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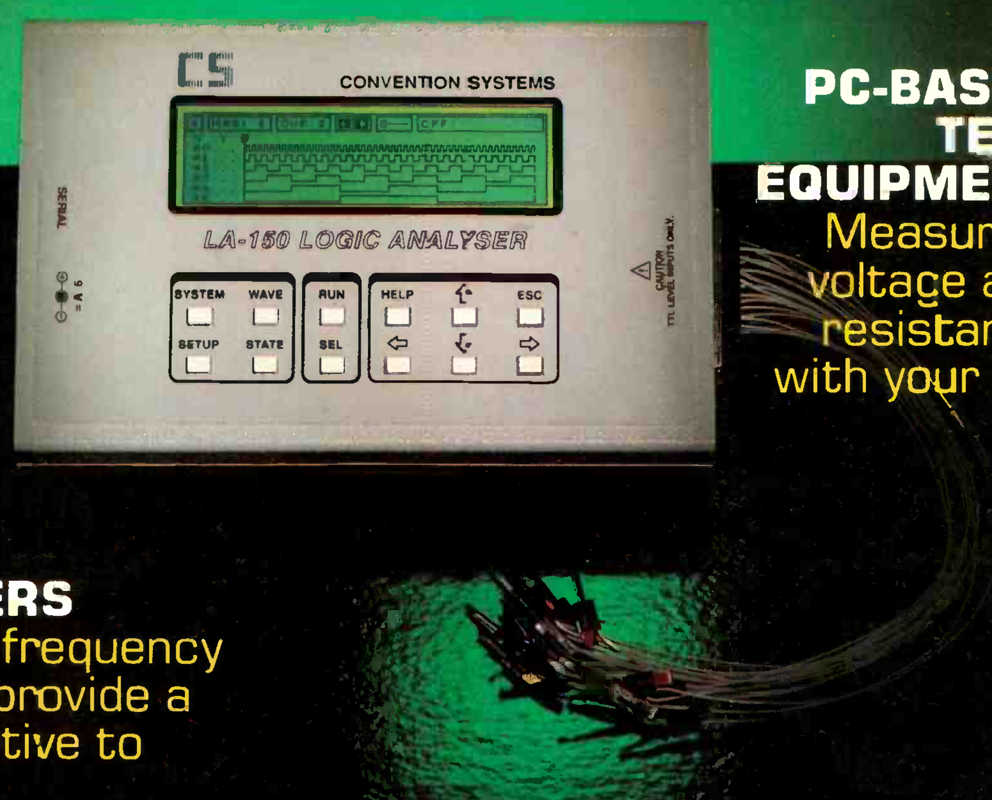

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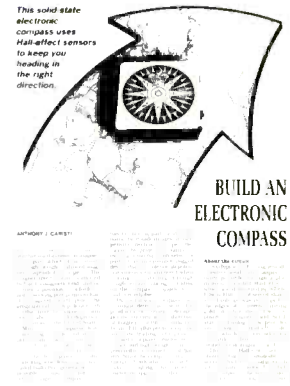

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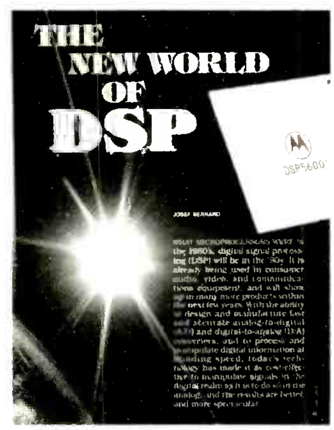

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AND MORE

ON THE COVER

Anyone who has spent time debugging complex digital circuits knows that a logic analyzer is an essential tool for the job. Besides the ability to sample and store the state of many digital signals, a logic analyzer can—as its name suggests—perform complex analyses on those signals to determine their timing and state relationships. You can view the acquired data on either a waveform screen or a state screen, and pull-down menus put the controls at your fingertips. Of course, there's a big price to pay for all that convenience; most commercial logic analyzers cost well over $1000. Our alternative, is a 16-channel, 50-MHz analyzer that you can build for less than $700. For all the details, turn to page 31.

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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.

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WHAT'S NEWS

A review of the latest happenings in electronics.

Base-3 logic system

A new family of digital logic, based upon the trinary ("base 3") system, has been developed by Edinboro Computer Instruments (Edinboro, PA). It is based on a new circuit, dubbed the "Tri-Flop"—a trinary version of the commonly used flip-flop. The Tri-Flop, with three output connections, can exist in any one of 27 states, compared to the Flip-Flop, with two output connections, which can exist in any of four states. The Tri-Flop allows significantly more data to be contained in the same size data registers that are presently used in binary systems. It could pave the way to fax and modem transmission speeds at least ten times faster than current rates, and allow a new wave of miniaturization in all kinds of electronics.

According to the device's developer and Edinboro Computer president, Tom Scarpa, the Tri-Flop has been in existence for more than 20 years. However, because there never was a practical way to interface the trinary device to existing binary-based electronic equipment, the trinary system had no practical or commercial value.

Recent developments in semiconductor theory have allowed the development of the circuitry required for such an interface. It includes a "Bi-Tri" binary-to-trinary translator that performs the conversion in hardware in nanoseconds; a "Tri-Bi"trinary-to-binary translator for getting the results of a trinary operation back into the world of conventional binary computers and digital logic; and a "Quad State Interface," which is similar to the three-state interface presently used in binary systems but which adds a fourth (high impedance) state that provides connection circuitry that can be switched open or closed, enabling only seelcted units to be connected to a common bus pathway, thus avoiding bus contention.

A 16-bit trinary memory register has been built that holds more than 43 million bits of data, which represents an incresase of more than 650 times that of conventional binary registers. A 32-bit trinary memory register, which holds more than 470,000 times the data contained in that of conventional binary units, has also been designed but not tested, according to Scarpa.

Initially, the company plans to apply the new circuitry to the field of telecommuncations. The new system, which, according to the company, promises to increase the speed of fax and modem communications tenfold, consists of an interface box at each end that will plug into the serial port of a conventional computer system.

Edinboro Computer plans to lease the equipment to high-volume communications users. Future applications of the trinary system are expected to be in medicine, industrial control, and military systems. By reducing the number of interconnections required in solid-state modules for equivalent functions, the Trinary system has the potential to enhance miniaturization and improve reliability. Medically implantable miniature computers for control of artifical organs and prosthetic devices are another possibility being considered.

IBM'S 16-MEGABIT MEMORY IC, shown on a postage stamp, can read all of its 16,777,216 bits of information in 1/25 of a second, which is several times faster than the blink of an eye.

16,000,000-bit memory chip

IBM has fabricated a 16-million-bit computer memory chip—four times the storage capacity of today's most advanced memory chips. The chip was at their existing semiconductor production line in Essex Junction, VT to demonstrate its manufacturing feasibility. The dynamic random access memory (DRAM) chip operates at a very high speed, accessing the first bit of data from one of its storage cells in 50 nanoseconds (ns) and subsequent bits at a sustained data serial rate of just 10 ns per bit. At that speed, almost all of the chip's 16,777,216 bits could be "read" in 1/25 of a second—several times faster than the blink of an eye.

The chip, which measures about 1/3 × 3/4 inch, is fabricated using an advanced version of CMOS (complementary metal-oxide-semiconductor) technology that allows for circuit patterns with dimensions as small as 0.5 micrometers wide. CMOS technology produces chips that are denser and use less power than those made using other semiconductor manufacturing techniques.

The greater density is achieved through the use of a memory cell (the area of the chip that stores one bit of data) that is only 4 micrometers square, which is approximately one-third the size of the memory cell in IBM's four-megabit chip. The memory cell uses a three-dimensional "trench" structure that is dug into the silicon to store the chip's bits, instead of placing the cell on the surface of the silicon as is done with other chips. Using the trench allows for greater memory capacity without significantly increasing the size of the chip.

The new chip's reliability is enhanced through the use of error correcting and checking (ECC) code during opeation. Use of ECC provides a five-fold improvement against failures compared to previous generations of chips.

IBM made no statement regarding planned availability, but our computers could use them now! **R-E**

VIDEO NEWS

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

DAVID LACHENBRUCH

• HDTV uncertainty. Widescreen TV sets with HDTV monitor capability are now on the market in Europe, but there is increasing uncertainty about the future of widescreen and HDTV broadcasting there. As reported in the U.S., manufacturer Thomson (which owns the RCA and GE brands here) now has TV sets on the market with 16:9 ratio picture tubes, designed to receive all TV standards, but specifically aimed at the satellite-transmitted European D2MAC system and the eventual transition to the high-definition HD-MAC version. However, after a fiasco in MAX broadcasting by satellite to England (**Radio-Electronics**, February 1991), powerful European forces are fighting to end Europe's commitment to MAC and HD-MAC. Those forces, some of them obviously aiming at keeping the entrenched conventional PAL and SECAM broadcasting systems, point to work being done in the United States on digital HDTV systems and are urging that the European community reconsider its commitment to analog HDTV. Thomson, although committed to pushing the MAC system, points out that its current widescreen TV sets have the ability to receive PAL and pick up transmission in any HDTV system with the use of a decoder.

• Hughes projection TV. Hughes Aircraft, which had been talking with Korea's Samsung about partnership on a unique new system of projection TV (**Radio-Electronics**, December 1990), now is discussing possible arrangements with the Japanese. Hughes would like to hook up with a company experienced in manufacturing and selling consumer electronics to exploit the consumer version of its lightvalve projection system, which has been widely used in military and commercial applications for computer displays. Hughes now has developed the system to the point where it can accommodate video's high speed, and the company feels that the system is ideally suited to HDTV.

Very little is known about the Hughes projection system as it applies to TV, except that it employs three LCD's as lightvalves and uses a cathode ray tube as the picture source. A high-intensity light shines into polarizing mirrors, in effect amplifying the picture from the high-resolution CRT, according to those who have seen the system. The projection system is Hughes' second recent venture in the field of consumer TV. The first is the Sound Retrieval System (SRS), which has been licensed to Sony and Thomson Consumer Electronics as an audio system for TV. However, Hughes has no plans to license its lightvalve projection system to all comers. Instead, it would rather have an exclusive partner to share in the development of the consumer version.

• A victory for 8mm. Sony, which lost the battle of VCR formats when its Beta system was eclipsed by VHS, has won the war of the camcorder formats. While the outcome was never in serious doubt in Japan or Europe, in the U.S. the full-size VHS format held a strong lead for several years, and in the compact field JVC pushed its VHS-C variation. The full-size VHS format has held a commanding lead in the U.S. over both mini formats—VHS-C and 8mm. However, in 1990, for the first time, the American public chose minis, with 51.3% buying the smaller formats, according to the Electronic Industries Association. Although the EIA doesn't break down its figures between 8mm and VHS-C, U.S. government import data indicate that some 70% of those compact videocassette recorders are in the 8mm format.

Two more important brand names have jumped aboard the 8mm bandwagon. Following RCA, Zenith, and Hitachi, the latest brands to offer 8mm camcorders in the United States are GE and Fuji. The GE brand, fielded by Thomson, also offers VHS and VHS-C formats. Fuji is offering camcorders on the U.S. market for the first time, and its products are exclusively in the 8mm format. More converts are expected, and virtually all brands could soon offer 8mm video equipment in addition to full-size VHS.

• New 8mm sound. When the 8mm format was introduced, it was equipped with two separate sound systems—stereo AFM and an 8-bit digital mono system. The digital system has since evolved into stereo. In the meantime, the VHS group has announced the development of a 16-bit stereo audio system as an option for Super VHS. Now the 8mm group, not to be outdone, has developed a 16-bit soundtrack for Hi8, the high-band equivalent of Super VHS. Like the S-VHS optional audio track, the Hi8 version uses sampling frequencies of 48 and 32 kHz, the latter designed to record from direct broadcasts of Japan's TV satellites with digital sound. Neither system is capable of direct recording from the compact disc's 44.1-kHz sampling frequency, presumably because of Japanese reluctance to antagonize recording companies, which fear copyright violation. Although it was announced more than a year ago, the S-VHS sound system wasn't available in any recorders at our press time. And the eleven 8mm manufacturers announcing the new Hi8 audio didn't set any specific time schedule for its availability, either. So far, the battle is between high-decibel digital press releases.

