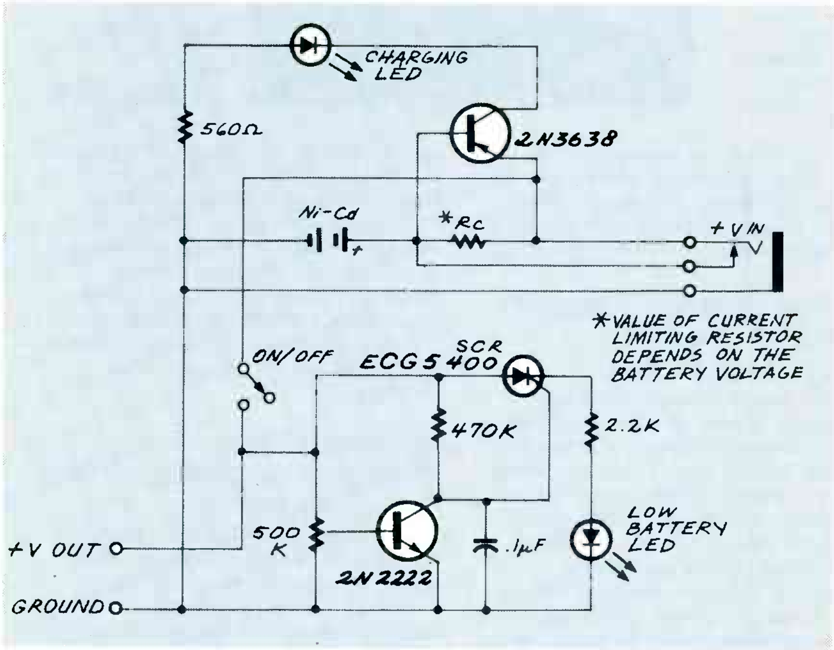

FIG. 1—THIS "INTELLIGENT" CHARGING CIRCUIT can be adapted for use with a wide range of batteries. One section monitors and controls the charging of the batteries and another section monitors the amount of charge left in the batteries when they're being used to power the circuit.

The second part of the circuit monitors the charge on the battery while the batteries are being used. The full battery voltage is put across the potentiometer and a certain value appears at the potentiometer's wiper. The NPN transistor is set up as a switch and, as long as the voltage at its base is high enough to keep it turned on, the collector-base junction conducts and keeps the collector at close to ground level.

When the battery voltage falls below a level determined by the potentiometer setting, the transistor turns off and the battery voltage appears at the collector. That triggers the SCR and lights the LED to warn you that the battery has to be recharged. The SCR latches and the LED stays lit until you turn off the power.

The critical element in the monitor circuit is the setting of the potentiometer, so you should use a multiturn unit. The circuit can be calibrated by hooking it up to a variable power supply and setting the voltage to the value you want for the trigger voltage.

The schematic shows the on/off switch for the circuit being powered and uses the single-pole, single-throw switch in the jack to change the power source from the batteries to the charger. If you trace through the connections, you'll see that the charger recharges the batteries and powers the circuit at the same time.

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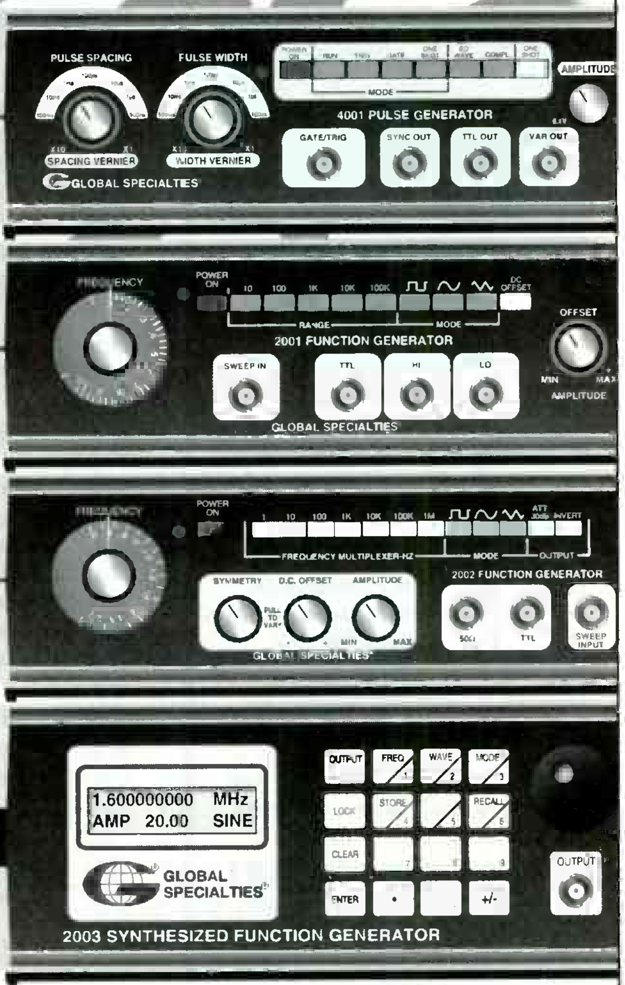

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DRIVEWAY ALARM

I have a summer cabin that's located at the end of a long driveway and I'm looking for some way to have an alarm that goes off when a vehicle pulls into the driveway. There are animals around so a photoelectric cell isn't practical. Because there are sensing circuits used on highways all the time, there must be a simple and reliable way to get the job done. I've been toying with the idea of an RF-based circuit that has coils under the road and uses the presence of a vehicle to transfer a signal from one coil to another. If you have any ideas, it would help me a great deal.—D. Ingebright, Seattle WA

I have a house in the country and was faced with the same problem a few years ago. I have to admit though, that the idea of solving it by burying coils in the driveway never occurred to me. Maybe that's because the mere thought of the work involved in digging up part of the driveway just seems like too much effort. The method I used is a lot easier, much more straightforward, and can be done without having to use a shovel.

I contacted the local road maintenance people, and bought a length of the same sort of wire they string across the road when they want to do a traffic count. It's just two lengths of wire, separated by foam, and sealed in a tough rubber overcoat. When a car goes across it, the weight compresses the foam and the two wires inside the cable touch each other—a simple on/off switch. I don't know who makes the stuff, but I'd be willing to bet you can get a length of that wire the same way I did.

Some of the road departments use a different detection method in which the cable they lay across the road is really nothing more than a hollow tube filled with air. When a car crosses over it, the increase in pressure forces an air switch to close. Different method, same idea. It doesn't matter which of the two materials you get since either of them will do the job for you—although an air switch may not be such an easy part to get a hold of.

The signal from the wire across my driveway triggers a simple RF circuit and that, in turn, sounds a bell in the house. The whole system took about an hour to set up and it's been working reliably ever since then.

CALL-WAITING DILEMMA

My wife is using a computer and modem on her job, and she's having a problem with call waiting on the line. Whenever an incoming call shows up on the line, the computer locks up and, to make matters worse, the incoming call is lost. Is there anything that can be done about that without doing away with the call-waiting service completely?—T. Edmonson, Birmingham, AL

This is a fairly common problem and, if you can't afford to have a separate data line, it can be a real pain in the neck when you're using a modem. It's bad enough losing the call, but imagine what it's like when call waiting causes the carrier to drop just at the tail end of downloading a huge file. It's practically enough to make you start using the U.S. mail again!

There are ways around the problem without discontinuing call waiting and, believe it or not, the answer is really simple. All that's needed is a bit of software that's so minor you can even write it yourself using BASIC or whatever language you prefer.

The basic approach is to temporarily change the values in a few of the modem's control registers. The exact method is going to vary with different modems, but the basic principle will be the same. Just about all popular modems have one register that controls the amount of time the modem will wait to disconnect, once carrier has been lost. In the Hayes series of modems it's the S10 register and the time can be set in tenth-of-a-second increments. I'm not familiar with the modem you have, but I'm sure that if you go through the manual (or call the manufacturer), you'll be able to get the information you need to make the modification.

I ran across a small public-domain

continued on page 22

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

KEEP IT SIMPLE

Regarding the article "Energy Consumption Monitor" (**Radio-Electronics**, December 1991): Sometimes we get so engrossed with today's technology that we lose sight of the simple way to do things. Although certainly not as elegant or convenient, the same thing can be done using a surplus watt-hour meter, which can be purchased at a flea market for a few dollars. (It's the same sort as the electric company uses at your house to bill you.)

The formula for finding power consumed at any given time is:

Watts = rev. × kWh × 360/sec

(The kWh rating can be found on the name plate.) You can count the number of revolutions by the black spot on the disk. The meter can be left in the circuit for any length of time—a week, a month, or whatever. You can read the consumption in kWh and use your electric company's rate to arrive at a monetary value.

JOHN L. KURSCHNER
Toms River, NJ

MOTOR-SPEED CONTROLLER CORRECTION

I have found the motor-speed controller circuit described in *Ask R-E* (**Radio-Electronics**, February, 1992) to be very handy. However, there was a schematic error showing the oscillator circuit to be grounded. I've enclosed a drawing of the corrected circuit (Fig. 1).

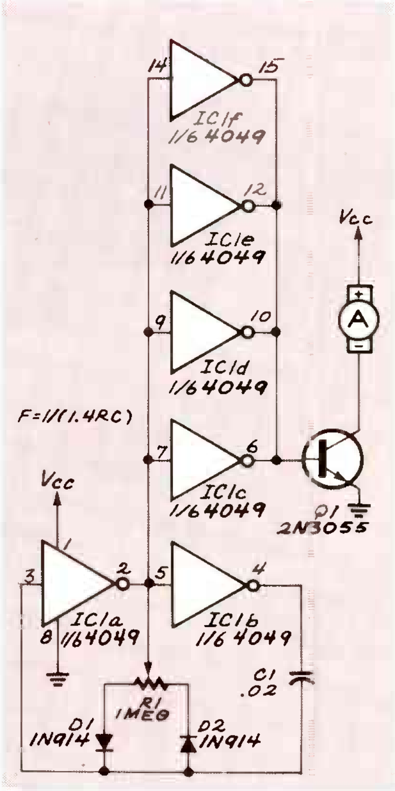

Fig. 1. This is the corrected schematic for the Motor-Speed Controller that appeared in February's Ask R-E.

CALVIN D. KAUFMAN
Highland, MI

Thanks to you and all the others who pointed out our error.—Editor

FLIGHTS OF FANCY

For the last few years I have read **Radio-Electronics** without much interest in the "Letters" section, but over the past few issues I've read it. I noted a letter in the February 1992 issue that is very wrong. It concerns the December 1992 *Drawing Board* column, written by Robert Grossblatt.

In the letter, the writer states that "high-speed aircraft all used generators and the electromechanical voltage regulators they required." I have spent the last 20 years as an Air Force airborne radar navigation technician working on KC-135's, B-52's, F-5/T-38's, U-2/TR-1's, and even the fastest of them all, the SR-71. We had engine-driven devices that were called generators on board, but all of them were 240-volt AC, 400-Hz, 3-phase machines. Voltage regulation was electronically controlled, and charging power for the aircraft battery was provided by a 28-volt DC transformer rectifier that had its own internal electronic controller. The old-style generator and the associated inverters that the writer described left the Air Force inventory with the old T-28 and its sister aircraft, which were piston-engine powered. All modern jet-powered aircraft have gone over to the alternator type of power generator, but the old name has stuck nonetheless.

RICHARD J. GOULET, MSgt, USAF
Wright-Patterson AFB, OH

ASK R-E ANSWERS

I read about the "Commercial Limiter" in *Ask R-E* (**Radio-Electronics**, January 1992) with great interest. I have some additional information that I think would be helpful to anyone undertaking such a project.

The article indicates that the audio signal can be obtained at the volume control or the speaker. While the latter is always true, the former might not be.

Many recent model TV's using conventional (potentiometer) volume controls use electronic volume attenuators that are generally incorporated into the sound IC. Those IC's are also used in sets with push-button and remote volume controls. In this type of system, no audio will be found at the volume control.

One reason for adopting this method is that it eliminates hum pick-up, which results from routing the audio signal to and from the volume control.

If a set uses an electronic attenuator and if the concept of the Commercial Limiter is understood, the circuit could be modified to take control of the attenuator line that controls the volume. That would preclude the necessity of using an additional amplifier stage, which could degrade the audio, particularly if the set has a good audio section like those found in stereo TV's.

In some of these sets, an increase in control voltage causes a decrease in volume, while in others it is just the opposite. Depending on the system, the photo resistor could be placed so that it will shunt the attenuator line to ground, pull it up to some positive value, or it could be placed in series with the line. The LED could be driven by a simple circuit that would cause it to light when the volume exceeds some value. An LM3915 (such as the one shown in the same *Ask R-E* column in the "Audio Light" circuit) would be ideal for that purpose.

If the limiter's input comes from the output of the power amp or any point after the volume control or attenuator, it will have to be readjusted each time the volume setting is changed. If the input comes from some point ahead of the volume control or attenuator, then the limiter's action will be independent of the volume setting.

In many of the sound chips that use electronic attenuators, there is a pin that is connected tot he output of the FM detector. From there, the audio is sent to the attenuator. That would be a good take-off point. In sets that do have audio at the volume control, audio can be taken from the "hot" side of the control and the photo resistor can be connected between the wiper and ground. All of those points can be easily found if the service literature is available.

By the way, I'd like to point out that there might be a problem with the circuit diagram for the Audio Limiter, shown on page 82. The PNP transistor must have a base voltage of about −0.6V with respect to the emitter for turn-on. Since the base is tied to V+, it will always be positive with respect to the emitter. Under these conditions it will never turn on. Perhaps it would if the emitter and the base were reversed.

The writer also indicated that the photo detector is wired in the feedback loop where a change in resistance will change the gain of the amp. Actually, the LM386 is operating in a fixed gain mode. The photo

continued on page 22

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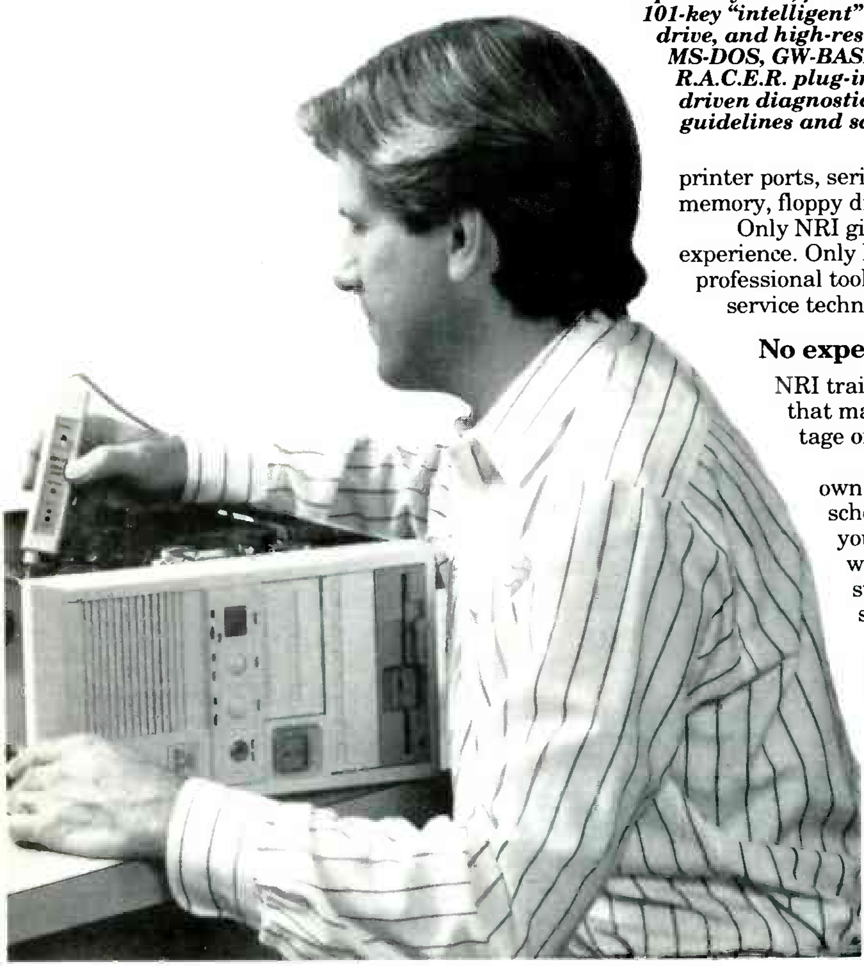

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LETTERS

continued from page 17

detector is wired across the signal source (the secondary winding of the transformer) and not in a feedback loop. A change in resistance acts to reduce the audio level by shunting it to ground before application to the "gain adjust," which is actually a level-adjust control. That doesn't involve the same principle as adjusting the gain of a stage.

The "Commercial Limiter" and the "Audio Link" illustrate an important concept. Projects such as these help us to understand how individual building blocks can be assembled to perform a task. I attribute a large portion of my knowledge of electronics to the projects and articles found in **Radio-Electronics**. Keep up the good work.

STEVE BABBERT
Worthington, OH

ASK R-E

continued from page 14

program that addresses this problem and I've put it on the RE BBS (516-293-2283) for you to download. The file is called CALL-WAIT.ZIP. It has a small BASIC program that was designed for a Hayes 1200-baud modem, but it should show you what has to be done and how to do it. The program is well-commented and all you'll really have to do to make it work with your modem is change a few numbers.

It really works. I've tried it with modems from Racal Vadic, US Robotics, and Hayes (after suitable patching), and never had a problem. If you find that it doesn't work, the best advice I can give you is to contact the modem manufacturer and let them come up with an answer. Call waiting is a common service and you can be sure that you're not the only one who's had this problem. If that fails, you'll just have to spring for a second phone line or drop call waiting—whichever method you prefer. Your phone company should have a way to disable call waiting temporarily as well. **R-E**

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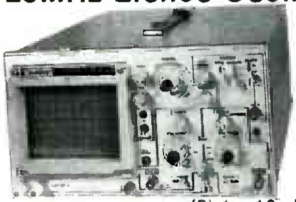

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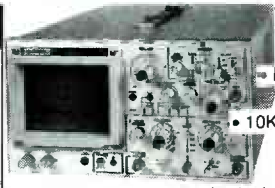

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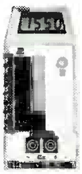

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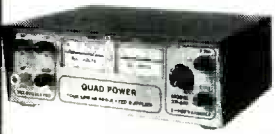

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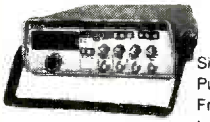

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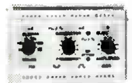

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The package, which consists of the *Video Frame Grabber* board, a 5¼-inch floppy disk, and a manual, allows you to capture real-time video at up to two frames per second. Pause and freeze modes are available for viewing and modifying the image. The package features scalable printing, user-defined margins, auto-exposure compensation, and anti-aliasing filtering for lower noise and less snow.

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RF DETECTOR/FREQUENCY COUNTERS. Two new pocket-sized counters from Startek each feature a 2-inch, 10-segment LED signal-strength bar graph that functions independently of the digital frequency counter. The bar graph, which can be used to locate or adjust an RF signal, will indicate the relative strength of an input signal at any frequency from 500 kHz to 3.5 GHz. The user can switch between dot-graph and bar-graph operation, and the sensitivity is adjustable.

The frequency-counter function has a range of 1 MHz to 1.5 GHz on the model *15-BG* and 1 MHz to 3.2 GHz on the model *35-BG*. Other than the frequency bandwidth, the only difference between the two models is that the *35-BG* is more sensitive above 500 MHz. Both counters have a display-hold switch with indicator and three switch-selectable gate times. Resolution is 1 kHz at 0.25 second, 100 Hz at 2.5 seconds, and 10 Hz at 25 seconds, over the entire range. The display consists of eight red LED digits. A 1-PPM TCXO time base is standard, and there are provisions for an optional, ultra-high-stability TCXO. With the Ni-Cd battery pack fully charged, the counter will operate for 3–5 hours. An AC adaptor/charger is standard.

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Models *15-BG* and *35-BG* bar-graph/frequency counters cost $220 and $265, respectively.—**Startek International Inc.**, 398 NE 38th Street, Fort Lauderdale, FL 33334; Phone: 305-561-221 or 80-638-8050 for orders only; Fax: 305-561-9133.

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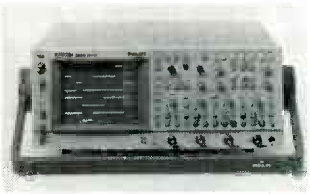

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pabilities on demand. Instant results are obtained by selecting the required function and channel from a set of built-in, fully automated voltage and timing measurement functions.

Triggering modes include logic state and pattern triggering, and glitch triggering. In addition to pre- and post-trigger signal display, the scopes have event delay and time-after-event delay.

Models *PM 3384* (100 MHz) and *PM 3394* (200 MHz) offer true four-channel operation, which provides full sensitivity with complete attenuation ranges on each channel. The 100-MHz *PM 3382* and the 200-MHz *PM 3392* offer 2 + 2 channel operation, a configuration that provides a cost-effective alternative to four fully featured inputs.

Models *PM 3382, PM 3384, PM 3392,* and *PM 3394* have list prices of $4490, $5490, $5990, and $6490, respectively.—**John Fluke Mfg. Co., Inc.**, P.O. Box 9090, Everett, WA 98206; Phone: 800-44-FLUKE.

SELF-TUNING TEST RECEIVER. For testing the modulation quality of mobile voice transmitters and verifying the accuracy of audio signalling tones such as DTMF and CTCSS, Optoelectronics' *R-10* communications test receiver is a quick, easy, and inexpensive alternative to costly modulation meters. The unit can automatically accommodate the enormous difference ratio between an unknown carrier of up to 1000 MHz and a modulating frequency as low as 50 Hz, without any manual tuning.

The *R-10* automatically determines and locks onto whatever carrier signal is the strongest within a 100-foot range. Once the signal is locked in, the *R-10* demodulates whatever FM audio is present on the carrier and outputs that audio to an internal power amplifier/speaker and the BNC output jack. For DTMF and CTCSS testing, the audio output is evaluated on a frequency counter or oscilloscope. For countersurveillance operations, the *R-10's* demodulated audio can be monitored to determine if a surreptitious transmitter is in the area.

CIRCLE 19 ON FREE INFORMATION CARD

The test receiver features two operating modes; a squelch capability that serves as a sensitivity control; audio gain, power, and low-battery indicators; and a rear connector that provides output to external frequency counters and other instruments. Power is supplied by an internal 9-volt battery. Options include a rechargeable battery pack and a telescoping whip antenna with swivel base.

The *R-10* test communications receiver costs $359.—**Optoelectronics Inc.**, 5821 NE 14th Avenue, Fort Lauderdale, FL 33334; Phone: 800-327-5912 or 305-771-2050; Fax: 305-771-2052.

MULTI-PURPOSE INTERFERENCE FILTER. Ace Communications' *MPIF-1* receiver filter eliminates a variety of unwanted signals. The compact (3 × 2 × 1½-inch) external filter eliminates most of the sources of interference common in broad-banded receivers. Unwanted signals are filtered from the 54–108 MHz, 174–220 MHz, and 512–806 MHz ranges, as well as the range above 869 MHz. A switchable notch will also eliminate interference on the 150–153 MHz range, which is a common source of interference in many areas. The use of BNC connectors makes the filter quite versatile; the *MPIF-1* can even be used on handheld receivers.

The *MPIF-1* multi-purpose interference filter has

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a suggested retail price of $59.—**Ace Communications**, Monitor Division, 10707 East 106th Street, Fishers, IN 46038; Phone: 817-842-7115; Fax: 317-849-8794.

POWER SUPPLIES. The "smart" front panels on the 15 instruments in Hewlett-Packard's new line of DC

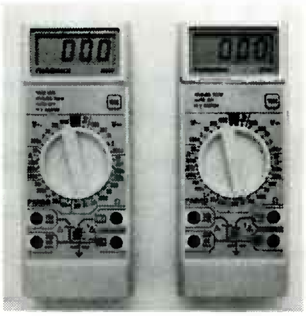
CIRCLE 21 ON FREE INFORMATION CARD

power supplies help provide fast, flexible, and precise output control. With outputs ranging from 200 to 2000 watts, the *HP 6000* series power supplies provide a variety of choices for benchtop or system applications that do not require HP-IB control of the power supply. The series consists of five power supplies (which vary by voltage ratings) in each of three power ranges: 200, 500, and 2000 watts.

All models have low output noise, extensive load-protection features, and the "smart" front panel. The peak-to-peak ripple and noise spans from a low of 3 mV p-p on the low-power, low-voltage models to a high of just 16 mV on the 2-kW, 120-volt model. Overcurrent, overvoltage, and over-temperature protection are provided for the device under test and for the power supply. Those features protect the device under test by disabling the output voltage of the power supply when potentially dangerous conditions occur. "Smart" front-panel controls provide three methods for setting the output voltage and current. A numeric-entry keypad allows the user to set the voltage quickly and precisely, while up/down buttons and rotary pulse generators permit the user to quickly and conveniently change the voltage and current settings in small increments. For repetitive benchtop tests, up to five states or sets of power-supply settings can be stored and recalled for easy sequencing among states. Front-panel controls also allow the user to calibrate the power supply. In addition, the output voltage can be controlled via an external voltage signal, allowing for computer control or analog modulation.

List prices for the *HP 6500* series of power supplies range from $1650 to $1750 for the 200-watt models, $2100 to $2300 for the 500-watt models, and $3650 to $3800 for the 2000-watt models.—**Hewlett-Packard Company**, Inquiries, 19210 Pruneridge Avenue, Cupertino, CA 95014; Phone: 800-752-0900.

HAND-HELD DIGITAL MULTIMETERS. Aimed squarely the field service technician, Fieldpiece's digital multimeter models *HB75* and *HB77* are professional-grade instruments that are durable and easy to use in the field. They include a built-in logic probe and a variable-pitch tone. The tone's pitch varies proportionally from high to low with high to low readings. In the field, that feature has two primary uses. First, intermittents can easily be found by listening for discontinuities in the tone while wiggling suspect connections. Second, one "odd" test point in a series of test points that are nearly the same can be found without waiting for the meter to display a number; instead, the technician can quickly scan the test points and "hear" the one that is different.



CIRCLE 22 ON FREE INFORMATION CARD

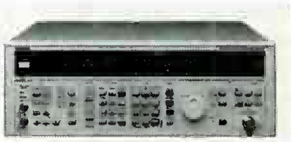
Both models have a built-in logic probe that responds up to 20 MHz. "Hi" and "lo" are indicated both in the display (with up/down arrows) and by a beeper with two different tones. Both DMM's also have a built-in capacitance meter that measures capacitors up to 200 µF in the circuit using the test leads.

Model *HB77* measures the true-RMS value of AC voltages and currents. Current ranges go from a low of 200 µA to 20 A. Because the meter is manual ranging, the voltage burden (the voltage across the device when current is flowing through it) is low—0.25 volts for the 200-µA range.

Both heavy-duty meters feature a drop-resistant housing, O-ring seals to protect against contaminants, MOV's to protect against transients, and full 600-V fusing on all current jacks. They come with a tilt stand and a hanger on the back, test leads, and fuses and batteries installed. Both DMM's have 24 ranges in AC and DC volts, AC and DC amps, and ohms, and both include a high-voltage indicator that warns the user when touching anything over 28 volts. A single rotary dial, with the "menu" of functions printed around it, makes the meters easy to understand and use.

The models *HB75* and *HB77* digital multimeters have suggested list prices of $139 and $179, respectively.—**Fieldpiece Instruments, Inc.**, 8322B Artesia Blvd., Buena Park, CA 90621; Phone: 714-992-1239; Fax: 714-992-1239.

2.7-GHz SYNTHESIZED SIGNAL GENERATOR. Designed for use in research and development, manufacturing, and servicing electronic products, Leader's model *3221* synthesized signal generator

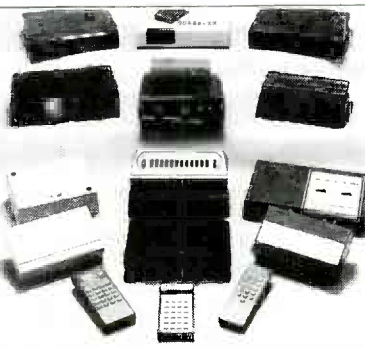


CIRCLE 23 ON FREE INFORMATION CARD

offers high-stability and high-purity outputs to 2.7 GHz. Its extensive modulation capabilities include seven modes with 14 simultaneous combination modulation modes—pulse, logic, DC-FM, and internal or external AM and FM. RF-output level engineering units are selectable between dBm and dBµ with 0.1-dB resolution. Three convenient presets are included for commonly used RF-output levels. One hundred preset memories allow storage and recall of all front-panel setting conditions. RF output on/of control and 50-watt reverse power-protection reset are accomplished with a single key. A continuous, variable RF-output mode allows ±5-dB variation in 0.1-dB increments for squelch adjustments. Edit functions for frequency, output level, and modulation make it easy to change operating parameters. Other standard features include GPIB and a GaAs FET pulse modulator.

The model *3221* synthesized signal generator costs $12,300.—**Leader Instruments Corporation**, 380 Oser Avenue, Hauppauge, NY 11788; Phone: 800-645-5104 or 516-231-6900. **R-E**

REMOTE CONTROL A-B SWITCH—lets you hook up your cable box by remote control, when needed, then unhook it just as easily! Restores TV, VCR features. Or, replace any A-B switch with this superb quality remote version. Bright LED indicators, JUST **$35,** INCLUDES SHIPPING. Visa, MC, or check. (C.O.D. $5 extra) Fast delivery, 30 day money back. **STAR CIRCUITS, P.O. Box 94917, Las Vegas, Nevada 89193 1-800-535-7827.**



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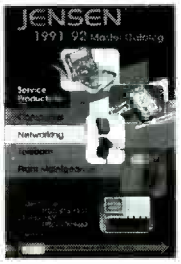

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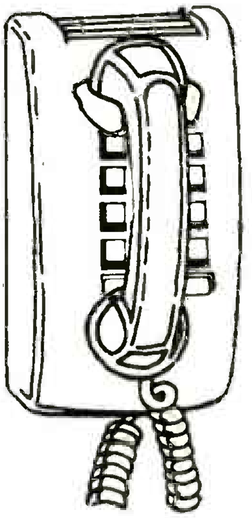

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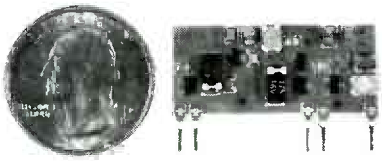

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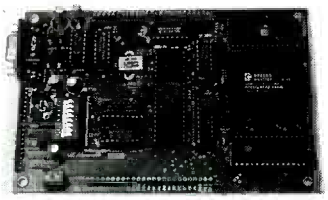

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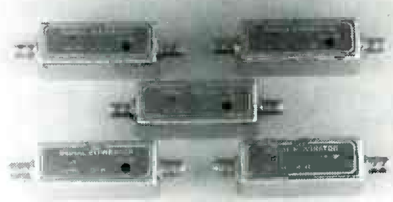

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NEW LIT

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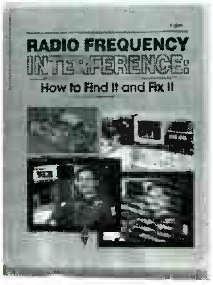
RADIO FREQUENCY INTERFERENCE: How to Find it and Fix it; book edited by Ed Hare, KA1CV, and Robert Schetgen, KU7G; The American Radio Relay League; 225 Main Street, Newington, CT 06111; $15.00 plus $3.00 shipping and handling ($4.00 for UPS).

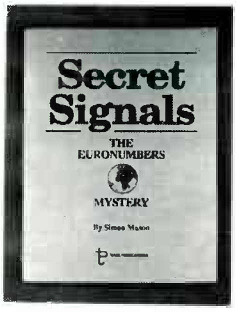
If you've ever experienced black bars flashing across your TV picture in a rhythmic pattern, a garage door opening or closing by itself, a buzz that drowns out AM stations, a touch-controlled lamp with a mind of its own, or anonymous conversations that interrupt music on your stereo you've experienced radio-frequency or electromagnetic interference (RFI/EMI). This 256-page book not only explains the mechanics of RFI/EMI, but also provides practical cures for the problem. Opening chapters offer general information on how to find the interacting equipment, locate help, and resolve conflicts. Subsequent chapters discuss RFI/EMI problems and provide cures for specific electronic systems, including transmitters, televisions, telephones, amateur-radio equipment, stereos and other audio gear, power lines and electrical devices, computers, and automobiles. The chapter on filter performance explains how to select a filter and provides test results and performance tables for dozens of low-pass, high-pass, power-line, and miscellaneous filters. In addition, the book also explains RFI/EMI regulations and standards, and provides a copy of the ARRL EMI/RFI report form, which can be used to file official EMI/RFI complaints.



CIRCLE 40 ON FREE INFORMATION CARD

SECRET SIGNALS: The Euronumbers Mystery; by Simon Mason. Tiare Publications, P.O. Box 493, Lake Geneva, WI 53147; Phone: 414-248-4845; $9.95 plus $2.00 shipping and handling ($3.00 outside the U.S.).

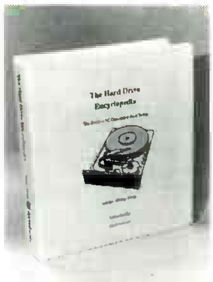
If you've ever tuned to the frequencies outside the shortwave and ham bands to the regions allotted to "fixed" stations, you might have heard broadcasts consisting of a single voice reading out long lists of numbers in four- or five-digit groups. While explanations for those mysterious broadcasts have ranged from commodity prices to lottery numbers, the most likely explanation is that they are coded messages sent to espionage agents. The end of the Cold War hasn't ended the transmission of coded numbers; they're still being sent, day and night, over all the shortwave-radio bands. This book, written by a man who has studied the European numbers stations for years and has monitored thousands of transmissions in the process, is an indispensable tool for tracking those stations from North America. It includes numerous traffic excerpts, identifiers, schedules, and clues turned up by hearing mistakes in transmissions. Descriptions of transmissions from "Bulgarian Betty," "Papa November," "The Russian Man," "Swedish Rhapsody," and "The Lincolnshire Poacher" are included, as is a complete frequency log with more than 300 entries that are listed by frequency and contain notes on formats and schedules.



CIRCLE 39 ON FREE INFORMATION CARD

THE HARD DRIVE ENCYCLOPEDIA: The Guide to PC-Compatible Hard Drives; by Adrian Alting-Mees. Annabooks, 12145 Alta Carmel Court, Suite 250-262, San Diego, CA 92128; Phone: 800-462-1042 or 619-271-9526; Fax: 619-592-0061; $89.00.

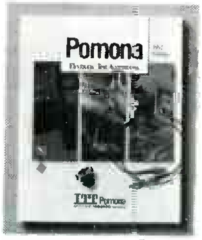
Consisting of more than 600 pages in a three-ring binder and a companion diskette of utilities, this book provides a complete reference on PC-compatible hard-disk drives. The book includes sections on ST-506, ESDI, SCSI, and IDE specifications, as well as a section covering five other interfaces. Other sections cover the physical and electrical characteristics of hard drives, logical encoding schemes, and file formats. Sections covering controller parameters, hard-disk drives, and manufacturers include extensive lists of related information. Another section lists the BIOS hard-drive tables for many popular BIOS's, and explains how to use the utilities on the companion disk to see the drive-type tables in your own BIOS. More than 1600 hard-drive model numbers are listed by manufacturer, so that if you have to install a drive but don't have a spec sheet, you can locate the important parameters in the included tables.



CIRCLE 37 ON FREE INFORMATION CARD

1992 ELECTRONIC TEST ACCESSORIES CATALOG; from ITT Pomona, 1500 East Ninth Street, P.O. Box 2767, Pomona, CA 91769-2767; Phone: 714-469-2900; Fax: 714-629-3317; free.

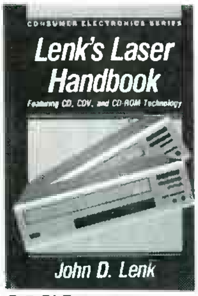
Specially featured in this 140-page catalog are an expanded line of oscilloscope-probe kits and two



CIRCLE 36 ON FREE INFORMATION CARD

new lines of test probes and clips for miniature and heavy-duty applications. Also featured are accessories designed to make testing SMT devices and high-density leaded components easier and more reliable. New products include new IC clip kits, coax/BNC universal adapter kits, digital multimeter test-lead kits, cable and patch accessories, and jumper kits. ITT Pomona's popular selection of jumpers and cables, boxes, plugs and jacks, connectors, adapters, single-point test clips, and static control devices are also described. An easy-to-use index is provided to help readers quickly locate specific products.

LENK'S LASER HANDBOOK: Featuring CD, CDV, and CD-ROM Technology; by John D. Lenk. McGraw-Hill, Inc., Professional Book Group, 11 West 19th Street, New York, NY 10011; Tel. 1-800-2-MCGRAW; $39.95.



CIRCLE 35 ON FREE INFORMATION CARD

This new addition to McGraw-Hill's Consumer Electronics Series is a practical reference book filled with the information needed to troubleshoot today's laser-based products. Aimed at service technicians and field-service engineers who work with laser-based technology, the book focuses on videodisc and compact-disc players, and CD-ROM units, using information that is applicable to all sorts of laser devices, including CD-I (compact-disc interactive) units. The book shows precisely how to repair laser-based equipment and how to pinpoint trouble in a component or module. Step-by-step and circuit-by-circuit examples are used to explain not only how laser equipment works, but also how to service it.