• One-pound projection TV. We haven't seen Fuji Photo's projection TV set, but the description from Japan sounds as if it could double as a pretty good flashlight. It weighs just one pound, and its dimensions are about the equivalent of two VHS cassettes stacked together. It operates on a rechargeable battery and can project a picture up to 40 inches diagonally. However, it has one thing that a flashlight doesn't—stereo speakers. **R-E**

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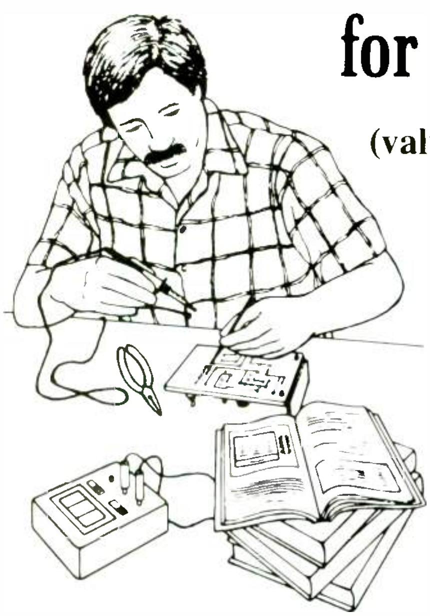

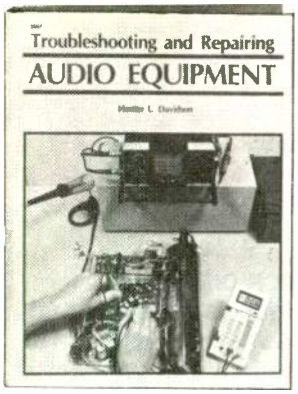

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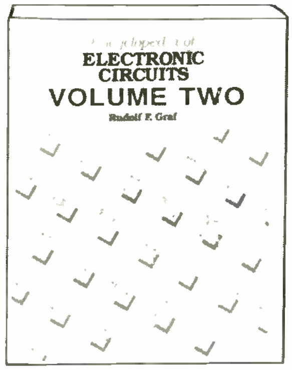

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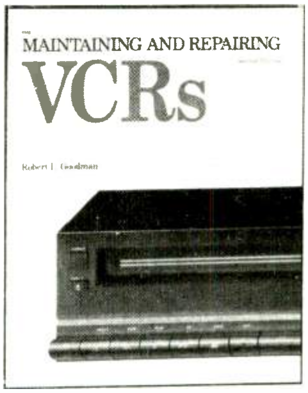

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SAFE CHARGING

I am using 12-volt 4-amp/hour rechargeable batteries for my camcorder and need a good charger for them. I've been using a transformer but I can never tell if I'm overcharging them. Do you have a circuit that can safely charge the batteries?—L. Shedler, Folsom, CA

When you consider all the brain damage you have to deal with if you want to use Ni-Cd's, it's amazing that anyone still uses them. That probably says more about the state of rechargeable-battery technology than anything else. Despite internal shorting and recharging hassles, they're more popular now than they ever were.

The key to success with Ni-Cd's is knowing how to recharge them without damaging the cells and there have been zillions of words published in this magazine and others (our words, of course, are much better) about how to take care of Ni-Cd batteries. A quick trip to your library will result in your finding out more than you ever wanted to know about the use and abuse of Ni-Cd's.

The rate of charge that can be used on a particular Ni-Cd cell depends on how it's constructed and its capacity. Most cells can't be rapidly charged without circuitry that monitors either their internal temperature or pressure, or both. That's because a Ni-Cd generates oxygen as it charges and, if the rate of charge is too high, the gas will be produced faster than it can be absorbed in the cell. As you can guess, the result of the overcharging is usually a rupture of the cell seals—and if that happens, the battery is history.

The safest charge rate for any cell is the so-called C10 rate. That refers to the time it would take a battery with a voltage of one volt per cell to reach full charge in ten hours. In more practical terms, the number is one tenth the rated amp hours of the battery. In the case of the cells you're using, that translates to a charging rate of 400 mA.

You can use any circuit you want to charge the battery as long as you calculate the correct resistor value to keep the charging current at 400 mA. Even the voltage you apply to charge the batteries isn't as important as keeping the charging current from exceeding the C10 limit.

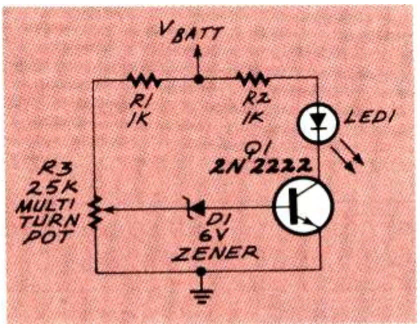

FIG. 1—WHEN CHARGING NI-CD's, this circuit will monitor the battery voltage and provide you with a signal when a certain, presettable voltage has been reached.

The circuit shown in Fig. 1 will monitor the battery voltage and provide you with a signal when a certain, presettable voltage has been reached. The signal can be used to sound an alarm, trigger a relay, or whatever else you might need. The relay could drop the charging rate by adding another resistor in series with the current limiter or even disconnect the charger completely.

When you first apply the charger to a drained battery, the voltage in the system will drop to the battery voltage and, as the battery continues to charge, the system voltage will rise. When it reaches a level determined by the setting of R3, Q1 will turn on and you'll get current flow through its collector-emitter junction. As shown it will turn on an LED but, as I mentioned, you can replace that with a relay or whatever you want.

There's absolutely nothing critical about building the circuit and its accuracy is totally dependent on how well you can tune R3. That's why it's listed as a multiturn potentiometer. All you have to do to calibrate it is to apply 12 volts and slowly adjust R3 until the LED (or, of course, the relay) turns on.

LACK OF TACH

I have a digital tachometer that I used successfully for years on an older car where it was connected to the ignition system's distributor points. I now own a 1985 Chevy with an electronic ignition system that I know nothing about. How can I pick up a suitable signal to use the tach, and do I have to modify the digital input?—T. Ulijasz, Brookfield, WI

A friend of mine had a similar problem a few years ago when he traded in his old car and got a new one. I had built a digital tach for him and he'd been using it on his old car for years. When we went to put it on his new car I opened the hood and discovered that he'd bought a diesel. And you think you have a problem!

I can't speak with authority on every car there is—I'll take them as they come. Since your car, unlike my friend's, has a "real" ignition system, there's always someplace to pick up an input for the tach.

Although you haven't mentioned it in your letter, I'm assuming that the electronic ignition in your Chevy is factory-installed. If that's the case, there are loads of books (like the Chilton manuals) that tell you everything you could want to know about the inner workings of your car. You might even be able to get information about the system from GM. What you really need is the schematic for the car's electrical system.

If it turns out to be absolutely impossible for you to find out how things are wired up in your car, you can always take the signal from the most obvious place of all: right off the spark plugs. Since you didn't tell me exactly how the tach was working in your old car, I'll have to do a bit of guessing.

The input conditioning you have should be good no matter where you pick up the signal in your car. You may have to change the value of the current-limiting resistor depending on the voltages you find in the car but that's about it. The digital tach I've been using in my car for about five

years takes its input from one of the plugs with no problems at all. I use a 1K resistor as a current limiter but you may find that you have to change that in your car.

It's always possible to pick up an input signal for your tach right from a spark plug. It can be done inductively by wrapping a few turns of wire around the ignition cable or by running a lead into the cap of the spark plug. Try an inductive pickup first because it's the safest way to go. You may have to experiment with the number of turns but, since such a huge spike is generated when the plug fires, you shouldn't have any trouble getting a pulse that can be fed to your tachometer.

If, for some reason, inductive coupling is impossible, you can get the pulse from the cap of the plug but you have to be careful when you do this. Don't, under any circumstances, cut into the ignition wire leading to the plug. The cables are designed to properly isolate the high voltages and messing with the insulation can cause problems from moisture or arcing and lead to misfiring or a substantial decrease in engine efficiency. And be sure to use cable that can safely handle the high voltage at the plugs. If you have problems with arcing, get yourself a good supply of RTV putty to insulate the cable.

You may also have to make some changes to the logic in your tach because the number of sparks per second at the plug may be different than the number you were getting from the distributor. Remember that you're getting one spark for each two revolutions of the engine.

MULTILAYER WOES

The keyboard connector on my AT motherboard broke so I unsoldered it from the board and replaced it with a new one. The problem I have now is that the board is a multilayer one and I think one of the traces in a middle layer has broken. Do you know of any way to repair a trace on an inner layer of a multilayer board?—V. Deeoh, New York, NY

You've got a big problem. I've been faced with shorts on inner layers and the only way I've been able to repair the board was to lift all the legs that sat on the trace and connect them to a totem-pole wire that I ran above the board.

If, as you suggested, you've broken a trace on one of the middle layers of the board, the only way I know to repair it is to make the connections with new wire on top of the board. I've never found a way to do anything to the copper buried inside the board.

That technique may not sound too difficult but it presupposes that you know which trace is broken, and which pins on which components are supposed to be connected together—You need the schematic.

If you don't have the schematic, I don't know if a repair is even possible. The internal copper is buried in the board and you can't usually hold to board up to the light and follow the traces.

I'm sorry to tell you that I think your chances of making a repair to a buried trace on an undocumented mother board are only slightly better than your chances of getting a quick answer from a government official. It's theoretically possible but I wouldn't count on it. **R-E**

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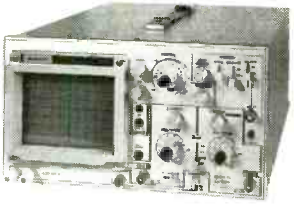

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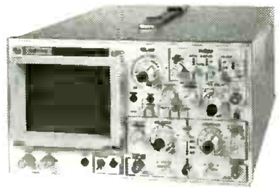

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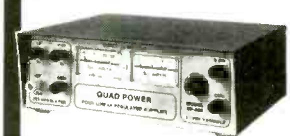

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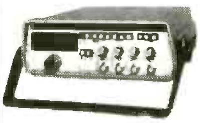

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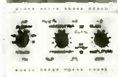

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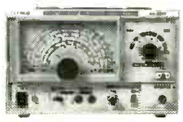

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LETTERS

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PARTS DILEMMA

I hope that my letter is just one of many that you receive saying that **Radio-Electronics** has let its readers down by featuring a construction project for which no parts kits are available. I refer to the "Sweep-Marker Generator" article, by John Wannamaker, that appeared in the February and March 1991 issues. Accumulating the necessary parts—some of which are a bit exotic—might not be difficult for engineers, but it is no easy task for hobbyists. While such articles are of academic interest, without a parts kit the ultimate interest is little more than academic.
SIMON L. SCHEINER
Cherry Hill, NJ

Your frustration about not having a parts kit available is understandable. My frustration at not being able to afford to make such a kit available is even greater. As you might have noticed, I do supply the one item that cannot be purchased elsewhere: the printed-circuit board. Along with the boards, I provide a list of parts suppliers with addresses and telephone numbers. Unfortunately, I neglected to mention in the article that I also offer (at my cost, $2.00) an information sheet that contains additional information that did not appear in the article that readers might want as they build the generator.

I order components just as any hobbyist would, and occasionally pay a penalty for not meeting minimum-order requirements. There are a great many people who order the PC boards and do everything necessary for the satisfaction they get from building from scratch. In the case of the sweep generator, the satisfaction seems to be not so much in the construction as in having such a unique device at their disposal—so that the gathering of components and the actual construction seem to be worth the inconvenience.