Opening with a discussion of the basics of CD players, the book goes on to explain various techniques for encoding and decoding as well as the basic principles of optical readout. Proper operation and installation are described, as are the test equipment and tools required for servicing and maintenance.

Typical circuits for compact-disc and videodisc players are explored, accompanied by schematics, block diagrams, and a discussion of the theory of operation. The book also discusses approaches to troubleshooting and adjusting CD and laser disc products based on the type of failure or symptoms of trouble. **R-E**

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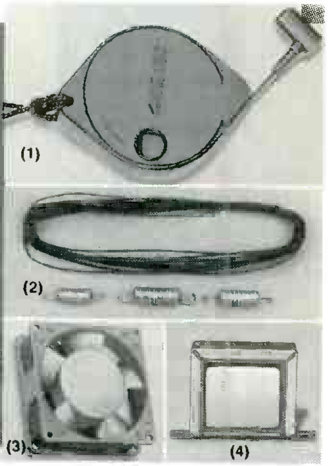

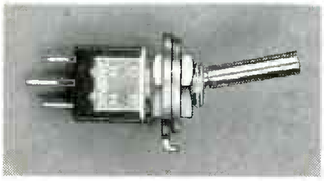

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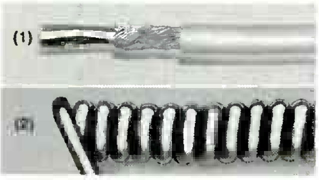

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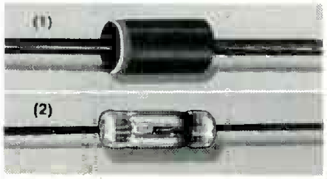

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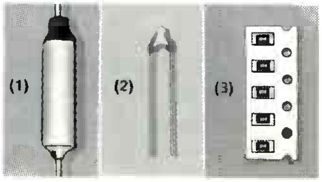

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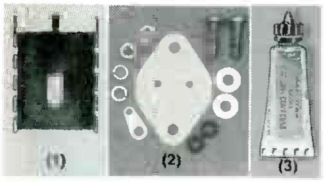

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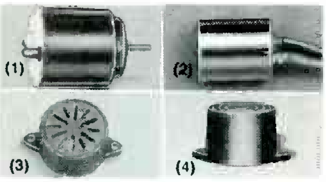

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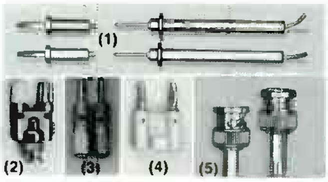

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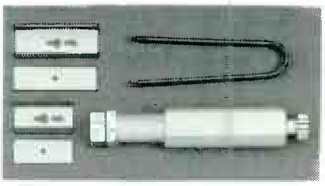

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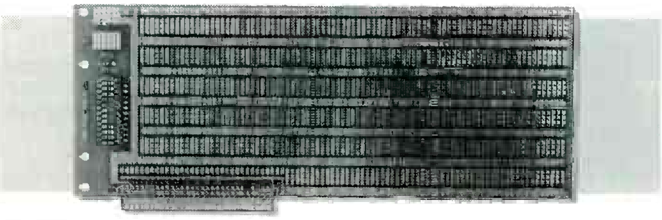

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BUYER'S GUIDE TO DMM'S

Today's bench DMM gives you more performance for your instrument dollar than ever before.

STAN PRENTISS

THE BENCHTOP DIGITAL MULTIMETER (DMM) IS THE workhorse test instrument in today's labs and sevice shops while the handheld DMM is the favored vertatile tester in the field. Bench/portable DMM's have seized the high ground where emphasis is on accuracy, resolution and automated testing. Benchtop DMM's are in use for electronic equipment testing, service, and calibration in both shop and field. They are also filling important roles in design departments, scientific labs, and as components in industrial data acquisition and automated test systems.

To be classed as a DMM, a meter is usually expected to be able to make the five basic electrical measurements: DC and AC volts, DC and AC current, and resistance. However, the term DMM now covers a wide range of instruments from the low-cost handheld, battery-powered units costing less than $100 to the AC line-powered bench/portable units whose base list prices can range from $200 to nearly $2700.

Benchtop DMM's are distinguished from handhelds by their rectangular cases and front-face displays and controls. Their long depth dimensions give them stability on a bench or other flat surface. Most are equipped with tilt bails to raise their front faces for easier user reading. Despite those differences, there is considerable overlap in features between high-end handheld and low-end benchtop DMMs.

In fact, some bench-type meters are little more than repackaged handhelds, and they cannot be distinguished by looking only at specifications. All handheld DMM's are portable, but benchtop DMM's are also portable, and those that are battery powered can be used conveniently in the field.

Many bench DMM's have liquid-crystal displays, typical of today's handhelds, but most of the high-end models have vacuum-fluorescent or LED displays that afford better viewing in subdued light. These displays can be used because the benchtop units have less restricted power budgets than the handhelds.

How they work

Figure 1 is a simplified functional block diagram of a DMM. In practice, both AC and DC voltage measurements are made by one circuit, and both AC and DC currents are measured by another. Typically there is a separate resistance measuring circuit.

The latest DMM's, both handheld and bench, include either a microcontroller (microcomputer-on-a-chip) or microprocessor for various control and self-check functions. A microprocessing function block has been omitted from the simplified diagram, but it would typically be located between the analog-to-digital (A/D) converter and the display.

The microprocessor or microcontroller provides control signals for the true root-mean-square (RMS) voltage and current converter if the DMM has one. Bench meters are more likely to have this feature than handhelds; thus it is not exclusive to either one. However, provision for interfacing with systems is an exclusive bench DMM feature.

Bench DMM manufacturers have used a number of different schemes to convert analog input signals into a digital readout. Among them are voltage-to-frequency, successive approximation, reciprocating remainder, and dual-slope integration conversion. However, the most popular scheme in use today is some form of dual-slope integration.

Figure 2 is a simplified block diagram of a dual-slope integrating DMM. Instead of converting voltage to frequency as is done in other methods, it is converted to time. The timing sequence for this technique is shown in Fig. 3. Switch S1 connects the unknown input voltage to the integrator consisting of input resistor R1 and an operational amplifier with capacitor C1 in its feedback loop.

Switch S1 remains in that position for the integration period. During this time, C1 is charged at a rate determined by R1. At the end of the integration period, C1 has a charge that is proportional to the input voltage. The op-amp causes the voltage across C1 to build linearly so the charging rate is governed by the current through resistor R1.

In the second phase of dual-slope operation, control logic switches S1 to connect a reference voltage to R1 and the input of the integrator. The reference polarity is always opposite to that of the unknown input voltage. Two references are used—one negative and the other

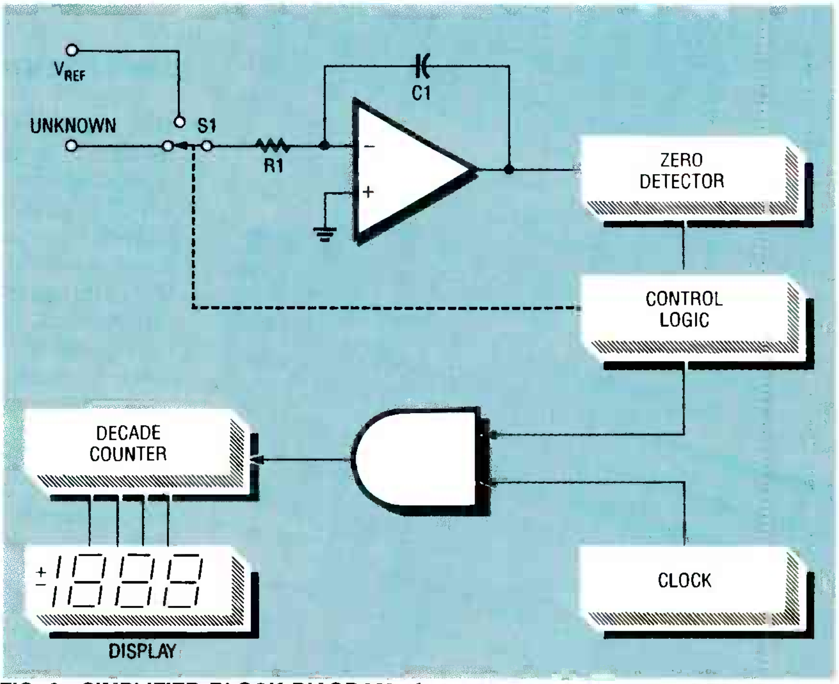


FIG. 2—SIMPLIFIED BLOCK DIAGRAM of a dual-slope integrating DMM. Switch S1 connects the unknown voltage to the integrator for the first half of the cycle, and the reference voltage for the second half. The time to discharge capacitor C1 is converted to a digital readout.

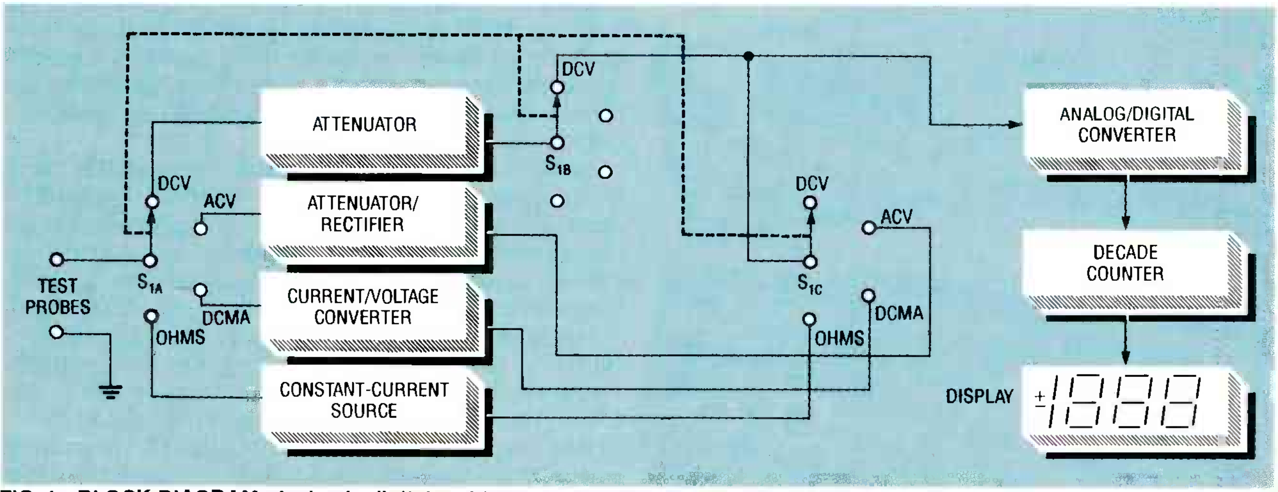


FIG. 1—BLOCK DIAGRAM of a basic digital multimeter.

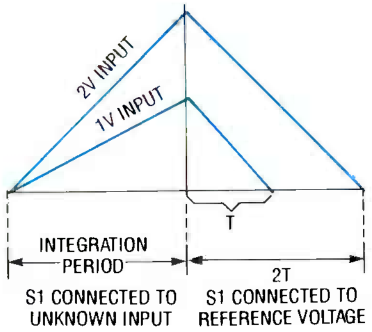


FIG. 3—DUAL-SLOPE INTEGRATION measuring sequence. The slope angle depends on the magnitude of the unknown input voltage and the time to discharge to zero is a function of that value.

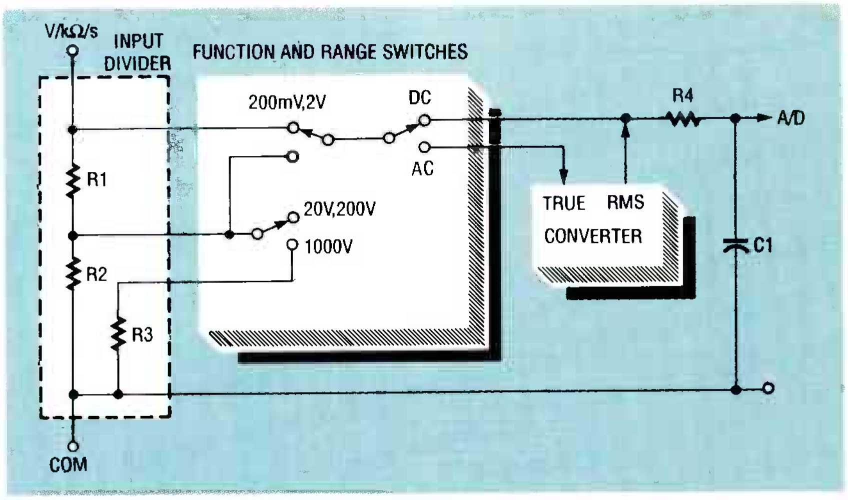


FIG. 4—SIMPLIFIED DIAGRAM of a typical voltage-measurement circuit.

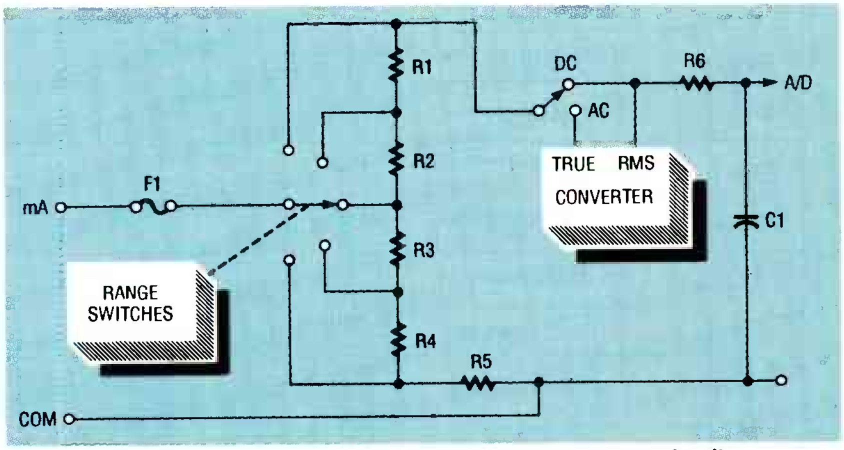


FIG. 5—SIMPLIFIED DIAGRAM of a typical current-measurement circuit.

positive. At the beginning of the second phase, the output from the clock is gated. Capacitor C1 is then discharged linearly by the reference voltage, and the clock is stopped when C1 is discharged through zero.

If the unknown input voltage is doubled, C1 charges up twice as fast. Since a constant reference voltage is applied to discharge the capacitor, the discharge rate will be constant. This means that the time to discharge C1 is doubled if the unknown input is doubled, as shown in Fig. 3. The accuracy of the dual-slope technique depends primarily on its reference voltages. This method is favored because errors introduced during charging are canceled during discharge. Some benchtop DMM A/D converters can now take 1000 readings per second. Hewlett-Packard's HP 34401A DMM can, for example, makes up to 50 range/function changes per second.

Figure 4 is a simplified diagram of a typical DMM circuit for measuring both AC and DC voltage. Many different proprietary circuits are used for true RMS AC and DC voltage conversion. As can be seen, the output of the true RMS converter goes to the A/D converter.

Both AC and DC current can be measured with the circuit shown in simplified form in Fig. 5. Again, the range switch block represents either manual or automatic range functions. Fuse F1 can represent two fuses in series, one rated for low current values, and the other rated for high current values. Those protect the meter against accidental damage and the user from shock. The true RMS converter functions in both the voltage and current measurement circuits and, as in the voltage circuit, the output goes to the A/D converter.

Several different resistance measuring circuits can be found in today's crop of bench DMM's. The most popular are the constant-current source and voltage-ratio techniques. The constant-current source supplies current to the unknown resistance value. The DMM then measures the voltage drop across the unknown. In the voltage ratio-method, shown in simplified form in Fig. 6, there is a voltage source and an internal divider consisting of a reference resistor (R_{REF}) and the unknown value (R_X). The value of V_{RX} is obtained from the lower op-amp.

Figure 7 illustrates a conventional 2-wire ohms converter found in most bench DMM's. It is based on a DC constant-current source. Figure 8 is a simplified schematic of a four-wire ohms converter that will eliminate measurement errors introduced by lead resistance in precision DMM's.

Alternate or optional battery power enhances the bench/portable meter's portability and improves its isolation from the AC line for certain critical measurements. It also ensures the safety of the user when making certain kinds of high-voltage and current measurements. Most low-cost, battery-powered bench DMM's use multiple "C" or "D" cells, or 9-volt transistor batteries, typically disposable alkaline. However, the battery power sources of the higher performance meters are typically multiple rechargeable nickel-cadmium (Ni-Cd) cells or sealed

TABLE 1—BENCHTOP DIGITAL MULTIMETER CHARACTERISTICS

Manufacturer	Model No.	BASIC FEATURES: Number of Digits	BASIC FEATURES: Display Counts	BASIC FEATURES	DC VOLTS: Basic Accuracy, %	DC VOLTS: Max. DC Voltage w/o Probe	DC VOLTS: Max. Resolution, µV	AC VOLTS: Basic Accuracy, %	AC VOLTS: Max. AC Voltage w/o Probe	AC VOLTS: Max. Resolution, µV	AC VOLTS: True RMS	AC VOLTS: Frequency Range, kHz	AC & DC AMPS: Max. Resolution, µA	AC & DC AMPS: Max Amps w/o Probe	OHMS: Max. Resolution, mΩ	OHMS: Max. Resistance, MΩ	SPECIAL FEATURES: Auto/Manual Ranging	SPECIAL FEATURES: Frequency Measurement	SPECIAL FEATURES: dB, dBm Readout	SPECIAL FEATURES: Offset/Relative Reference	SPECIAL FEATURES: Continuity & Audible	SPECIAL FEATURES: Min./Max. Hold	SPECIAL FEATURES: Diode Test	SPECIAL FEATURES: System Interface	SPECIAL FEATURES: Other (See Notes)	Price
Analogic	DP100	5½	200,000	LCD	0.0035	450	0.1	0.35	450	1.0	•	50	1.0	2.0	1.0	20	•	•	—	•	—	—	—	232(ST)	(B/AC)(DM)(TM)	595
B & K	2831A	3½	2000	LED	0.1	1200	100	0.5	1000	100	—	40	0.1	20	100	20	—	—	—	—	•	—	•	—	—	295
	2832	3½	2000	LCD	0.5	1000	100	1.0	1000	100	—	500	0.1	20	100	20	—	—	—	—	•	—	•	—	(B/AC)(CA)	195
	2833	4½	20,000	LCD	0.05	1000	10	0.5	1000	10	•	50	0.01	20	10	20	—	•	•	—	•	—	•	—	(B/AC)(DH)	356
Beckman	350	3½	2000	LCD	0.1	1500	100	0.6	1000	100	—	10	0.1	10	100	20	—	—	—	—	•	—	•	—	—	259
	360B	3½	2000	LCD	0.1	1500	100	0.6	100	100	•	40	0.1	10	100	20	—	—	—	—	•	—	•	—	(TM)	329
Daetron	MM300A	4½	20,000	LCD	0.2	500	10	2.0	500	1000	—	0.06	1000	2	1.0	20	•	•	—	•	•	•	—	232(OP)	(BG)(M)(PH)	450
Fluke	37	3½	3200	LCD	0.1	1000	100	0.5	1000	100	—	30	0.1	10	100	32	•	—	—	•	•	•	•	—	(BG)(CO)(DH)	269
	45	5	100,000	FL	0.02	1000	1.0	0.2	750	1.0	•	100	0.1	10	1	300	•	•	•	•	•	•	•	232(ST),488(OP)	(DH)	635
	8010A	3½	2000	LCD	0.1	1000	100	0.5	750	100	•	50	0.1	10	100	20	—	—	—	—	—	—	•	—	(CO)	379
	8012B	3½	2000	LCD	0.1	1000	100	0.5	750	100	•	50	0.1	2	1	20	—	—	—	—	—	—	•	—	(CO)	389
	8050A	4½	20,000	LCD	0.03	1000	10	0.5	750	10	•	50	0.01	2	10	20	—	—	•	•	—	—	•	—	(CO)	479
	8840	5½	200,000	FL	0.005	1000	1.0	0.16	1000	1.0	(OP)	100	10	2	1	10	—	—	—	—	—	—	—	488(OP)	—	875
	8842A	5½	200,000	FL	0.003	1000	0.1	0.08	1000	0.1	(OP)	100	1.0	2	0.1	20	—	—	—	—	—	—	—	488(OP)	—	1095
Goldstar	DM7241	4½	20,000	LCD	0.05	1000	10	0.5	750	10	—	50	0.1	10	10	20	—	—	—	—	—	•	—	—	(DH)	229
Hewlett-Packard	34401A	6½	1,200,000	FL	0.0035	1000	0.1	0.06	750	0.1	•	300	0.01	3	0.1	120	•	•	•	•	•	•	•	232, 488(ST)	(M)(DM)(PH)	995
	3468A/B	5½	300,000	LCD	0.018	300	1.0	0.26	300	1.0	•	300	1.0	3	1.0	30	•	—	—	—	—	—	—	—	(B/AC)	1095
	3478A	5½	300,000	LCD	0.006	300	1.0	0.20	300	1.0	•	300	1.0	3	0.1	30	•	—	—	—	—	—	—	488(ST)	—	1295
Keithley	175A	4½	20,000	LCD	0.03	1000	10	0.5	750	10	•	100	0.01	10	10	200	•	—	—	—	—	•	—	488(OP)	(B/AC)(OP)	495
	196	6½	3,029,999	LED	0.003	300	0.01	0.15	300	1.0	•	100	0.001	3	0.1	300	•	—	—	•	—	•	—	488(ST)	—	1495
	197A	5½	219,999	LCD	0.01	1000	1.0	0.35	750	1.0	•	100	0.001	10	1.0	220	•	—	•	•	—	•	—	488(OP)	(B/AC)(OP)	659
	199	5½	302,999	LED	0.006	300	1.0	0.15	300	1.0	•	100	0.01	3	1.0	300	•	—	—	•	—	•	—	488(ST)	—	1045
	20001	7½	21,000,000	FL	0.0007	1100	0.01	0.03	750	0.1	•	2000	.00001	2	0.001	1000	•	•	•	•	—	•	—	488(ST)	(CF)(TM)	2695
Kenwood	DL712	3½	2000	LCD	0.1	1100	100	0.75	850	1000	•	0.5	0.1	10	100	20	•	—	—	—	—	—	—	—	(B/AC)	249
Leader	856	4½	20,000	LED	0.05	1000	10	1.0	750	100	•	100	10	3	10	30	•	•	•	•	•	—	—	232 or 488(OP)	(BG)	800
Protek	HC-797	4¾	32,000	LCD	0.04	1000	10	0.4	750	10	•	30	0.1	10	10	30	•	•	—	•	•	•	•	232(ST)	(BG)(CF)(M)	350
Simpson	460-6	4½	20,000	LCD	0.07	1000	10	1.5	750	10	•	100	0.1	10	10	20	—	—	•	—	•	—	•	—	(BG)(B/AC)	500
	461-2R	3½	2,000	LED	0.10	1000	100	0.5	750	100	•	50	0.1	2	100	20	—	—	—	—	—	—	•	—	(B)	300
	464-4	3½	2,000	LED	0.10	1000	100	1.0	750	100	•	100	0.1	10	100	20	—	—	—	—	•	—	•	—	—	360
	467-2	3½	2,000	LCD	0.10	1000	100	0.5	750	100	•	5	0.1	2	100	20	—	—	—	—	•	—	•	—	(BG)(PH)	420

Triplett	4800	4½	25,000	LCD	0.04	1000	10	0.5	1000	10	•	100	0.01	2	10	25	•	•	•	•	•	—	•	—	(M)(PN)(TM)	600
Yokogawa	7551	5½	200,000	LED	0.005	1000	1.0	0.2	700	1.0	—	0.2	0.01	2	1.0	200	•	—	•	•	—	—	—	232 or 488	(M)	895
	7552	5½	**200,000**	LED	0.005	1000	1.0	0.2	700	1.0	—	—	100	20	1.0	200	•	•	•	•	—	—	—	232 or 488	(M)	995
	7561	6½	**2,000,000**	LED	0.003	**1000**	1.0	—	—	—	—	—	—	2	**0.1**	**200**	•	—	•	•	—	—	—	232 or 488	(M)	1195
	7562	6½	2,000,000	LED	0.003	1000	1.0	0.15	700	1.0	—	—	0.01	2	0.1	200	•	—	•	•	—	—	—	232 or 488	(M)	1295

NOTES:
(BG) Bar graph
(B) Battery operation
(B/AC) Battery & AC line powered
(CA) Capacitance measurement
(CF) Crest factor
(CO) Conductance measurement
(DH) Display hold
(M) Memory
(PH) Peak hold
(TM) Temperature measurement
232 RS-232 compatible
488 IEEE-488 (GP1B) compatible
(OP) Optional
(ST) Standard

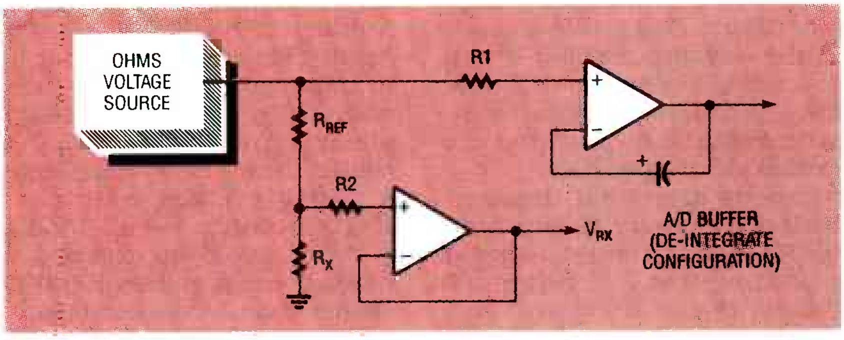


FIG. 6—SIMPLIFIED DIAGRAM of a typical DMM voltage ratio resistance-measurement circuit.

lead-acid batteries. Manufacturers offer power options: 117 or 220 volts, 50 to 60-Hz line, and/or batteries.

Some bench DMM's have been designed for dual use as portable or rack-mounted instruments. Rack mounting is used in systems applications. The purchaser can specify the case style desired.

Available bench DMM's

If you examine Table 1, Digital Multimeter Characteristics, included here you will see 3-1/2-digit bench/portable DMM's list priced below $200, and higher performance instruments priced for more than $2600—a price spread of better than an order of magnitude. Those prices include only the bare necessities such as basic test leads, power cord, and manuals. Most DMM accessories such as probes and carrying cases are extra expense items.

The basic electrical measurement functions in bench DMM's are usually supplemented with special features, many of which are can also found in the handhelds. The most common examples are diode test and audible continuity. As stated earlier, bench models are more likely to include true RMS AC voltage and current measurement than handhelds, and system compatibility is an exclusive feature with the bench models. Many bench DMM's can also display such math functions as min/max hold, and provide readouts in dB and dBm.

With their focus on accurate measurement, many DMM's have only a few of the special features found in handhelds.

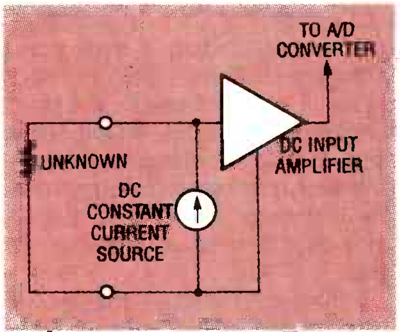


Fig. 7—SIMPLE 2-WIRE ohms converter.

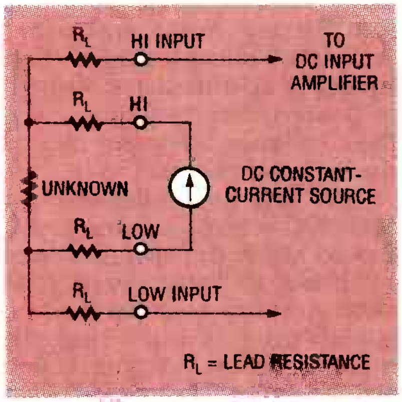


FIG. 8—SIMPLIFIED 4-WIRE ohms converter for eliminating lead resistance errors. Current is supplied by a separate current source.

The line separating the features of handhelds from those of benchtop DMM's is fuzzy, at least in the $200 to $300 price price range. Features such as peak hold, sleep mode, and capacitance measurement are more likely to be found on the handhelds.

But it's worth keeping in mind that, generally speaking, you get what you pay for in bench/portable DMMs. Prices have been raised on many of the models that have been on the market for ten years or more. However, there is general agreement that you can get more for your DMM dollar today than ever before. This is due, in part, to the ongoing transfer of advanced A/D converter IC's and microprocessor devices to instrumentation, and intense worldwide competition.

Experts agree that the most critical parameter in benchtop DMM's (and the one you should look at first) is DC voltage accuracy. It can be stated in a number or ways: ± (% of reading + number of least significant digits), ± (% of reading + % of range), ± (% of reading + number of counts), and even parts per million (ppm) of reading as ± (ppm of reading + ppm of range). Regardless of the form used, it will be given at a specified ambient temperature, usually between 18°C and 28°C, with relative humidity up to 90%.

Accuracy ratings might be given for periods of one year, six months, 90 days, or even 24 hours. To cut through all this complexity, most manufacturers give short forms of their accuracy specification known as basic DC-voltage accuracy. That is what we used in our characteristics table.

After you have checked out basic DC-voltage accuracy, you should study the specifications and literature to be sure that the meter you are considering is a quality product built ruggedly enough to meet your needs and includes all of the accepted user safety and instrument protection features for that class of product. Next you might want to examine the basic AC-voltage accuracy rating.

A 5-1/2- or 4-1/2-digit DMM can be expected to offer higher accuracy and resolution than a 3-1/2-digit DMM, and this should be kept in mind during your search. The 1/2 in the specification of the DMM display refers to the use of the digit 1 in the most significant digit (MSD) position. The full scale on a 4-1/2 digit display, for example, is 9999, but the additional digit 1 permits the display to show a value that is 100% higher (19999) in what is known as the 100% overrange condition.

There is a close but not absolute correlation between the number of display digits and counts. For example a 3-1/2-digit DMM might have 2000 or even 3200 counts, a 4-1/2-digit meter typically has 20,000 counts, but it could have more. A 5-digit DMM will have 100,000 counts, but a 5-1/2-digit meter would be expected to have a count of at least 200,000. Rather than try to define such confusing designations as a 4-3/4 -digit DMM, it is a lot easier to look for the display count that we have listed in our selection table.

As you move upscale in bench DMM's, prices rise accordingly. Therefore, it becomes even more important to pay attention to the reputation of the manufacturer, and inquire about any guarantees or warranties being offered. Not surprisingly, even some reputable manufacturers who are willing to offer 3-year warranties on their handheld and low-cost bench DMM's are reluctant to offer more than a one-year warranty on their most sophisticated bench models. However, one-year warranties can usually be extended for a fee. We suggest that you carefully read and compare specifications, literature, and any available evaluations of products before you buy any bench DMM.

In searching for the bench DMM best suited to your needs, you should consider the value of such features as autoranging vs. manual ranging. Autoranging automatically determines the proper range and polarity for the DMM to display a measurement with the best resolution. Manual ranging allows you to override the autoranging function and make manual se-

ANALOGIC'S DP 100.

BECKMAN INDUSTRIAL'S MODEL 360

lections. While some DMM's have both, many high-performance DMM's do not include autoranging. This is acceptable because those instruments will be used in controlled environments where the ranges of unknown signals are generally known.

Measurement capabilities

In addition to basic DC-voltage accuracy, you will want to know the maximum DC voltage that can be measured without a plug-in probe, and maximum DC-voltage resolution. Basic DC-voltage accuracy will range from 0.1% in 3-1/2-digit (2000 count) meters to 0.003 % in 5-1/2-digit (200,000 count) meters. A rating of 1000 volts maximum DC voltage is commonplace in modern bench DMM's; it will be obtained at the high end of as many as five ranges, typically 200 mV, 2 V, 20 V, 200 V, and 1000V. Maximum DC-voltage resolution should typically be a value of 100 microvolts or less.

The AC-voltage specifications also include basic accuracy, maximum resolution, and maximum (RMS) value without the use of a probe. Frequency range in hertz over which AC measurements are valid is another variable included under AC volts. Basic AC-voltage accuracy is typically a fraction of the DMM's DC-voltage accuracy; in some cases it is as much as an order of magnitude less.

Maximum AC resolution, also measured in microvolts, typically matches the values for DC volts. Maximum voltages for bench DMM's are typically between 750 and 1000 volts AC RMS. Expect five AC voltage ranges comparable to the DC voltage ranges. The ability to measure true RMS voltage is a popular feature for bench

DMM's; most bench DMM's either offer this feature or make provision for it as an option.

Maximum ratings for AC and DC current in amperes that can be measured without a probe are also important for the bench DMM user. Don't be surprised to find that handhelds have higher maximum current ratings than high-performance bench meters to protect against the unknown conditions encountered in making current measurements in the field. They could be only 2 amperes. However, you can expect the bench meter to have better current resolution—0.1 microampere or better.

Maximum resistance values that can be read on a bench DMM are typically 20 megohms or better, but they could be as

FLUKE'S DUAL-DISPLAY MODEL 45

high as 300 megohms. However, maximum resistance resolution could be 1 milliohm or less in the high-end models. The diode tests and conductance measurement functions are less popular in high-performance DMM's.

Special features

Beyond the capability for measuring the five basic electrical parameters and doing diode tests, many DMM functions are considered to be special. In general, with the exception of system compatibility, none are exclusive to bench DMM's.

Because of their normally controlled working environments, accuracy and resolution outrank versatility in the selection of a bench DMM. It has been found that specialized temperature, frequency, and even capacitance measuring instruments are preferred over

GOLDSTAR'S MODEL DM-7241

those functions in DMMs used in labs or shops. Manufacturers will, however, include these functions if they find a demand for them. But if you don't need them you could be paying a lot for a feature with lower performance than is obtainable in a specialized instrument.

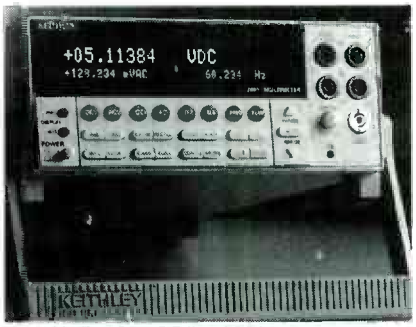
By contrast, the handhelds follow the Swiss Army knife philosophy of stuffing as many "tools" as is practical in a single package. Battery conservation and protection against personal shock and destruction of the DMM are, as you might expect, more important characteristics in handhelds.

True RMS voltage and current: This feature provides accurate measurement of nonsinusoidal waveforms such as square waves, pulses, or the outputs of silicon-controlled rectifiers. This function, either standard or optional, is widely found in bench DMM's, but less often found in handhelds. You can be sure that any DMM with the true RMS measurement feature will cost more than a comparable meter without that feature.

System compatibility: Some bench DMM's offer an EIA RS-232C and/or IEEE-488 interface as either standard or optional features. The RS-232C interface allows data to be interfaced to any serial printer or computer. The data can be filed, manipulated, printed, or transmitted by modem. Internal DMM circuits format the measurement data transmission. Host computer software permits remote operation of all instrument functions.

IEEE-488 (also known as the general purpose information bus or GPIB), is a parallel interface bus that consists of eight bidirectional data lines and eight signal grounds (three wires for handshakes between equipment, and five wires for management). Some DMM's permit both RS-232C and GPIB interfaces. Although RS-232C interfaces are becoming more popular because of the proliferation of personal computers in laboratories, the IEEE-488

HEWLETT-PACKARD'S MODEL 34401A



KEITHLEY'S MODEL 2001

bus is still widely used in industrial data acquisition systems.

Decibel (dB) and dBM readout: DMM's with this function measure and display the dB gain or loss of amplifiers, filters or attenuators. The dBm readout is referenced to 1 milliwatt and 600 ohms.

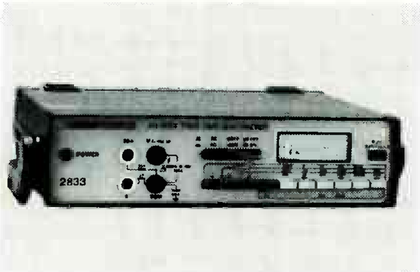
Offset/relative reference: This function stores the input in memory as a zero "reference". Any subsequent input is automatically compared to the reference in memory, and the display shows the difference (±) between these two values. It is also a handy feature for nulling out test lead resistance or measuring the dB gain for the stages of an audio amplifier. Relative reference works in all functions and ranges, and is a feature found on high-end handhelds and low-end benchtops.

Frequency or period: Some DMM's can also measure frequency or its reciprocal period. Bench-type DMM's are likely to have frequency responses in the megahertz range, especially if they have six or more readout digits. Some DMM's now have AC voltage input ranges as high as 15 MHz and AC current input to 1 MHz. These can be translated into period. You will want to know accuracy, sensitivity, maximum input, and trigger level for these measurements.

Temperature measurement: Some bench DMM's have the capability for measuring temperatures with one or more standard thermocouples or a resistance temperature detector (RTD). Here again, the specified accuracy and resolution will be important in your decision if you want this feature in your multimeter.

Continuity beeper and diode test: Continuity, diode and transistor checks can be made quickly on DMM's with this feature without looking at the display. A continuous tone indicates continuity, while a beep signals a forward-biased diode or transistor. The beeper is easily heard in a noisy industrial environment.

Min/max hold: DMM's with this feature store the highest and lowest readings, permitting you to monitor a signal for seconds, or even days. Collected average values during the period are calculated and displayed, and when the recording period ends, you can examine the readings at your convenience. Overloads or manual stop/starts won't erase memory until you give the command. Min/max recording is possible when measuring AC and DC voltage or current, and resistance. This feature is also found on some handheld meters.



B&K PRECISION'S MODEL 2833

Analog Bar Graph: The analog bar graph is a segmented analog needle simulator. It performs the same role as a VOM needle, while eliminating the mechanical/inertial distortion inherent in a needle's movement. This feature is not widely available in bench DMM's.

Sleep mode: This feature automatically shuts off power if you forget or if no measurements are taken for a specified length of time, say 60 minutes. This conserves battery life. It is found in some battery-powered bench meters.

Peak hold: This feature is useful for recording transients as low as 1 millisecond, especially from intermittent power lines or connections. This mode can also be used to measure the plus and minus peak values of sine waves up to about 450 Hz. It permits easy measurement of both peak line voltage and line current in power supplies and electrical equipment. However, it is rarely found on bench DMM's.

Data hold: This feature is known by different proprietary names such as "touch hold" or "probe hold." It allows you to keep your eyes on the probes and on the circuit under test. The DMM's microcomputer determines when the input signal is steady, alerts you with a beep, and then captures and holds the measurement on the display until you are ready to view it. It

BENCHTOP DMM SOURCES

Analogic Corp.
8 Centenial Drive
Peabody, MA 01960
(508) 977-3000
CIRCLE 301 ON FREE INFORMATION CARD

Beckman Industrial Corp.
Instrumentation Products Div.
3883 Ruffin Road
San Diego., CA 92123-1898
(619) 495-3200
CIRCLE 302 ON FREE INFORMATION CARD

B&K Precision
6470 W. Cortland St.
Chicago, IL 60635
(312) 889-1448
CIRCLE 303 ON FREE INFORMATION CARD

Daetron
935 The Queensway, Box 641
Toronto, Ont. Canada M8Z-5Y9
(416) 676-1600
CIRCLE 304 ON FREE INFORMATION CARD

John Fluke Mfg. Co.
Box 9090, MS 250E
Everett, WA 98206
(800) 443-5853 (800-44-FLUKE)
CIRCLE 305 ON FREE INFORMATION CARD

Goldstar Precision
13013 E. 166 St.
Cerritpos, CA 90701
(213) 404-0101
CIRCLE 306 ON FREE INFORMATION CARD

Hewlett-Packard Company
19310 Pruneridge Ave.
Cupertino, CA 95014
(800) 752-0900
CIRCLE 307 ON FREE INFORMATION CARD

Keithley Instruments, Inc.
28775 Aurora Road
Cleveland, OH (216) 44139
(216) 248-0400
CIRCLE 308 ON FREE INFORMATION CARD

Kenwood USA Corp.
2201 E. Dominguez St.
Long Beach, CA 90810
(213) 639-4200
CIRCLE 309 ON FREE INFORMATION CARD

Leader Instruments Corp.
380 Oser Ave.
Hauppauge, NY 11788
(516) 231-6900 (800) 645-5104
CIRCLE 310 ON FREE INFORMATION CARD

Prema Precision Electronics Inc.
4650 Arrow Highway
Building E-5
Montclair CA 91763
(714) 621-7292
CIRCLE 311 ON FREE INFORMATION CARD

Protek Inc.
P.O. Box 59
Norwood, NJ 07648
(201) 767-7242
CIRCLE 312 ON FREE INFORMATION CARD

Simpson Electric Co.
853 Dundee Ave.
Elgin, IL 60120
(708)697-2260
CIRCLE 313 ON FREE INFORMATION CARD

Triplett Corp.
One Triplett Drive
Bluffton, OH 45817
(419) 358-5015
CIRCLE 314 ON FREE INFORMATION CARD

Yokogawa Corp.-America
2 Dart Road
Newnan, GA 30265
(404) 253-7000
CIRCLE 315 ON FREE INFORMATION CARD

automatically updates with each new measurement.

Reading spec sheets

Manufacturers' specification sheets can be quite confusing because they do not follow a uniform format. They can be especially intimidating for the first time DMM buyer trying to decipher the baffling terminology. The wise buyer should understand such terms as CMR, NMR, and RMS, average, and peak AC readout.

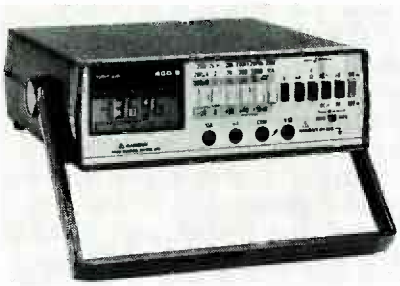
Definitions of some of the commonly used terms in DMM specificastions sheets will be helpful to you. Remember that the manufacturers are trying to attract your attention to their instrument's more glamorous features which may or may not be something you need. So brochures do not necessarily rank the qualities that are of most importance to you in any logical order. The burden for interpreting these specifications falls on you, the prospective buyer and user. But this also holds for a lot of other purchases such as appliances, automobiles or home-entertainment products.

Noise is an especially severe problem in DMMs due to their high accuracy, resolution, and sensitivity. DMM's used in systems are more susceptible to noise than those used just in isolated measurement applications. Long signal leads and coupling between adjacent signal leads compound the problem in systems.

Noise can be defined by its origin relative to signal input lines on the DMM. Normal-mode noise enters with the signal and is superimposed on it. Common-mode noise is common to both the high and low signal inputs. Common mode noise becomes normal-mode noise when it flows into the DMM's signal inputs.

Normal-mode noise originates from power-line pickup, electromagnetic fields or even from within the device being measured. Noise can be sinusoidal, spikes or white noise. There are two techniques used to reduce normal-mode noise: integration and filtering. Integration stretches the measurement out over a fixed period of time during which amplitude variations are averaged out. If the integration period includes a sufficient number of periodic noise cycles, the noise will be averaged out.

LEADER'S MODEL 856


SIMPSON'S MODEL 460-6

TRIPLETT'S MODEL 4800

Filtering slows down the conversion process or measurement speed so it is used judiciously. Integration does a better job of rejecting line-related noise, and filtering is better for broadband noise.

Common-mode rejection (CMR) is a measure of the change in output voltage when both inputs are changed by equal amounts of AC and/or DC voltage. It is the measure of an instrument's ability to cancel undesirable signals entering the measurement circuit between the input and ground. A reasonable value for CMR in a bench DMM is 100 volts DC or peak AC from any earth input.

Normal-mode rejection (NMR) is a logarithmic measure of attenuation of normal-mode noise components at specified frequencies in dB. For an amplifier used in instrumentation, the normal-mode signal is the actual difference signal being measured. This signal often has noise associated with it.

DC voltage uncertainty = [(ppm of reading) × (measured value) + (ppm of range) × (range used)]/1,000,000.

Percent uncertainty = (ppm uncertainty)/10,000.

AC voltage uncertainty = [(% of reading) × measured value) + (% of range) × (range used)]/100.

Crest factor (CF) expresses the waveform's peak value ratio to that of its RMS value. Crest factors in true RMS meters actually specify their dynamic ranges.

Self-test: DMM's with a microprocessor-controlled self-test feature usually run through this routine when they are turned on and the results show up on the display as segments that appear as rapidly as four times per second.

Self-check capability is extremely important for the assurance of accuracy and continued calibration to laboratory or international standards. Nevertheless, all DMM's, even those with this feature should be recalibrated at least once a year for maximum accuracy and reliability.

Input impedance is the combined AC and DC resistance at the input of the DMM. An input impedance of 10 megohms or better virtually eliminates measurement errors caused by loading in most circuits.

The outstanding characteristics of bench-type DMM's have been highlighted primarily on a basis of published specifications and unusual features. In an evaluation section that follows we have selected a cross-section of available benchtop DMM's and discussed some of their outstanding features. All of the bench multimeters discussed in this article are capable of making the five basic electrical measurements: AC and DC voltage, AC and DC current and current.

Selected reviews

Analogic offers the DP100, with a 5-1/2-digit LCD display capable of measuring voltage current and resistance. It is also a frequency counter capable of measuring up to 25 MHz as well as an RTD temperature meter. The portable DP100 is powered from both built-in rechargeable batteries and the AC line. It offers ±0.003% basic DC-voltage accuracy, 0.1-microvolt sensitivity and the ability to measure true RMS AC voltage and current, and 2- or 4-wire resistance. The DPM includes RS-232C compatibility or optional IEEE-488.2 converter.

B&K Precision offers three bench DMM's all capable of making the five basic measurements—AC and DC voltage and current, and resistance. The model 2831A is a 3-1/2-digit meter with a LED display that also offers continuity checking and diode test. It has a 0.1% basic DC-voltage accuracy rating. The model 2833 with a 4-1/2-digit LCD display, features true RMS voltage and current measurement. It has basic 0.05% DC-voltage accuracy. Other features include audible continuity check, diode test, data hold, dBm readout, and frequency measuring.

The B&K model 2832, with a 3-1/2 digit LCD display, measures capacitance. It's basic DC-voltage accuracy is stated at 0.5%. Other features include audible continuity check and diode test. This DMM can be powered from the AC line or six "C" cells.

Beckman Industrial Corp. offers two 3-1/2-digit bench/ portable DMMs with LCD displays, the models 350 and 360 B. Both are packaged in similar cases with a front-panel rotary function switch, and both have basic 0.1% basic DC-voltage accuracy and 22-megohm input impedance. In addition to the five measurement functions, the meters provide audible continuity checking and diode testing. The model 360 offers true RMS AC voltage and current measurement as well as temperature measurement with a type K thermocouple. Both meters are powered by six "D" cells and are built for field use.

John Fluke Mfg. Co. offers a family of seven bench/portable DMM's with 3-1/2 to 5-1/2-digit displays. Some also offer diode test and others measure conductance. There is, however, considerable variation in the special features offered. The 3-1/2-digit model 37 has a basic DC-voltage accuracy of 0.1% and the 5-digit model 45 has a basic DC-voltage accuracy of 0.02%. The model 45 has a dual vacuum-fluorescent display and it can measure frequency and display dB and dBm. It also has the min/max hold feature.

Fluke is also offering two 5-1/2-digit models in the 8800 series, the 8840A and 8842A. The 8840A offers 0.005% basic DC-voltage accuracy, while the 8842A has 0.003%. Both feature optional true RMS AC voltage and the ability to measure frequency to 100 kHz.

Goldstar Electronics offers the DM-7241 with a 4-1/2-digit LCD display. It has a basic DC-voltage accuracy of 0.05% and a resistance range to 20 megohms.

Hewlett-Packard offers four benchtop DMM's. The HP34401A has a 6-1/2-digit vacuum-fluorescent display and features true RMS AC voltage and current measurement. Resistance is measured in ohms with 2- and 4- wire circuits. In addition, the model 34401A measures frequency, period, and continuity, and can do diode tests and DC:DC ratios. DC-voltage accuracy is given as 0.0035% while AC-voltage accuracy is 0.06%. The meter's bandwidth is 3 Hz to 300 kHz. Its math functions include null, min/max average, dB and dBm readout, and limit test. Both the IEEE-488.2 and RS-232C interfaces are standard.

Keithley Instruments offers five bench/portable DMMs. The model 2001 has a 7-1/2- digit display and a rated basic DC-voltage accuracy of 0.0007%. Basic AC-voltage accuracy is given as 0.03%, and bandwidth is 1 Hz to 2 MHz. The 2001 can measure resistance values from 1 micro-ohm to 1 gigohm. It takes 2000 readings per second with 4-1/2-digit resolution, 300-500 with 5-1/2-digit resolution, and between 45 and 200 with 6-1/2-digit resolution.

The 2001's standard measurement functions include AC crest factor, frequency from 1 Hz to 15 MHz, true RMS, and peak and average AC. It also makes DC in-circuit current measurements, and offers simultaneous displays. Options include a ten-channel scanner. GPIB (IEEE-488.2) output is standard.

Kenwood USA Corp. offers the model DL-712 that has both manual and autoranging. Other standard features of the DMM include diode test, data hold, and continuity checking.

Leader Instruments' model 856 has a 4-1/2-digit LED display which includes a bar graph. Equipped with autoranging, it measures true RMS and frequency. The 856 also does diode test and continuity checks, displays dB and dBm, and makes data comparisons. Its basic DC-voltage accuracy is 0.05%.

Simpson Electric offers four 4-1/2- and 3-1/2-digit benchtop DMM's. They all feature true RMS AC measurement. The 4-1/2-digit 460-6 offers Ni-Cd battery/AC-line operation and 0.07% DC volts accuracy. The 467-2, a 3-1/2-digit DMM, has peak hold.

Triplett Corp. offers the model 4800, a 4-1/2-digit benchtop DMM with true RMS readout. Its features include data memory, peak hold, dBm readout, autoranging, temperature measurement, and diode test.

Yokogawa offers the 5-1/2-digit models 7551/7552 and the 6-1/2-digit models 7561/7562. They are rated for basic DC-voltage accuracies of 0.005% and 0.003%, respectively. These DMM's can be calibrated with external signals. The 7552 and 7562 offer RMS AC measurement, while the 7551 offers AC mean measurement. The 7552, however, offers both frequency measurement and a 20-ampere range. The RS-232C or IEEE-488 interfaces are standard on all these models. **R-E**

MIDI LIGHT CONTROLLER

Our MIDI light controller can turn an ordinary musical performance into a concert!

EDWARD J. KEEFE JR.

MOST SMALL BANDS USUALLY HAVE such a hard time paying for travel and instruments that their shows must forgo any type of sophisticated lighting. The lights provided by the clubs and bars where they play do little to showcase a band's talent. With the MIDI (Musical Instrument Digital Interface) light controller presented here, that can all end. A simple microprocessor with a handful of components can transform their act into a full fledged "concert." Everything that is needed to synchronize lights and music already comes out of the MIDI port of MIDI keyboards. This circuit will make use of that information and enhance the show.

MIDI is a communications protocol originally created for interfacing synthesizers and other electronic devices. It has evolved into a communications standard that is used in all phases of audio and video production. MIDI allows devices to talk to each other with different types of control and data values. The values can be either CHANNEL, SYSTEM, REAL-TIME, or SYSTEM EXCLUSIVE messages. MIDI communication is achieved through multi-byte messages, each consisting of one STATUS byte followed by one or two DATA bytes. Real-time and exclusive messages are exceptions to that rule.

Two types of data bytes are sent over the MIDI cable, STATUS and DATA. Status bytes are eight-bit binary numbers in which the most-significant bit is set to "1." A status byte sets the function of the data bytes that follow it, and a new status byte is required for each new action. The MIDI specification also outlines RUNNING STATUS. That defines the action for all data bytes that follow a status byte, until a new status byte is sent. That way more information can flow down the cable. Data bytes are eight-bit binary numbers in which the most-significant bit is set to "0."

The MIDI light controller presented here reacts to NOTE ON, NOTE OFF, START, STOP, and CONTINUE status bytes. The data bytes are used to determine which light to control and how

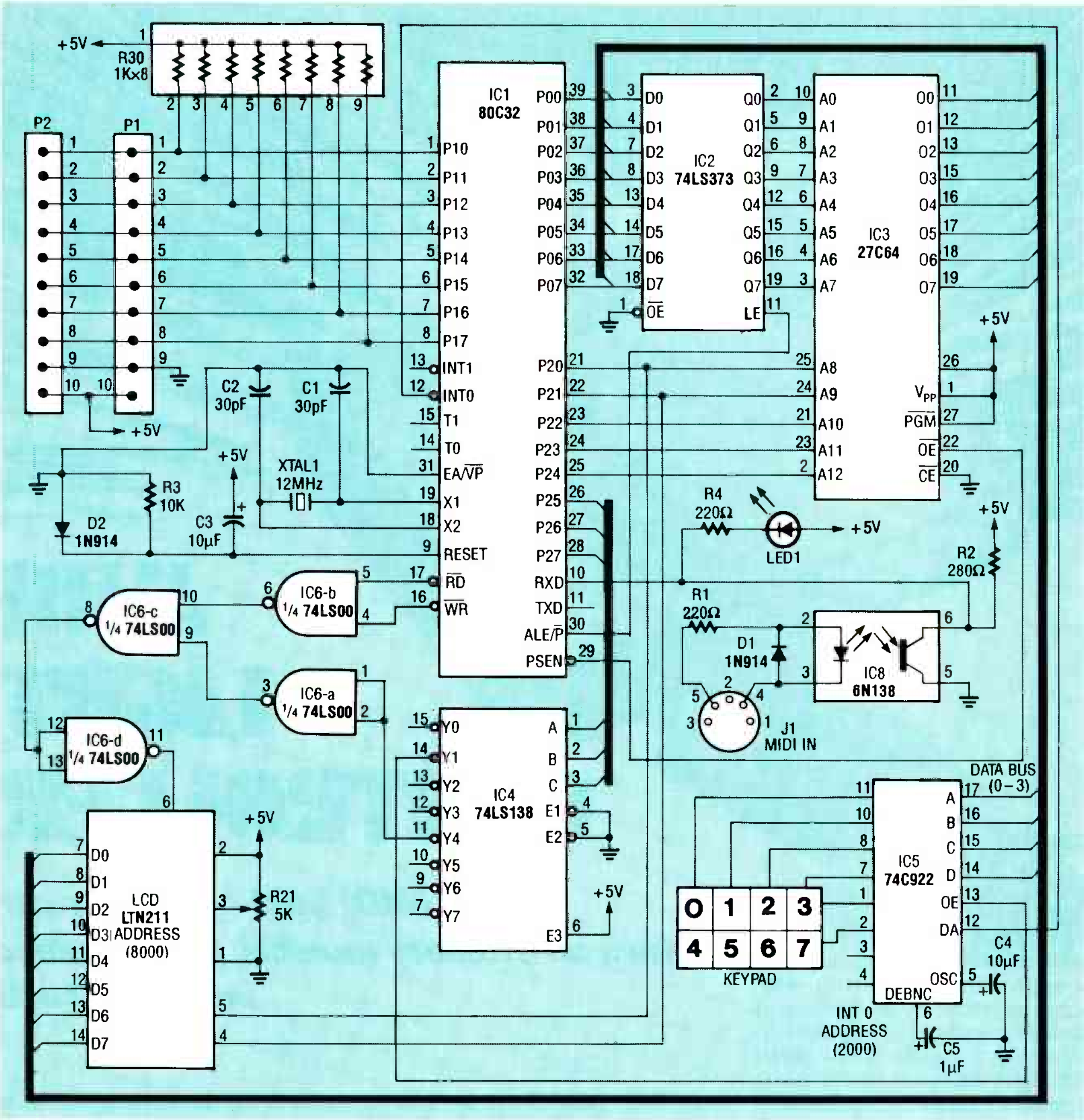


FIG. 1—SCHEMATIC OF THE MAIN PROCESSOR BOARD. The MIDI signal is fed in through an optocoupler (IC8) to the microcontroller (IC1).

to respond to different conditions on the MIDI. It can operate on any of the 16 MIDI channels, and will respond to note information from octaves 1–8. The MIDI light controller is user-configured. You have control over whether the lights will latch, toggle, or stay off in reaction to note information on the MIDI by setting the OUTPUT TYPE keyboard selection.

When a STOP command is received (STOP, START, and CONTINUE commands synchronize all elements of a MIDI system), the lights can either all go off, all go on, or light selectively, depending on the user's STOP DEFINE parameters. That is useful for creating a "scene" between songs and during breaks on stage. The CONTROL OCTAVE determines which range of notes will be used to control the lights. The operating channel is set by selecting CHANNEL DEFINE. The message CHANGE CHANNEL # will be displayed on line 1. Line 2 will toggle between "1" (channels 1–8) and "2" (channels 9–16). You must select "1" or "2" for the desired range of channels (1–8 or 9–16) and select the desired channel.

The lights are controlled by note information on the MIDI. They can respond to actual notes of a song or notes that are placed in the sequence specifically for the light controller. To use existing notes, you would select the channel and octave from the sequence, and enter them on the keyboard. If the lights are to be controlled by a separate track, you would enter the note information for each light, keeping all notes in one octave. Timing and synchronization is provided by a sequencer. (A sequencer is any instrument that can store and read back MIDI data.)

The light controller will also work directly from a keyboard without the aid of a sequencer by connecting a keyboard's MIDI output to the jack on the light controller. As you play the keyboard, the appropriate lights will illuminate.

The circuit

Figure 1 shows a schematic of the main processor board. The MIDI signal is fed in through IC8, an HP 6N138 optocoupler. Any optocoupler can be used as long as it has a rise time of less than 2 microseconds, and can turn on with less than 5 mA. The MIDI signal has the following operating specifications: 31.25-kHz baud rate, asynchronous, 1 start bit, 8 data bits, and 1 stop bit, with a period of 320 microseconds per serial byte. The signal is well suited to the serial portion of the Intel 80C32 microcontroller (IC1) that has built-in transmit and receive serial ports, 128 bytes of internal RAM, two interrupt lines (each with programmable priority), and external memory addressing capability up to 64K. The CMOS version of the 8032 was used because of its higher speed and lower power consumption.

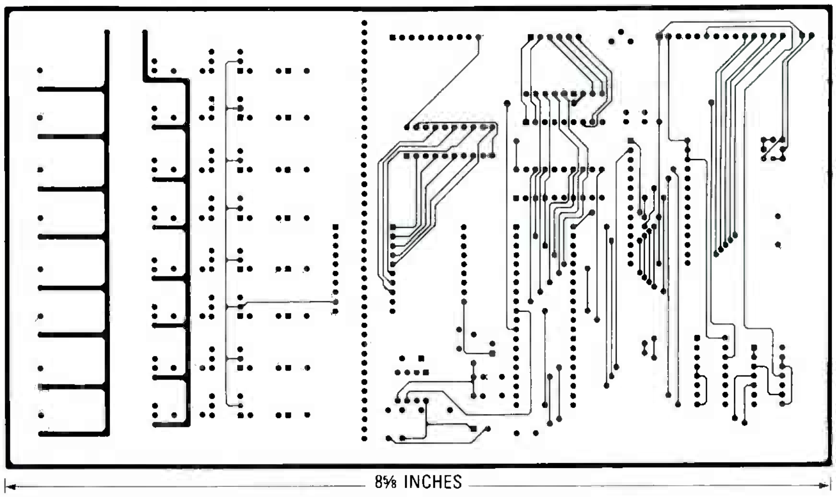
The output of optocoupler IC8 enters the serial receive port (pin 10) of microcontroller IC1. Software in the 27C64 EPROM (IC3) controls port setup and baud-rate selection. At power up, a small reset circuit (R3, D2, and C3) initializes the microcontroller. An oscillator is made up of a 12-MHz crystal (XTAL1) and two 30 pF capacitors (C1 and C2).

The address and data buses of the microcontroller are multiplexed. To remove the low-order address information, a 74LS373 8-bit latch is used. The 74LS373 is strobed with the ALE (ADDRESS LATCH ENABLE) signal from the microcontroller, and address data is removed. The 27C64 EPROM (IC3) is used to store program data. The EPROM is enabled by the microcontroller's PSEN (PROGRAM STORE ENABLE) line.

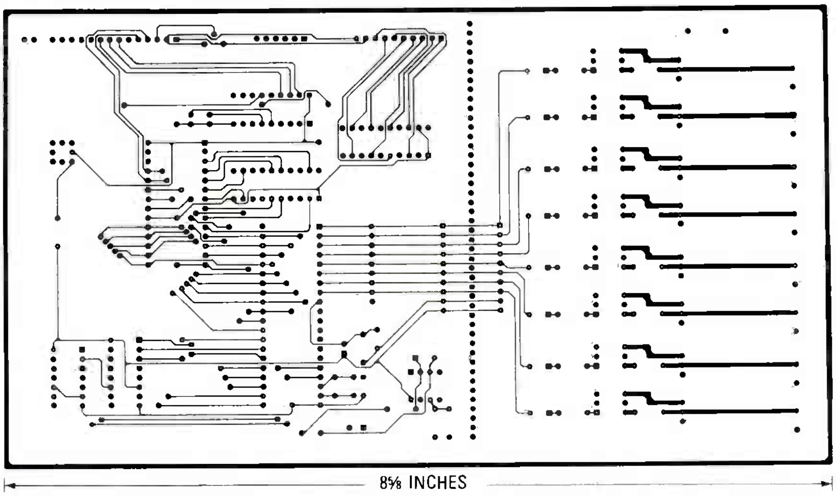
The keyboard and LCD circuits both require an address signal to interact with the data bus. A 74LS138 (IC4) is used to generate a signal when certain addresses are reached (1000h, 2000h, 4000h, 6000h...). The keyboard is mapped at external address 2000h. The keys are scanned by the 74C922 keyboard controller chip, IC5. All keyboard action, including debouncing, is handled by IC5. The scan rate is controlled by C4, and debouncing by C5.

The LCD is mapped at external address 8000h. An Optrex LTN211 two-line LCD module is used to display current channel and mode information. Also, user-definable selections are displayed there. Function data is written to the module at address 8000h, and display data is written at 8200h. Address selection and read/write functions are established by IC6, a 74LS00. Contrast of the LCD is altered by R21. Output from the microcontroller is on port 1, pins 1–8. A resistor network, R30, is used to pull-up output lines. The lines drive the Triac and LED sections.

Figure 2 shows the high-power output section of the light controller. Eight identical drivers are used to control the output channels. An output from IC1 is passed through a 1N914 diode and a 120-ohm resistor that drives an MOC3010 Triac-driver optocoupler. Output from the optocoupler is sent to a high-power Triac. The circuit is designed with 6-amp Triacs, which are fused at 5 amps for added protection. The 120-volt AC input to the Triacs must



COMPONENT SIDE FOIL PATTERN for the light controller.



SOLDER-SIDE FOIL PATTERN for the light controller.

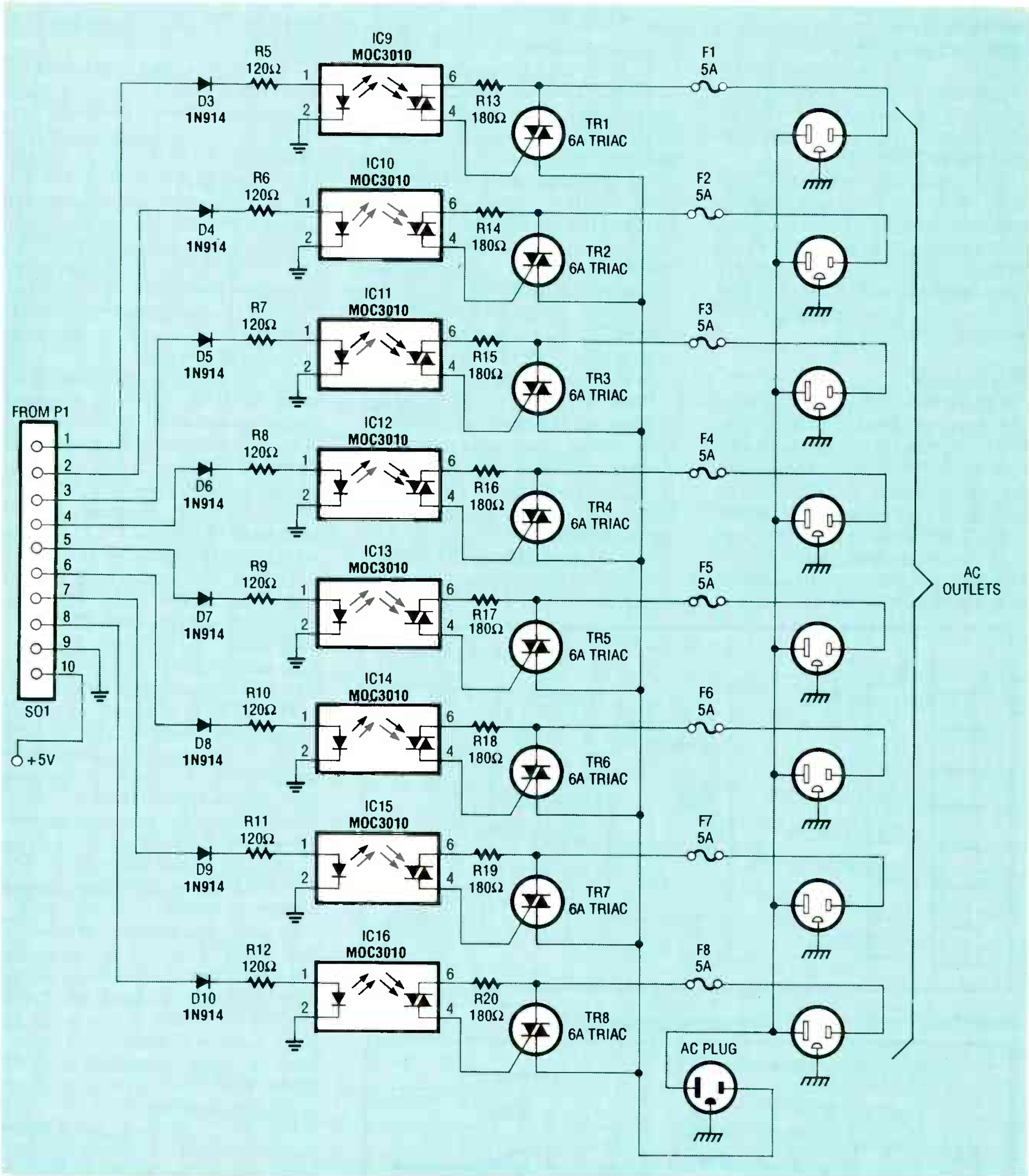


FIG. 2—HIGH-POWER OUTPUT SECTION. An output from the microcontroller is passed through a 1N914 diode, a 120-ohm resistor, an MOC3010 Triac-driver optocoupler, and finally to a high-power Triac.

be connected to a circuit that can handle the current. Power consumed by the light controller at 120 volts AC with all eight channels operating at full power is 4400 watts—that's almost 40 amps! Most household wiring is 15 or 20 amps per circuit breaker, so the AC input should be separated into multiple circuits to control that much power.

Figure 3 is the LED display section. It's used to indicate which output channel is active. It also helps you set up MIDI sequences without having to hook up any external lights.

A clean 5-volt DC power source is required for the light controller. The author used a self-contained 5-volt supply that includes a built-in transformer, rectifier, and regulator. The supply accepts a 120-volt AC input and outputs 5-volts DC. You can use a similar supply if you like, although they are more expensive. Otherwise any 5-volt supply will do.

Software

Software for the light controller is interrupt-driven. Upon reception of MIDI data, an interrupt is generated. The software jumps to the interrupt routine for the serial port. First the interrupt is cleared, then the byte is placed in the receive buffer. As more data comes in, it is buffered. The keyboard also generates an interrupt any time a key is pressed. As in the serial section, first the interrupt is cleared.

The main monitor loop of the program simply tests to see if data is in the receive buffer or the keyboard flag is high. If data is in the buffer, the byte is checked for a high MSB indicating a status byte. If it is a status byte, the status register is updated. The status will then remain until a new status byte is received. The program then continues the main monitor loop. If the byte is data, it is examined to determine the action to be taken. Depending on the current user-set mode of the controller, a light will be turned on, a light will pulse, or nothing will happen. If the data turns out to be bad, it is flushed.

After examining the data and acting upon it, the main monitor loop is resumed. When the key flag is high, the data in the temporary buffer is examined. The action desired is stored in the appropriate register. The main monitor loop is then resumed. All user-defined actions are entered on the keyboard. As options are entered, the LCD displays the choices available. The option being defined is displayed on the top line, and the selections are cycled through. Press the key for the desired action. If more information is needed for the chosen item, it will be presented on the LCD. The source code for the EPROM and some sample files to run on a sequencer are available on the RE-BBS as a self-unarchiving zip file called MLC1.EXE. A programmed EPROM is available from the source mentioned in the Parts List.

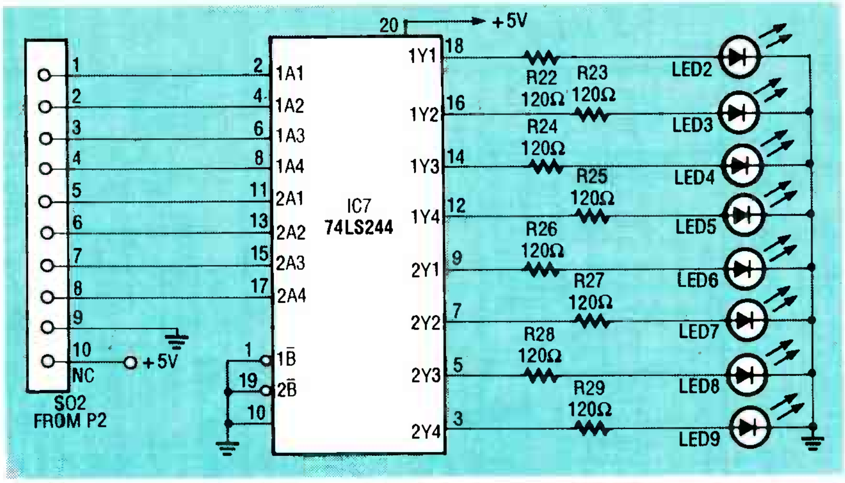


FIG. 3—LED DISPLAY SECTION. These LED's will indicate which output channel is active without having to set up the full-power lights.

All resistors are ¼-watt, 5%, unless otherwise noted.
R1, R4—220 ohms
R2—280 ohms
R3—10,000 ohms
R5, R6, R8, R10, R12, R15, R17, R19, R22–R29—120 ohms
R7, R9, R11, R13, R14, R16, R18, R20—180 ohms
R21—5000 ohms, potentiometer
R30—1K × 8 SIP resistor
Capacitors
C1, C2—30 pF, mica
C3—10 µF, 16 volts, electrolytic
C4—10 µF, tantalum
C5—1 µF, tantalum
Semiconductors
IC1—80C32 microcontroller
IC2—74LS373 8-bit latch
IC3—27C64 EPROM
IC4—74LS138 3-to-8 demultiplexer
IC5—74C922 16-key keypad encoder
IC6—74LS00 quad NAND gate
IC7—74LS244 octal buffer/line driver
IC8—6N138 optocoupler
IC9–IC16—MOC3010 optoisolator
D1–D10—1N914 diode
TR1–TR8—any 6-amp Triac in a T0-220 case
LED1–LED9—Chassis-mount light-emitting diode, any color
Other components
XTAL1—12-MHz crystal
F1–F8—5-amp fast-blo fuse
P1, P2—10-pin header strip
SO1, SO2—10-pin header socket
J1—5-pin DIN socket
Miscellaneous: inverter (for use with LCD backplane, see text), 5-volt power supply (see text), project case, grounded AC linecord, 8 grounded AC outlets, wire, solder, etc.
Note: The following items are available from Audio Visual Imagery, P.O. BOX 332, Randolph, MA 02368:
- **PC board—$35.00**
- **Programmed 27C64 EPROM—$10.00**

A diskette with the sample files will be included with any order. Please add $1.50 S&H to any order. MA residents must add 5% sales tax.

Construction

The PC board for the light controller can be made using the foil patterns we've provided, or it can be purchased from the source mentioned in the Parts List. A parts-placement diagram is shown in Fig. 4. Notice the row of pads to the left of the P1 header that divides the board down the center; the board can be cut there if you want to remotely locate the power section of the board and then run low-voltage wiring between the two sections.

If you are going to cut the board in two, do it before stuffing it, as it will be easier. Install the components according to Fig. 4, and check your work as you go. The pads marked "INV" on the board are for a voltage inverter (see parts list), if used. It that generates the proper voltages for the backlight on the LCD if the LCD you use has one. If it does have a backlight, and you wish to use it, install the inverter and connect the LCD's backlight terminals to the pads marked "BL" on the board.