Should the article not have been published? Let me indicate the enthusiasm I've heard thus far from some of the orders for boards:

"...this new generator looks fabulous and I can't wait to get started."

"I've been looking for a long time for such a generator..."

"Your project is perfect for my needs."

"...anxiously awaiting the next issue of **Radio-Electronics** *so that I can get the artwork to make the boards. Thanks."*

In addition to the above, as a school teacher I believe that academic interest alone makes the publication of many such articles worthwhile.
JOHN WANNAMAKER

STANDING UP FOR MACINTOSH

I was slightly amused by Jeff Holtzman's rebuttal to Raymond Cheng's letter in the April 1991 issue of **Radio-Electronics**, but when he brought up Apple Computer's Macintosh, I had to write this letter.

He mentioned that "Windows has done more for promoting advanced computing environments than everything done by all the Amigas (and all the Macintoshes)...". Give me a break! Windows on MS-DOS machines are nothing more than feeble attempts to turn them into a Macintosh. However, you encounter fewer problems on a Mac than you do with any version of Windows. The Mac is far more consistent, easier to use, and overall better to use than a cheap IBM clone using Windows.

Mr. Holtzman also stated that "Apple continues its steady decline in the marketplace." Wrong again. There may be *more* dime-a-dozen MS-DOS clones than there are Macs, but the facts are: Macs are out there. In fact, Apple has lowered its prices on them, introduced new ones, and just about sold more Mac Classics than they can make. Apple computers still dominate the educational market, ever since the introduction of the Apple IIe. The new Macintosh LC will bridge the gap between Apple IIe computer labs and Mac labs. People should consider it a blessing that there are other computers available, without having to resort to the MS-DOS world. **Radio-Electronics** should be more courteous to people who use computers other than your favorite.

As long as there is a choice in selecting a computer other than an MS-DOS clone, there will definitely be "advanced computing environments" in the near future.
WESLEY FITZPATRICK
Tuscaloosa, AL

APRIL FOOLS

I just received by April 1991 issue of **Radio-Electronics** and couldn't believe the article "Poor Man's Laser Printer." Has anyone *really* tried to do this? I have to be honest—I read the article fully expecting it to be a gag.

The author, Paul Renton, made it sound so simple. I've been in the copier business for over ten years and I can tell you flat out, *it's not that easy*. First off, the copier is designed with a focal length based on the "original" being *flat* on the glass. A monitor is curved, and because of the case, it will be an inch or more off the glass. Second, the author says you need to remove the exposure lamp. That's right, you would—except for the fact that any copier I've worked on will give you an error message when the lamp circuit is open. The copier won't ever run with the lamp out. Third, what do you do with a copier that has a moving top? The drive system won't handle the weight of a monitor sliding back and forth. Fourth, why does the author *not* have a laser printer? He has an $8000 copier in the photo. I'd like to think he could afford a $900 laser printer.

You folks have some fine articles in your magazine but, come on guys, get real! (By the way, the "C" clamps were a nice touch.)
JEFFREY J. WILLARD
New Cumberland, PA

AN ELEGANT SOLUTION

I enjoyed your article, "Poor Man's Laser Printer" (April 1991), but I think that the "C" clamps and Bungee cords are an inelegant solution somewhat below **Radio-Electronics** usual above-average standards. Here is my suggestion:

Build a sturdy, reinforced wooden mold around the entire project, excluding access areas for the copier's paper tray, output bin, and controls. After covering any openings on the monitor and copier cases with masking tape, carefully align the monitor on the copier glass, and fill the mold with ready-mix concrete (one or two cubic yards should be enough). Before the concrete sets, embed part of a length of heavy chain in it. Allow the concrete to cure for a couple of days.

I believe you will find that this improvement will hold the monitor and copier very securely together. It has other advantages, too. The printer's serviceability will be improved, by reducing the number of "Field Replaceable Units" (FRU's) to just one. After retirement from original service, the FRU's can be reused as off-shore moorings for yachts. In this time of concern about overloaded landfills, it is good design practice to provide for reuse of FRU's.

ROBERT BARNHILL
Boca Raton, FL

CAN'T BE FOOLED AGAIN!

You're right, I was able to save a bundle with the "Poor Man's Laser Printer" (April 1991). Since I have a copier that has a plater that moves, I found it difficult to keep the monitor in place. The C-clamps were too expensive, so I opted for a 2-by-3 and some threaded rod to bolt the monitor to the plater. (I got those for nothing; I'm in the home-remodeling business.) The lamp on the copier was already burned out, I think. Well, let's put it this way: When I opened the case and pulled out some wires, the lamp stopped working. Who said you need an electronics degree!

Copies came out great, after a little adjustment on the monitor's contrast. The only thing I haven't figured out is how to use the monitor while it's still bolted down.

P.S. I wrote to you on my typewriter—you know, the old Smith Corona Portable. The plans you printed in last year's April issue on how to add a monitor to that typewriter were wonderful. The typewriter and the car battery make this better than any portable on the market today. It's true QWERTY, too, and has non-volatile memory (me!). I can't wait for next year's April issue!

LANCE HAVILLARD
Gaithersburg, MD

PC REALITIES

I am a 70-year-old retired missile engineer with not enough time in the day for my hobbies and life's necessities. Two of my hobbies, amateur radio (K6SAR) and computer hacking, drew me to **Radio-Electronics**. Your magazine's composition just about fulfills my needs. The elementary electronics articles are good fundamental reviews that refresh—and in some cases, instruct—my dwindling memory regarding basics. Information on projects and advanced equipment is food for thought and personal planning.

I chuckled and nodded my head as I scanned Raymond Cheng's letter "Amiga Amigo" in the April issue. I, too, feel that my favorite computer is being short-changed by the media. In my situation, my computer chronology took the following steps: a Commodore 64; an Atari 1040ST (30MB hard disk, etc.); and an IBM clone (386SX) package including CD ROM, sold by DAK Corp. I use the computers according to their specialties—the Commodore for packet radio, the Atari for graphics and DTP, and the IBM clone for the rest of my needs.

I love them all, and wouldn't part with any of them. I decided to buy the IBM clone because I could see the handwriting on the wall. Popular interest in, and factory support for, the other two machines that I have are dropping off. Programmers are leaving those computers in droves. Even technical magazines that once supported them are disappearing from the newsstands.

One other indication of that trend is that the local Commodore and Atari clubs no longer exist, whereas the IBM-user club is bursting at the seam with members. Of course, another problem is the lack of standardized operating systems for those machines. I agree with Mr. Cheng that the Atari is far superior to the IBM clone but, unfortunately, it is a dying breed. Once again, the consumer has been led down the primrose path, only to be left—expensively—high and dry.

While, in essence, I agree with Jeff Holtzman's reply, I take him to task for using sarcasm and getting into mud-slinging. That should be a no-no for **Radio-Electronics** editors.

ED GLEMBOTSKI
San Luis Obispo, CA

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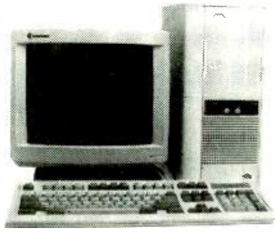

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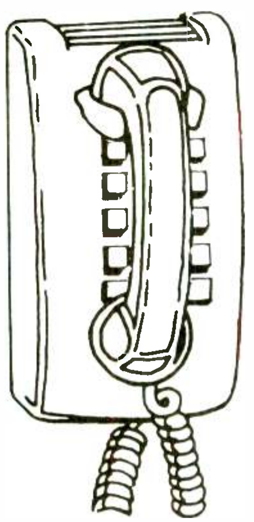

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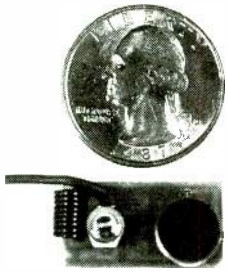

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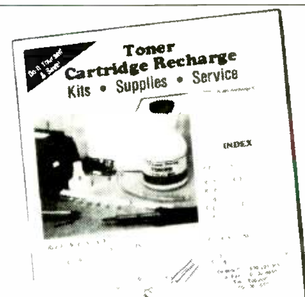

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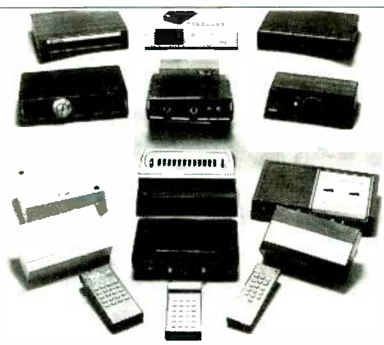

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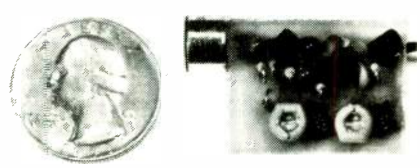

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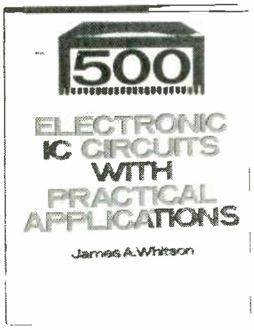

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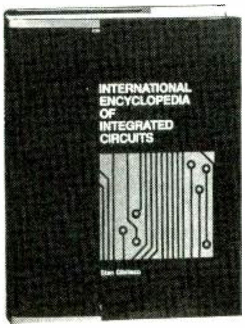

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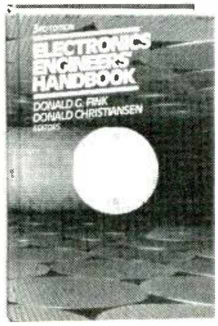

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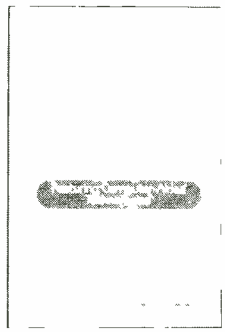

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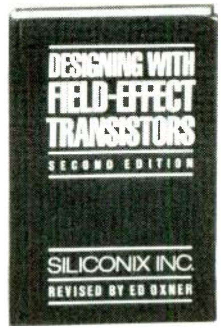

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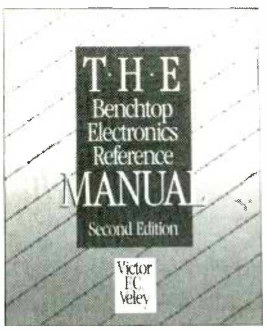

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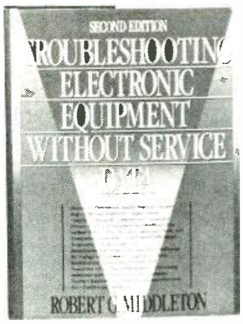

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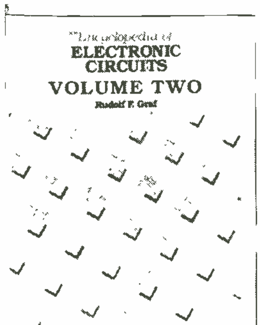

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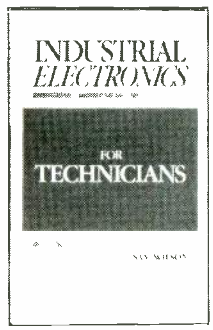

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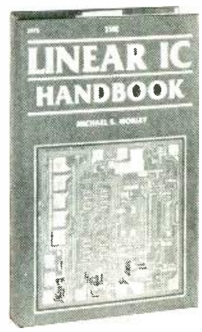

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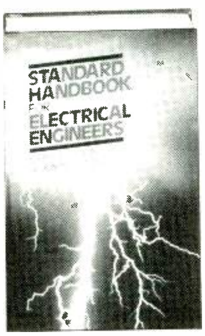

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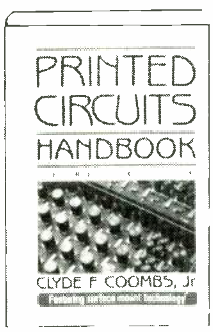