Any kind of case will do for this project, as long as everything fits inside—keep in mind the power supply you will use and be sure to leave room for it. If you use a metal enclosure be

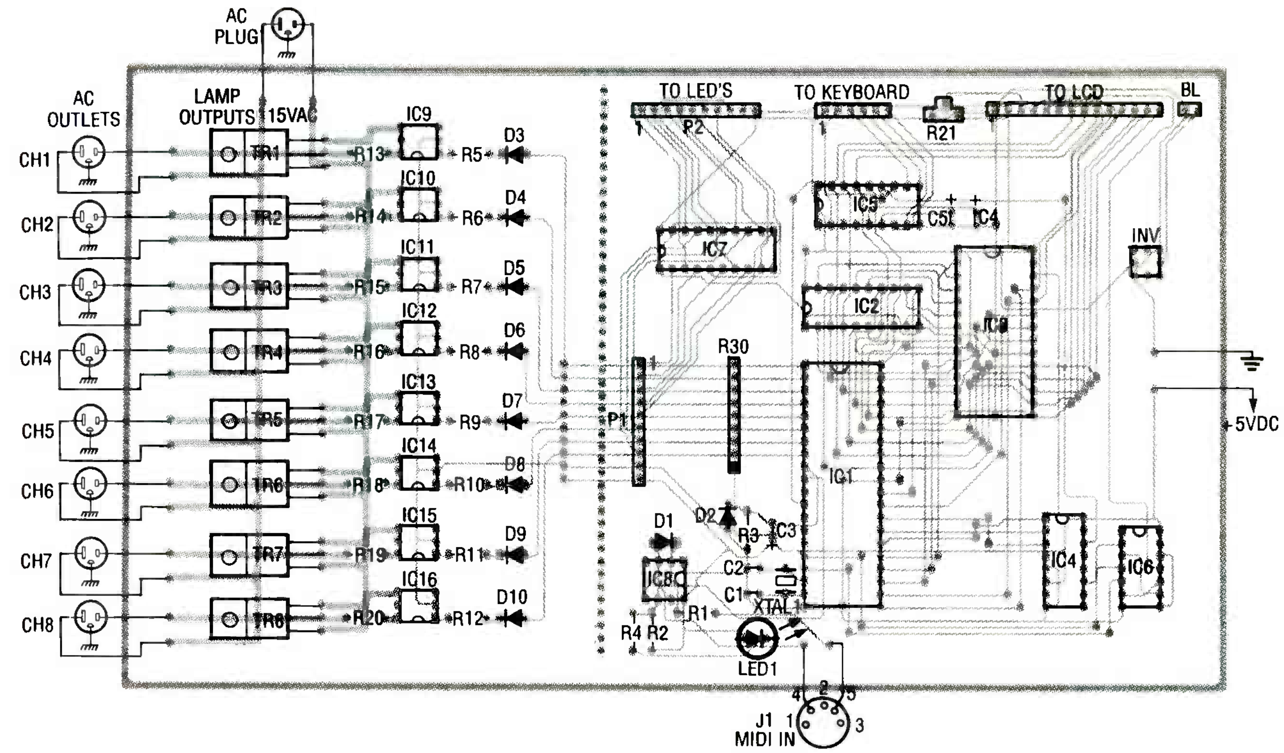


FIG. 4—PARTS-PLACEMENT DIAGRAM. The PC board can be cut down the row of pads to the left of the P1 header if you want to run low-voltage wiring between the two sections.

sure to ground it to the AC safety ground as shown in Fig. 2, and also properly ground all eight AC outlets.

As a reminder, the light controller can output about 5 amps per channel, and any wire common to all eight outputs must carry about 40 amps. The controller's internal AC wiring must therefore be chosen accordingly. Also, if your house wiring is rated 15 or 20 amps per circuit breaker, the AC input to the controller should be separated into at least two circuits. Figure 5 shows the current version of the PC board.

Testing

To test the light controller, simply adjust R21 to the middle of its range, and apply a clean 5-volt DC power source to the circuit. A message will appear on the LCD. Adjust R21 for the best-looking display. Plug a MIDI cable into the MIDI IN jack (J1) on the light controller. The other end should be placed in the OUTPUT jack of a sequencer or the THRU jack of a synthesizer. (If you're not using a sequencer, connect it to the OUTPUT jack of the keyboard.) At power up, the light controller is on MIDI channel 1. Make sure your MIDI equipment is sending notes out on channel 1. As notes are sent, LED1 will light, indicating that data is being sent over the MIDI. As notes are received and examined, the appropriate LED(s) will light (as long as the notes are in the CONTROL OCTAVE of the light controller).

If the circuit does not work, check the supply voltage. Make sure XTAL1 is oscillating. Check for a 1-microsecond reset pulse on pin 9 of IC1 at power up. If the reset circuit does not produce a pulse, the circuit will not start up. At power up, the eight LED's should light and then extinguish. If that does not happen and the clock and reset circuits are working, check the wiring of the LED's and the Triac section. If nothing happens still, the problem is with the microcontroller. Check the wiring of the ADDRESS and DATA bus. The circuit will function without the keyboard and LCD sections. If the circuit seems to be working (responding to MIDI notes, turning on LED's) but the keyboard and/or LCD do not respond, check the wiring of IC4 and IC6. Check for READ and WRITE (RD and WR) signals from IC1, pins 17 and 18 respectively.

Along with source code and HEX data for the EPROM, sample songs are provided in the zip file on the RE-BBS. (The sample files are also included with any order from the source men-

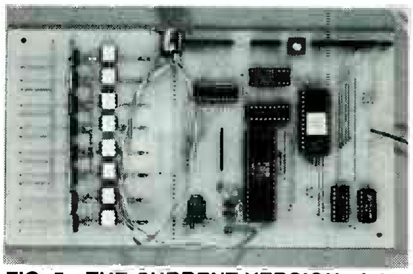
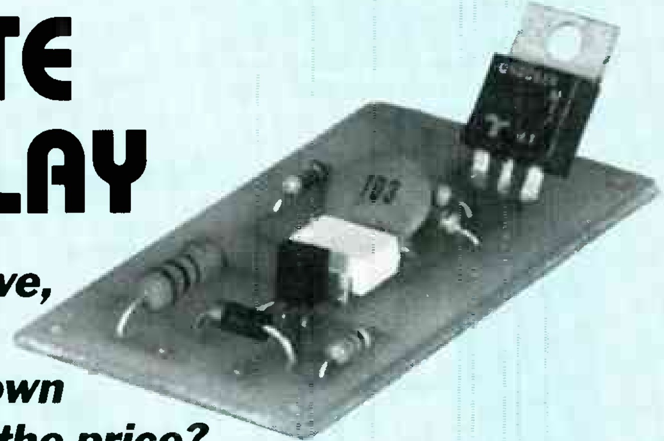


FIG. 5—THE CURRENT VERSION of the PC board, shown here with all parts installed.

tioned in the Parts List.) Three samples are provided in both *.WRK and *.MID formats that will help you get started. The songs were set up using a Roland MT-32, Cakewalk 3.0, and our MIDI Light Controller. The MIDI Light Controller and knowledge of your sequencer's operation will provide you—and your audience—with a great looking show. **R-E**

SOLID STATE RELAY



Why buy expensive, commercially made solid-state relays when you can make your own solid-state relays at a fraction of the price?

RODNEY A. KREUTER

SOLID-STATE RELAYS MAKE IT A cinch to connect digital logic to the nasty world of 115 volts (or more). These handy little devices make it possible for a battery-operated supply to turn on 100-watt light bulbs, 10-horse power motors, a lawn sprinkling system, or almost anything else you can imagine.

Solid-state relays, or SSR's, usually consist of an optoisolator and a Triac, which is used as an AC switch. There are many SSR variations such as those using reed relays in place of the optoisolator, and those using SCR's instead of Triacs, but most consist of less than a dozen parts.

Solid-state relays can provide isolation from 2 to 7.5 kilovolts and can drive tens of amps. They're usually offered in a plastic-filled cube with a heat sink on the bottom and screws for attaching the four wires—nothing could be simpler.

There are three common complaints with SSR's: First is the cost—twenty dollars apiece is about average. Second is the fact that they can't be repaired. When SSR's go bad, the fix could usually be a two-dollar Triac, but you can't get inside the plastic potting compound to repair it. Third is the fact that most SSR's made in large quantities are usually rated at about 10 amps. Who wants to pay for a ten-amp relay when all he needs is a two-amp relay? Besides, the larger the Triac, the larger the leakage currents.

There is hope for readers of **Radio-Electronics**, however. Using all new parts, the solid-state relay presented in this article can be built for less than eight dollars. An added bonus is that it can be repaired if anything goes wrong.

Operation

The basic operation of a solid-state relay is much like a switch that is controlled by an input voltage or current. That is illustrated in Fig. 1. Keep in mind that this switch can only be used for AC voltages because it will "latch up" on DC. (A Triac will turn off only when the current drops to zero.)

Our SSR circuit is shown in Fig. 2. Diode D1 provides protection in case you connect the input backward. Resistor R1 limits the input current. If you would like to use an SSR that requires a large input voltage (to increase the noise immunity) you can make R1 a large value. If you make R1 470 ohms, the relay will need about 12 volts to turn on. The power rating of R1 is a function of the maximum input voltage. For inputs up to 10 volts, a 1-watt resistor is needed.

The voltage across Q1's collector-emitter junction is almost constant (with a minimum input of three volts) at 1.75 volts (typical LED voltage) plus 0.7 volts (typical V_{BE}), or 2.45 volts. The voltage across R1 will therefore be the input voltage minus about 2.5 volts.

The minimum input voltage needed to turn on the SSR is a function of the minimum LED current (the LED inside IC1) and R1. The minimum for the MOC3010 is 15 milliamps. That works out to an input voltage of about 4 volts using the components shown. You can reduce the minimum voltage needed by decreasing R1 or by using an optoisolator that requires less LED current. Since the LED needs about 1.75 volts across it before it begins to emit light, operation below three volts isn't practical. The maximum current through the LED is set by resistor R2.

When the voltage across R2 reaches about 0.65 volts, Q1 begins to conduct, shunting current from the LED. The result is that, although the current through R1 rises as the input voltage rises, the current through the LED stops increasing at about 15 milliamps. The minimum LED current, therefore, is not the minimum current you can pass through the LED; rather it is the minimum LED current that will operate the Triac.

Probably the most misunderstood aspect of solid-state re-

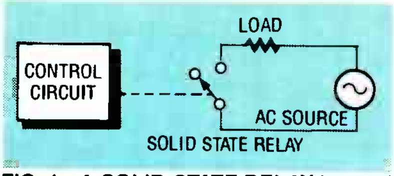


FIG. 1—A SOLID-STATE RELAY is much like a switch that is controlled by an input voltage or current.

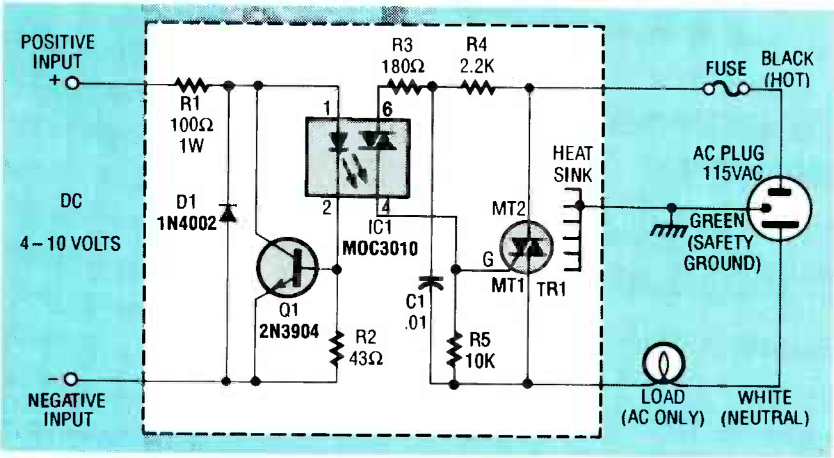


FIG. 2—SSR CIRCUIT. Diode D1 protects the unit if you connect the input backward, and R1 limits the input current.

lays is that the input requirement is really current, not voltage. That means that the driving circuit must be able to supply the current necessary to operate the LED in the SSR. In the example shown, the current is about 15 milliamps. The current can come from a current source as in Fig. 3 or a current sink as in Fig. 4. Most circuits can sink more current than they can source. For example, TTL can source only one milliamp or so, but it can sink 10 to 15 milliamps. If you must use a logic family that can't source or sink much current, such as the output of most computer ports, you can use a transistor to provide a current sink as shown in Fig. 5.

Zero-voltage switching

Some of the newer SSR's provide zero-voltage or zero-crossing switching. In normal operation the trigger side of the relay is totally asynchronous to the AC side. That means that a trigger could occur during any part of the AC sine wave. If the trigger occurs near a peak (90 or 270 degrees), a large current will flow into the load almost instantly. That creates a lot of RFI (radio frequency interference) and also is very hard on the filament of ordinary light bulbs. In order to prevent that, zero-crossing SSR's accept the trigger at any time but delay turning on the AC load until the next time the AC voltage passes through zero volts.

Safety

Building an SSR requires putting 110 volts on a printed circuit board. From an electrical point of view, that can be perfectly safe. However, it's probably a good idea to cover all printed circuit runs on the 110-volt side of the PC board with silicone sealer. Also, try to use only isolated Triacs (where the case is electrically isolated from the Triac), and ground the heat sink to the AC safety wire (green, or earth ground).

Choosing a Triac

There are three basic requirements when choosing the output Triac. First is to make sure that it will handle the voltage required. The minimum for a 115-volt AC line requires a 200-volt Triac. A 220-volt line requires a 400-volt Triac. Remember that those are the minimum so, for a few cents more, it pays to use the next highest voltage rating.

The next requirement is current. A 6-amp Triac will handle 6 amps only if it is properly heat

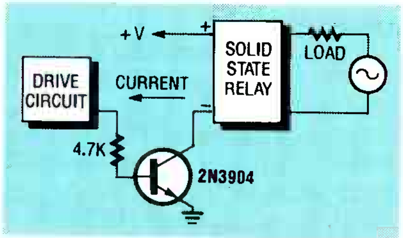


FIG. 5—IF YOUR CIRCUIT can't source or sink much current, use a transistor as a current sink.

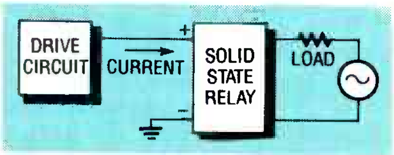


FIG. 3—THE INPUT REQUIREMENT of an SSR is current. Here the driving circuit is shown as a current source.

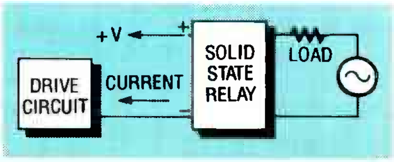


FIG. 4—THE DRIVING CIRCUIT is shown here as a current sink.

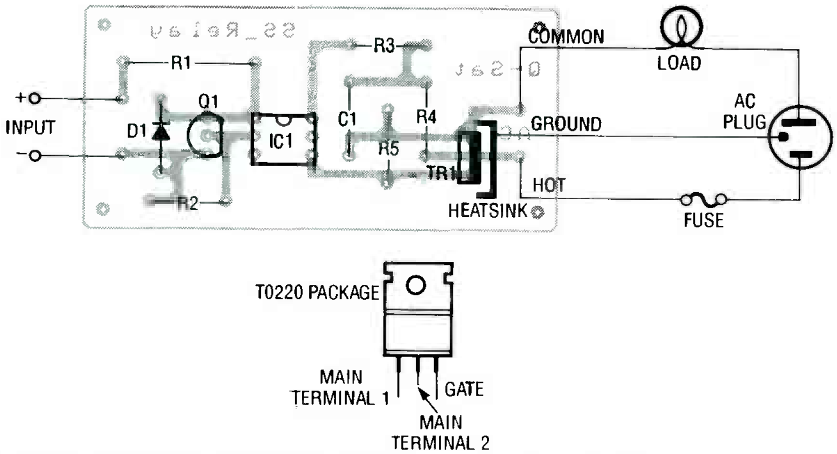


FIG. 6—PARTS-PLACEMENT DIAGRAM. You must heatsink the Triac and connect the heatsink to earth ground, even if you're using an isolated Triac.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—100 ohms, 1-watt (see text)
R2—43 ohms (see text)
R3—180 ohms
R4—2200 ohms
R5—10,000 ohms
Capacitors
C1—0.01 µF, 500 volts, ceramic
Semiconductors
IC1—Motorola MOC3010 Triac-output optoisolator (or MOC3011 for zero-crossing switching, see text)
D1—1N4002 diode (or any 1-amp, 100-volt or greater diode)
Q1—2N3904 NPN transistor
TR1—Teccor Q4006L4 Triac (or equivalent, see text)

Note: The following items are available from Q-Sat, PO Box 110, Boalsburg, PA 16827:
- **A printed circuit board for two solid-state relays, can be cut in two or left together (part number SSR-PCB)—$8.00 postpaid**
- **A complete kit minus heat sinks for two solid-state relays (sorry, sold in multiples of two only, part number SSR-KIT)—$18.00 postpaid**

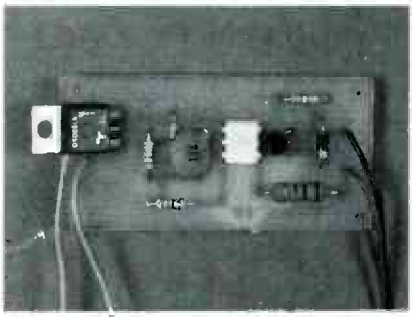
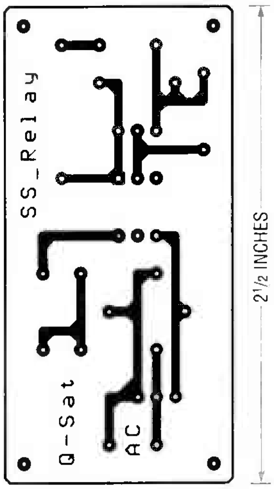


FIG. 7—THE AUTHOR'S PROTOTYPE. The board is shown here without a heatsink on the Triac, although one should definitely be used.



SSR FOIL PATTERN shown actual size.

sinked. As a word of warning, motors draw a lot more current on start-up than they do during normal operation, sometimes as much as ten times more.

The third requirement is the gate current. The Motorola MOC3010 optoisolator will provide about 100 milliamps of drive current for the output Triac. That should be adequate for any Triac you can find in a TO-220 package.

Although not a strict requirement, an isolated Triac is a good safety precaution. Isolated Triacs provide electrical isolation from the electrical connections to the case. Early Triacs were not normally isolated. That meant that you had to use mica washers and thermal grease. Thermal grease is still a good idea, but the mica washer isn't required for isolated Triacs. If you don't know whether or not your Triac is isolated, simply measure the resistance from each lead to the case. An isolated Triac will measure open on all three leads.

Warning: The Radio Shack 400-volt, 6-amp Triac (part number 276-1000) will work well in this circuit, but it is *not* isolated. You *must* use a TO-220 mica washer and thermal grease if you plan to use that device.

TABLE 1—TYPICAL TRIAC-OUTPUT OPTOISOLATORS

Motorola Type	Blocking Voltage	LED Current (mA)	Maximum R2 (ohms)	Zero Crossing Switching	AC Line Voltage
MOC3009	250	30	22	No	115
MOC3010	250	15	43	No	115
MOC3011	250	10	68	No	115
MOC3012	250	5	130	No	115
MOC3020	400	30	22	No	220
MOC3021	400	15	43	No	220
MOC3022	400	10	68	No	220
MOC3023	400	5	130	No	220
MOC3030	250	30	22	Yes	115
MOC3031	250	15	43	Yes	115
MOC3032	250	10	68	Yes	115
MOC3040	400	30	22	Yes	220
MOC3041	400	15	43	Yes	220

Construction

For a simple SSR, an optoisolator such as the Motorola MOC3010 will be sufficient. For a zero-crossing SSR, an MOC3031 will do. Many companies make optoisolators. Make sure yours has a Triac output and that the pinouts are compatible with your design. Table 1 shows some typical Triac-output optoisolator specifications.

Although the SSR can certainly be built without a printed circuit board, using the foil pattern we've provided will make building it a simple task. You can also buy a pre-made PC board from the source mentioned in the parts list. Figure 6 shows the parts-placement diagram. The only precaution, other than the one about working with 110 volts, is to heatsink the Triac. If you leave the leads on the Triac long, it should be a simple matter to find some heat sink to attach to the Triac. Just remember to connect the heatsink to an earth ground. Even if you're using an isolated Triac, the earth ground is still necessary. Otherwise you should buy your solid-state relays from a reliable company—don't build them yourself. Figure 7 shows the author's completed prototype.

Remember that SSR's can switch only an AC line. Trying to switch a DC line will result in a relay that closes but never opens. **R-E**

ANTHONY J. CARISTI

A DIGITAL ALTIMETER

Add new dimensions to your next trip to the mountains with our pocket-sized electronic altimeter.

IF YOU ENJOY HIKING OR DRIVING through mountainous country—but without knowing how far above sea level you are—this project will be of interest. It's a simple, easy-to-build, compact electronic altimeter that provides altitude readings from zero to 1999 feet with a resolution of 1 foot. The device has a 3½-digit LCD readout and is powered by a common 9-volt battery.

The altimeter's small size and light weight allows it to be easily carried wherever you travel. The modest power drain of the circuit ensures many hours of operation on a single 9-volt battery. If desired, the instrument can also be powered by the 12-volt electrical system of any vehicle.

The electronic altimeter is a pneumatically operated device that responds to absolute atmospheric air pressure. It operates on the same principle as the aneroid altimeters found in every aircraft.

Absolute atmospheric pressure is a mathematically definable parameter that varies inversely with altitude. At sea level the pressure is 14.7 pounds per square inch, and decreases as altitude increases.

The heart of the altimeter is a high-quality solid-state absolute-pressure sensor that is sensitive enough to detect changes in altitude as small as one foot. The surrounding circuitry amplifies the analog voltage output of the sensor, and converts it to digital form to drive the display.

The sensor

The pressure sensor was developed by Motorola Semiconductor Products, Inc., Phoenix, AZ. It's designed to respond to absolute atmospheric pressure, which is defined as pressure measured with respect to a perfect vacuum (zero pounds per square inch absolute, or 0 PSIA). Over the altimeter's range of interest, 0 to 1999 feet, the absolute atmospheric pressure varies from 14.696 PSIA to 13.67 PSIA (which corresponds to 29.92 to 27.82 inches of mercury, respectively).

Inside the sensor is a monolithic silicon piezoresistor that is ion-implanted on a thin silicon diaphragm. The pressure sensor contains two chambers separated by the silicon diaphragm. One of the sensor's chambers is exposed to atmospheric pressure by means of an external port. The other chamber is evacuated to as perfect a vacuum as possible, and sealed. That way the diaphragm of the sensor is under constant stress in accordance with the difference between atmospheric pressure on one side, and an essentially "perfect" vacuum on the other. The mechanical stress placed on the diaphragm (and the piezoelectric resistor) causes the sensor to generate an output voltage that is proportional to the applied pressure as seen by the open port of the solid-state sensor.

Refer to the schematic of the altimeter circuit shown in Fig. 1. The piezoresistor within the sensor (IC4) is connected between pins 1 and 3, and is driven by the 5-volt power supply in the circuit. The taps on the resistor, connected transversely across the element, are brought out to pins 2 and 4 of the sensor.

Under normal conditions in which atmospheric pressure causes a stress on the piezoelectric resistor, the sensor differential output voltage is a finite but very small value—about 20 millivolts. Over the range of interest for climbers (0 to 1999 feet), the sensor's output voltage will change only about 1.4 millivolts.

A differential amplifier, composed of three sections of an LM324N quad op-amp (IC1), provides voltage amplification of the sensor output. The gain of the amplifier can be adjusted by potentiometer R3 to allow for the normal tolerance difference between different sensors. The DC voltage level at pin 8 of IC1 is set to 2.5 volts when the altimeter is at zero altitude (sea level). At 1999 feet, the amplifier output falls to about 2.4 volts.

The DC voltage from the differential amplifier (IC1) drives an ICL7106CPL analog-to-digital (A/D) converter (IC3). That chip, which is used in many commercial DMM's, converts the differential voltage from IC1 to digital form and drives the 3½-digit liquid crystal display (DSP1). An external reference voltage, generated by R14–R17, provides the proper conversion factor between the analog input voltage and the desired digital display in feet.

As described earlier, the output voltage of the amplifier section is set to 2.5 volts by R3 when the altimeter is at sea level. That voltage is fed to the negative analog input of IC3 (pin 30). Since the altimeter must read zero at sea level, the positive input of IC3 (pin 31) must see a constant 2.5-volts. That way the differential input voltage between the positive and negative inputs will be zero, and the display will read 000 as desired. As the elevation of the altimeter increases, the voltage fed to pin 30 decreases while the voltage at pin 31 remains constant. As a result, the net difference in voltage is detected by IC3 and converted into an increasing digital display readout of altitude.

There is one other factor that must be taken into consideration in a pneumatically sensing altimeter of this type. Changing weather conditions cause changes in barometric pressure from the standard value of 14.7 PSI (or 29.92 inches of mercury at sea level). As with any altimeter that reacts to absolute air pressure, the effect of changing barometric pressure must be canceled out.

In this project the effect of barometric pressure is canceled out by means of BARO SET potentiometer R11 which can be adjusted for about 2.4 to 2.6 volts at its wiper. Therefore, R11 must be set so that the voltage at pin 14 of IC1-d causes the display to indicate the correct known altitude at any reference location. Once that is done, the altimeter is calibrated for the current barometric reading—but changing weather conditions can change the readings significantly. You will probably have to recalibrate the altimeter before each use, or simply set it to zero and use it to measure a relative altitude.

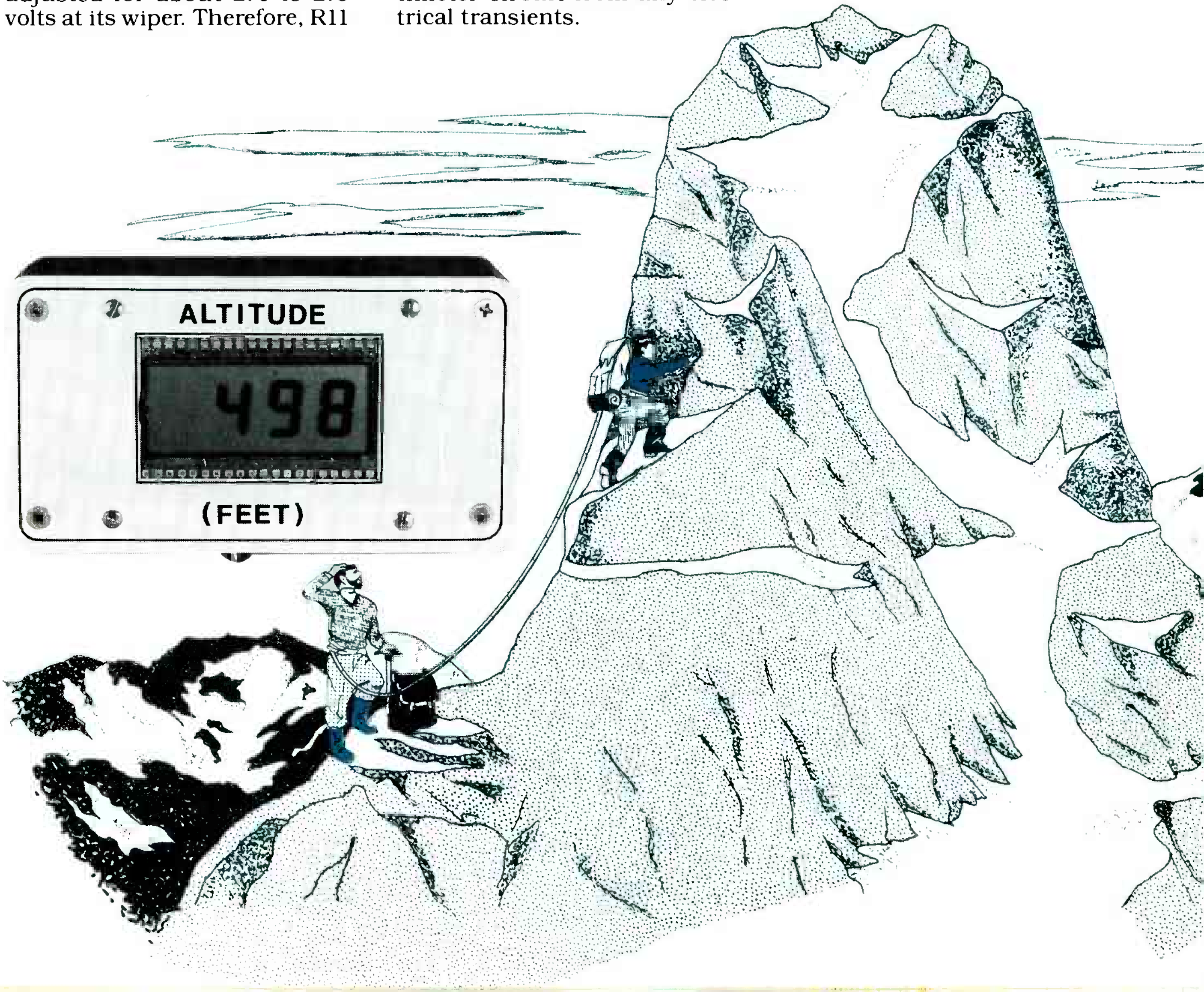
Power for the altimeter comes from a 9-volt battery or from a vehicle's 12-volt electrical system. Either source is fed to an AN78L05 fixed 5-volt regulator (IC2). The altimeter's modest current drain of about 6½ millamperes allows many hours of operation from a 9-volt battery. When 12 volts is used as the power source, a resistor and diode are used to isolate the altimeter circuit from any electrical transients.

Construction

The altimeter is built using two single-sided PC boards—one analog and one digital.

The two PC boards can be made using the foil patterns we've provided, or they can be purchased from the source mentioned in the Parts List. Point-to-point wiring can also be used. Parts-placement diagrams for the analog and digital boards are shown in Figs. 2 and 3, respectively.

You should use sockets for the two DIP IC's, but because of the limited space in the prototype's enclosure, only low-profile sockets would fit. Do not install the IC's in the sockets until instructed to do so. Note that the altimeter's accuracy will suffer if metal-film resistors, where specified, are not used. Also



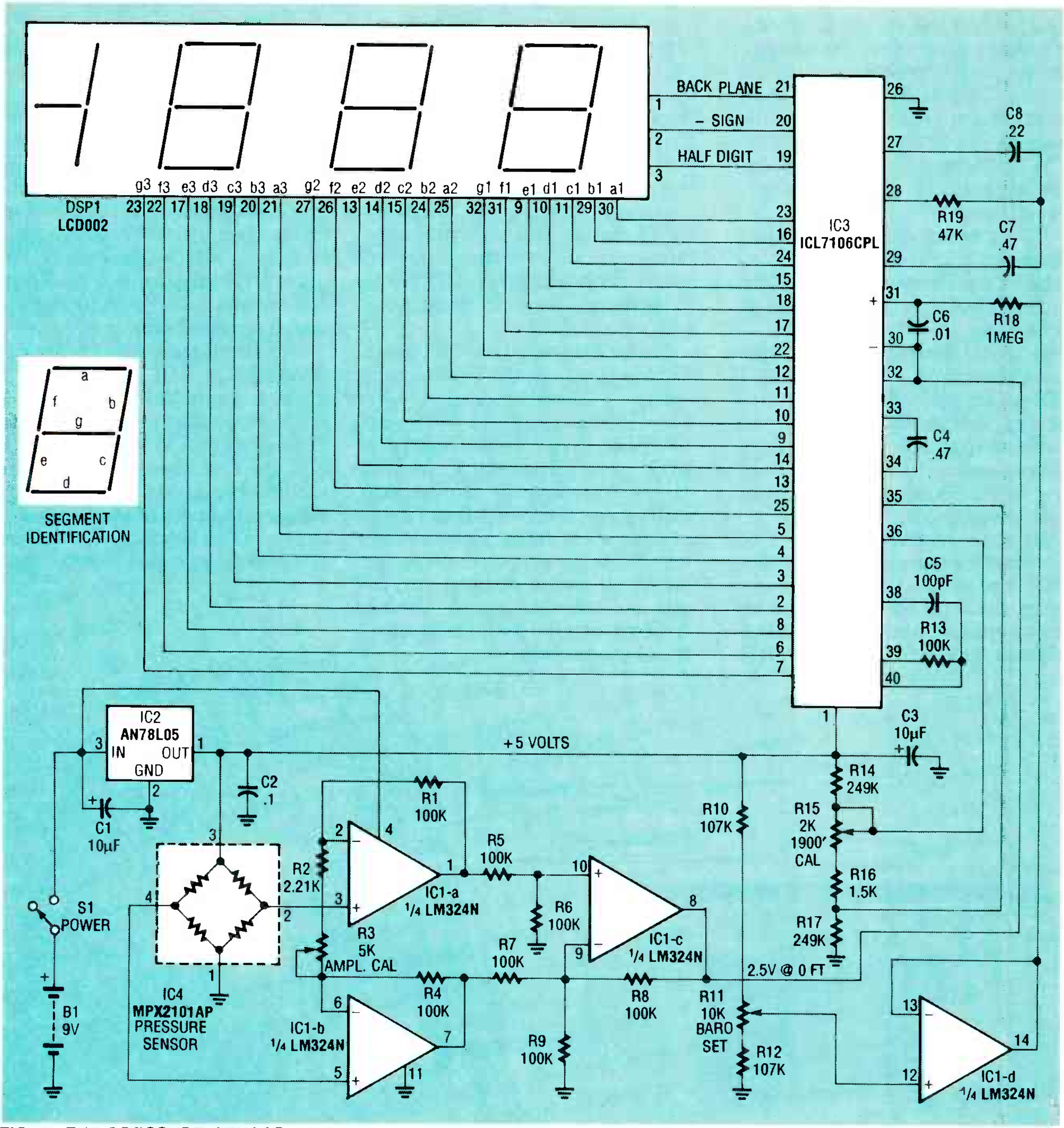


FIG. 1—THE PRESSURE SENSOR (IC4) has an analog output that is converted to digital form by IC3 and then displayed on the LCD.

note that R20 and D1 (shown on the analog board in Fig. 2) are to be installed only if you wish to power the unit from a vehicle's 12-volt source.

The pressure sensor should be handled with care. Its leads must be bent at right angles so that the sensor lies flat on the analog board. Use two long-nose pliers when bending the leads—one to prevent stress on the lead where it enters the plastic body and the other to bend it. Before forming the leads, locate pin 1 of the sensor; it's identified by a notch cut into the lead. Then you'll be able to form the leads in the correct direction. Mounting hardware for the sensor is optional because the leads will hold it in place. No pneumatic connection to the sensor's pressure port is required, except calibration.

The LCD module can also be mounted in a socket if you like; you can make one for it by cutting a 40-pin DIP socket in half lengthwise. To keep the altimeter as compact as possible, the LCD module is mounted on the copper side of the digital board, *after* all of the components are installed on the component side. (You can install a socket for the LCD now, but don't install the LCD just yet.) Mounting the LCD on the copper side allows the digital board to be mounted on the cover of the enclosure.

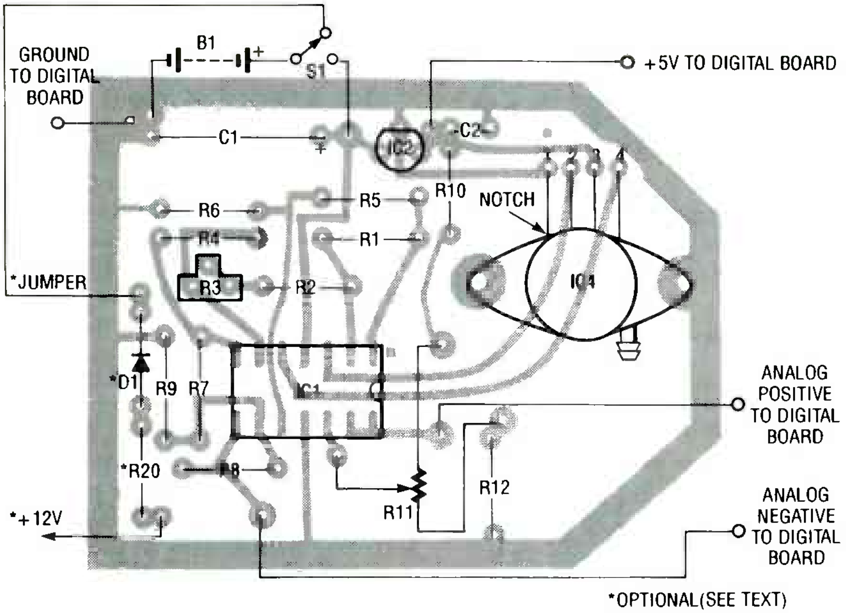


FIG. 2—PARTS-PLACEMENT DIAGRAM for the analog board. Note the components that are optional for 12-volt use. Also note the four connections that must be made to the digital board (see Fig. 3).

Obtain a clip for the 9-volt battery, or salvage a connector taken from an exhausted battery. Be sure to observe proper polarity on the battery connector. Power switch S1 and potentiometer R11 should be installed on the side of the enclosure, easily accessible to the user. If you are dealing with limited space (a small enclosure), use a miniature toggle or slide switch for S1. Once R11 is set, it's best if it can not be accidentally changed during the use of the altimeter. Therefore, R11 should be a screwdriver-adjusted part. If mounting R11 is a problem, the resistor can be epoxied in place next to the power switch. A multiturn potentiometer will make it easier to calibrate the unit.

A number of jumper wires, labelled JU1–JU20, are required on the component side of the digital board to complete the circuit. You must solder a jumper wire between each pair of pads—JU1 to JU1, JU2 to JU2, and so on. Use #24 or #26 insulated stranded wire. Examine both boards carefully for bad solder joints, shorts, and improperly installed components before continuing.

Final assembly

When both boards are completed, power, ground, and the two differential output wires from IC1-c and IC1-d must be connected between the analog and digital boards, as indicated in Figs. 2 and 3. Use insulated stranded wire for those connections and be sure to allow sufficient length to permit proper mounting in the enclosure. In the prototype, the boards are placed one above the other.

12-volt power

If you want the option of powering the altimeter from a vehicle's 12-volt source, R20 and D1 must be installed on the analog board. To allow operation from either the 9-volt battery or 12-volt source, a miniature jack can be installed in the enclosure to allow connection to the vehicle's electrical system and still allow portable use. Be sure to observe proper polarity when wiring the altimeter for 12-volt operation. You can make a power cable by putting a mini plug on one end and, most likely, an automotive cigarette lighter plug on the other. Just be sure to plug the cable into the altimeter first, to avoid having a live male connector completely exposed.

The altimeter can be wired for 12-volt power exclusively, or as a combination 9- and 12-volt unit. Follow the wiring diagrams in Figs. 4 and 5 for the selected power-source option. Give the project one final visual inspection before continuing with the checkout. Figure 6 shows the author's prototype.

Electrical checkout

Before proceeding, make sure the IC's are not in the sockets. You'll need an accurate DC voltmeter with an input resistance of at least 1 megohm to perform the checkout.

Use a fresh 9-volt alkaline battery or a well-regulated DC power supply to power the circuit. If the power supply has current-limiting capability, set the limit to 10 milliamps to protect the project in the event of a malfunction. (The normal current drawn by the circuit is about 6½ millamperes.) Set the supply for 9- or 12-volts output, as applicable.

First, check voltage regulator IC2. Apply power to the circuit and measure its output voltage. Anything between 4.75 and 5.25 volts is good. In case of trouble here, check the orientation of C1 and IC2, and the polarity of the power supply. Measure the terminal voltage of the battery or supply while it is powering the circuit to be sure it is delivering at least 7 volts to the regulator. Disconnect power and measure the resistance between the 5-volt line and ground to be sure there is no short circuit. As a last resort, try a new regulator.

Check the analog circuit next. Insert IC1 into its socket, and apply power to the circuit. Measure the voltage at pin 8 of IC1; adjust R3 for a reading of 2.5 volts. Measure the voltage at pin 14 of IC1 while rotating potentiometer R11 over its range. Make sure the range of adjustment is about 2.4 to 2.6 volts. If you don't see the correct voltages, check the wiring and components associated with IC1. Check the pressure sensor for correct orientation. Try changing IC1 as a last resort.

Disconnect power from the circuit and insert IC3 into its socket. Place the readout in its socket on the solder side of the

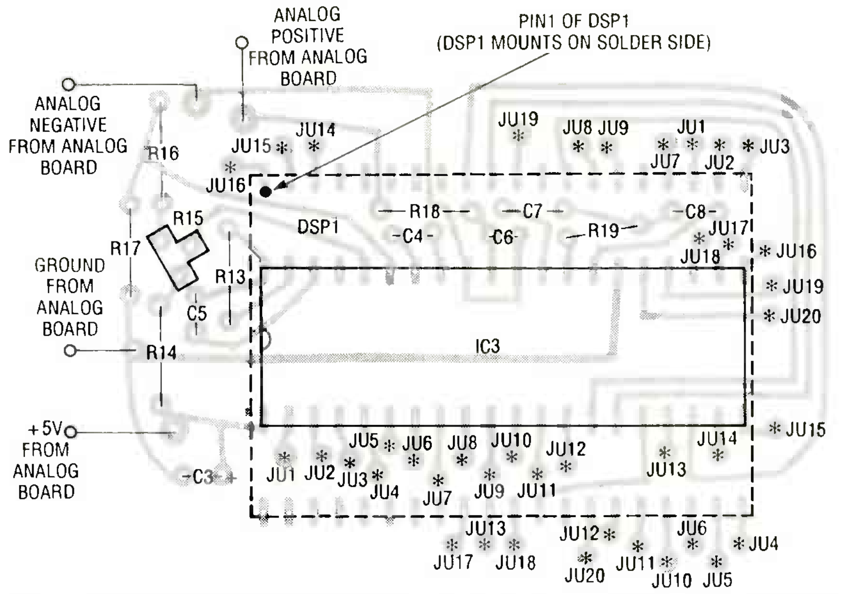


FIG. 3—PARTS-PLACEMENT DIAGRAM for the digital board. Note that the LCD module mounts on the solder side of the board after all other components are installed *and* the board is tested (see text for details). Also note the twenty pairs of pads labelled JU1–JU20. You must solder a jumper wire between each pair of pads; for example, JU1 to JU1, JU2 to JU2, and so on.

by IC3 at pin 1 of the readout. A normal indication at pin 1 is a 5-volt peak-to-peak square wave with a period of about 140 microseconds.

If the readout displays digits but the numbers do not ascend and descend with adjustment of R11, the fault is most likely with the components or wiring of IC3. Check all parts to be sure they have the correct value. The reference network composed of R14–R17 can be checked by removing IC3 from its socket and measuring the voltage between pins 35 and 36 of the socket while adjusting R15 over its range. Normal indication is 15 to 35 millivolts with pin 36 positive with respect to pin 35.

Operation of IC3 can be checked by removing IC1 from its socket and temporarily shorting pins 8 and 14 of IC1

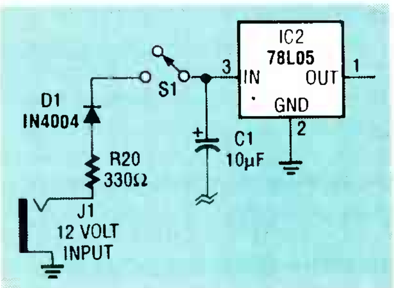


FIG. 4—WIRE THE ALTIMETER as shown here for 12-volt power exclusively.

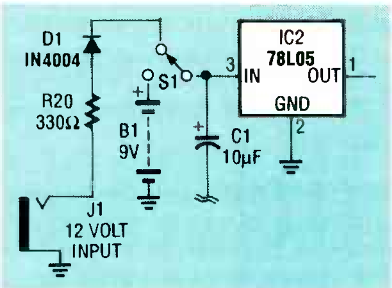


FIG. 5—THE ALTIMETER IS SHOWN wired for both 9- and 12-volt operation.

FIG. 6—HERE'S THE AUTHOR'S PROTOTYPE. Notice the four wires that connect the analog and digital boards together.

digital board in accordance with Figs. 3 and 7. If you didn't use a socket for the display, position it so that its terminals are flush with the component side of the board and solder.

With the LCD installed, set R15 to mid position, apply power, and adjust R11 over its range. The display should indicate some number that can be varied via R11 between approximately −1000 and +1000.

If the display is completely blank, check the orientation of the LCD module and IC3 to be sure that they have not been placed backwards in the circuit. If available, an oscilloscope can be used to verify the presence of the backplane signal generated

socket. That causes the differential input voltage fed to the A/D chip to be zero, and the display should read 000.

Once the display is operating properly, operation of the altimeter can be verified before final calibration. Set R15 to mid position and adjust R11 for a display of about 20 or 30 feet.

Physically move the altimeter higher and lower to observe the change in altitude reading. Hold the project horizontally or vertically as you make this test; a change from one orientation to the other can cause the readout to vary 3 or 4 feet, due to gravitational force on the extremely sensitive solid-state pressure sensor.

You should be able to detect and resolve 1 or 2 feet of vertical displacement. It is normal for the display to fluctuate 1 or 2 digits. Additionally, it should be noted that the altimeter is a pressure-sensitive device and will respond to any variation in barometric pressure, in which a change in pressure of only 0.001 inch of mercury at sea level will

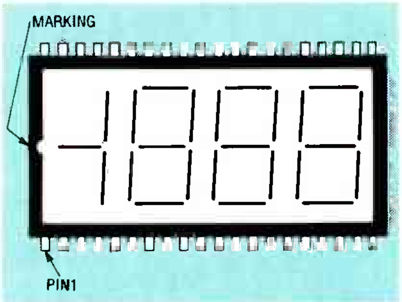


FIG. 7—THE LCD MODULE has a marking similar to that on an IC, indicating where pin 1 is. Note that the module mounts on the solder side of the digital board, so be careful where pin 1 goes.

cause a change of 1 foot in the altitude reading.

Even though the resolution of the instrument is 1 foot, the altimeter will not have either the accuracy or stability to indicate altitude that accurately.

PARTS LIST

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

R1, R4–R9—100,000 ohms, 1% metal film
R2—2210 ohms, 1% metal film
R3—5000 ohms, cermet PC-mount potentiometer
R10, R12—107,000 ohms, 1% metal film
R11—10,000 ohms, PC-mount potentiometer, screwdriver adjust
R13—100,000 ohms
R14, R17—249,000, 1% metal film
R15—2000 ohms, cermet PC-mount potentiometer
R16—1500 ohms, 1% metal film
R18—1 megohm
R19—47,000 ohms
R20—330 ohms (optional for 12-volt operation)

Capacitors
C1—10 µF, 25 volts, axial electrolytic
C2—0.1 µF, 50 volts, ceramic disc
C3—10 µF, 25 volts, radial electrolytic
C4, C7—0.47 µF, 50 volts, metal film
C5—100 pF, 50 volts, ceramic disc
C6—0.01 µF, 50 volts, ceramic disc
C8—0.22 µF, 50 volts, metal film

Semiconductors
IC1—LM324N quad op-amp
IC2—AN78L05 5-volt regulator
IC3—ICL7106CPL A/D converter (Intersil)
IC4—MPX2101AP semiconductor pressure sensor, 15 PSI absolute (Motorola)
D1—1N4004 silicon diode (optional for 12-volt operation)
DSP1—3½-digit LCD module (DigiKey LCD002)

Other components
J1—Miniature jack (optional for 12-volt operation—also requires matching plug)
S1—SPDT minature slide or toggle switch
B1—9-volt transistor battery, alkaline or heavy duty

Miscellaneous: 9-volt battery clip, IC sockets, #24 gauge stranded hookup wire, enclosure, hardware, plastic tubing, tee fitting, clamp, soda or wine bottle, food coloring, solder, etc.

Note: The following parts are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463:

- **Set of 2 etched and drilled PC boards (analog and digital)—$19.95**
- **LM324N op-amp (IC1)—$2.00**
- **AN78L05 regulator (IC2)—$1.50**
- **ICL7106CPL A/D converter (IC3)—$17.50**
- **MPX2101AP pressure sensor (IC4)—$39.50**
- **Set of 13 metal-film resistors—$4.95**

Please add $2.75 postage/handling.

Final calibration

To perform the final circuit adjustment, you will need a tape measure, three lengths of ¼-inch outside diameter clear plastic tubing, a tee for a three-way connection, and a clear plastic or glass bottle of clean drinking water. A soda or wine bottle is a good choice. Be sure that the inner diameter of the plastic tubing allows it to be stretched over the pressure port of the sensor for an air-tight seal. The suggested test setup is shown in Fig. 8.

In this procedure, the absolute pressure that represents 1900 feet of altitude will be simulated by drawing a partial vacuum to cause a column of water to rise in the straight, clear tube. This procedure uses basic laws of physics to set a desired pressure differential.

As noted earlier, absolute air pressure, under standard conditions, is 14.696 PSI at zero altitude (sea level). At 1900 feet, the pressure falls to 13.716 PSI. The pressure levels can also be specified in other units such as inches of mercury or inches of water. In this case, the desired pressure differential between zero altitude and 1900 feet, 0.98 PSI, is equivalent to 27.13 inches of water, rounded out to 27⅛ inches. Thus, to simulate the change in pressure from zero to 1900 feet, a column of water 27⅛ inches high can be used.

Set up the altimeter and apparatus as shown in Fig. 8. In this test, the water in the vertical tube is drawn up to the required height of 27⅛ inches by drawing a vacuum at the open end of the tubing.

With no vacuum applied to the open end of the plastic tube and the pressure sensor connected as shown in Fig. 8, turn on the altimeter and allow a minute for the circuit to stabilize. Adjust R11 for an altitude reading of some small positive number, such as 50 feet or so. The number selected is not significant.

Now, gently draw vacuum at the open end of the tubing so that the column of water rises 27⅛ inches above the level of

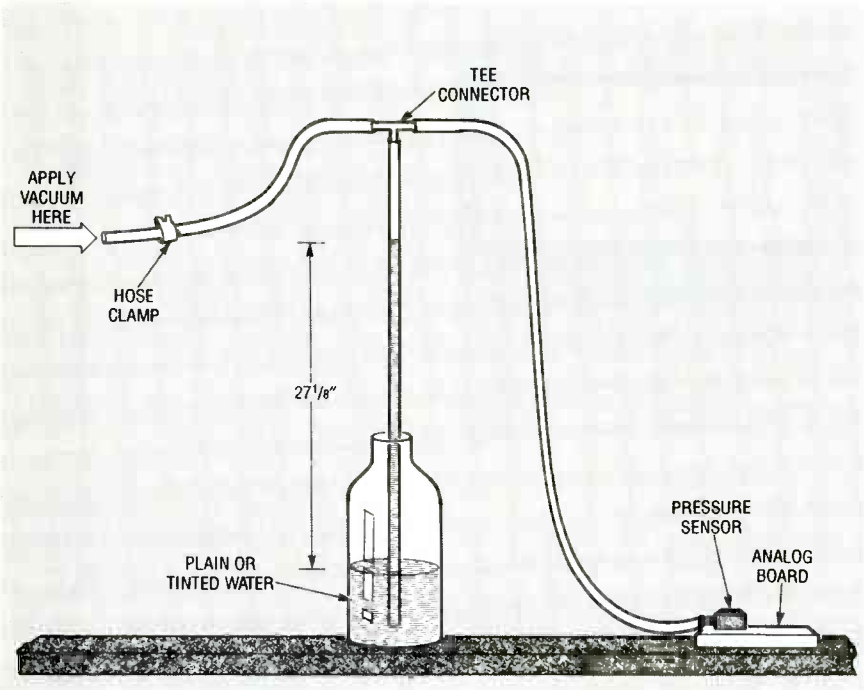


FIG. 8—CALIBRATION SETUP. You will need a tape measure, clear plastic tubing, a tee connector, and a clear bottle with water in it. Food coloring will make the water easier to see. See text for details.

water in the bottle. You can clamp the hose to maintain the required vacuum. Make sure you have a solid column of water with no air bubbles in it. Allow the display to reach a stable level and note the reading. Adjust R15 so that the display indicates 1900 feet more than the original reading (50 feet) set previously.

Repeat the above test as necessary until you are satisfied that the change in altimeter reading is as close to 1900 feet as possible when the water column is drawn up 27⅛ inches. This completes calibration.

Using the altimeter

Since the altimeter is subject to the variations of barometric readings, the instrument must always be corrected for the current barometric pressure before starting out on an excursion. You do not have to know the actual barometric reading to do this. Simply turn the unit on, allow a minute for the circuit to stabilize, and set R11 to obtain a display that represents the known existing altitude at your location.

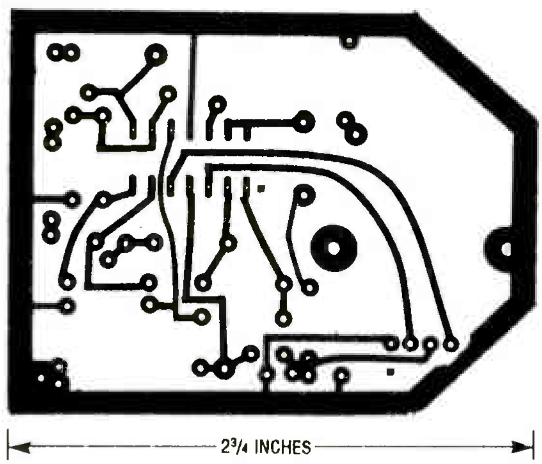
Learning the true altitude of your home can be done by taking the altimeter to a location such as an airport where the altitude is documented, setting the altimeter to reflect the correct altitude, and then returning home immediately. The reading of the altimeter at your home will then be your reference altitude. For best accuracy, do this during a period of steady barometric pressure conditions.

For future use, before leaving home with the altimeter, simply turn it on and allow a minute or so for the display to stabilize. Then set R11 so that the reading is equal to the reference altitude at your home.

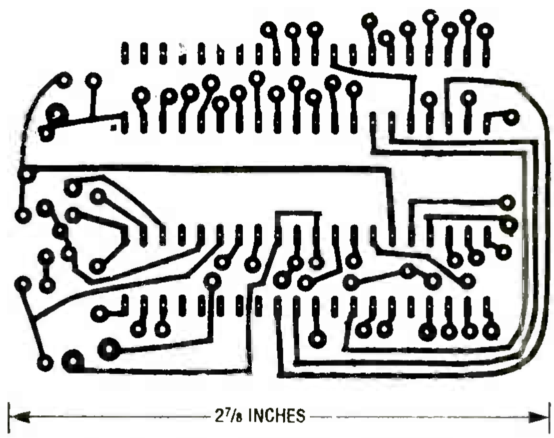
Once set, do not readjust R11 since you will have no reference against which to adjust it. At a later time, if you travel to another location with a known altitude, R11 can be readjusted to reflect a more accurate altitude if the barometric reading has changed since the original setting of R11.

When taking an altitude reading, turn the unit on and allow about a minute for the circuit to stabilize. Remember, if there is a sudden change in air pressure such as might occur with a changing weather, the reading can fluctuate. Wait for the display to settle down.

Be sure to turn off your battery-powered altimeter when not taking altitude readings. That will conserve power and provide extremely long battery life, which should be about 10 or 15 hours of altimeter operating time when using an alkaline battery. R-E



FOIL PATTERN for the analog board.



FOIL PATTERN for the digital board.

BUILD THIS MICROPROCESSOR DEVELOPMENT SYSTEM

Construction details for our inexpensive 1802 microprocessor development system.

LAST TIME WE DISCUSSED THE CIRcuitry for our 1802 development system and described how the software functions. This time we'll talk about construction and operation.

Construction

The complete unit uses three PC boards, corresponding to the sections of the circuit (main, keypad/display, EPROM). Foil patterns are provided if you want to make your own boards; boards and kits are also available commercially (see the parts list).

The main chassis measures 8″ × 4.6″ × 1.5″. As shown in Fig. 7, S1 (reset) and S2 (EPROM power) mount on top of the chassis, as does a four-connector terminal block that brings several voltage sources out of the chassis for use by experimental circuits (developed on the breadboard). In addition, there is space for two 63-row solderless breadboards, and two 63-row power buses. Further, the rear edge of the case is slotted to allow the pins of P3 to protrude.

The power supply enters one side of the chassis through a grommet; the 6-wire telephone jack for the keypad/display unit fits in a slot on the other side.

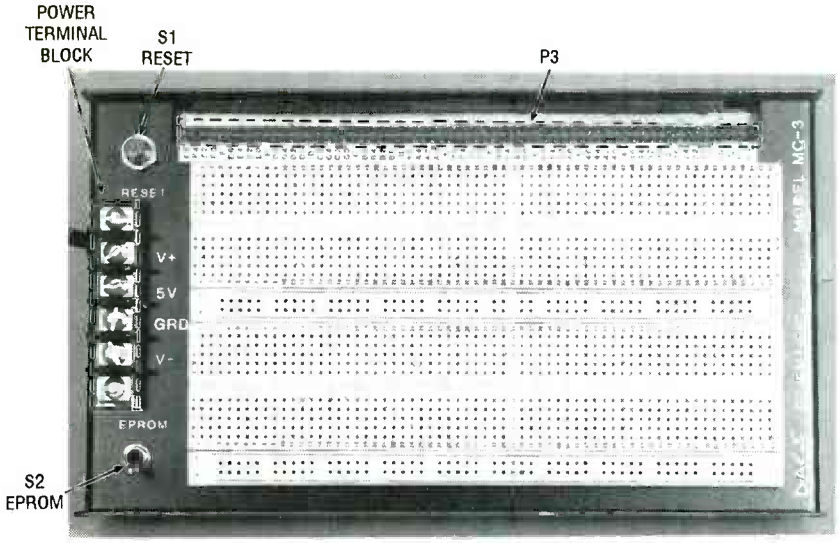


FIG. 7—MAIN CHASSIS ASSEMBLY. The terminal block on the left delivers power to breadboard circuits. Note that P3 consists of separate wire-wrap pins that protrude through a slot in the case.

Main board

Mount all parts on the main PC board, as shown in Fig. 8. Resistors R13–R24 must be ⅛-watt units in order to mount on 0.3″ centers. All other resistors mount on 0.4″ centers. Sockets should be used in all IC positions, and are required for IC20 (the EPROM burner slot) and IC22 (the EPROM that contains the operating system). You can buy a pre-programmed EPROM (see the ordering information in the parts list for details) or burn your own using the hex dump shown in Listing 1.

The operating system requires the first output port, IC2. The other output ports can be installed during assembly, or as the need arises. In addition, you can eliminate IC3–IC13 if you don't need parallel inputs. The author recommends that you install at least two output ports (IC2 and IC3) and two input ports (IC8 and IC9).

You must install the operating-system EPROM at IC22 (0000h), and 8K of RAM at IC19 (E000h). You needn't install components at IC20 and IC21 unless you need additional memory.

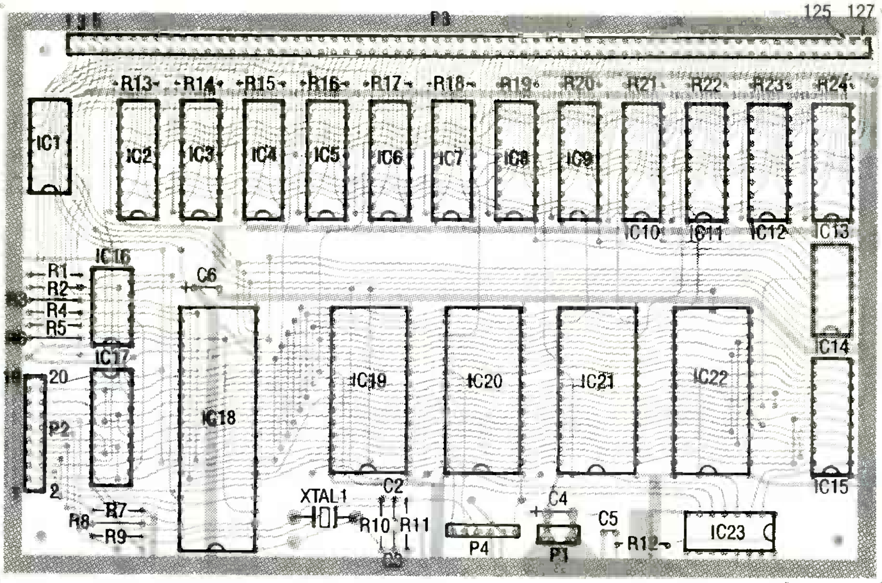


FIG. 8—MAIN PC BOARD. Note that R13–R24 must be ⅛-watt units to fit in the available space. Sockets are required for IC20 and IC22, and optional but recommended elsewhere.

The bus connector (P3) consists of 128 individual wire-wrap pins, each measuring 0.075″. The best way to install them is to insert them through the board and into a female header to hold them perpendicular while soldering. Figure 9 details the function of each pin.

Connect one wire from ground to the reset switch, and another to the pad marked *reset* on the main board. Figure 10 shows the completed main board.

Keypad/display assembly

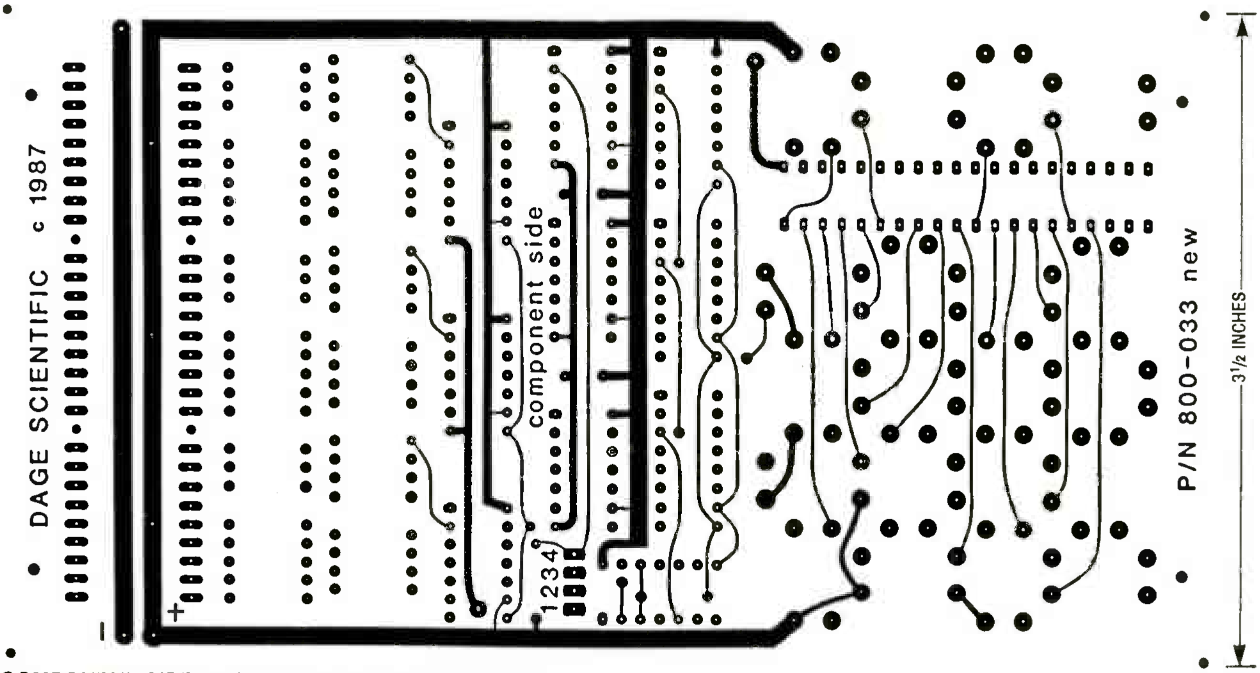
Assemble the keypad/display unit as shown in Fig. 11. Mount the IC's without sockets, as there is not enough clearance to use them. However, mount each display using half a socket under the rear row of pins only. Doing so angles the display about 20 degrees for better viewing. The pull-down resistors for the key switches must be ⅛-watt units to fit the 0.3-inch mounting centers.

The six-conductor telephone cord connects directly to the foil side of the board, as shown in Fig. 12; secure the cord with a nylon wire wrap. The other end of the cord has a modular plug that fits into J1 on the main board. The color codes in phone cords and connectors seem to vary, so we haven't provided specific details. It doesn't matter which color you use for which signal; just make sure that you're consistent at both ends of the cable. Figure 13 shows the completed keypad/display board.

EPROM board assembly

Assemble the EPROM board as shown in Fig. 14. Mount a six-pin female connector (J1) on the solder side of the board; it will mate with P4 on the main board, and serves to hold the EPROM board in place. The completed EPROM board is shown in Fig. 15. When mounted properly, the EPROM board rides about ½″ above the EPROM that is being programmed (see Fig. 16). In front of this connector are two solder pads used to connect the EPROM programming voltage. Connect the ground side (gnd) only if the programming voltage doesn't have a common ground with the main board.

In case you want to install RAM in IC20, remove the EPROM circuit; otherwise every



COMPONENT SIDE OF THE KEYPAD/DISPLAY BOARD.