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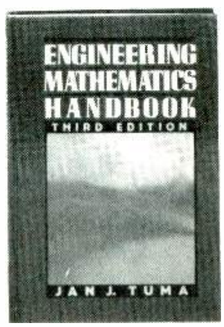

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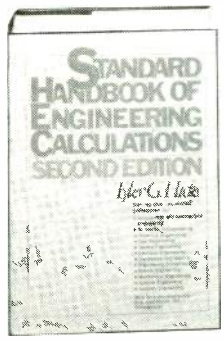

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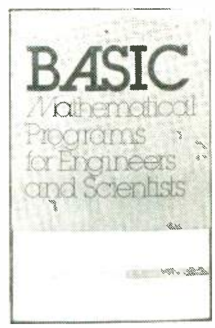

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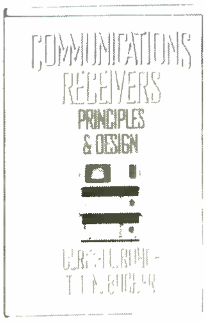

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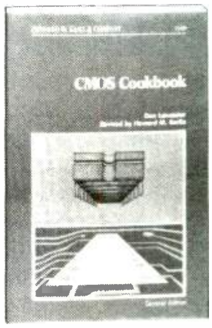

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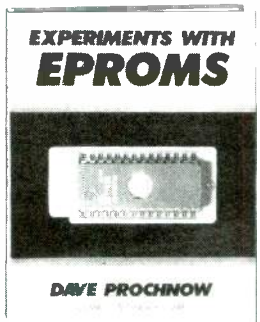

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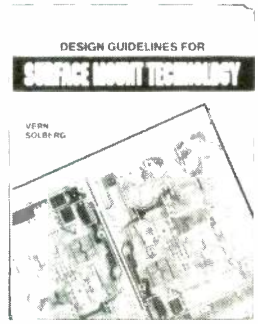

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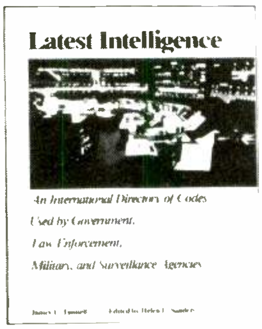

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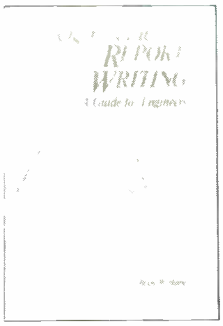

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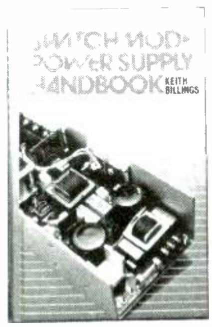

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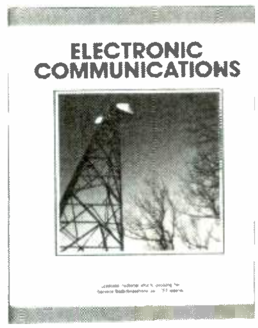

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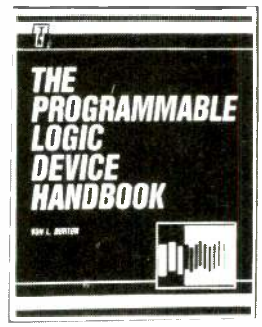

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EQUIPMENT REPORTS

HS25 Heavy Duty "Stick" Style Multimeter

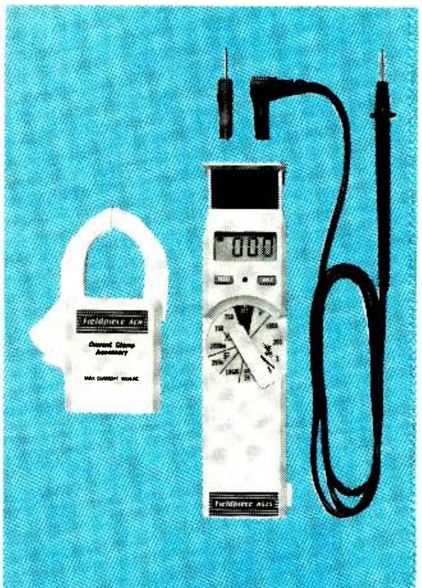
Portable multimeters have been around for a long time—and with good reason. Technicians and engineers need portability, and handheld operation is required for many testing jobs. DMM manufacturers have known this for years, of course, and they've been trying year after year to come up with the perfect multimeter for field service. It seems, though, that it's taken a new company to come up with the answer. At least that's the impression we got after trying the *HS25* multimeter from Fieldpiece (8322B Artesia Blvd., Buena Park, CA 90621.)

The obvious difference between the *HS25* and other multimeters is its shape. The meter is less than 1-3/4 inches wide, less than an inch thick, and about 7-1/4 inches tall. The probe jacks are at the top of the meter rather than being on the front face. Although they will accept any standard sleeved multimeter probe, we liked the set of probes that are supplied with the meter. The common probe is reasonably standard, and has a lead length of about 3 feet. The hot lead, however, is quite different. It's about an inch long!

The inch-long test probe allows you to use the multimeter in much the same way as you would a logic probe or one of the "pen"-type meters. You always have the display in a handy place—in your hand, where the *HS25* fits comfortably.

The front of the meter features a rotary function selector, RESET and HOLD pushbuttons, a 3-1/2 digit display, and a red warning LED. Fieldpiece's design seems to have been intentionally selected to allow you to operate all of the controls with the same hand that you're using to hold the meter. The center selector is longer on one side than the other so that your thumb can easily find and operate it. The reset and display-hold controls are also within easy reach.

The *HS25* measures AC voltage in three ranges (2000 mV, 200 V and 750 V), DC voltage in three ranges (2, 200, and 1000 volts), resistance in two ranges (200 and 2000 ohms) and capacitance in one range (200 µF). The meter's accuracy is more than adequate for most field applications. A diode-test function is offered on the meter, as is a logic-probe function.



A new multimeter from a new company

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A feature that adds both safety and convenience is a dangerous-voltage warning. When the voltage on the test leads is higher than 28 volts, a warning beep sounds and the front-panel LED blinks. While that can "wake you up" if you encounter a voltage higher than expected, it also makes the meter ideal to quickly test for the presence of, for example, 120 volts AC.

Meter accessories

The *HS25* doesn't feature a built-in current-measuring function. But Fieldpiece does offer an interesting current-clamp accessory that converts the multimeter into a heavy-duty clamp meter. The clamp accessory is designed to plug into the jacks on the top of the meter. To make the connection, the top of the meter body slips into a sleeve on the clamp. The result is a snug fit that converts the DMM into a one-piece ammeter that measures AC currents to 300 amperes.

If the combination of the meter and probe doesn't fit where you need to make your measurement, you can use the clamp head separately, using a set of deluxe test leads from Fieldpiece. The set includes two leads with replaceable tips. Remove the tips, and you can plug the clamp meter into the probe handles so that you can use it remotely. (That also lets you use the clamp head with any other multimeter.)

Since the meter is meant for field service, it's sure to take a lot of "everyday" abuse. Fortunately, the *HS25* is a heavy-duty meter. Its bright yellow case is made of Valox, and can withstand drops of up to ten feet. It is sealed against contaminants. The case in which the meter comes packed can also be used as a storage case for added protection. Even if you forget to turn the meter off before you throw it back in your tool kit, you don't have to worry—an auto-off feature takes care of it for you. The meter uses MOV's (metal oxide varistors) so that it can withstand potentials of up to 1000 volts, and transients up to 6000 volts on any voltage range. (In other function ranges, maximum protection is 500 volts.)

We found that the meter fit our hands easily—just as it was designed to do. It also fit our pockets pretty well. (The short probe can be inserted tip-first for safer storage.) With a suggested list price of $119, it fit our pocketbooks pretty well, too. Two other "Stick" meters are available at lower prices. The $99 *HS23* offers no logic probe function, and the $79 *HS21* also removes the dangerous-voltage warning and capacitance functions. The current clamp is available for $24.95.

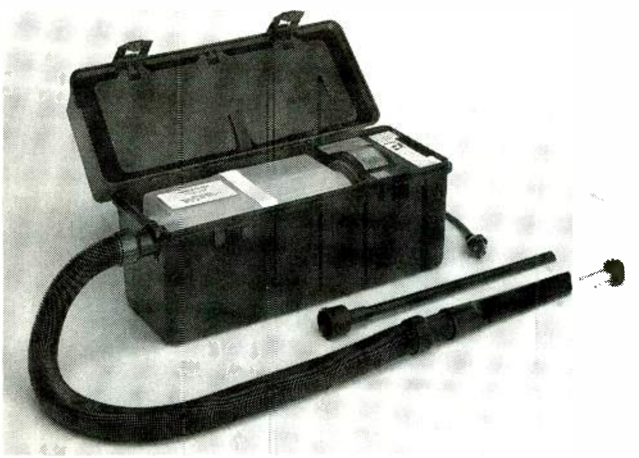
After using the Fieldpiece *HS25* for a while, we got the feeling that, although it was the first "stick" multimeter we've seen, it won't be the last. **R-E**

NEW PRODUCTS

Use the Free Information Card for more details on these products.

SERVICE VACUUM. Specially designed to make the customer-service job safer and easier, the *3M Service Vacuum* features parts made of a material that dramatically reduces the potential for electric shock, a replaceable one-horsepower motor that provides more cleaning power than most vacuums, and three highly effective filters.

The Service Vacuum's hose assembly, wand, and crevice tool are all made from a material that slows the flow of electricity and drains away static charge. That protects the technician from shock and protects sensitive electronic parts from electrostatic discharge (ESD).



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The disposable filters are encased in a durable, spill-proof plastic cartridge that is easier to remove and safer to dispose of than conventional vacuum bags. When the filter is full, the user simply replaces the entire cartridge. Three types of filters are available. The fine-particle filter traps extremely fine particles, such as color laser-printer toner or particles from equipment requiring clean-room conditioners. The toner/dirt filter traps unwanted toner from most copiers and laser printers, and can be used for cleaning typewriters and data processing equipment. The dust/dirt filter traps dust and larger particles such as lint and cotton fibers, and is intended for cleaning computers, paper shredders, card punches, and collating machines.

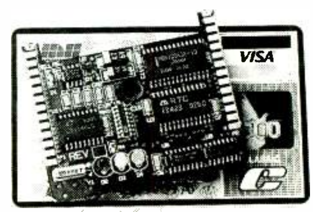
The *3M Service Vacuum* costs $209.—**3M Electronic Products Division**, P.O. Box 2963, Austin, TX 78769-2963; Phone: 800-321-9668.

BATTERY-CONDITIONING SYSTEM. Designed for use with the Motorola 8000, 950, Ultraclassic, and other compatible cellular phones, the *MC-01* is the first in a series of consumer-targeted conditioner/rapid chargers introduced by *Surecharge*. It uses the patented Discovery Battery Conditioning System circuitry, which automatically conditions and rapid-charges Ni-Cd batteries. The conditioning process increases the life expectancy of Ni-Cd batteries by at least five times as compared to conventional charging methods. The Discover System also ensures delivery of 100% of the rated energy every time the battery is conditioned—even batteries with reduced capacity can be automatically rejuvenated. An environmental bonus is that the system prevents users from prematurely discarding rechargeable batteries.

CIRCLE 20 ON FREE INFORMATION CARD

The MC-01 cellular-telephone battery conditioner/charger has a suggested retail price of $220.—**Surecharge Industries Inc.**, 278 East 1st Avenue, Vancouver, B.C., Canada V5T 1A6; Phone: 800-661-4405 or 604-876-6710; Fax: 604-876-9229.