LISTING 1—HEX DUMP OF OPERATING SYSTEM (0000—04FF)

```
0000  71 00 F8 00 B3 F8 09 A3 D3 F8 FE B2 F8 FF A2 E2
0010  F8 00 B4 F8 60 A4 F8 00 B5 F8 70 A5 F8 00 B8 F8
0020  91 A8 34 3A E3 62 00 62 01 E2 D8 69 FB FF 3A 3D
0030  D8 D8 69 FA F0 C2 02 24 30 52 C0 04 A1 F8 00 52
0040  62 22 F8 06 A7 F8 00 52 7B 61 D8 22 27 87 3A 45
0050  30 22 FF FF FF FF FF FF FF FF FF FF C0 E0 00 D3
0060  E2 96 73 86 73 93 B6 83 A6 46 B3 46 A3 30 5F D3
0070  96 B3 86 A3 E2 12 72 A6 F0 B6 30 6F FF FF FF FF
0080  21 7D 13 19 4D 89 81 3D 01 0D 05 C1 A3 51 83 87
0090  D3 7B 7A 7B 7A 7B 7A 7B 7A 7B 7A 7B 7A 7B 7A 7B
00A0  7A 30 90 99 B6 89 A6 D5 FF D4 00 CE 46 B8 46 A8
00B0  46 B9 46 A9 46 A7 46 32 C3 E9 08 28 73 27 87 3A
00C0  BA 30 CA 48 59 19 27 87 3A C3 D4 00 EE D5 87 73
00D0  97 52 60 60 60 02 A7 22 02 B7 22 22 22 89 73 99
00E0  73 8A 73 9A 73 88 73 98 73 87 73 97 73 D5 60 42
00F0  B7 42 A7 42 B8 42 A8 42 BA 42 AA 42 B9 42 A9 60

0100  60 60 87 73 97 73 22 42 B7 02 A7 D5 87 73 97 73
0110  88 73 98 73 F8 00 B8 F8 91 A8 F8 02 B7 A7 27 97
0120  3A IE F8 00 52 62 22 F8 01 52 62 22 D8 69 FB FF
0130  3A 22 D8 69 FB FF 3A 22 D8 69 FB FF FA 0F 3A 22
0140  F8 10 B7 27 97 3A 43 F8 00 AA F8 00 52 62 22 F8
0150  01 52 62 22 D8 69 FB FF 3A 78 F8 08 AA D8 69 FB
0160  FF 3A 78 D8 69 FB FF FA 0F 32 47 F9 80 AA 60 72
0170  B8 72 A8 72 B7 F0 A7 D5 F6 33 6E 1A 30 78 FF FF
0180  88 73 98 52 F8 FF B8 F8 F0 A8 F8 05 58 18 F8 DF
0190  58 18 99 F6 F6 F6 F6 BA D4 02 09 9A 58 18 99 BA
01A0  D4 02 09 9A 58 18 89 F6 F6 F6 F6 BA D4 02 09 9A
01B0  58 18 89 BA D4 02 09 9A FF 01 58 18 09 F6 F6 F6
01C0  F6 BA D4 02 09 9A 58 18 09 BA D4 02 09 9A 58 09
01D0  BA 72 B8 F0 A8 D5 87 73 88 73 98 73 89 73 99 73
01E0  E6 72 B9 72 A9 E2 F8 00 B8 F8 91 A8 F8 00 52 62
01F0  22 F8 06 A7 E9 7B 61 D8 27 87 3A F5 E2 60 72 B9

0200  72 A9 72 B8 72 A8 F0 A7 D5 88 73 98 52 F8 00 B8
0210  F8 80 A8 9A FA 0F 32 1D FF 01 18 30 16 08 BA 72
0220  B8 F0 A8 D5 F8 00 B9 A9 D4 01 80 D4 01 D6 FF F0
0230  D4 01 0C 8A 52 FE 33 4A F8 04 A7 89 FE A9 99 7E
0240  B9 27 87 3A 3B 89 F1 A9 30 28 8A F6 33 5C F6 33
0250  56 F6 33 A0 30 24 D4 00 A3 D4 01 80 09 73 D4 01
0260  D6 FF F2 D4 01 0C 60 8A FE 33 88 F8 FF B8 F8 F7
0270  A8 02 FE FE FE FE 52 8A F1 52 08 28 58 18 02 22
0280  BA D4 02 09 9A 58 30 5E 8A F6 33 94 F6 33 9A F6
0290  33 9C 30 24 02 59 09 F3 3A 59 19 38 29 30 59 FF
02A0  F8 02 B1 F8 C8 A1 F8 FF B8 F8 FA A8 E8 49 73 49
02B0  73 09 73 E9 F8 D1 73 F8 79 73 F8 22 73 30 24 FF
02C0  42 70 22 78 22 52 30 D8 52 F8 FF B0 F8 F9 A0 F0
02D0  73 40 73 40 73 40 73 60 E2 92 B0 82 A0 22 F8 00
02E0  7E 73 F6 C5 F8 01 73 10 10 80 73 90 73 20 83 73
02F0  93 73 84 73 94 73 85 73 95 73 86 73 96 73 78 73

0300  97 73 88 73 98 73 89 73 99 73 8A 73 9A 73 8B 73
0310  9B 73 8C 73 9C 73 8D 73 9D 73 8E 73 9E 73 8F 73
0320  9F 73 F8 03 B3 F8 29 A3 D3 80 AF 90 BF 0F FA 0F
0330  AA B7 30 3B D4 01 0C 8A FE 33 59 90 BF 80 AF 8A
0340  B7 32 49 2F 2F 2A 8A 30 41 0F A9 2F 0F B9 1F D4
0350  01 80 D4 01 D6 FF F2 30 34 8A F6 33 98 F6 33 98
0360  F6 33 66 C0 00 09 D4 01 0C 8A FE 33 89 F8 04 A7
0370  89 FE A9 99 7E B9 27 87 3A 70 8A 52 89 F1 A9 D4
0380  01 80 D4 01 D6 FF F2 30 66 8A F6 3B 93 89 5F 2F
0390  99 5F 1F 97 AA 30 3B FF F8 03 B1 F8 9F A1 D1 F8
03A0  IF A7 20 27 87 3A A2 40 BF 40 AF 40 BE 40 AE 40
03B0  BD 40 AD 40 BC 40 AC 40 BB 40 AB 40 BA 40 AA 40
03C0  B9 40 A9 40 B8 40 A8 40 B7 40 A7 40 B6 40 A6 40
03D0  B5 40 A5 40 B4 40 A4 40 B3 40 A3 40 B2 40 A2 40
03E0  7A CE C4 7B 40 F6 22 22 C0 02 C0 FF FF FF 46 BB
03F0  46 AB 16 E6 F5 A7 26 9B 75 16 16 B7 17 F8 00 BD

0400  AD AC EB 97 3A 09 87 32 13 8C F4 AC C7 1D C4 27
0410  1B 30 03 8C A9 8D B9 D4 01 80 F8 FF BE F8 F0 AE
0420  9D F6 F6 F6 F6 BA D4 02 09 9A 5E 1E 9D BA D4 02
0430  09 9A 5E D4 01 D6 FF F0 D5 46 BB 46 AB 16 E6 F5
0440  A9 26 9B 75 B9 19 16 16 46 BC 46 AC 99 3A 52 89
0450  32 6A 0B 5C D4 01 80 D4 01 D6 FF F0 EC 0B F3 3A
0460  66 1B 1C 29 30 4C 9C B9 8C A9 D4 01 80 D4 01 D6
0470  FF F0 D5 46 B7 46 A7 27 17 27 87 C4 C4 3A 77 97
0480  27 17 27 C4 C4 3A 77 D5 D4 04 39 04 88 04 A0 FF
0490  00 D4 01 0C C0 02 24 FF D4 03 EE 00 00 00 00 30
04A0  09 7B F8 40 B7 57 F8 80 B7 07 7A F8 C0 B7 57 34
04B0  A1 F8 FE B2 A2 12 E2 69 22 6A 22 6B 22 6C 22 6D
04C0  22 6E 22 7B 7A 6F 67 66 65 64 63 62 61 22 3D B7
04D0  F8 00 B8 F8 91 A8 E3 7B 62 01 62 00 61 55 D8 E2
04E0  3E D6 F8 00 B8 F8 91 A8 E3 62 00 62 01 E2 D8 69
04F0  22 F8 00 52 62 7B 61 22 D8 3F E8 FF FF FF FF FF
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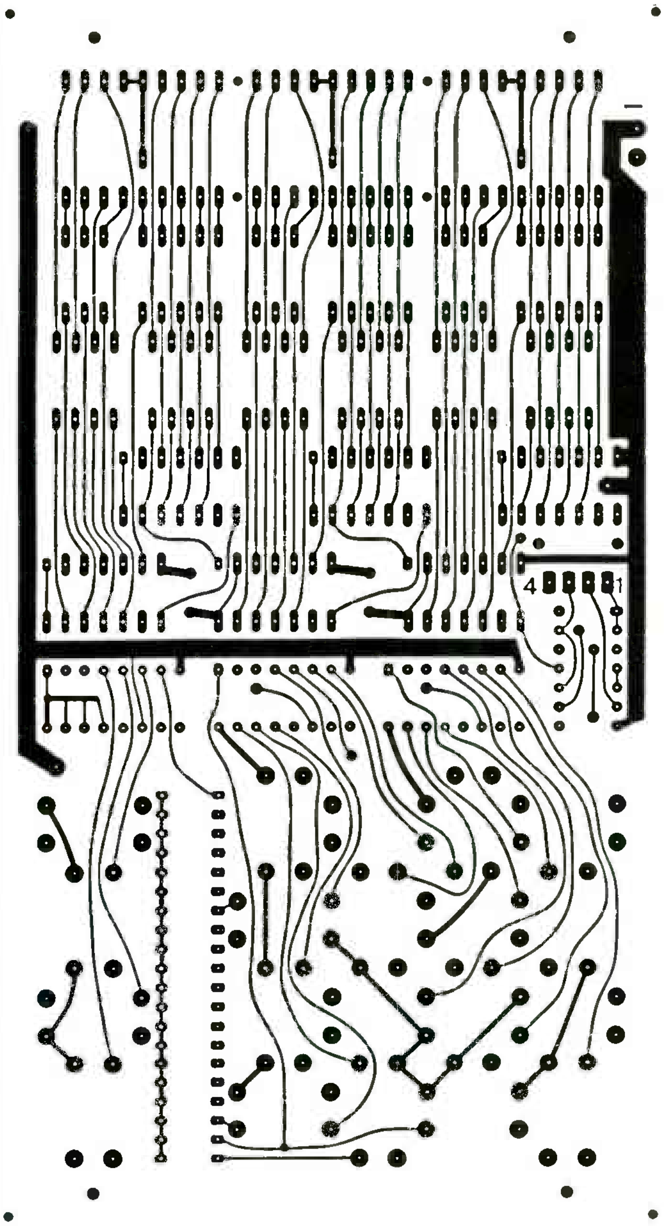
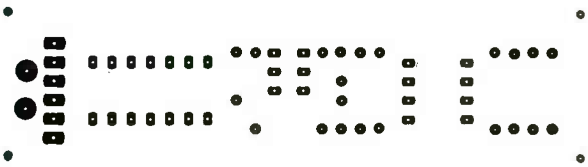


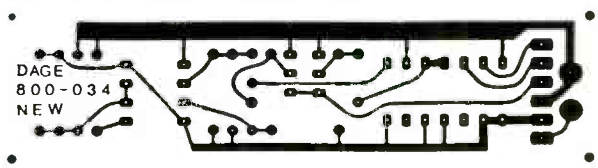
3½ INCHES

SOLDER SIDE OF THE KEYPAD/DISPLAY BOARD.



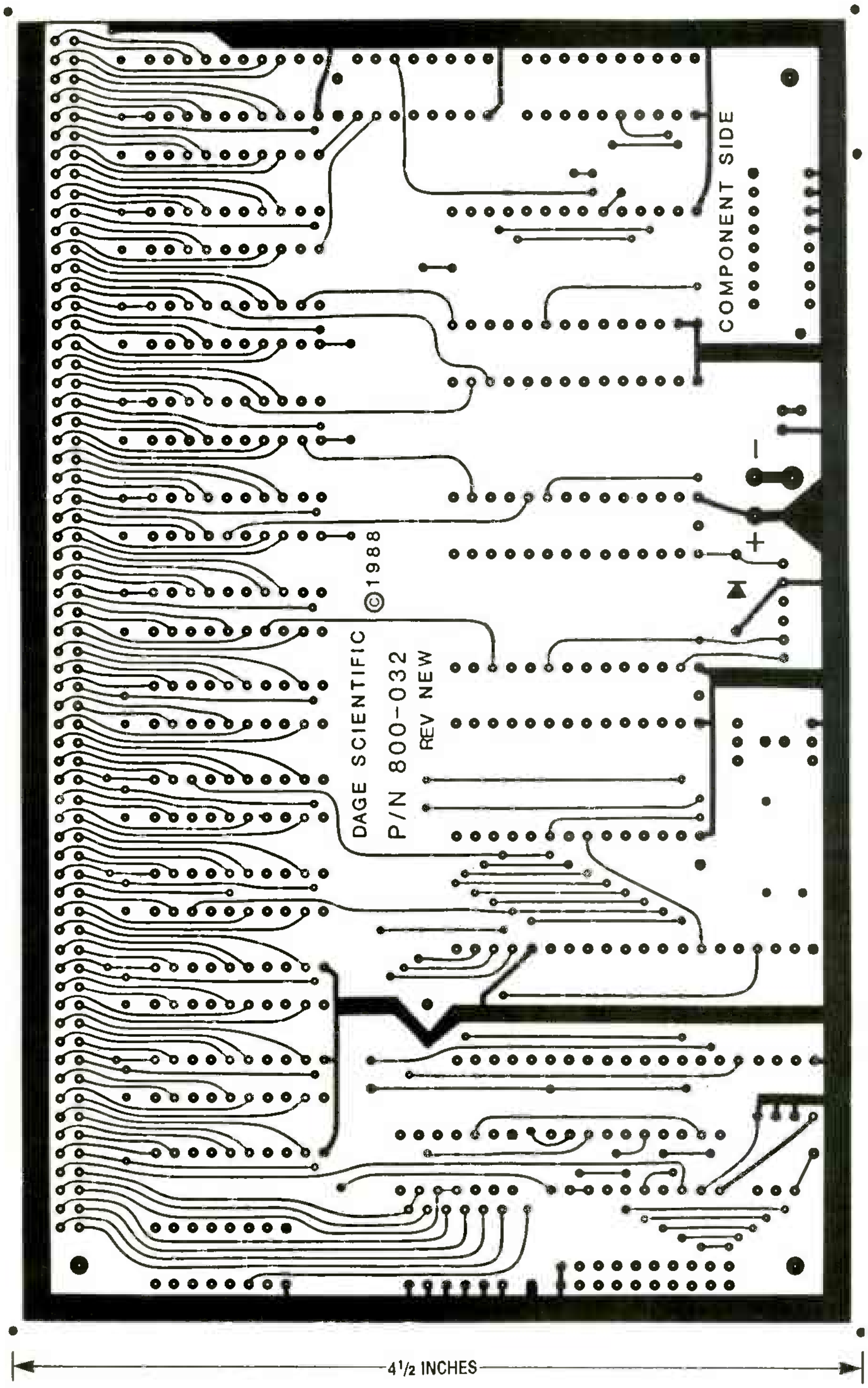
3 INCHES

COMPONENT SIDE OF THE EPROM BOARD.



3 INCHES

SOLDER SIDE OF THE EPROM BOARD.



COMPONENT SIDE OF THE MAIN PC BOARD.

PARTS LIST—MAIN BOARD

All resistors are ¼-watt, 5%, unless otherwise noted
R1, R3–R8, R11, R12—1000 ohms
R2—150,000 ohms
R9—30,000 ohms
R10—22 megohms
R13–R24—51,000 ohms, ⅛ watt

Capacitors
C1—1 µF, 35 volts, tantalum
C2, C3—20 pF, ceramic
C4—10 µF, 25 volts, tantalum
C5, C6—0.1 µF, mini ceramic

Semiconductors
IC1—74HC238 3-to-8 line decoder
IC2–IC13—74HC373 octal D latch
IC14—74HC138 3-to-8 line decoder
IC15—74HC373 octal D latch
IC16—74HC86 quad 2-input XOR gate
IC17—74HC299 8-bit shift register
IC18—1802 microprocessor
IC19—6264 static RAM
IC20—see text
IC21—see text
IC22—2764 EPROM (with operating system)
IC23—4556 dual 1-of-4 decoder

Other components
XTAL1—2.010 MHz crystal
P1–P4—wire-wrap pins, 0.025" square × 0.75"
J1—6-conductor telephone jack

PARTS LIST—KEYPAD/DISPLAY BOARD

All resistors are ¼-watt, 5%, unless otherwise noted
R1–R20—51,000 ohms, ⅛-watt
R21–R68—330 ohms
R69—100,000 ohms

Semiconductors
IC1–IC6—74HC164 8-bit shift register
IC7—74HC00 quad 2-input NAND gate
IC8–IC10—4021 8-bit shift register

Other components
DS1–DS3—dual 7-segment LED display, 0.5", common anode
S1–S20—SPST, normally open, pushbutton, PC mount

access to that location will incur a 50-ms delay.

After assembling each board, check all work, and correct any mistakes. Then apply power, and hold down the 0 key. If all is well, all segments and decimal points of the display should light up. If they do not, remove power and check all connections again.

Electronic construction is complete; now you can mount the boards in their proper chassis locations.

Operation

Boot up normally; the display should read "A-0000." The "A" indicates Address Select mode; the zeros indicate the current address.

Actually, the monitor program has four modes: Address Select, Memory Monitor, Run, and Debug.

When the display shows "A-," the monitor is in the Address Select mode. Any time the operating system is in control, pressing F4 returns you to Address Select mode.

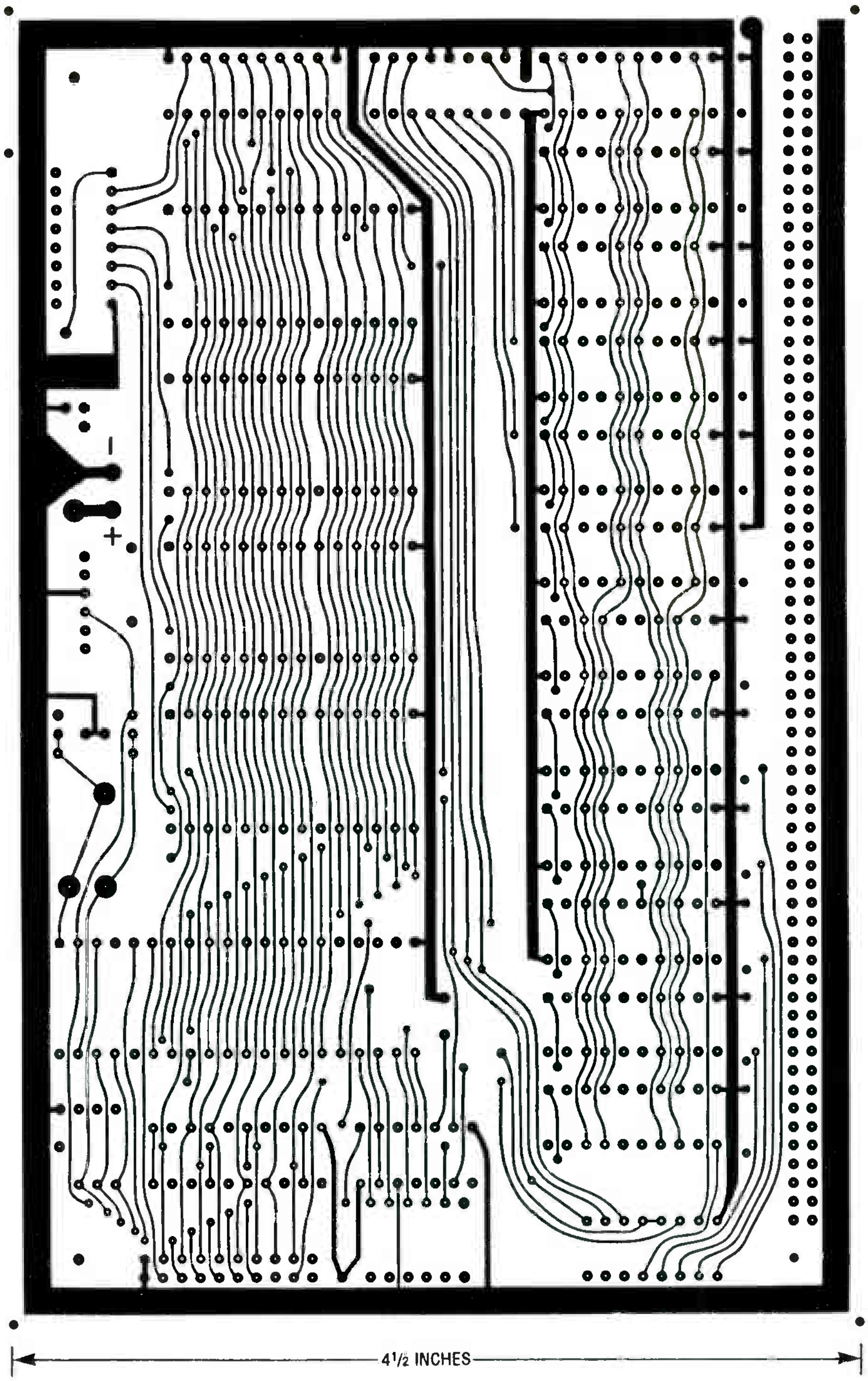
To enter a new address, just press the corresponding keys. The digits you enter scroll from right to left; if you make a mistake, simply enter new digits until you see correct address displayed.

After entering the desired address, you have three choices, with corresponding keys:

PARTS LIST—EPROM BOARD

All resistors are ¼-watt, 5%, unless otherwise noted
R1, R4—22 megohms
R2—47,000 ohms
R3—100,000 ohms
Capacitors
C1—0.001 µF, Mylar
C2—100 pF, ceramic
C3—0.001 µF, Mylar
C4—0.02 µF, 5%, Mylar
C5—0.1 µF, ceramic
Semiconductors
IC1—74HC02 quad 2-input NOR gate
IC2—555 timer
D1—1N4148 diode
Q1, Q2—2N4124 NPN transistor
Miscellaneous: Chassis & hardware, power supply, telephone cord & connectors, terminal block, toggle switch, push button switch, solderless breadboarding connectors, PC boards.
Note: The following items are available from Dage Scientific, 6124 Baldwin St., Valley Springs, CA 95252 (209) 772-2076:
- **Kit including everything but power supply (Model MC-2)—$195**
- **Surplus power supply (+12, +5, −5)—$11**
- **Operating system in EPROM—$10**
- **Set of 3 PC boards and manual—$35**

Please add $5 shipping & handling per order. California residents add applicable sales tax.



SOLDER SIDE OF THE MAIN PC BOARD.

Monitor (F1), Run (F2), and Debug (F3).

Monitor mode allows you to examine and modify memory contents on a byte-by-byte basis. Run mode lets the CPU execute the program at the current address. Debug mode inserts a breakpoint at the current address.

To enter Monitor mode, type the desired address and press F1. That address and its contents will appear. For example, 0000.FF indicates a hexadecimal value of FF at address 0000h.

In this mode, the function keys take on new meanings. F1 stores the currently displayed value into the currently displayed address and moves on to the next address. F2 displays the next address. F3 displays the previous address.

To change the currently displayed value, use the hex keys to roll new digits into positions 5 and 6. If you make a mistake, simply enter new digits until the correct value appears. Memory contents will not be altered until you press F1. When you do press F1, the currently displayed value will be stored at the displayed address, and the next address will be displayed. If the value can not be stored into memory, the address counter will not increment. (It's possible to program values one byte at a time into an EPROM using that procedure, but there's a better way, as discussed below.) And remember: Press F4 at any time to return to Address Select mode.

After storing a program in memory, you can execute it using the Run command. Starting from Address Select mode, enter the desired starting address and press F2. The monitor program then transfers control to your program. If your program hangs, press the

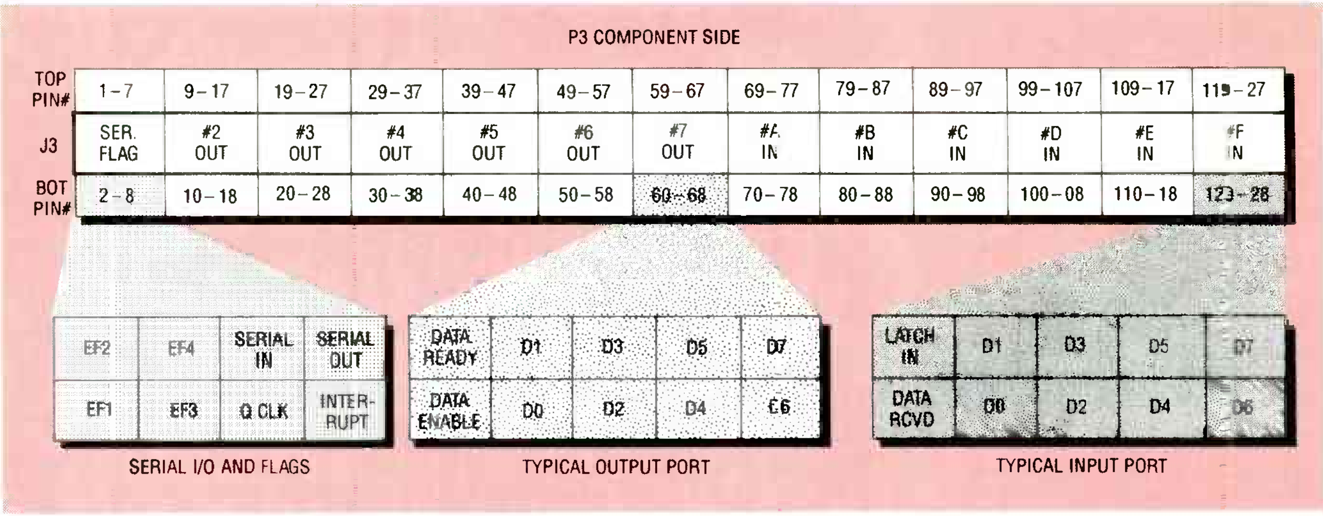


FIG. 9—PLUG P3 CONNECTIONS. The 128 pins of P3 consist of one group of 8 pins (for serial I/O, EF flags, Q clock, and interrupt) and 12 groups of 10 pins each. Those 12 groups break down into six input ports and six output ports, each with pinouts as shown.

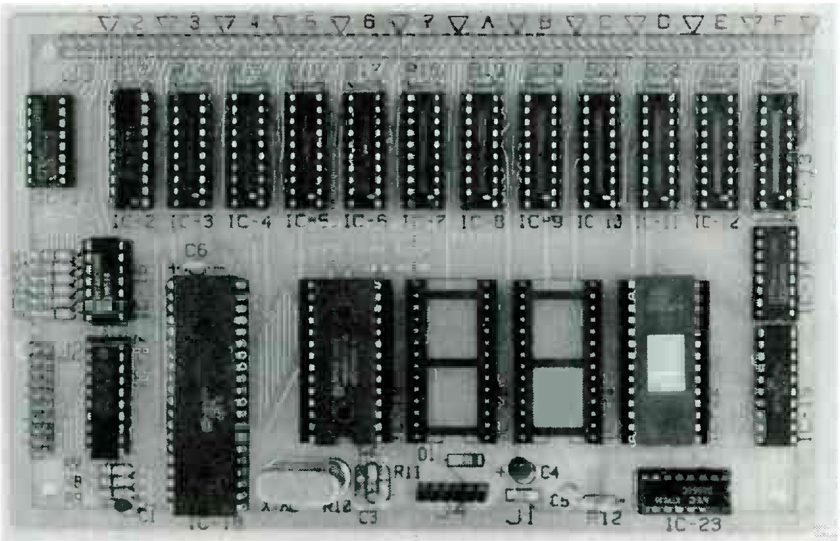


FIG. 10—THE COMPLETED MAIN BOARD. Sockets should be used in all IC positions, and are required for IC20 (the EPROM burner slot) and IC22 (the EPROM that contains the operating system).

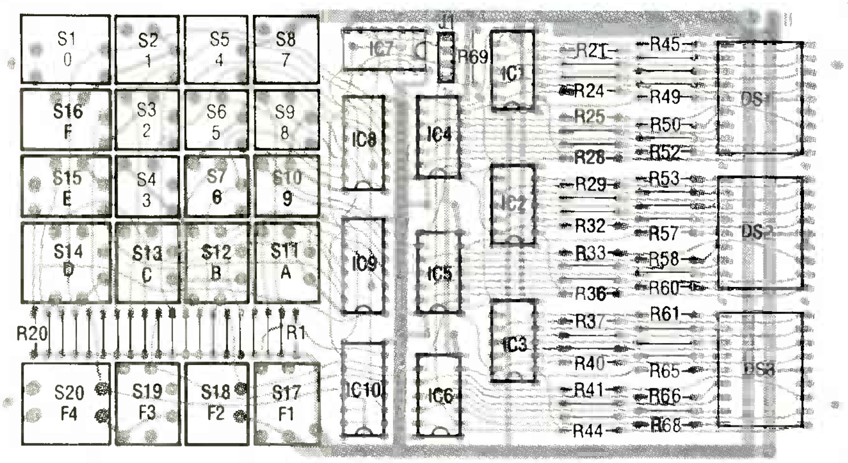


FIG. 11—KEYPAD/DISPLAY PC BOARD. Mount all parts as shown here. If you use our case, don't use IC sockets except under the rear row of display pins.

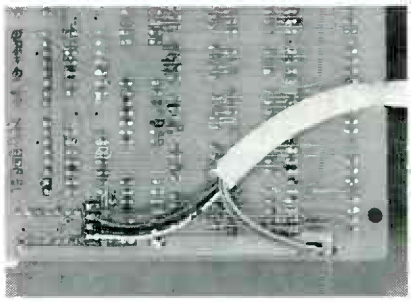


FIG. 12—PHONE CABLE connections. Solder the wires directly to the foil side of the board.

reset switch to regain monitor control.

In case your program doesn't work the first time, you can use Debug mode to track down problems. Use Address Select mode to select a likely address for troubleshooting and press F3. You'll return to Address Select mode. Now enter the desired starting address and press F2. Later, when the CPU hits the breakpoint address, it will start executing a special debug program that allows you to view the CPU's internal registers, and to verify that what you intended to happen is indeed happening.

You can set only one break point at a time; you cannot breakpoint addresses in ROM. When your program reaches the breakpoint, it will halt and display the current address. You are now in the Debug mode.

In Debug mode, the display appears the same as in Monitor mode. However, as you press the hex keys the display will show the internal register number (in positions 1–4) and the value in

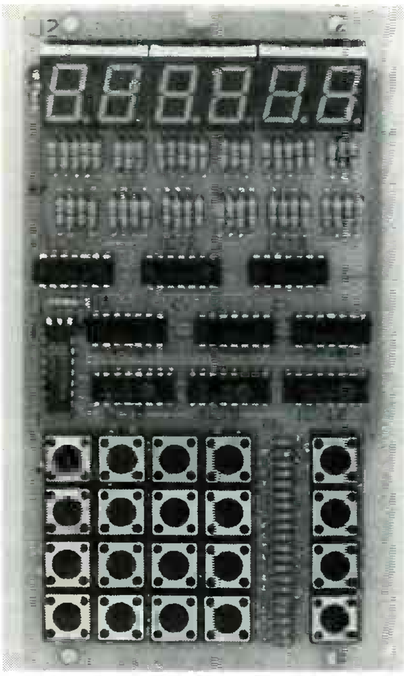


FIG. 13—COMPLETED KEYPAD/DISplay board. Mount each display using half a socket under the rear row of pins only, to provide better viewing.

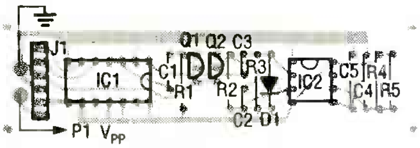


FIG. 14—EPROM PC BOARD. Mount all parts except J1 on the component side of the board; mount J1 on the foil side.

FIG. 15—THE COMPLETED EPROM board. A six-pin female connector (J1) on the solder side mates with P4 on the main board.

that register (in positions 5–6).

The debug program uses registers 0 and 1, which have been reserved for DMA and interrupt. Pressing hex key 0 displays the contents of the D register in positions 1 & 2, the X register in position 3, and the P register in position 4. Pressing hex key 1 displays Q in position 2 (set = 1, reset = 0) and DF in position 4.

While in debug mode, register contents can be altered by first selecting a register pair and then pressing function key F3. Change the value by rolling new digits in from right to left. When the correct value appears, press F1; otherwise press F3 to back out without changing the current register. Registers D, X, P, Q, and DF can also be modified by selecting hex keys 0 and 1 as described above. To exit debug mode and continue execution, press F2. Of course you can press F4 to return to Address Select mode.

The debug breakpoint alters program memory by replacing three bytes at the selected address. When the user program reaches the breakpoint address, the debug program takes over and restores the original three bytes to the proper locations. However, if the user program never reaches the breakpoint, those three bytes will never be restored. In that case you must restore them either by continuing execution at the breakpoint, or by reentering the bytes manually using Monitor mode. If you continue at the breakpoint, the debug program will restore the three bytes and immediately jump into Debug mode. As usual, you can modify registers, continue execution, or return to Address Select mode.

TABLE 1—MOVE UTILITY ADDRESSES

Address	Memory Contents
FF03	Start address (hi)
FF04	Start address (lo)
FF05	End address (hi)
FF06	End address (lo)
FF07	Destination address (hi)
FF08	Destination address (lo)

EPROM programming

With the EPROM programming board connected to J4 and the proper programming voltage available, flip the EPROM switch to on, and you are ready to program the EPROM mounted at IC20. All that is required to program a location is to "write" to it. As mentioned earlier, you can do this byte at a time using the Monitor mode. However, due to the error-prone nature of that procedure, the author recommends a more automated procedure.

The preferred method is to enter your program in RAM and then transfer it to EPROM with the operating system's built-in "move" utility, which in fact will move a block of data anywhere in memory, not just to EPROM. Start the utility by running at 0488. Doing so transfers the move utility itself to RAM starting at FF00. Now enter the start, end, and destination addresses as shown in Table 1.

Double-check your values to ensure that they are correct, and then run at FF00. The display will show the remaining number of bytes to be transferred. It will be changing rapidly, but will at least give some idea about how things are progressing. In case data cannot be transferred correctly, the program will terminate and the display will show the address that didn't change.

That about wraps things up. Actually, now that the hardware's built, the real fun is just about to begin. R-E

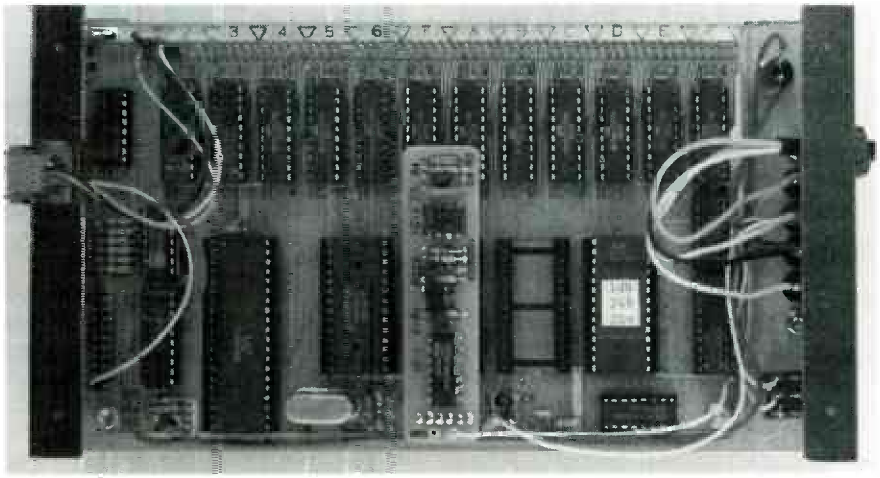


FIG. 16—THE EPROM BOARD mounts on the main board and rides about ½" above the EPROM that is being programmed.

Stop throwing away those used Polaroid batteries—use them in your electronic experiments instead!

MARC SPIWAK

DID YOU EVER NOTICE HOW POLAROID cameras never need batteries? That's because every pack of film you buy contains a brand-new Polaroid Polapulse battery to power the camera's motor and flash. Some people might consider that a modern convenience: Every change of film also replaces the battery. The worry of dead batteries is over, once and for all—or is it? While these flat 6-volt cells certainly make instant-picture taking as convenient as possible, they can be harsh on our environment, or at least our landfills. To add insult to injury, the Polapulse battery that you throw out with your old film pack is still in pretty good shape.

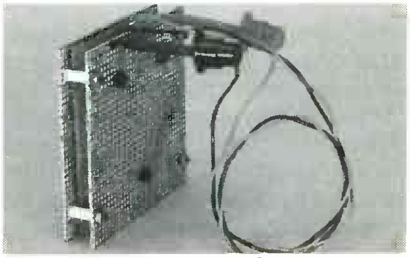


FIG. 1—THE BATTERY JIG lets you recycle "old" Polapulse batteries.

Most people, however, would have no use whatsoever for these used but still perfectly good batteries. The batteries, which can be accessed only by breaking open the film holder, don't fit into any standard battery holder. But readers of this magazine should certainly be able to find hundreds of uses for these "recycled" 6-volt cells.

Using the Polapulse.

To get at the battery, all you have to do is crack open the plastic film holder—after the film is finished, of course. Just be careful of the metal leaf-spring's sharp edges. You'll find the battery itself mounted on a piece of cardboard with its two contacts exposed on one side. Holding the battery with the contacts nearest to the top, positive is on the right. You can remove the battery from the cardboard mount if you'd like to work with a smaller overall package.

The one problem with using the batteries is that it's hard to make reliable electrical contact with the battery's positive and negative terminals. It's virtually impossible—as well as unsafe—to solder to the terminals. That's where our handy battery jig comes in. It allows you to use a Polapulse battery for whatever the need may be, and pop in a new one when it's dead.

The jig is fashioned from two pieces of perforated construction board, four screws and spacers, and some contact springs from a sacrificed AA-cell holder. Two of the springs make electrical contact with the battery, and a third spring helps to hold the battery in place. Mini-hook leads are soldered to the contact springs, and small nylon screws hold the springs to the fixture.

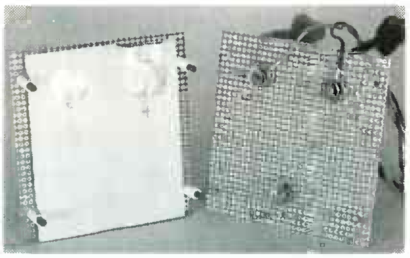


FIG. 2—THE BATTERY JIG uses two pieces of perforated construction board, screws, spacers, and springs from an AA-cell holder. Nylon screws hold the contact springs to the fixture.

You can, of course, use alligator clips or other connectors that better suit your needs. And you may wish to modify the mechanical construction as well. In any case, do try to get the most use possible from these batteries before they are thrown away. R-E

WORKING WITH LED DISPLAY DRIVERS

Learn all about 7-segment display decoder/drivers in our continuing coverage of optoelectronic IC's.

RAY M. MARSTON

IN OUR LAST INSTALLMENT WE looked closely at theory and practical applications of the LM3914-series of LED bargraph driver IC's and concluded with 7-segment display systems. In this article, we'll examine 7-segment display driving techniques in detail, concentrating on decoder/driver devices and circuitry.

Display latching

In the last article we introduced 7-segment displays and simple BCD-to-7-segment decoder/driver IC's that can be used to activate those displays. Figure 1 shows how three sets of those IC's can be used with a trio of decade counters to make a simple digital-readout "frequency" meter. In the figure, the amplified external frequency signal is fed to the input of the series-connected counters with one pin of a 2-input AND gate. The other input is derived from a timebase generator.

When the timebase input signal is low, the AND gate is off, and there is no input to the counters. When the timebase gate signal switches high, a brief RESET pulse is fed to all three counters, setting them all to zero. Simultaneously, the input gate turns on and remains on for one second. During that time the input-frequency pulses are summed by the counters. At the end of the one-second period, the gate turns off as the timebase gate signal goes low again. That ends the count and enables the display modules so that they give a steady reading of the total pulse count, and therefore the frequency. The whole process repeats itself again one second later when the timebase gate signal goes high.

The simple system illustrated has one major drawback: The display blurs during the counting period, becoming stable and readable only when each count is complete and the input gate is off. Figure 2 shows a circuit for frequency meters designed to overcome display blurring. In the circuit, a 4-bit data latch is wired between the output of each counter and the input of its decoder/driver IC.

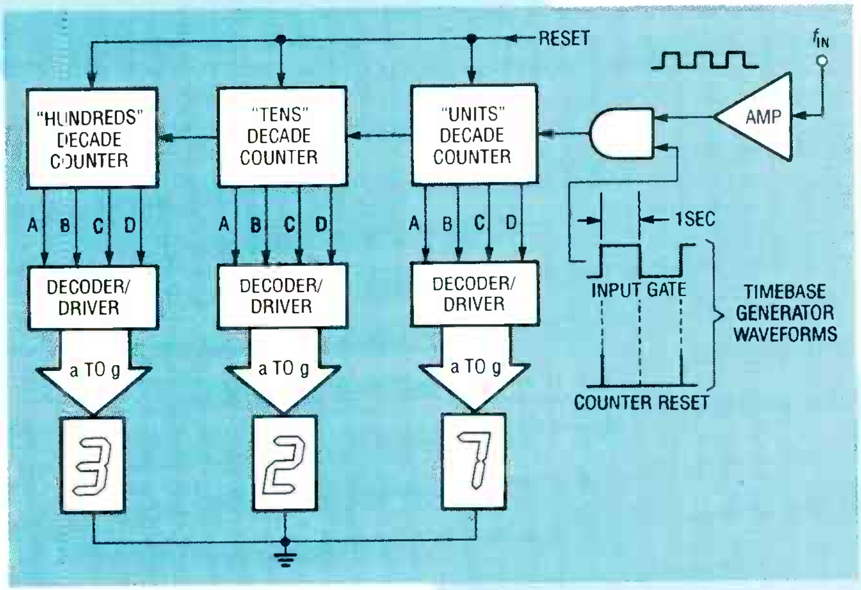


FIG. 1—SIMPLE DIGITAL frequency-meter circuit.

When the timebase gate signal goes high, a reset pulse is fed to all counters, setting them to zero. Simultaneously, the input gate is turned on, and the counters start to sum the input signal pulses. The count continues for one second while the 4-bit latches prevent the counter output from reaching the display drivers. As a result, the display remains stable during that interval. At the end of the period a brief LATCH-ENABLE pulse is fed to all latches.

The instantaneous binary-coded decimal (BCD) outputs of each counter are then latched into memory, and also fed to the display via the decoder/driver IC's. That steadies the reading of the display to give a total pulse count, which corresponds to the input signal frequency. A few moments later, the sequence repeats itself with the counters resetting and then counting the input frequency pulses for one second, and so on.

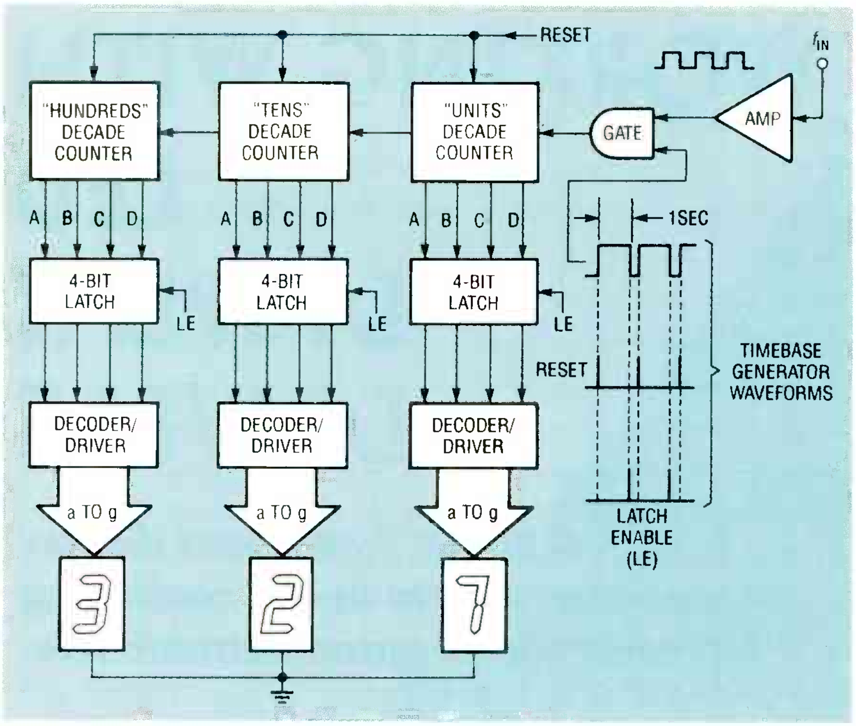


FIG. 2—IMPROVED DIGITAL frequency-meter circuit.

The circuit in Fig. 2 generates a stable display that is updated once per second. In actual circuits, the count periods shown in Figs. 1 and 2 can be set at any decade multiple or submultiple of one second, provided the display is suitably scaled. Many commercial decoder/driver IC's are available with built-in 4-bit data latches.

Multiplexing

You can see in Figs. 1 and 2 that at least 21 connections must be made between the IC circuitry and the 7-segment displays of a 3-digit readout. Similarly, at least 70 connections must be made for a 10-digit display. The number of IC-to-display connections can be significantly reduced with a technique known as *multiplexing*. Figures 3 and 4 illustrate multiplexing.

Figure 3 shows how each digit of a 3-digit common-cathode LED display is individually activated with only 10 external connections. In the display circuitry, all "a" segments are connected together, as are all other sets of segments ("b" to "g"). Thus only seven external "a" to "g" connections are made to the display, regardless of the number of digits used. However, no 7-segment display is illuminated by signals on the segment wires unless the display is enabled by tying its common terminal to ground. In Fig. 3, enabling is achieved by activating switching transistors Q1, Q2, and Q3 with suitable external signals. However, this scheme calls for an additional connecting wire for each display module.

Figure 3 also shows how three different sets of segment data can be selected with switch S1-a, and each of the three display modules can be selected with switch S1-b and Q1, Q2, or Q3. S1-a and S1-b are ganged together to form a two-pole rotary switch which provides the multiplexing. These switch elements represent a fast-acting electronic switch capable of cycling the contacts through positions 1, 2, and 3 fast enough for flicker-free multiplexing.

The operating sequence of the circuit shown in Fig. 3 will be discussed here. Assume initially that the contacts of S1-a and S1-b are in position 1 so that S1-a selects segment data of display module 1 (1_{a-g}), and S1-b activates display module 1 with Q1. Module 1 will then show an illuminated number "3." Moments later the switch contacts move to position 2, selecting segment data 2 (2_{a-g}) and illuminating module 2 with Q2. Module 2 will then be illuminated to show the number "2." Moments after that, the switch contacts move to position 3, causing module 3 to show the number "7." Thus only one digit is ever on at any one time.

In practical displays, the sequence is repeated fast enough so that you do not see the display segments being turned on and off. Your eye's persistence of vision makes it look as if the three digits are all lit up together. The multiplexing frequency must be about 1 kHz.

Figure 4 shows a more realistic arrangement for multiplexing a 3-digit frequency meter. The multiplexer (MUX) is located between the outputs of the three BCD data latches and the input of a display-driving BCD-to-7-segment decoder/

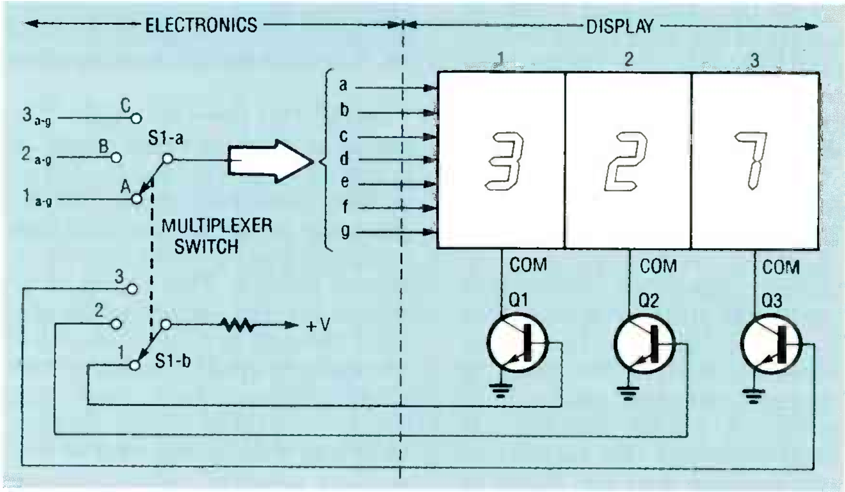


FIG. 3—MULTIPLEXING METHOD for a 3-digit common-cathode LED display.

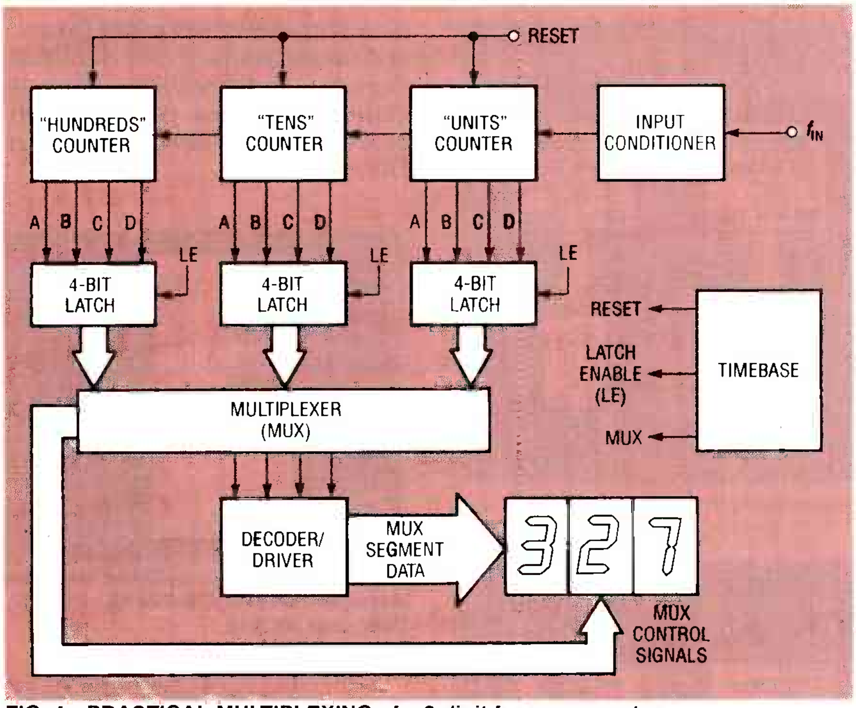


FIG. 4—PRACTICAL MULTIPLEXING of a 3-digit frequency meter.

driver IC. The scheme shown has two major advantages: Only one decoder/driver IC is needed (regardless of the number of readout digits), and its multiplexer includes only five ganged 3-way sequencing switches. One of those switches is for control data, and four are for BCD-segment data. That arrangement saves three ganged 3-way switches, as compared with the eight needed in Fig. 3.

Commercial large-scale integrated (LSI) IC's now available can perform all of the counting, latching, multiplexing, decoding, timing, and display-driving functions in Fig. 4. A device of this complexity is typically packaged in a dual-in-line package (DIP) with only 20 pins. Those pins provide for all necessary connections to the power supply, display modules, and inputs. Therefore, a complete 4-digit counter can be built with a dedicated IC in a circuit such as that shown in Fig. 5. Another example of an LSI IC in a display circuit is the 3½-digit digital voltmeter (DVM) chip shown in Fig. 6.

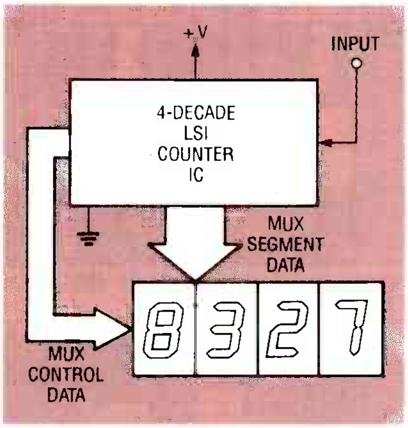


FIG. 5—4-DIGIT COUNTER CIRCUIT based on an LSI chip.

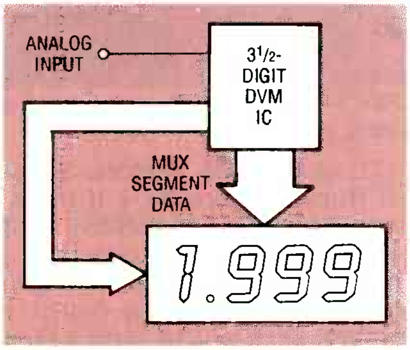


FIG. 6—3-1/2-DIGIT VOLTMETER based on an LSI chip.

Ripple blanking

Unless there is automatic suppression of the two unwanted leading zeros, the 4-digit circuit in Fig. 5 will give an actual reading of 0027 if it is used to measure a count of 27. Similarly, if the 3½-digit circuit of Fig. 6 measures 0.1 volt, it will display 0.100 volt unless the two unwanted trailing zeros are automatically suppressed.

In practical circuits, automatic blanking of leading or trailing zeros can be performed with a *ripple-blanking* technique, as shown in Figs. 7 and 8. Each decoder/driver IC (with a BCD input and 7-segment output) is provided with a RIPPLE-BLANKING INPUT (RBI) and scripple-blanking output (RBO) pins.

Assuming those pins are active-high, if the RBI terminal is held low (logic 0), the 7-segment outputs of the IC are enabled, but the RBO terminal is disabled (held low). If the RBI terminal is biased high (logic 1), the 7-segment outputs become disabled in the presence of a BCD 0000 input, and the RBO output goes high under the same condition. The RBO terminal, therefore, is normally low and goes high only if a BCD 0000 input is present at the same time the RBI terminal is high.

Figure 7 shows the ripple-blanking technique for leading-zero suppression in a 4-digit display with a reading of 207. The RBI input of the thousands or most significant digit (MSD) decoder/driver is tied high, so the readout is automatically blanked in the presence of a zero when the RBO terminal is high. Consequently, the RBI pin of the hundreds IC is high, the readout shows 2, and the RBO terminal is low. The RBI input of the tens unit is low, so the readout shows 0 and its RBO output is low. The units readout shows the least significant digit (LSD), which does not require zero suppression. Its RBI pin is grounded and the readout shows 7. The display therefore gives a total reading of 207.

In the leading-zero suppression circuit, Fig. 7, the ripple-blanking feedback is applied backwards from the MSD to the LSD. Figure 8 shows how trailing-zero suppression is accomplished by reversing the direction of feedback from the LSD to the MSD. Therefore, when an input of 1.1 volts is fed to that circuit, the LSD is blanked, because its BCD input is 0000 and its RBI input is high. The RBO

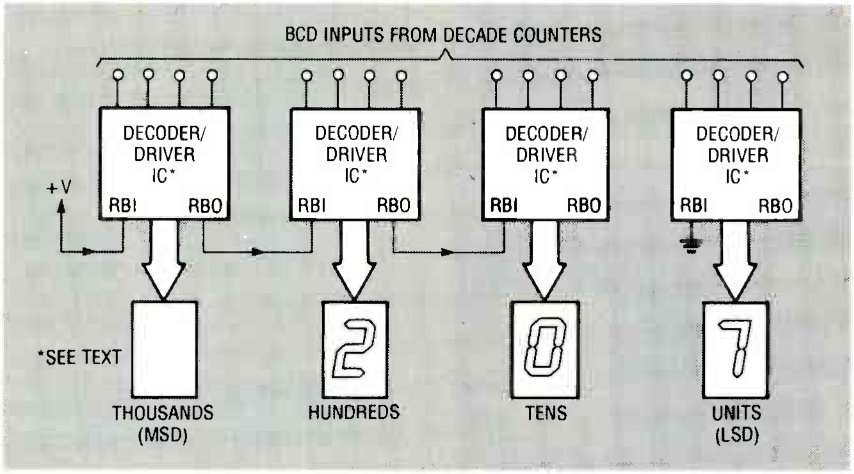


FIG. 7—RIPPLE-BLANKING for leading-zero suppression in a 4-digit counter.

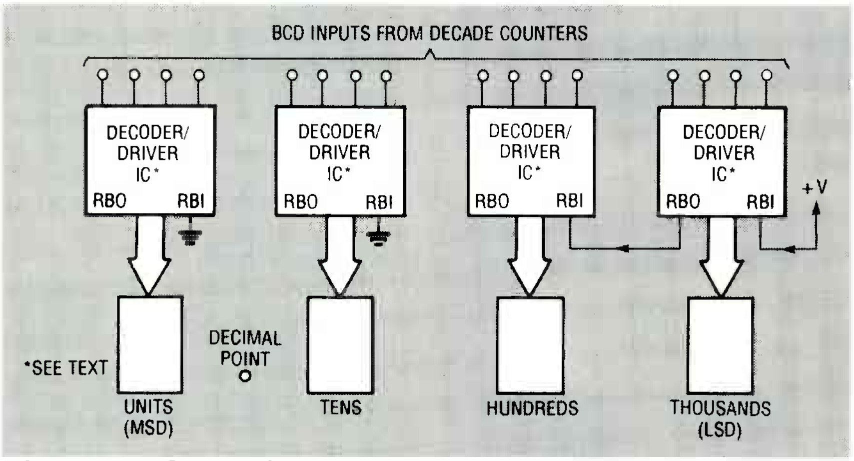


FIG. 8—RIPPLE-BLANKING for trailing-zero suppression of the last two digits of a 3-1/2-digit DVM readout.

terminal is high under that condition, so the hundredth's digit is also blanked in the presence of a 0000 BCD input.

Most decoder/driver IC's have RIPPLE-BLANKING INPUT and RIPPLE-BLANKING OUTPUT pins. Usually these pins are active-low. If a decoder/driver IC does not include integral ripple-blanking logic, it can usually be obtained by adding external logic circuitry similar to that shown in Fig. 9. The RBO pin is connected to the BLANKING INPUT pin of the decoder/driver IC. Figure 9 shows an active-high circuit in which the output of the 4-input NOR gate goes high only with a 0000 BCD input. The RBO output goes high only if the 0.0 input is present when RBI is biased high.

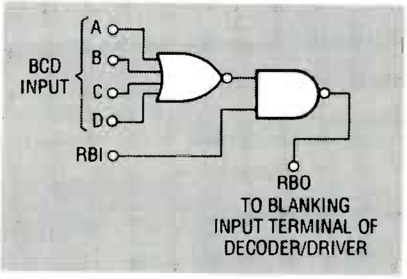


FIG. 9—ACTIVE-HIGH ripple-blanking logic.

Decoder/driver IC's

Many decoder/driver IC's are available commercially as both TTL and CMOS devices. Some of those devices have integral ripple-blanking capability, and others have built-in data latches. A few of those devices have built-in decade-counter stages. Let's look at some of the most popular of those devices.

The 7447A and 7448 7-segment decoder/driver IC's are in the standard TTL family. They are also available in a low-power Schottky (LS) form designated as 74LS47 and 74LS48, respectively. All of those IC's have integral ripple-blanking facilities, but do not include data latches. Figure 10 shows the pinout common to those devices, each of which is housed in a 16-pin DIP.

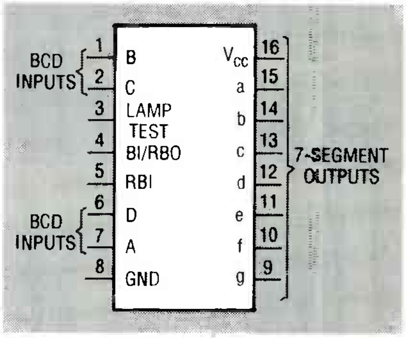


FIG. 10—PINOUT for BCD-to-7-segment decoder/drivers IC's 7447A, 74LS47, 7448, and 74LS48.

The 7447A/74LS47 has an active-low output designed for driving a common-anode LED with external current-limiting resistors (R_X), as shown in Fig. 11. The 7448/74LS48 has an active-high output that drives a common-cathode LED in a manner similar to that of the circuit in Fig. 11, but with the common terminal of the display connected to ground. In all cases, the R_X current-limiting resistors should be chosen to limit the individual segment currents below the following absolute limits:

7447A = 40 mA
74LS47 = 24 mA
7448 and 74LS48 = 6 mA

Figure 12 shows how a 7448/74LS48 can drive a liquid-crystal display (LCD), using a pair of 7486 or 74LS86 quad 2-input XOR gate IC's. An external 50-Hz square wave applies the necessary phase signals to the display.

As shown in Fig. 10, each of the 7447/7448 IC's has three input control pins: LAMP TEST, BI/RBO, and RBI. The LAMP TEST pin drives all display segments on when the pin goes to logic-low with the RBO pin on or at logic-high. When the BI/RBO pin is pulled low, all outputs are blanked. The BI/RBO pin also functions as a RIPPLE-BLANKING OUTPUT pin. Figure 13 shows how to connect the RIPPLE-BLANKING pins to give leading-

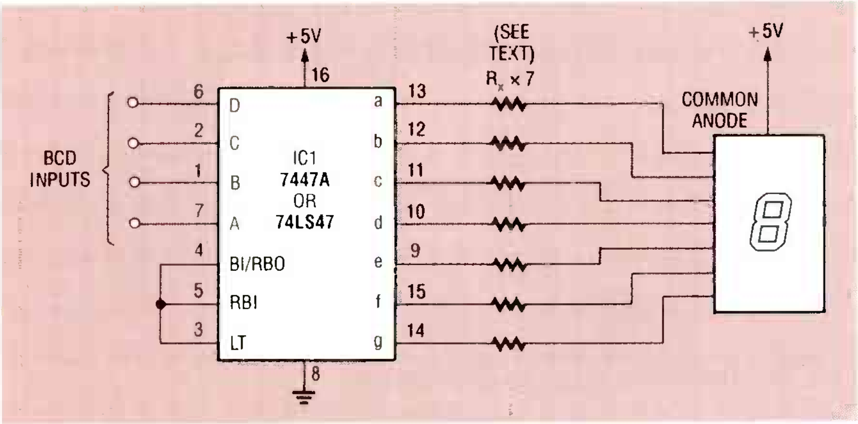


FIG. 11— **DRIVING a 7-segment common-anode LED display with a 7447A-type decoder/driver.**

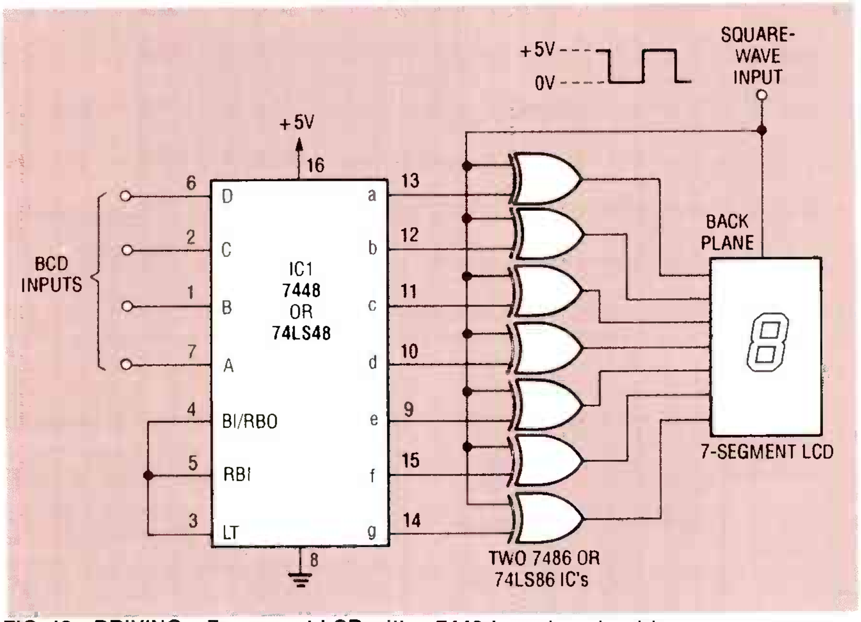


FIG. 12—**DRIVING a 7-segment LCD with a 7448-type decoder drivers.**

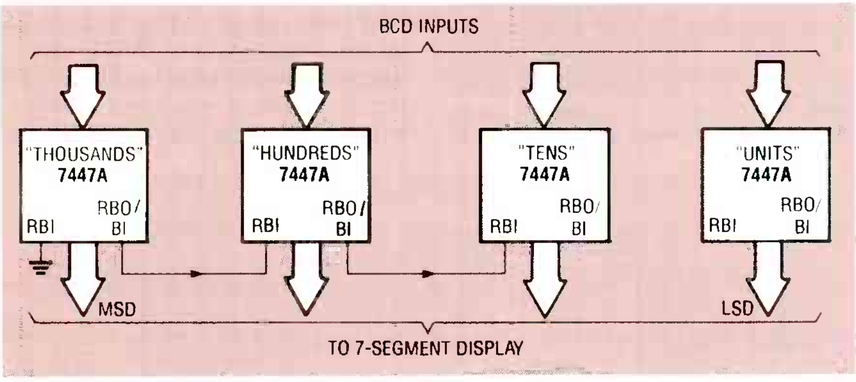


FIG. 13— **SUPPRESSION OF FIRST THREE digits of a 4-digit display with 7447A-type decoder/drivers.**

zero suppression on the first three digits of a 4-digit display.

The 4511B is a BCD-to-7-segment decoder/driver IC with an integral 4-bit data latch, but it lacks built-in ripple-blanking. That CMOS device features NPN bipolar transistor output stages capable of handling output currents up to 25 mA. It can drive most popular 7-segment displays. Figure 14 is a functional diagram of the IC. The 4511B will operate from any 5- to 18-volt power supply.

The 4511B has three input-

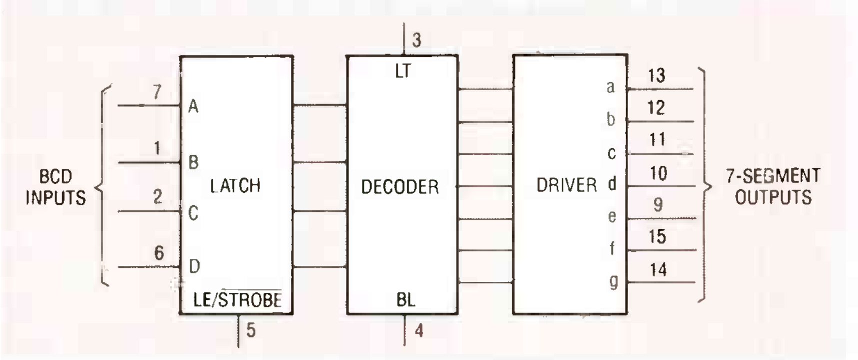


FIG. 14—FUNCTIONAL DIAGRAM of the 4511B IC.

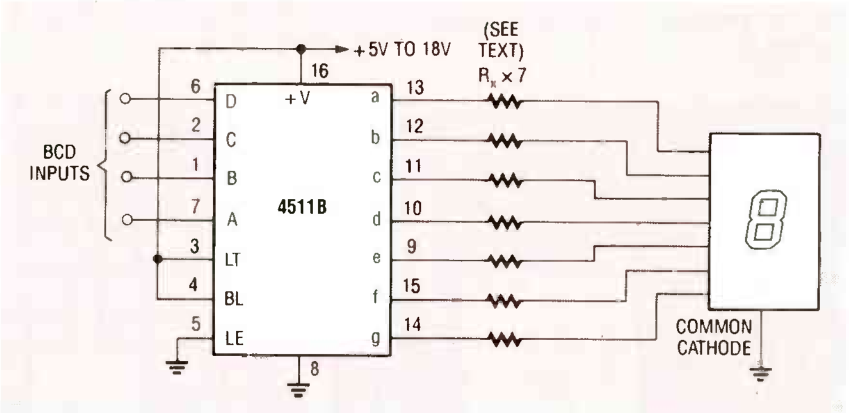


FIG. 15—DRIVING a 7-segment, common-cathode LED display module with a 4511B.

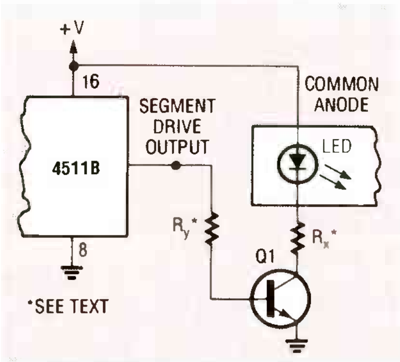


FIG. 16—DRIVING a common-anode LED lamp or segment with a 4511B.

control pins: LAMP TEST (LT), BLANKING (BL), and LATCH ENABLE/STROBE (LE/S). The LAMP TEST and BLANKING inputs are active-low, and the LATCH ENABLE/STROBE input is active-high. In normal operation, LAMP TEST and BLANKING are made high and LATCH ENABLE/STROBE is held low.

When the LATCH ENABLE/STROBE pin is low, BCD input signals are decoded and fed directly to the 7-segment output pins. If LATCH ENABLE/STROBE

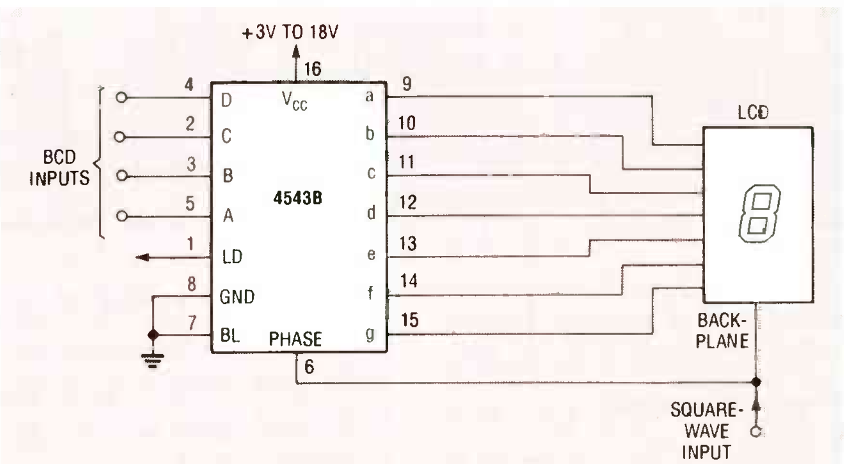


FIG. 17—DRIVING a 7-segment LCD with a 4543B.

goes high, the BCD input signals present at the moment of transition are latched into memory and fed (in decoded form) to the 7-segment outputs, while LATCH ENABLE/STROBE remains high. If the LAMP TEST input is grounded, all output segments are activated, regardless of the BCD inputs. If the BLANKING input is grounded (while LAMP TEST is positive), all output segments are blanked.

Figure 15 shows the basic connections for driving a common-cathode LED. A current-limiting resistor (R_X) must be wired in series with each display segment, and it must have a value chosen to hold the segment current below 25 mA. Note that the segment outputs of the 4511B are not internally current-limited. Therefore, the device has no output-overload protection.

Figure 16 shows how to modify the circuit in Fig. 15 to drive an LED common-anode display. In the example shown in Fig. 16, an NPN buffer transistor must be used between each output-drive segment and the input segment of the display. Resistor R_X sets the operating segment current of the display in those examples, and R_Y sets the base current of the transistor.

The 4511B can also drive 7-segment liquid-crystal displays (LCD) with an external square-wave PHASE signal and a set of XOR gates similar to those of Fig. 12. In practical circuits, however, it is better to use a 4543B IC for that specific application.

The 4543B is a 7-segment CMOS decoder/driver with an integral 4-bit data latch. It was designed for driving LCD's, but it can also drive most other 7-segment displays.

The 4543B has three input control pins: LATCH DISABLE (LD), PHASE, and BLANKING (BL). In normal use, the LATCH DISABLE pin is biased high and the BLANKING pin is tied low. The state of the PHASE pin depends on the display that is being driven. For driving LCD displays, a square wave (approximately 50 Hz, swinging fully between the ground and V_{cc}) must be applied to the PHASE pin. The PHASE pin must be grounded for driving common-cathode LED's and it must be tied to logic-high for driving any common-anode displays.

The display can be blanked at any time simply by driving the BLANKING pin to the logic-high state. When the LATCH DISABLE pin is in its normal high state, BCD inputs are decoded and fed

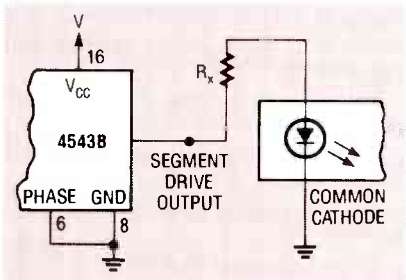


FIG. 18—DRIVING A common-cathode LED lamp or display segment with a 4543B.

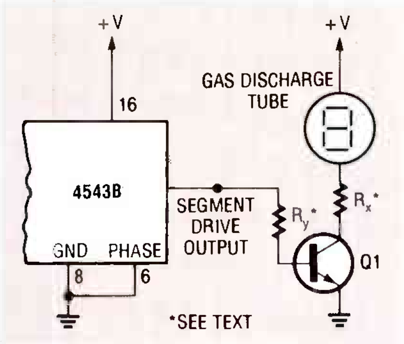


FIG. 19—DRIVING A gas-discharge tube or display segment with a 4543B.

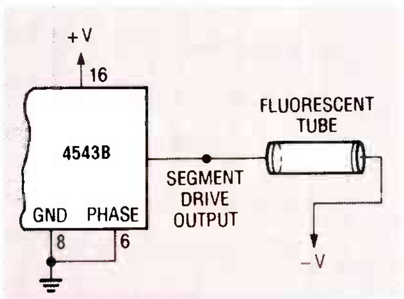


FIG. 20—DRIVING A fluorescent tube or display segment a 4543B.

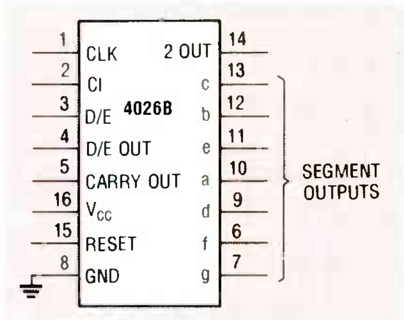


FIG. 21—PINOUT of the 4026B decade counter with 7-segment outputs.

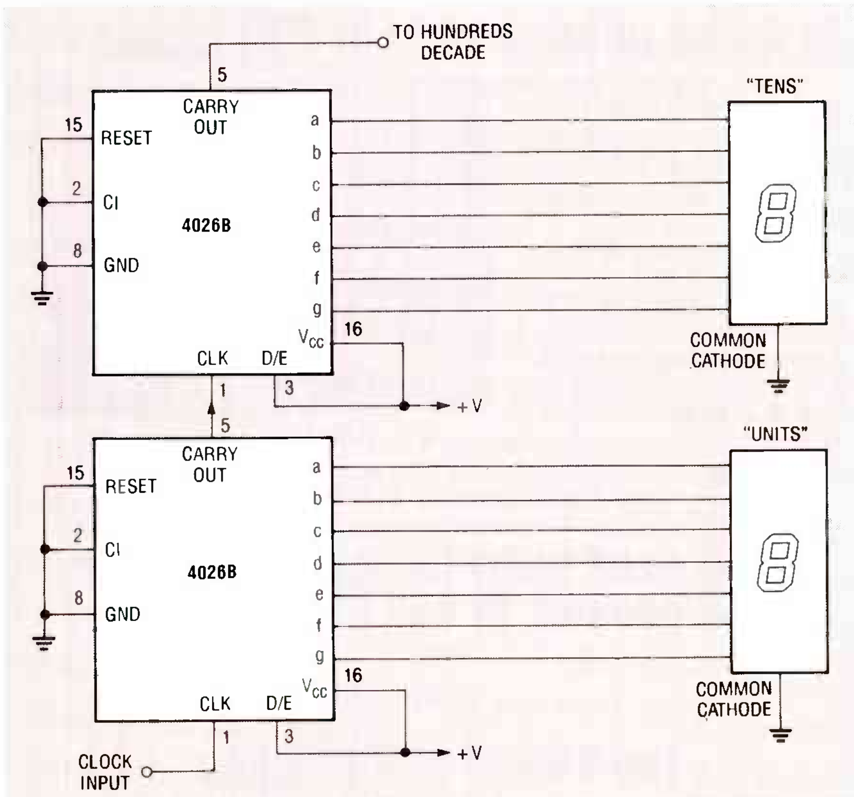


FIG. 22—CASCADING TWO 4026B decade counters.

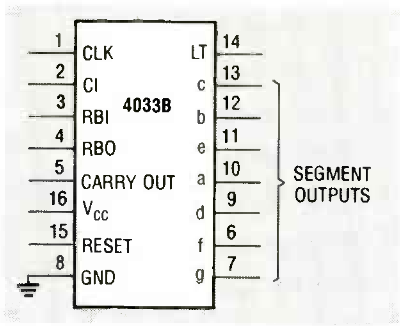


FIG. 23—PINOUT for the 4033B decade counter with 7-segment outputs and ripple blanking.

directly to the 7-segment output pins of the IC. When the LATCH DISABLE pin is pulled low, the BCD input signals present at the moment of transition are latched into memory and fed (in decoded form) to the 7-segment outputs while LATCH DISPLAY remains low.

Figure 17 shows a method for using the 4543B to drive an LCD, and Figs. 18–20 show how that circuit can be modified to drive other 7-segment displays.

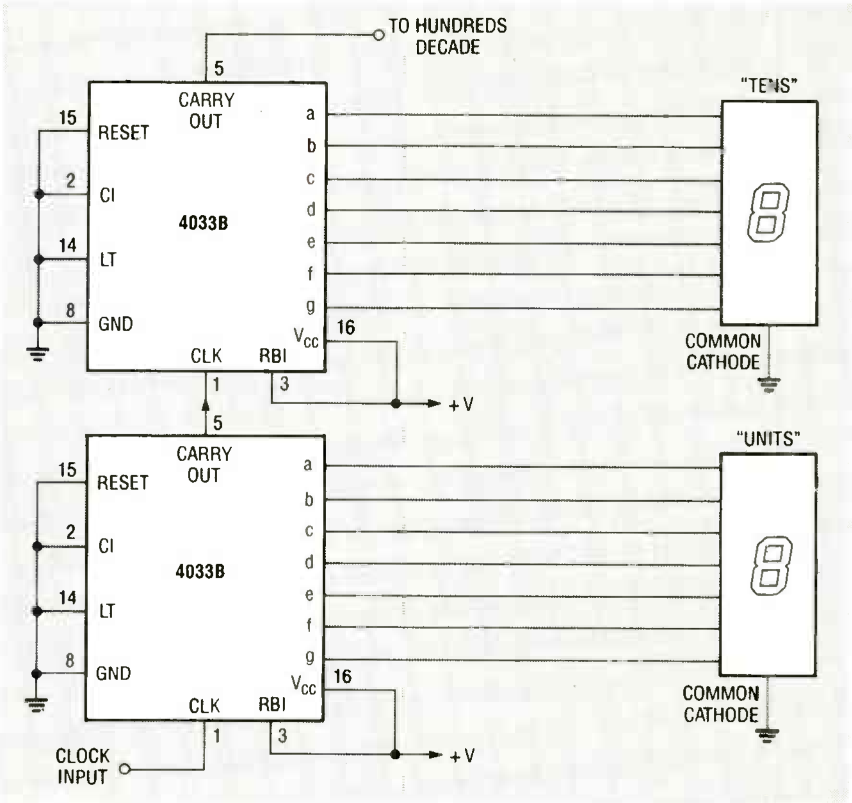


FIG. 24—CASCADING TWO 4033B decade counters without zero suppression.

The value of R_X in Fig. 18 must be chosen to limit the output drive current to below 10 mA per segment (individual LED lamp). If higher drive currents are needed, use a buffer transistor between the output of the 4543B and the input of the display segment.

Figure 21 shows the pinout of the 4026B, a complete decade counter with integral decoder/driver circuitry. It can drive a 7-segment common-cathode LED display directly. The segment output currents are internally limited to about 5 mA with a 10-volt supply or 10 mA with a 15-volt supply. Therefore, the display can be connected directly to the output of the IC without external current-limiting resistors. The 4026B does not include a data latch and is not capable of ripple blanking.

As shown in the Fig. 21, the 4026B has four input control pins and three auxiliary output pins. The input pins are designated: CLOCK (CLK), CLOCK INHIBIT (CI), RESET (RESET), and DISPLAY/ENABLE (D/E). The IC has a Schmitt trigger on its CLOCK (CLK) input line, and clock sig-

continued on page 93

AUDIO UPDATE

Let's Phase the Music: More comments on papers from the 91st AES convention

LARRY KLEIN

Acoustic phase, and its audibility, has been a subject of controversy ever since Hermann von Helmholtz addressed the subject in the late 1800's. Yet, despite all we've learned about hearing since Helmholtz, and the current availability of sophisticated new research tools, the controversy lingers on. The argument is not, as one might think, simply an abstract, if sometimes heated, debate among philosophical psychoacousticians. It has real-world consequences for the way audio signals should be recorded an audio equipment should be designed.

I've been aware ever since I built my first Williamson amplifier in the early 1950's that signal phase *shift* was a significant audio parameter—at least in power amplifiers. In its early incarnations, the Williamson suffered from marginal instability because the 20-dB negative feedback loop sometimes shifted positive at the frequency extremes. That frequently resulted in pulsing woofers at one end of the spectrum and RF oscillation at the other. But aside from such obvious instability disturbances, I've never felt that linear phase shift posed a severe threat to fidelity.

In the early 1980's, many speaker manufacturers decided that the conventional two or three drivers installed on the single vertical front panel of a system resulted in acoustic phase shifts caused by the different path lengths to the listener's ears of the woofer and tweeter signals. That was usually "solved" by stepping a cabinet's front panel so that the woofer was several inches forward of the tweeter. Aside from generating new opportunities for advertising copy writers (and some expensive pot-bellied speakers), the arrangement's audible advantages were elusive—at least to my ears. And, in any case, it seems to me that on a purely theoretical basis such "time alignment" would only hold when a listener's ears were also aligned exactly on axis with the acoustic center of the two (or more) drivers.

I once saw/heard a speaker-phase demonstration using a two-way system with a movable tweeter. A square wave was fed to the system and the speaker's output picked up by microphone and displayed on an oscilloscope. As the tweeter installed on top of the system was slowly shuttled back and forth over a five-inch distance, the square wave would visibly distort and then restore itself as its high- and low-frequency harmonic components shifted in and out of phase. I stood in front of the display for several minutes, really trying to hear the waveform distortion that was clearly evident on the scope screen. Following in the tradition of Herr von Helmholtz, I never did hear any effect. All of this is background for the latest phase controversy beautifully delineated in the following Audio Engineering Society (AES) preprint.

> **INTERCHANNEL SPEAKER PHASE**
>
> Most of us first encountered "phase" as an audio phenomenon when we were told to make sure that the right and left speakers of our stereo system were connected in proper polarity. That meant that when presented with, say, a positive audio pulse from both amplifier channels, the cones of both woofers would move simultaneously in the same direction. If the speakers were wired incorrectly, the cones would move in opposite directions, and bass performance would suffer. In addition, the 180-degree phase differences in the high frequencies would confuse the ear's localization system, disturbing the stereo sound-stage image and imparting a vague "phasiness" to the reproduced sound. In general, speaker polarity/phase, if correct in the original installation, remains so unless the connections are changed. R-E

Observations on the Audibility of Acoustic Polarity [Greiner and Melton (3170 K-4)].

To understand what is meant by absolute polarity, it helps to use a simple musical example, such as the sound of a kickdrum. The impact on the drum head produces an air compression that moves outward and is picked up by a recording microphone. Ultimately, it is reproduced by a forward-moving speaker cone as an air compression. However, anyone who deals with electronics knows that the original electrical signal from the microphone has had its polarity flipped probably dozens of times by the recording and reproduction electronics before it reaches the speaker. In fact, there's a 50–50 chance that the initial kickdrum impact is being reproduced by a speaker cone that is pulling at the air rather than pushing it. In other words, what reaches our ears is an air rarefaction, although the original was a compression. It follows that our eardrums are also being pulled rather than pushed. Does it make a difference? That's what Greiner and Melton set out to explicate in their paper.

The audibility—or inaudibility—of absolute inversion is a recent element in the ongoing discussion. Unlike other phase shift phenomena discussed earlier, polarity inversion does *not* change the shape of a transient signal nor shift the phase relationship among its component elements. However, as the authors state, it does present to the ear a fundamentally different signal.

A major part of the authors' research effort involved extensive, carefully controlled listening tests to determine the types of signals most sensitive to polarity inversion. It seems self evident that highly asymmetrical signals were most likely to be audibly changed by inversion. For example, note the trombone waveform shown in Fig. 1.

In general, it could be said that acoustic polarity inversion is clearly audible in some circumstances (particularly with test signals), although most of the time with real-world music it is not. It seems that even when waveforms have clear asymmetries as in Fig. 1—and not all of them do—other effects inherent in the complex nature of most musical tones tend to mask the identifying characteristics of the inversion.

The authors conclude that "while polarity inversion is not easily heard with normal complex musical program material, as our large-scale listening tests showed, it is audible in many select and simplified musical settings. Thus it would seem sensible to keep track of polarity and to play the signal back with the correct polarity to assure the most accurate

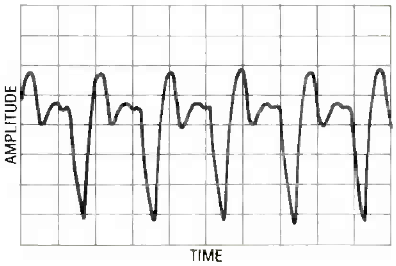


Fig. 1. Trombone waveform. In general, reed instruments show the greatest asymmetry.

reproduction of the original waveform."

No one can argue with the above as an ideal goal, but exactly how is it likely to be realized? Assuming that (1) we have a recording with all the instruments recorded in phase, that (2) our three-way speaker doesn't have its mid-range connected in inverted polarity to flatten the system's frequency response (a no longer common practice), and that (3) anyone in authority cared enough to manufacture discs and tapes with all their polarity ducks in a row, how would the consumer know when he had it right?

Next month I'll discuss one more AES paper and then call it quits for the 91st Convention. **R-E**

PHASE INSENSITIVITY

It is well known that loudspeaker cone travel is seldom equally linear in both its outward and inward excursion. In other words, the speaker cone's push on the air may not be exactly equal to its pull, even when driven by a low-distortion, highly symmetrical sinewave. It seems probable to me that most human ears are also asymmetrical in their responses to the compressions and rarefactions of an impinging acoustic waveform and therefore generate harmonic distortions. Whether any individual listener's degree of hearing asymmetry correlates with their sensitivity to absolute phase is an open question. I noted with interest that Greiner and Melton suggest at one point that a distorting sound system may increase the audibility of polarity inversion.

I know for a fact that I've always been comparatively insensitive to phase. For example, in the early days of quadrophonics I was evaluating a four-channel synthesizer that attempted to generate artificial rear channels by tapping off the front channel, "wobbulating" it at a 25-Hz rate, and feeding it to a pair of rear speakers. The four-channel effect, for better or worse, was barely perceptible to my ears. A friend dropped in unexpectedly while I was doing my listening and greeted me with, "Hi Larry ... (three-second pause) ... your rear speakers are out of phase." I sat alongside him on the couch between the wobbulated rear speakers and for the life of me couldn't hear what he had detected instantly—and claimed was giving him a headache!

I also know that some listeners are incredibly sensitive to very small percentages of tape flutter, a phase-shift phenomenon, but the numbers have to get pretty bad before I hear it. In case you are wondering, my *overall* acuity and sensitivity were (by test) pretty good in those days, so my phase insensitivity was, in effect, an independent variable. I wonder what the normal distribution of phase sensitivity is, and whether ignoring it may not skew the results of psychoacoustic studies of phase. **R-E**

COMPUTER CONNECTIONS

The personal digital assistant.

JEFF HOLTZMAN

Gadget lovers take heed: Personal Digital Assistants (PDA's) will be the fastest-growing segment of the computer business within two years—maybe by the end of this year. What is a Personal Digital Assistant? It's a paperback-size computer that bridges the gap between calculator-like organizers on the one hand, and hefty notebooks on the other. In so doing, the PDA hopes to provide both power and ease of use, but without the size, weight, and battery-life and -weight constraints of a notebook PC.

Numerous technologies are coming together to make this category a reality. Low-voltage CPU's, system controllers, video controllers, and DRAM's from Intel, Cyrix, AMD, Western Digital, and others promise to drastically lower power consumption. The chips run at 3.3 volts, and could more than double battery life, from 3.5 to 8.0 full hours. Emerging standards for credit-card sized memory modules seem to be taking hold. Hard-disk drives continue to shrink. Integral Peripherals has introduced 20- and 40-megabyte drives in 3-ounce packages that measure 2" × 3", and that consume 500 mW of power during operation and 15 mW in the "sleep" mode. IBM, Conner, Seagate, and others will ship similar drives later this year.

Look for two basic approaches to the PDA. One, promulgated by PC vendors, amounts to a miniature DOS machine with a QWERTY keyboard that allows touch typing. It has a full 80 × 25 (640 × 200, CGA-level graphics) non-backlit LCD screen. The other, promulgated by consumer electronics companies (e.g., Sony), consists of a proprietary device using a stylus input in place of a keyboard.