PROGRAMMABLE CONTROLLER. Measuring only 1.89 × 2.25 inches, the *Micro-440* from *Blue Earth Research* is a single-board controller designed for industrial control, data acquisition, home automation, and OEM applications. Based on a 12-MHz Intel 83C51FB microcontroller, the unit can be programmed for remote stand-alone or local interactive operation from a terminal or PC. On-chip software allows the *Micro-440* to be programmed in either BASIC or 8051 assembly language. A real-time clock/calendar module allows event recording or other date-and-time-based operations, and can generate interrupts for precise event timing in periods ranging from 1/16 second to one hour.



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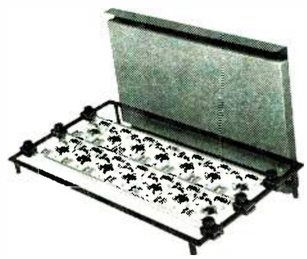
The controller offers 32K bytes of battery-backed CMOS SRAM in addition to its 16 bytes of ROM. The RAM can be used to store user programs, operating parameters, and collected data. A RAM-write protect feature can be used with BASIC file commands to "lock in" user programs for automatic execution.

A total of 14 digital I/O lines can be used to monitor switches and contacts or to drive transistors, relays, etc. Dual RS-232C serial ports allow simultaneous communication with a PC and printer.

An expansion port can be used to add memory or I/O to the base unit. Up to eight analog inputs can be used to read temperature, pressure, or other 0–5-volt sensors. One channel is used to monitor the controller's input supply voltage for power-fail detection in battery-powered applications. The unit can be powered from almost any 6- to 16-volt DC source. A lithium backup battery maintains the RAM and clock for more than 10 years.

The *Micro-440* programmable controller costs $199 in single quantities (OEM versions start at $99 in 1,000's). A complete system design package that includes the *Micro-440*, Macro Assembler, Symbolic Debugger and Utility programs, user manuals, a plug-in DC power supply, an applications module, and PC cable costs $379.00.—**Blue Earth Research**, 310 Belle Avenue, Mankato, MN 56001; Pnone: 507-387-4001; Fax: 507-387-4008.

PC-BOARD HOLDER. The low-profile design of *Production Devices' model PC502* increases productivity by allowing fast, comfortable loading and soldering of PC boards. The spring-loaded rails provide a firm grip on each board. Once adjusted, board changing is fast and efficient. For multi-board assembly, extra rails are available optionally. The unit's skid-resistant, adjustable legs allow the steel frame to be changed from a one-inch low-profile position to a three-inch-high sloping position. After component stuffing, the holder can be flipped over for cutting and soldering. The PC-board holder rests on four non-skid bumpers and has a cover that is adjustable for component tension. Standard memory foam and conductive foam are available. The holder can reasonably accommodate boards with measurements as large as 19.6 × 9.0 inches.



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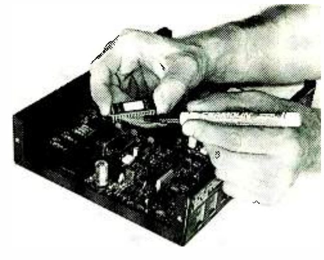
The model *PC502* PC-board holder costs $85.00.—**Production Devices**, 356 North Marshall Avenue, El Cajon, CA 92020; Phone: 800-824-4226.



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DEOXIDIZER PEN. Now available in convenient, pen-style applicators, *Caig's Cramolin Deoxidizer* is a fast-acting solution that improves conductivity on connectors and contacts by dissolving resistive oxides from metal surfaces. Effective on all metal surfaces, Cramolin also provides protection from future oxidation. The pen applicator provides precise application of Cramolin non-flammable, non-corrosive, non-toxic, ozone-safe deoxidizer. The pen includes two easily replaceable chisel-head tips and one round-head tip.

The *Cramolin Deoxidizer Pen* costs $9.95—**Caig Laboratories, Inc.**, P.O. Box J, Escondido, CA 92033-3679; Phone: 619-743-7143; Fax: 619-743-2460.

BENCH-TOP DIGITAL MULTIMETER. Intended for use in schools, engineering labs, and technician's workbenches, *B&K Precision's 2831A* is a 3½-digit DMM with 0.1% DC voltage accuracy and AC voltage response to 40 kHz. The instrument measures current to 20 amps, voltage to 1200 VDC or

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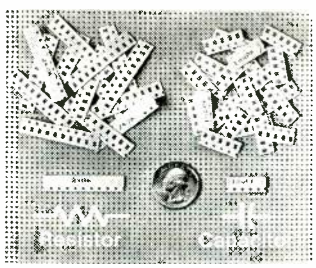
1000 VAC, and resistance to 20 megohms.

The digital multimeter features resolution to 0.1 mV, 0.1 amp, and 0.1 ohm for precise readings. An audible continuity-check feature sounds a tone for resistances under 10 ohms. It also includes a diode-test function. All functions are overload protected, with high-energy fusing on current ranges. For added convenience, the *2831A* features an oversized, bright LED readout and a combination tilt handle/bail. It is designed for AC operation, and can be used worldwide (110/220/240 VAC, 50/60 Hz). Included with the instrument are test leads, spare fuses, and an instruction manual.

The model *2831A* bench-top DMM has a suggested list price of $295.—**B&K Precision**, Division of Maxtec International Corporation, 6470 West Cortland Avenue, Chicago, IL 60635; Phone: 312-889-1448.

SURFACE-MOUNT COMPONENTS. *Communications Specialists* is offering surface-mount resistors and capacitors in small quantities and in individual values. The components are sold in strips of either 10 resistors or five capacitors.

Each strip of 10 surface-mount resistors costs $2.50; each strip of five capacitors costs $1.25 (minimum order $10.00).—**Communications Specialists Inc.**, 426 West Taft Avenue, Orange, CA 92665-4296; Phone: 800-854-0547 or 714-998-3021; Fax: 714-974-3420.



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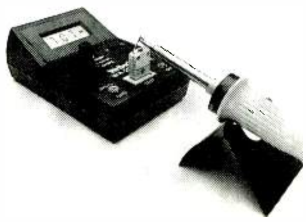
SOLDERING-IRON ANALYZER. Electrical engineers, quality-control personnel, and electronic reworkers can use the *Weller WA2000* soldering-iron analyzer to determine whether their soldering stations are in compliance with the DOD-2000 specification. The analyzer can accurately test tip temperature, tip-to-ground resistance, and tip-to-ground noise (mVRMS). Test results are easy to read on the large LCD readout in degrees Fahrenheit or Centigrade. The portable unit has a battery life of 50 hours and comes with a zippered carrying case and accessories.



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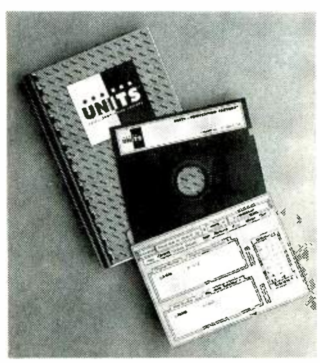
The *WA2000* soldering-iron analyzer has a suggested retail price of $450.—**Weller**, P.O. Box 728, Apex, NC 72502.

UNITS CONVERSION SOFTWARE. Designed to free students, engineers, architects, scientists, and manufacturers from the drudgery of searching through numerous tables of conversion factors for the one conversion factor needed, *David Taylor's Units + Conversion Factors* applications software comes complete with a disk library containing units and conversion factors that enable conversions between billions of units. Users can also add their own items to the disk library if they wish.

The program also does



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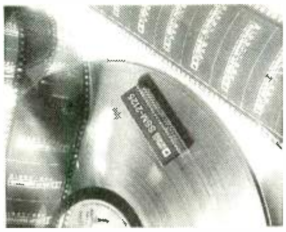
units dissection and transplantation. It can dissect compound units and display the nature of the subunit, can transplant other units into a dissected compound, and can display the conversion between a unit and a transplanted unit. The software can also display the SI dimensional form of most common quantities.

Units + Conversion Factors costs $89.95.—**David F. Taylor, Jr.**, P.O. Box 562, Commerce, TX 75429; Phone: 903-886-7301.

SINGLE-CHIP SURROUND-SOUND DECODER. With a fully integrated auto-balance function along with active decoding matrix, center mode control, and noise generator, *Analog Devices' SSM-2125* combines all the core functions of a complete Dolby Pro-logic surround-sound system on a single IC. Auto-balance provides dynamic correction of left-right input signal-level imbalances, eliminating the need for manual user adjustments and improving center-channel dialogue separation—replacing a cumbersome discrete circuit composed of up to 24 active and passive components. With over 100-dB dynamic range and 0.015% THD, the *SSM-2125's* 18-bit equivalent audio performance rivals that of compact discs and digital audio tape.

The complete *SSM-2125* integrates up to thirty operational amplifiers, ten voltage-controlled amplifiers (VCA's), a proprietary operational conveyor amplifier that provides a current-input summing block, two dual-output rectifiers, two log-difference amplifiers, comparators, random logic, and a digital noise source. A user-selectable Pro-Logic bypass mode provides a high-fidelity two-channel signal path without the need for external relays, while thin-film resistors and laser trimming eliminates the need for external gain



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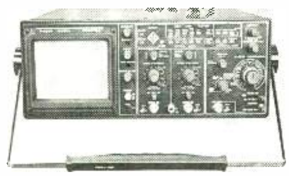
and offset trimming circuitry. A unique VCA cell combines transparent audio performance with minimum die area. The *SSM-2125* is available in a 48-pin plastic DIP.

The *SSM-2125* surround-sound IC is priced beginning at $15 in hundreds. The IC is available to *Dolby licensees only.*—**Analog Devices**, Precision Monolithics Division, Attention: Dan Parks, 1500 Space Park Drive, Santa Clara, CA 95052; Phone: 408-562-7513.

NO-CLEAN SOLDER-CREAM EVALUATION KIT. Eliminating flux-residue cleaning from electronic soldering can provide both environmental and productivity advantages. A no-clean flux system from *ESP Solder Plus* yields clear, hard, non-corrosive residues. *Kit-9* contains five 35-gram barrels of solder-cream alloys: one of Sn63 alloy with no-clean, off-fillet solder cream; one barrel of Sn62 with off-fillet residue; and one each of Sn63 and Sn62 with on-fillet no-clean residue. The kit includes a reusable hand dispenser for precise deposits of solder cream, and ten molded smooth-flow dispensing tips.



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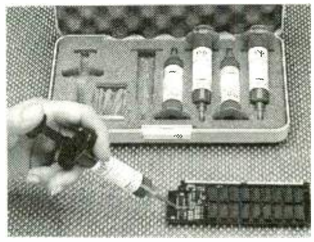
The *Kit-9* solder-cream evaluation kit costs $89.—**ESP Solder Plus**, 14 Blackstone Valley Place, Lincoln, RI 02865-1145; Phone: 800-338-4353 or 401-333-3800; Fax: 401-333-4954.

DIGITAL STORAGE SCOPES. Two real-time digital storage oscilloscopes from *Protek* feature 20-MS/second sampling and "Vu-Write" cursor CRT readouts. The 40-MHz model *P2849* (pictured) and the 20-MHz model *P2820* also deliver a vertical resolution of 256 dots, a 1024-dot horizontal resolution, indicating memory of 2048 words, reference memory with storage of up to four signals, and an 8-MHz effective storage frequency. Analog functions include dual-time base on the *P2840*, push-button switch selection with vertical and horizontal



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mode select for fast setup and readout, and a front-panel layout designed for easy operation. In addition, the scopes offer a memory function, plus cursor readouts to indicate time, amplitude, frequency, duty cycle, and phase shift.

The models *P2840* and *P2820* digital storage oscilloscopes cost $1630 and $1450, respectively.—**Protek**, P.O. Box 59, Norwood, NJ 07648; Phone: 201-767-7242; Fax: 201-767-7343. R-E

NEW LIT

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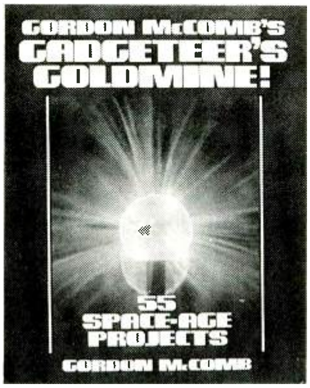
GORDON McCOMB'S GADGETEER'S GOLDMINE! 55 SPACE AGE PROJECTS; by Gordon McComb. Published by TAB Books Inc., Blue Ridge Summit, PA 17294-0850; Phone: 1-800-233-1128; $18.95.

Although some of the projects in this book are decades old and others are brand new, they all share a common thread: They are intended to spark the builder's spirit of invention. The classic designs serve to give the reader a solid foothold in the techniques of "gadgeteering," while some of the unique new ideas serve as a jumping point from which readers can create their own designs. The projects range in complexity from a simple Jacob's Ladder to a complete laser light show, and include a plasma sphere generator, a Tesla coil, a Kirlian camera, a superconductor disc, a radiation detector, a fiber-optic communication disc, a laser alarm system, a computer control interface, a holography darkroom, and a seismograph.



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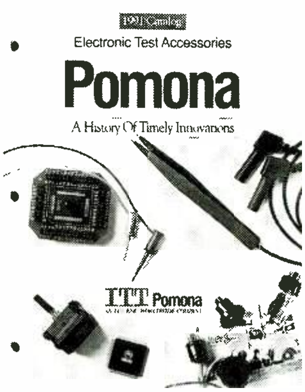
The book is divided into 26 chapters, each of which presents one or more hands-on projects that readers can duplicate in their home workshops. Several chapters also include information vital to the understanding of one or more of the projects. The book explores the science of lasers, how fiber optics work, the nature and dangers of high-voltage devices, what radioactivity is and how it is measured, the history of holography, lightwave communications, and piezoelectricity. The projects are fully illustrated, and a list of parts sources appears in the appendix.

ELECTRONIC TEST ACCESSORIES; from ITT Pomona Electronics, 1500 East Ninth Street, P.O. Box 2767, Pomona, CA 91769; Phone: 714-623-3463; Fax: 714-629-3317; free.

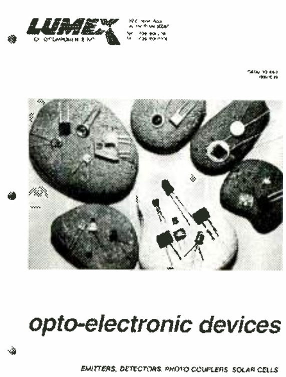
Highlighted in this 140-page catalog are a new 32-pin PLCC (0.05 pin spacing) clip for popular EEPROM devices, and 100- and 132-pin SMT test clips for Motorola 68020/68030 and Intel 80386SX microprocessors. Additional accessories included in the brochure are intended to make testing SMT devices easier and more reliable. The catalog also features new IC clip kits, coaxial/BNC universal adapter kits, digital-multimeter test-lead kits, cable and patch accessories, and jumper kits. Ten major product categories, which are presented in an easy-to-use index, include a selection of jumpers and cables, boxes, plugs and jacks, connectors, adaptors, single-point test clips, and static-control devices.



CIRCLE 14 ON FREE INFORMATION CARD

OPTOELECTRONIC DEVICES (Catalog 86-1, Issue IV); from Lumex Opto/Components Inc., 292 East Helen Road, Palatine, IL 60067; Phone: 708-359-2790; Fax: 708-359-8904; free.

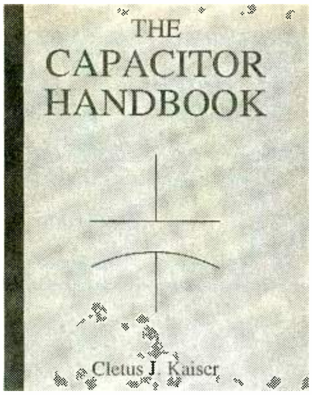
This 52-page catalog contains detailed descriptions, dimensions, and specifications for hundreds of state-of-the-art optoelectronic components. Included are emitters, detectors, laser detectors, photo-transistors, photodiodes, optoisolators, photo-reflectors, emitter-detector assemblies, choppers, photo interrupters, custom assemblies with IC controllers, chips, and remote-control receiver modules. Those items have practical applications in a wide variety of consumer, industrial, and business products and systems, including audio and visual equipment, computer drives, copy machines, word processors, phones, fax machines, controllers, spectrum analyzers, medical equipment, alarms, and meters. The catalog also contains a chart that cross references part numbers for 15 manufacturers such as Sharp, Honeywell, NEC, and Siemens; a two-page applications chart; and sections on characteristics, circuitry, package outlines, and specific selection guides.



CIRCLE 15 ON FREE INFORMATION CARD

THE CAPACITOR HANDBOOK; by Cletus J. Kaiser. Published by CJ Publishing, 2851 West 127th Street, Olathe, KS 66061.

Although capacitors are in common use, they are frequently misused due to misunderstanding their characteristics. This book aims to clear up the confusion by providing practical guidance in understanding the construction and application of capacitors. It combines theory with circuit application advice to help readers understand what goes on in each component and in the final design. An opening chapter covering the fundamentals of capacitors as a general category is followed by chapters on spe-



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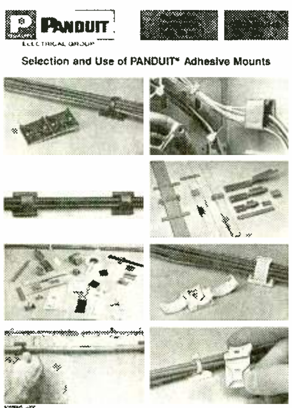
cific types of capacitors, including ceramic, plastic-film, aluminum-electrolytic, tantalum, glass, and mica.

SELECTION AND USE OF PANDUIT ADHESIVE MOUNTS (Technical/Application Data Sheet TADS-WA-14B); from Panduit Corporation, Attention: Product Manager, Wiring Accessories, 17301 Ridgeland Avenue, Tinley Park, IL 60477-0981; Phone: 1-800-777-3300, ext. 7346; free.

Designed to explain how to choose and use adhesive mounts for wire and cable, this eight-page bulletin provides information on types of adhesive that



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are available, guidelines for surface preparation, and short listings of applications and markets. A table includes dimensions, temperature ranges, adhesive type, maximum loads, and cable ties.

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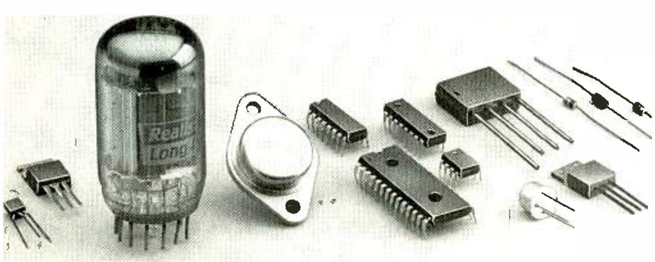

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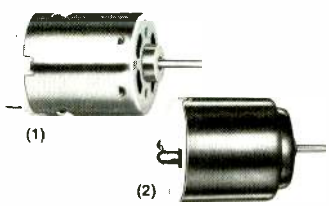
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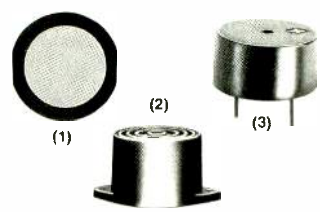
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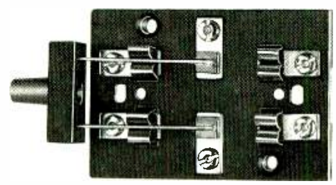

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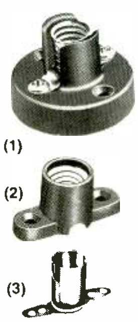
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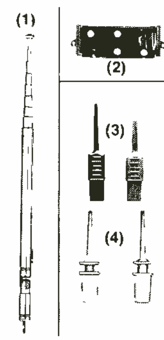
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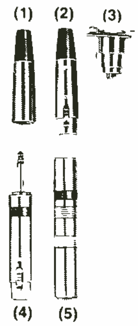
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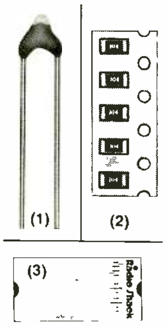

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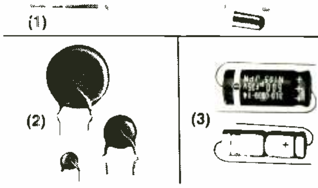
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CIRCLE 78 ON FREE INFORMATION CARD

GERARD ROBIDOUX AND
ROBERT DMITROCA*

LOGIC ANALYZER

Troubleshooting digital circuits is a cinch with this 16-channel, 50-MHz logic analyzer.

A LOGIC ANALYZER IS AN INVALUABLE tool for debugging complex digital circuits. Not only can it sample and store the state of a large number of digital signals, it can perform complex analysis on the signals to determine their timing and state relationships. The acquired data can be displayed on either a waveform screen or a state screen. With four different pull-down menus available, all the controls are right at your fingertips!

The essence of all digital logic circuits is the simultaneous operation of many signal paths. As an example, consider a typical desktop personal computer, such as the IBM PC. In order for the microprocessor to write to a single byte of memory, it must assert 20 address lines, 8 data lines, and over a half-dozen control lines. In total, over 34 signal paths must operate correctly and simultaneously for the computer to function properly.

When a digital circuit fails, it becomes very difficult to debug. Traditional diagnostic tools, such as the oscilloscope, can usually monitor 4 channels at the most. Other tools, such as logic probes, can only display the current state of a signal, and cannot be used to analyze how the signal varies with time.

Those problems led to the development of the logic analyzer. At its most primitive level, the logic analyzer may be considered to be an oscilloscope with a large number of channels, except that only the high-low state of a signal may be seen rather than a continuous analog waveform. Commercial logic analyzers typically have 16 to 300 channels.

Until now, most logic analyzers have cost well over $1000, which has severely limited their use. Currently, most low-cost logic analyzers consist of cards which plug into personal computers. Those devices require a personal computer to operate and, therefore, are not very portable and tie up the resources of the computer.

Recent advances in CMOS and bipolar technologies, however, make it possible to build a practical, low cost, self-contained logic analyzer. We will show you how you can build a portable, 16 channel, 50-MHz logic analyzer, all for under $700!

Theory

Figure 1 shows a block diagram of the logic analyzer. Connection to the circuit under test is made through an acquisition "pod," or connector array, which contains a set of wires terminated with test clips. The clips are used to attach to the various points in the circuit being tested.

All of the lines contained in the acquisition pod are inputs: the logic analyzer never sends a signal to the device it is connected to. The pod also contains clock and ground inputs as well as data-input lines. More sophisticated units may also contain inputs that qualify the clock, inhibit triggering until certain conditions are met, and so on.

Signals coming in from the acquisition lines enter voltage comparators, which are used to periodically sample the input sig-

*Gerard Robidoux and Robert Dmitroca are partners in Convention Systems, a software consulting company specializing in the design of low-cost test instrumentation.