The DOS version may well conform to a spec developed by Phoenix Technologies, called the Companion PC (CPC). A CPC will be based on an 8086-level computer-on-a-chip developed by Chips & Technologies (see the January 1992 issue of this column for more information), PCMCIA memory cards, Phoenix BIOS and power management software, and special battery technology developed by Duracell. As for software, Microsoft has delivered a ROMable version of DOS 5.0, and promises to do the same for Windows 3.1. Lotus might supply a suite of applications, including a task switcher, although Microsoft Works could very well provide steep competition.

Tantalizing views of the other category have been revealed by Sony. And there are persistent rumors that Apple and Sony are working together to put a Mac-style interface on this new breed. Sony has released one such device in Japan, but apparently has no plans to market it here.

FIG. 1—DYCAM'S MODEL 1 digital camera stores 32 shots, each with a resolution of 376 × 240 × 256 gray levels. It's a harbinger of the future for PC-based digital imaging.

Electrical power usage remains a major issue with portable computers of all configurations. In the ROMable versions of DOS 5.0 and Windows 3.1, Microsoft has introduced an Advanced Power Management (APM) Application Programming Interface (API), co-developed with Intel and Phoenix, that provides the system with information about which peripherals are not being used, so it can remove and thereby conserve power. Several battery manufacturers have introduced flat, wide batteries that provide both a better fit with today's sleek designs, and more power. For example, Portable Energy Products has a battery that measures 2.6" × 3.9" × 0.3" and produces two volts at three amps.

One interesting device is the "Commuter Computer," introduced by Memorex at the January Consumer Electronics Show (CES). The device weighs 1.3 pounds, lists for $599, and includes a word processor, scheduler, notepad, the DR-DOS 5.0 operating system, carrying case, power adapter, and cables; an external 1.44 megabyte floppy drive is available for $299.

Multimedia update

Here's an imaginative use of multimedia: The Virtual Press Conference. Redgate Communications of Vero Beach Florida plans to outfit more than 100 movers and shakers of the computer industry with 1.2-meter satellite dishes, TV's, VCR's, fax machines, and dedicated phone lines, at a cost of about $2 million. Redgate will then broadcast to them hour-long interactive press conferences, during which they can ask questions, receive printed materials by fax, and record the whole thing on VHS tape. The viewers will pay nothing for the service; Redgate in-

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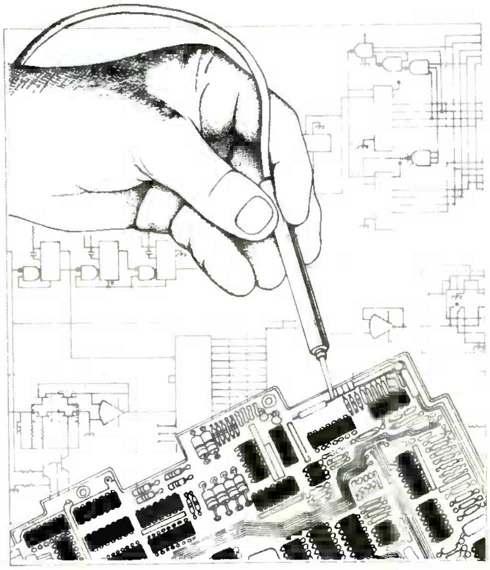

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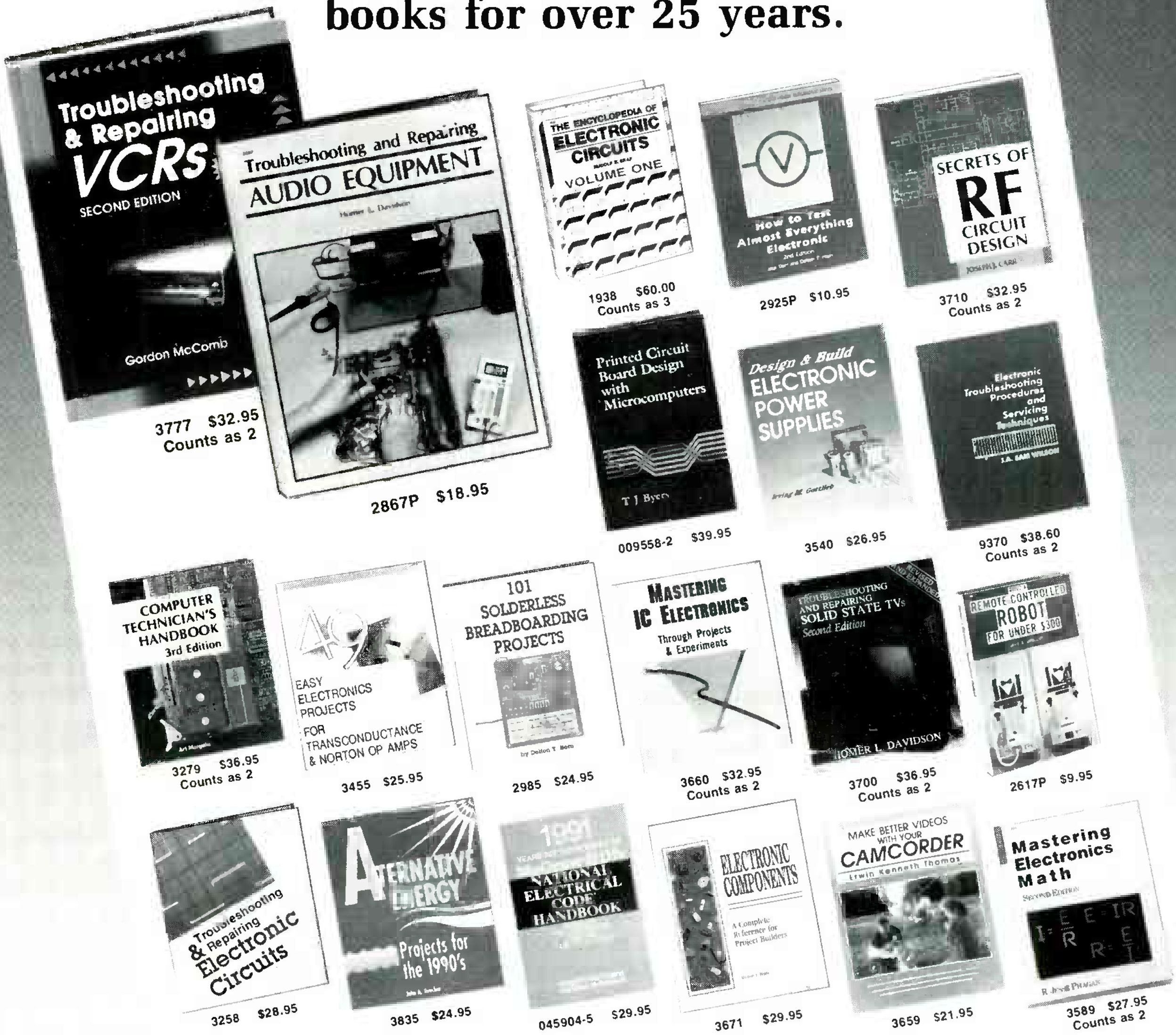

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The Multimedia PC Marketing Council has upgraded the "baseline" spec for a multimedia PC to include a 386SX. The original version specified a 10-MHz 286, which simply didn't provide enough horsepower to run serious applications. In addition, the rapid infusion of 386 technology into general buying habits makes 286 compatibility less of an obstacle than it once was.

Apple has released a multimedia extension to its System 7.0 software. It's called QuickTime, and it provides developers with a standard software architecture for integrating time-variant data (sound, video, animation). In introducing the product, Apple CEO John Sculley said that QuickTime will be the major legacy from his tenure at Apple—more important even than the Macintosh.

The QuickTime architecture includes four components: system software, file formats, compression/decompression technology, and user-interface standards. Apple hopes it will become a cross-platform standard with support for Mac, DOS, Windows, UNIX, Silicon Graphics, DEC, and Cray systems. The video format is 160 × 120 pixels, running at 15 frames per second. That's obviously no competition for broadcast-quality video (BQV); Apple hopes that the standard will evolve to accommodate more powerful hardware that can support BQV.

Apple has announced a QuickTime "player" that will allow PC-based Windows users to experience QuickTime movies. (Corel Systems, of CorelDraw fame, wrote the file-format translator.) In addition, Microsoft has announced support for QuickTime; add-ins for the Mac versions of Excel and Word will allow end-users to build simple movies within the respective applications. You could use this technology to combine a series of spreadsheets into an animated demonstration of how sales are projected to grow.

In response, IBM quickly demonstrated technology with twice the resolution and the same frame rate. Naturally it runs under OS/2 2.0. One demo showed how advanced features of OS/2 allowed several program processes to control separate halves of a duet in sync.

Product watch

The Dycam Digital Still Camera Model 1 is the first of a new breed of all-electronic snapshot takers. The Dycam is an easy-to-use, lightweight, hand-held camera that allows you to take as many as 32 pictures, then upload them to your PC or Mac for bit-map editing or desktop publishing. (Logitech markets a nearly identical version under its own name.)

Despite flawed installation instructions, getting the Dycam going is easy. Attach a base mount to the main unit and plug in a wall-mount charger. When the LED starts blinking, the battery is fully charged. Then it's just point, shoot, and upload the images to your PC via an RS-232 port.

The Dycam comes with control software for both PC and Mac; I tested the PC version, which actually comes with both Windows and DOS versions. I found the Windows version unstable, due to frequent UAE's (Unexplainable, unintentional, unwanted Application Errors); consequently I worked mostly with the DOS version.

The DOS-based software works pretty well. The main screen consists of a series of "thumbnails," miniature versions of each image. To view an enlarged version, use the arrow keys to highlight the desired image, press Enter, and the software downloads, decompresses, and displays the complete image; the whole process takes about 10 seconds per shot, depending on system speed.

Documentation is both clear and brief and it includes both Mac and PC instructions in one booklet; the software includes on-line help in the form of brief summaries of keystroke options.

The camera can operate in two modes, regular and tripod. Unfortunately, to switch modes you must download different software to the camera, a process that takes about 45 seconds. In regular mode, you just point and shoot; the camera determines shutter speed and whether to use the flash. Tripod mode allows you to set the shutter speed manually, from 1 to 640 milliseconds. Shutter bugs would probably prefer to set shutter speed in familiar inverse time units ($1/t$, e.g., 1/60, 1/30, etc.). There's no way to attach a standard remote shutter release, but you can take a picture from the keyboard (Alt-T).

The software allows you to save images to disk in a variety of formats, including EPS, TIFF, PCX, a proprietary Dycam format, and others. The software provides some ability to adjust image contrast and brightness, but for optimal results you'll want to use a third-party tool (e.g., PhotoShop). When the camera is full, you will have to clear it out (Alt-C) to make room for more, and you cannot selectively delete pictures from memory. Although the camera maintains a time/date clock, you cannot include a time/date stamp as part of the image.

When I first learned of the Dycam, I thought it would be an ideal way to develop product and screen shots for the magazine. Unfortunately, that will not be feasible. The problem is not limitations with the software, but the optics. The lens system provides image quality comparable to a $20 instant camera—but the Dycam lists for almost $1000. The CCD provides a total resolution of 376 × 240 pixels, which is less than found in a TV. It compensates by providing 256 levels of gray, which definitely helps, because the eye responds better to variation in tone and color than to absolute resolution. Even the best shots, however, come out grainy. Shots of people generally fare better than inanimate objects.

Add-on lenses are available, including wide-angle, telephoto, and macro (close-up). Other accessories include an adapter for 12-volt auto operation.

Despite its limitations, the Dycam opens a world of possibilities for users who don't need publication quality. For example, a real estate agent could publish house shots to give prospective clients some idea of layout. Schools could create classroom newsletters.

Dycam is to be commended for being first to market with an all-electronic digital camera. An improved optic system, faster software, and more reliable Windows operation would make it a must-have item for professional desktop publishers. Keep your eye on this one. If you're interested, contact Dycam, Inc., 9588 Topanga Canyon Blvd., Chatsworth, CA 91311 (818) 998-8008.

News bits

Slate Corporation is a technology leader in the fledgling Pen-computing market. Two officers of the company, **Dan Bricklin and Bob Frankston,** designed the first spreadsheet for personal computers, VisiCalc. The dynamic duo is at it again, with a pen-based spreadsheet called At-Hand. At-Hand reads and writes 1-2-3 and Excel files, and runs under the PenPoint operating system. It's scheduled to ship in the second quarter.

After several false starts with portable and notebook PC's, the new IBM is trying a new tack. Big Blue just bought a 6% chunk of the French company, Groupe Bull, which owns Zenith Data Systems. The deal provides the rights for **IBM to sell ZDS portables,** and will give Groupe Bull access to IBM's RISC technology. The deal also provides for swapping microprocessor technology; one report indicates that GB will join IBM, Apple, and Motorola in developing the PowerPC, part of last summer's accord between IBM and Apple.

Worried about Japanese encroachment on American markets? Maybe it's time to start learning how to deal with them on their own terms—literally. A company called BayWare (415-949-3190) has introduced a Windows-based program that the company claims can teach the essence of Japanese in four to eight weeks, by studying only an hour per day. **Power Japanese** was developed using my favorite multimedia authoring system, ToolBook, and it includes an audio output device that connects to a standard parallel port. The device, which is housed in the connector shell, contains an 8-bit D/A converter and it can drive headphones or an audio amplifier. Software includes 2000 files of native Japanese speech, animated writing sequences, and a set of progressive lessons. The company plans to release versions in French, Spanish, German, and advanced Japanese.

Big-bucks consumer-oriented advertising is becoming the rule in the PC business. You've probably seen Intel's flashy "Vacancy" ads on cable. Now Microsoft is gearing up for a **$30 million Windows promotion,** including $8 million for TV spots alone. 1992 is going to be remembered in the PC industry as the year the battle for graphical operating environments became really down and dirty. **R-E**

DRAWING BOARD

One step backward to automotive regulators and two steps forward to our oscilloscope.

ROBERT GROSSBLATT

Just when I thought we had driven in the final nail on the whole business of automotive charging systems, I got a letter with some stuff in it that I have to pass on. Even though we spent all our time talking about alternator-based systems, there was a lot of mail from people who had generators. The voltage regulators we designed were specifically aimed at alternators but a regulator is still a regulator is still a regulator and, if you give it some thought, the one we designed can be used with a generator as well.

The most important factor in modifying the design is to realize that regulators for generator have to handle much larger amounts of current and because of that, our existing circuit can't drive the generator directly. The standard way to do deal with this is to use relays and that's exactly what was done by Craig Shippee, a reader from Bridgewater, Massachusetts who sent his design to me in the mail.

His circuit, shown in Fig. 1, does several interesting things. First, the basic design is the one we did for an alternator with a pulled-up field (one side of the alternator's field windings are hard wired to the *positive* side of the battery) but the generator is set up with a grounded field (one side of the field hard wired to *ground*). The other interesting part of the design is that it uses only one DPDT relay instead of the two or three relays found in standard generator regulators.

Craig's circuit is a classic example of what happens when need comes up against ingenuity and experimentation. He said that he couldn't give me the exact specifications on the relay he used because he salvaged an old 30-amp light relay from a dead truck. The relay opens when the regulator doesn't want it to charge the battery, and the 40-amp diode makes sure there's no backflow of current from the battery to the generator.

If you're going to use the circuit, make sure the relay is rated high enough to handle the maximum output current of the generator and tweak the 500-ohm potentiometer to get the cut-in point that's best for your system. Craig is using the circuit on a tractor but there's no reason why it can't be used with any generator-based automotive electrical system.

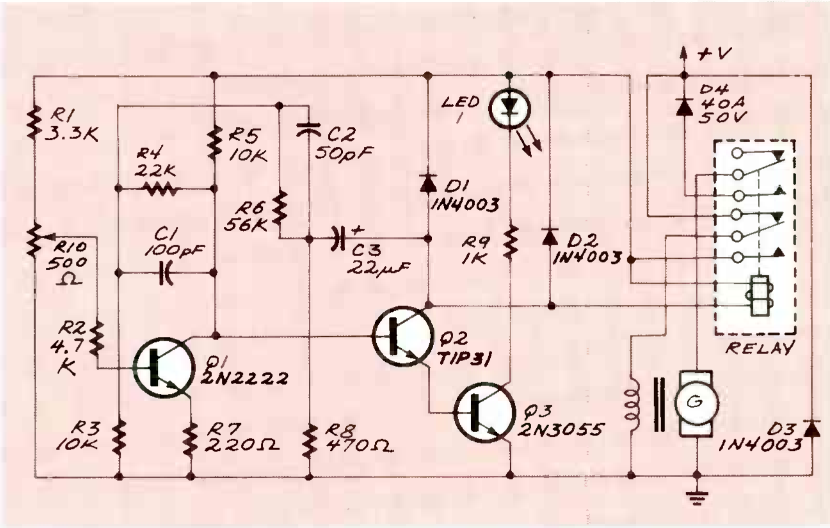

FIG. 1—A REGULATOR FOR A GENERATOR has to handle a lot of current, so a relay must be used.

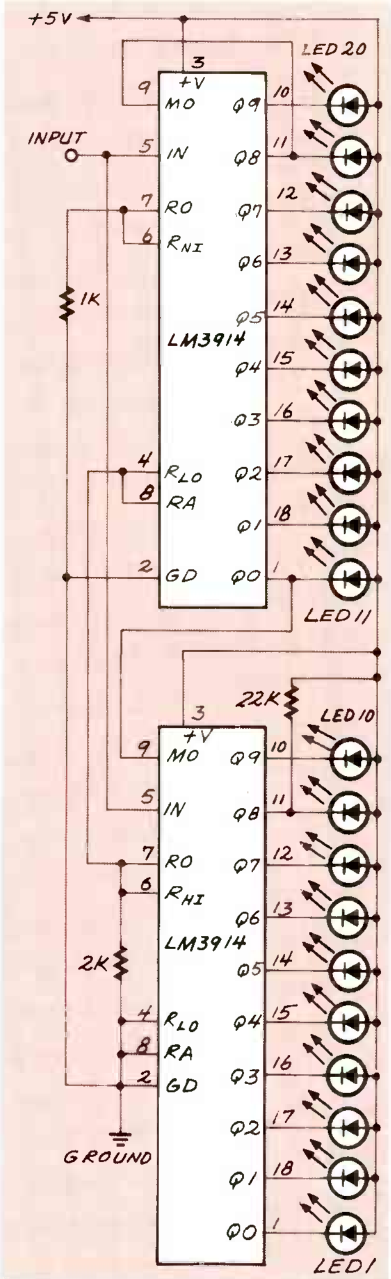

FIG. 2—TO EXPAND THE VERTICAL display to twenty elements we'll have to add a second LM3914 to the circuit. The 3914's were designed to be easily cascaded.

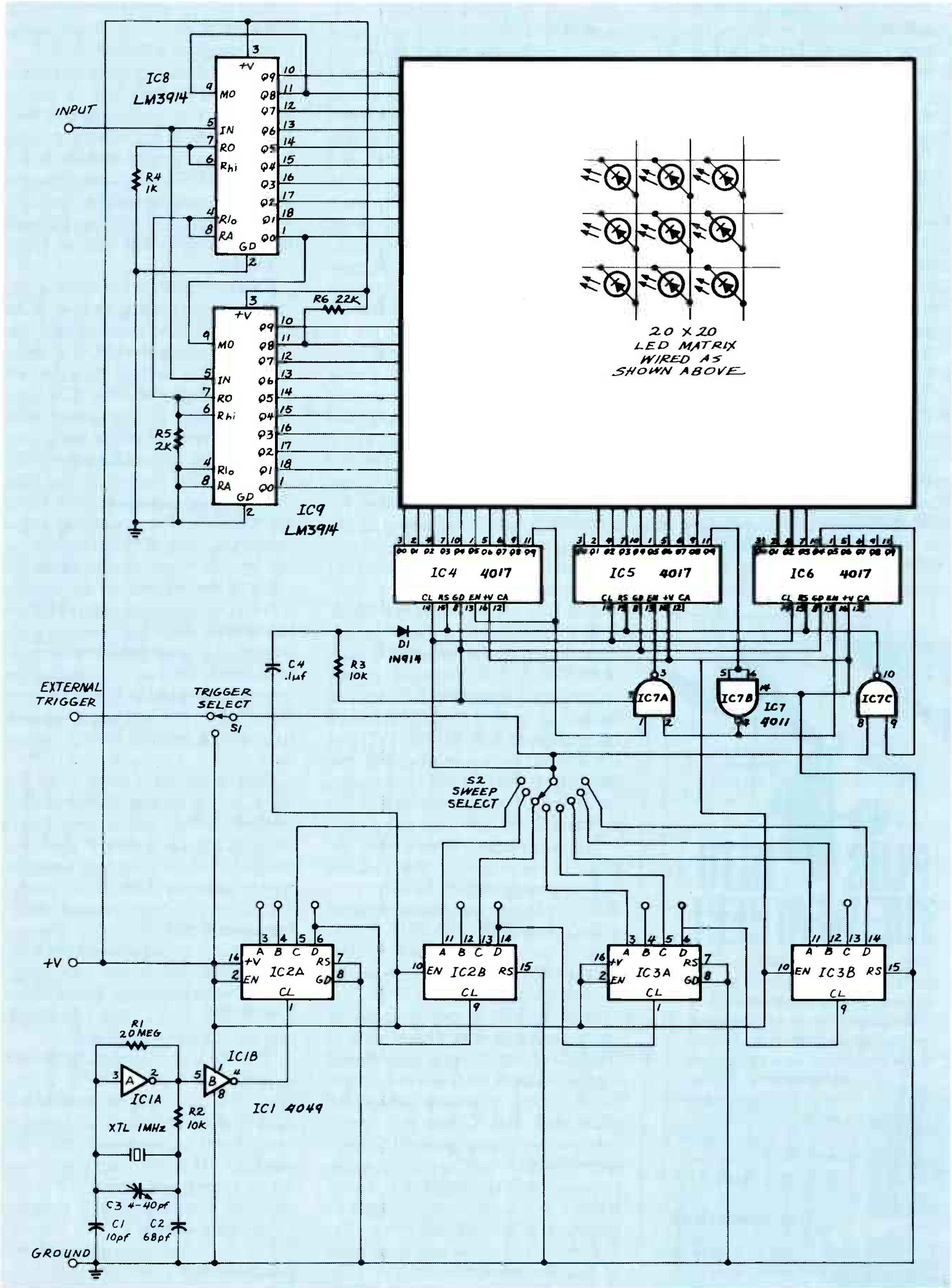

FIG. 3—COMPLETE SCOPE SCHEMATIC SO FAR. All we have to add is an input amp and a pad arrangement to prescale the input voltages.

Some good thinking went into the modification and, in the words of Jimmy Hatlo, a "Tip of the Hat" to Craig Shippee for a good job, a great letter, and taking the time to pass it on. Let me hear some more from you.

But back to the scope.

The next step we have to take is to expand the vertical display to the full twenty elements we specified in the design criteria. Since we're using an LM3914 as the LED driver, we'll have to add a second chip to the circuit. The 3914's were designed with that in mind, so it doesn't take much though to string two (or more) of them together.

The circuit for doing that is shown in Fig. 2. While the actual wiring is simple, there are a few points that should be made a bit clearer. I'll also mention here that all of that information (and a lot more) can be gotten from the 3914's data sheet. One of the most important things when you're designing circuits is to be absolutely familiar with the components on the board. It's okay to discover things by accident but only if you then take the time to figure out what happened and why. You can't control what you don't understand.

There are four ways the 3914 can be set to operate: single-chip dot, single-chip bar, cascaded dot, and cascaded bar. In order for the 3914 to reliably know what mode to work in (dot or bar) when two or more chips are cascaded for an expanded display, its internal mode-select amplifier has to watch the state of three pins: MODE SELECT (pin 9), +V (pin 3), and the cathode of LED9 on pin 11.

That last piece of information—the state of pin 11—is critical only when you're doing an expanded dot display. Remember that having a dot display means you want to have only one out of twenty LED's on at any one time. The 3914 controlling LED11—LED20 has to know for sure when one of the earlier LED's is being lit. The circuit in Fig. 2 has the MODE CONTROL pin of the first 3914 connected to the first LED output (pin 1) of the second 3914. That's because when the input signal is driving one of the second bank of LED's (12–20), there will always be some voltage at pin 1. It may not be enough to light the LED but it will be enough to turn off the LED's in the first 3914. As a result of that, the last LED on the first 3914 will always be turned off when any of the LED's on the second 3914 are being lit.

The same sort of reasoning applies to what keeps the second 3914 from lighting an LED when the input voltage to the whole circuit is in the range of the first 3914. In that case, however, the control for the second 3914 is being provided by the voltage on pin 11.

In order for the circuit to be as linear as possible and have each of the LED's indicate equal increments in input voltage, you have to be careful about the reference voltage for each chip. The IC has an internal reference-voltage generator and, even though it can be configured to provide different voltages, we're using it in the plain vanilla mode to generate a 1.2-volt reference. On the second IC in the chain, we have to set the reference voltage a bit higher. Remember that the first 3914 has to respond to input signals from 0 to 1.2 volts while the second 3914 has to respond to input signals in the range of 1.2 to 2.4 volts.

That sounds more difficult than it really is. All we have to do is use the voltage at the top end of the comparator chain in the first 3914 as the low voltage for the bottom end of the second 3914. By doing that, the absolute working-voltage range for the second 3914 will be 1.2 volts higher than the first one, or 1.2 to 2.4 volts.

This isn't quite the end of the story because we have to give some thought to LED current as well. The drive current for the LED's is determined by the voltage from the +V rail on one side and the IC's reference voltage on the other side. There's a ratio of about ten-to-one between the current for each of the LED's and the current drawn from the reference voltage at pin 7. Since the second 3914 is working with a reference voltage twice as high as the first 3914, we have to adjust the value of the resistor on the second 3914. A simple application of Ohm's law tells us that if we have twice the voltage but want the same amount of current, we have to double the value of the resistor. Since we used about 1K on the first 3914, we have to use a 2K resistor on the second one.

Before we turn away from the 3914, let me repeat that while it's a relatively simple chip to use, there's more going on inside it than you imagine. The only way you'll ever be able to get a good handle on using it is to work your way through the information in the data sheet. The way to do that is to call or write the folks at National Semiconductor (2900 Semiconductor Drive, Santa Clara, CA 95052-8090, 408-721-5000) and ask for the data sheet.

The complete schematic for the scope so far is shown in Fig. 3. Just about the only thing we have to add to it is an input amp and a pad arrangement to prescale the input voltages. The time has also come for us to deal with some of the mechanical problems in the scope—mainly the wiring of the display. While it's certainly not impossible to hand wire four hundred LED's, it's a lot easier to use a commercially available multi-LED module. **R-E**

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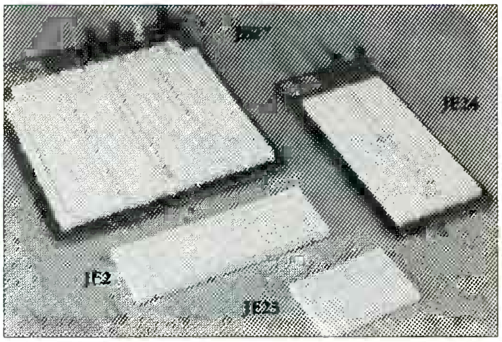

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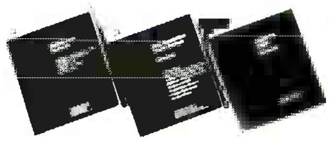

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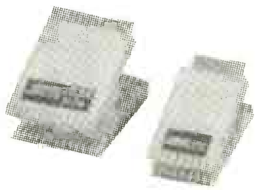

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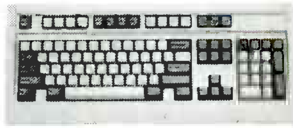

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74LS374	.69	.59

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LM339N	.39	.35
NE555V	.29	.25
LM556N	.49	.39
LM723CN	.49	.39
LM741CN	.29	.25
LM1458N	.35	.29
LM1488N	.45	.39
LM1489N	.45	.39
ULN2003A	.69	.59
LM3914N	1.95	1.75
NE5532	1.19	1.09
7805T	.45	.41
7812T	.45	.41

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Part No.	Function	Price
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41256-150	256K DIP	150ns.......1.69
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511000P-10	1MB DIP	100ns.......5.49
41256A9A-10	256K SIPP	100ns 18.95
41256A9B-80	256K SIMM	80ns......20.95
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2N2222A	.25	1N4148	.07
1N4735	.25	2N3055	.69
2N3904	.12	1N270	.25

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MPC121 SPDT, On-Off-On (Toggle) **1.19**
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DB25S	Female, 25-pin	.75
DB25H	Hood	.39
DB25MH	Metal Hood	1.35

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XC556R	T1 3/4, (Red)	.12
XC556Y	T1 3/4, (Yellow)	.16

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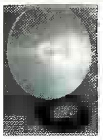

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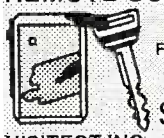

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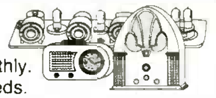

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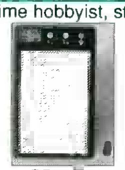

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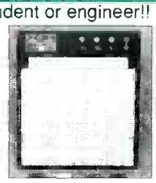

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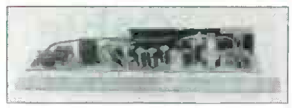

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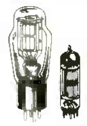

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DISPLAY DRIVERS

continued from page 72

nals do not have to be preshaped. The counter is reset by driving the RESET pin high.

The CLOCK INHIBIT pin must be grounded to allow normal counting. When CLOCK INHIBIT is high, the counters are inhibited. The display is blanked when the display ENABLE pin is grounded.

The three auxiliary output pins of the 4026B are designated DISPLAY/ENABLE OUT (D/E OUT), CARRY OUT (CARRY OUT), and 2 OUT (2 OUT). The DISPLAY/ENABLE OUT signal is a slightly delayed copy of the DISPLAY/ENABLE input signal. The CARRY OUT signal is a symmetrical square wave whose frequency is one-tenth of the clock input frequency, and is used when cascading 4026B counters. The 2 OUT pin goes low only on a count of two. Fig. 22 shows the circuit connections for cascading stages.

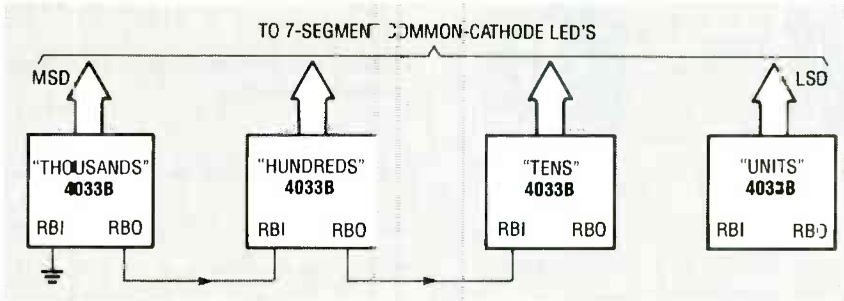

FIG. 25—MODIFICATION of Fig. 24 circuit to obtain automatic leading-zero suppression.

Figure 23 shows the pinout pattern of the 4033B, a modified version of the 4026B. The DISPLAY ENABLE and DISPLAY ENABLE OUT pins of the 4026B have been eliminated and replaced by RIPPLE-BLANKING INPUT (RBI) and RIPPLE-BLANKING OUTPUT (RBO).

Figure 24 shows the wiring scheme for two 4033B's in normal use. The RESET, CLOCK INHIBIT, and LAMP TEST pins are all grounded, and the RIPPLE-BLANKING INPUT pin is positive. That configuration does not blank leading or trailing zeros.

If cascaded 4033B's are to give automatic leading-zero suppression, the circuit in Fig. 24 must be modified as shown in Fig. 25 to provide ripple-blanking. In Fig. 25, the RBI pin of the most significant digit (MSD) is grounded, and its RBO pin is connected to the RBI pin of the next least-significant stage. That pattern is repeated on all except the LSD, which does not require zero suppression. If trailing-zero suppression is required, the direction of ripple-blanking feedback must be reversed. The RBI pin of the LSD is grounded and its RBO pin is wired to the RBI pin of the next least-significant stage. **R-E**

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