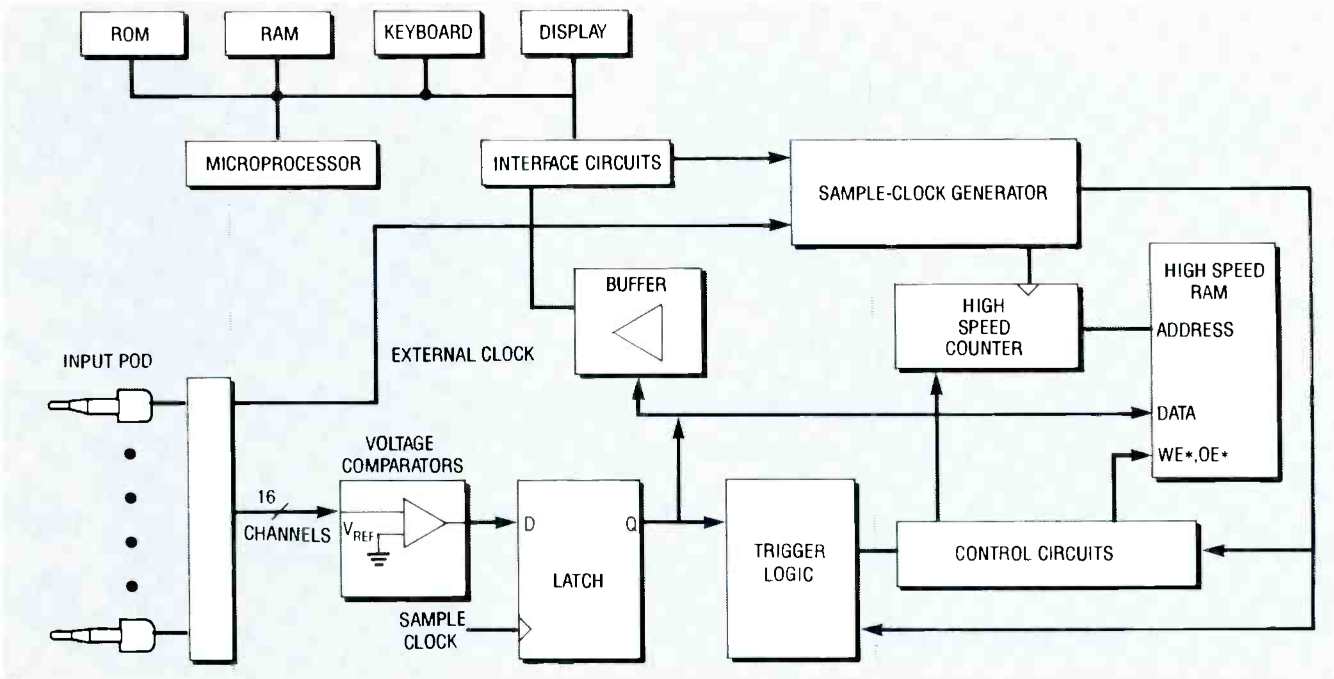
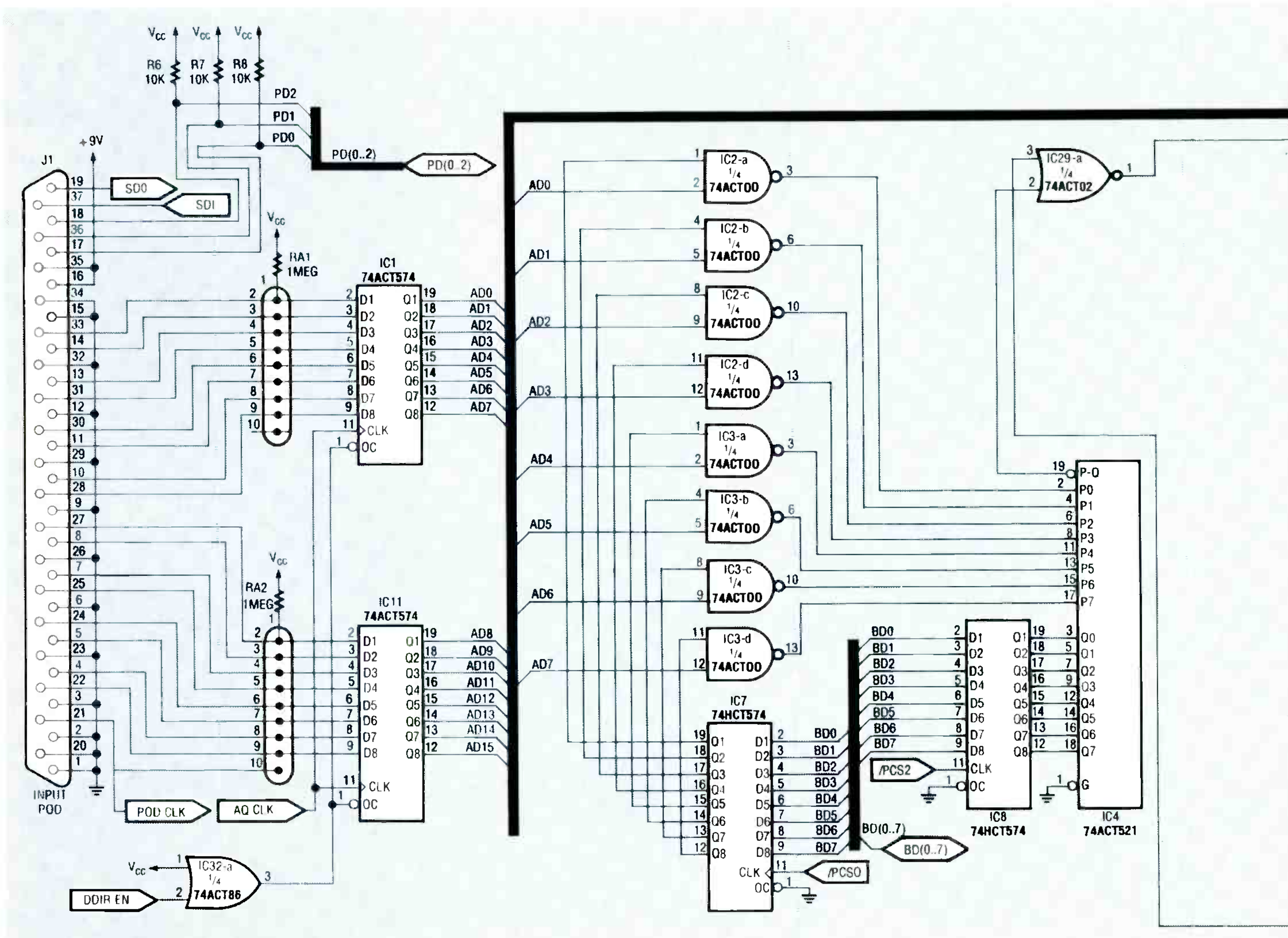


FIG. 1—A BLOCK DIAGRAM OF THE LOGIC ANALYZER. Signals from the acquisition lines enter the voltage comparators and are sampled by the input latches; they then flow into the high-speed RAM and the trigger logic. The final stage is the user interface.



nals and determine their logic level. All logic families have a defined high and low level. For example, the TTL logic family defines a low as a voltage between 0 and 0.8 volts, and a high between 2.4 and 5.0 volts. Some logic analyzers have a variable voltage-threshold, which allows you to define the high and low voltage levels depending on your particular application.

The logic analyzer that we present here recognizes only TTL and 5-volt CMOS levels. Since the vast majority of digital logic is designed with those two families, that's not a serious limitation, and it also eliminates the need for expensive high-speed voltage comparators.

After voltage comparison, the signals entering the logic analyzer are sampled by the input latches. Digital storage scopes (DSO's) use the same sampling technique. The sampling rate is determined by an internal timebase, or from an external clock input. The sampling rate is usually adjustable in a 1-2-5 sequence from a very high frequency to a very low frequency (a few hundred MHz to less than 100 Hz).

With a very fast clock, you can see the operation of the circuit in great detail for a very short period of time. With a slow clock you can see the operation of a circuit for a longer time, but with less accuracy. If you were debugging a high speed digital circuit, such as a microprocessor, you would use a very fast clock. A slower clock would be used to troubleshoot a very slow circuit, such as a 1200-baud serial interface.

The external CLOCK input is used when you want the sampling rate to be controlled by an external circuit. A good example of that is when you attach a logic analyzer to the data and address lines of a microprocessor to trace program execution. The logic analyzer's external CLOCK line is connected to a memory strobe line, such as AS* (68000 family) or ALE* (8088 family). The logic analyzer would then capture the status of the processor at each bus cycle.

After being captured by the input latches, the input signal data flows to two places: the high speed RAM and the trigger logic. Let's take a close look at the trigger logic first.

In most digital designs, we're interested in the operation of the circuit at a very specific point. The action of the trigger logic allows us to obtain only that range of data in which we are interested. For each of the signals being monitored, we can specify a trigger pattern of high, low, or "don't care" (either high or low). When the logic analyzer is enabled, it will continuously sample the input data lines until the trigger pattern is recognized. At that point, sampling will either stop, or continue for a preset number of samples. That feature lets us see the state of the signals occurring before, or, perhaps, both after the trigger point.

The high speed static RAM stores the values of the input channels being monitored. That RAM is often known as the acquisition data buffer, since it provides a storage space for the data being acquired from the input data lines.

Notice that a logic analyzer, unlike an oscilloscope, is not a "real-time" device. An oscilloscope can immediately and continuously shows the voltage at the probe. The logic analyzer, on the other hand, stores the signal data until a trigger pattern is recognized. The

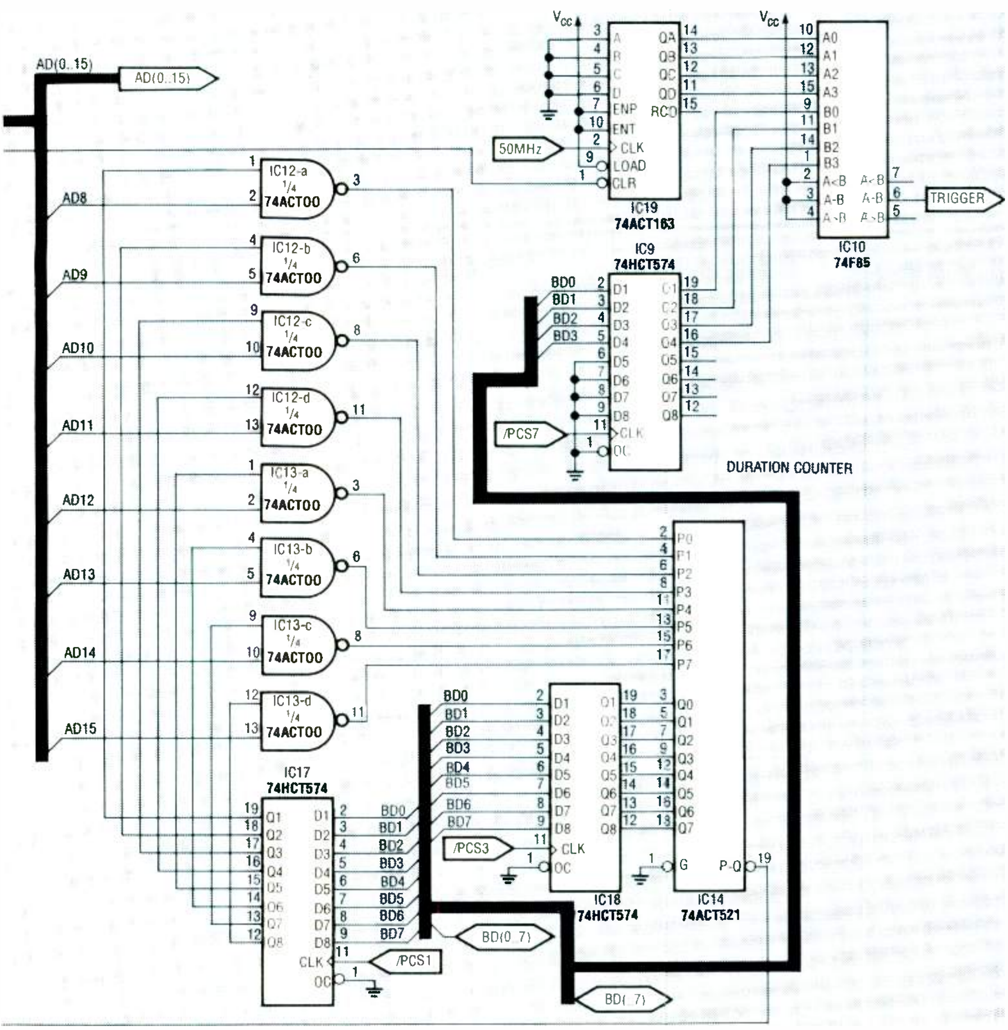


FIG. 2—INPUT BUFFERS AND TRIGGER LOGIC. The input pod contains 16 data-channel inputs, an external clock input and a ground connection. The input data enters resistor arrays RA1 and RA2, and into latches IC1 and IC11. The acquired data is routed into the trigger logic and to the high-speed RAM.

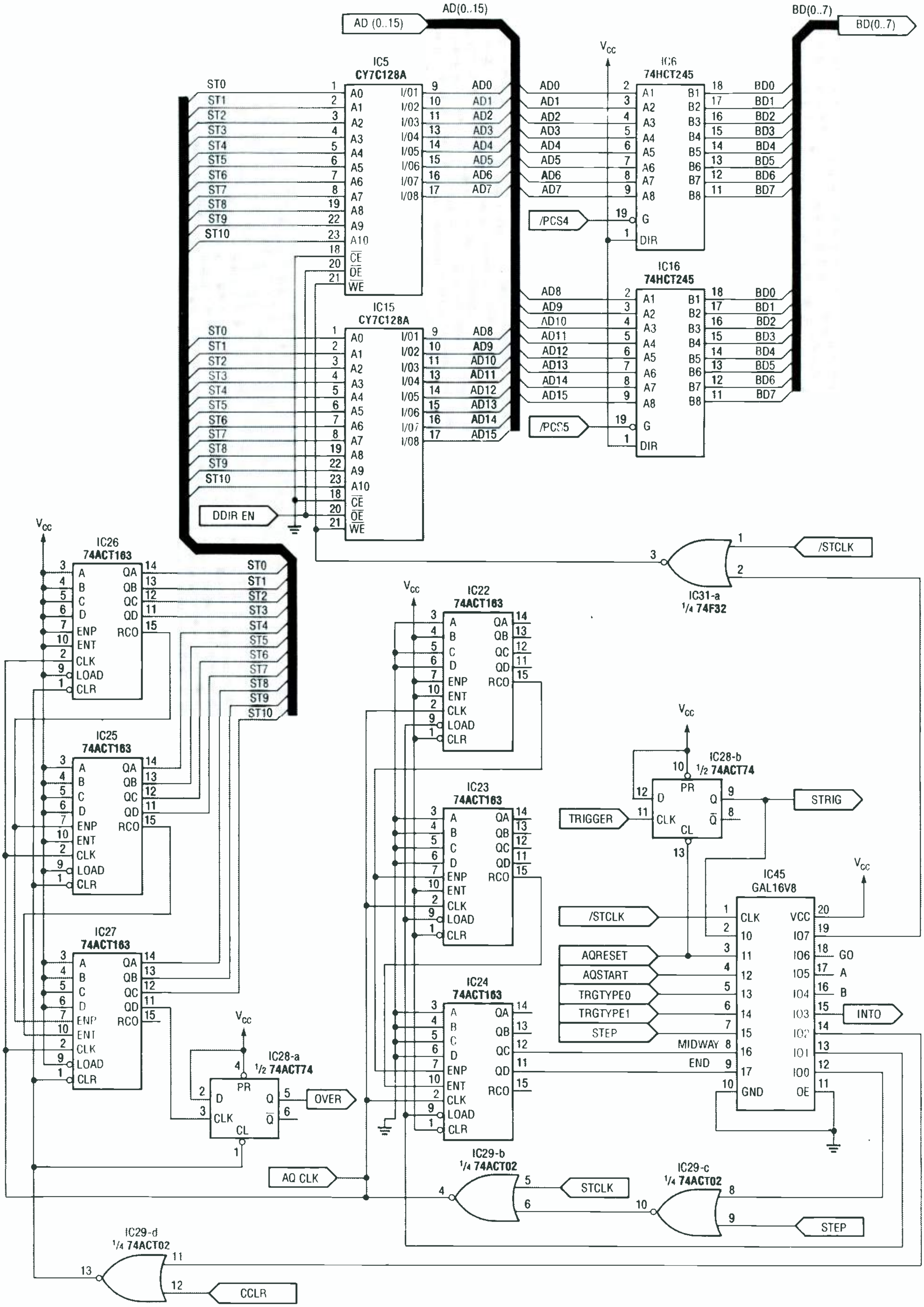


FIG. 3—THE ACQUISITION SECTION, consisting of high-speed RAM storage and control logic, is the heart of the logic analyzer.

signal data is shown only after that has occurred.

The last section of the logic analyzer is the user interface, which consists of a keyboard and display that are built right into the unit.

Circuit description

Now that we've looked at the block diagram of the logic analyzer, we'll turn our attention to how the unit operates. The schematic in Fig. 2 shows the input pod and trigger logic. The input pod connector, J1, contains 16 data-channel inputs, the external clock input and the ground lead connection. It also carries other signals that can be used by external pods.

The data to be sampled goes into J1, through resistor arrays RA1 and RA2, and into latches IC1 and IC11. The level of each channel is latched using the AQ—CLK signal (the sampling clock). Pull-up resistors RA1 and RA2 drive the inputs of the latches high if nothing is connected to the input. The acquired data (AD[0..15]) is routed to the trigger logic and to the high speed RAM storage (Fig. 3).

The trigger condition of the input data may be set to high, low, or "don't care." The "don't care" circuits for the first eight inputs are formed from IC2, IC3, and IC7, and the last eight inputs from IC12, IC13, and IC17. If an input is set to a "don't care" condition, the input of the corresponding NAND gate is set low. That forces the output to be high regardless of the input from the data latch. If the NAND input is set low, the data is simply inverted.

The outputs from the NAND gates are presented to the eight-bit comparators, IC4 and IC14. The output of those IC's (pin 19) goes low whenever the P and Q inputs match.

Masking of IC8 and IC18 latches is performed by the following technique. If the trigger bit to either IC is low, a high is written to the latch. Similarly, if the trigger bit is high, a low is written. For "don't care" conditions, a high value must be written, since we have forced the P input to high (by disabling the NAND gate). The upper and lower trigger outputs of IC29-a forms an active-high trigger output.

PARTS LIST

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

R1–R8—10,000 ohms
R9—470 ohms
R10—0 ohms, or jumper wire
RA1, RA2—1 megohm, 10-pin bussed SIP resistor array

Capacitors

C1–C11, C13–C20, C23, C25, C27–C38, C40–C49, C58–C60—0.1 µF, ceramic axial
C12, C24—3.3 µF, 10-volt tantalum
C21, C22—10 pF, ceramic disc
C26—100 µF, 25-volt tantalum
C39—50 pF, ceramic disc
C50–C57—22 µF, electrolytic

Semiconductors

IC1, IC11—74ACT574 8-bit latch
IC2, IC3, IC12, IC13—74ACT00 quad 2-input NAND gate
IC4, IC14—74ACT521 8-bit comparator
IC5, IC15—CY7C128A 2K × 8 15-ns static RAM (SRAM)
IC6, IC16—74HCT245 octal transceivers
IC7–IC9, IC17, IC18, IC39—74HCT574 8-bit latch
IC10—74F85 4-bit comparator
IC19, IC22–IC27—74ACT163 4-bit counter
IC20—74HCT138 3-to-8 demultiplexer
IC21—TL7705A voltage supervisor and reset control
IC28—74ACT74 dual D-type flip-flop
IC29—74ACT02 quad 2-input NOR gate
IC30—V25 high-integration microprocessor
IC31—74F32 quad 2-input OR gate
IC32—74ACT86 quad 2-input XOR gate
IC33—74F160 4-bit counter
IC34—74ACT153 dual 4-to-1 mulitplexer
IC35–IC37—74LS390 dual bi-quinary counter
IC38—74ACT151 8-to-1 mutiplexer
IC40—Dallas Semiconductor DS1213C "Smart Socket" and 32K × 8 100-ns SRAM or Dallas Semiconductor DS1235 integrated battery backed RAM
IC41, IC42—MAX232 RS-232 tranceiver and charge pump
IC43—7805 5-volt regulator
IC44—GAL16V8-15LP PLD
IC45—GAL16V8-10LP PLD
IC46—128K × 8 250-ns EPROM
LCD panel—Sharp part no. LM24014W

Other components

XTAL1—16-MHz HC-49 crystal
XTAL2—20-MHz 14-pin DIP package oscillator
XTAL3—50-MHz 14-pin DIP package oscillator
Case—Pactec CM69-120
Key switches (12)—75120-002/0000
AC adapter—9 VDC at 1 amp secondary output

Connectors

J1—Right-angle DB37 connector
P2–P4—3-pin socket strip
J3—Right-angle DB9 connector
J4—20-pin socket strip (2 × 10)
P1—7-pin socket strip (1 × 7)
J2—Power connector (2.3-mm barrel)
Keyboard—7 × 1 row-header
Acquisition clip—DB37 connector with 18 wires and micro-clips.
P1—2 × 10 row-header connector for LCD panel

Sockets

20-pin machined sockets for IC1 and IC11
32-pin socket for IC46
14-pin machined socket for IC32
84-pin PLCC socket for IC30

Hardware

4 ⅜-inch standoffs with 4-40 internal thread
4 ⅝-inch standoffs with 4-40 internal thread
18 4-40 screws with pan head, ¼-inch length
2 4-40 nuts
1 TO-3 heatsink and heatsink grease

The minimum trigger-duration circuit is made from IC9, IC19, and IC10. That circuit ensures that the trigger is present for a minimum amount of time before the trigger pattern is actually recognized, which prevents glitches from causing a false triggering to occur.

The desired trigger-duration count is contained in the latch of IC9. Whenever the trigger pattern occurs, 4-bit counter IC19 is enabled. That counter runs at 50 MHz (20 ns per count). When the desired duration count and the counter value match, the TRIGGER output (pin 6 of IC10) will go high, indicating that a valid trigger pattern has been recognized. If the trigger disappears before the desired duration count has been reached, the counter is cleared. It will start over when the trigger becomes valid again.

The circuit shown in Fig. 3 contains the heart of the logic analyzer: the high speed RAM storage and the control logic. Data for the lower eight channels is stored in IC5, while IC15 stores the data for the upper eight channels. Both IC5 and IC15 are 2K × 8 15-ns SRAMS.

An 11-bit binary counter is formed from IC25, IC26 and IC27. That counter drives the address inputs of the RAM IC's. The address is incremented by 1 for each cycle of the AQ—CLOCK (acquisition clock) signal.

The TRIG function lets you specify the position of the trigger position within the acquisition data buffer. When PRE is selected, the trigger is set at the start of the buffer. When the trigger condition is met, data is sampled until the entire acquisition buffer is filled. In the MID trigger mode, the trigger point is set at the middle of the data buffer. The first half of the buffer may or may not contain data that was sampled before the trigger point. In the POST trigger mode, storage of data will stop immediately after the trigger condition is recognized.

An 11-bit binary counter is formed from IC22, IC23, and IC24. That counter holds the current position within the acquisition data buffer. The position counter is reset whenever the trigger condition is recognized, after which it is incremented by 1 for each cycle of the AQ—CLOCK signal.

The acquisition section control is formed by IC45, IC29, and portions of IC28 and IC31. The TRIGGER output from IC10 to a constant high level (STRIG) is converted by IC28-*b*. A finite state machine, IC45, coordinates the signals coming in from the microprocessor, trigger logic, and position counters, and generates the appropriate outputs to control the acquisition cycle.

TRGTYPE0 and TRGTYPE1 are used to inform the state machine where the trigger should be positioned in the acquisition buffer (for example, they set the PRE, MID, or POST modes). AQSTART tells the logic analyzer to begin looking for the trigger condition, and to start storing data into the acquisition buffer. The MIDWAY and END signals from the position counters tell the state machine how much buffer has been filled since the trigger.

When a trigger has been recognized and the acquisition buffer filled up, the state machine will assert the INTO line, informing the microprocessor that acquisition data is now available.

The STEP, CCLR, and DDIR—EN

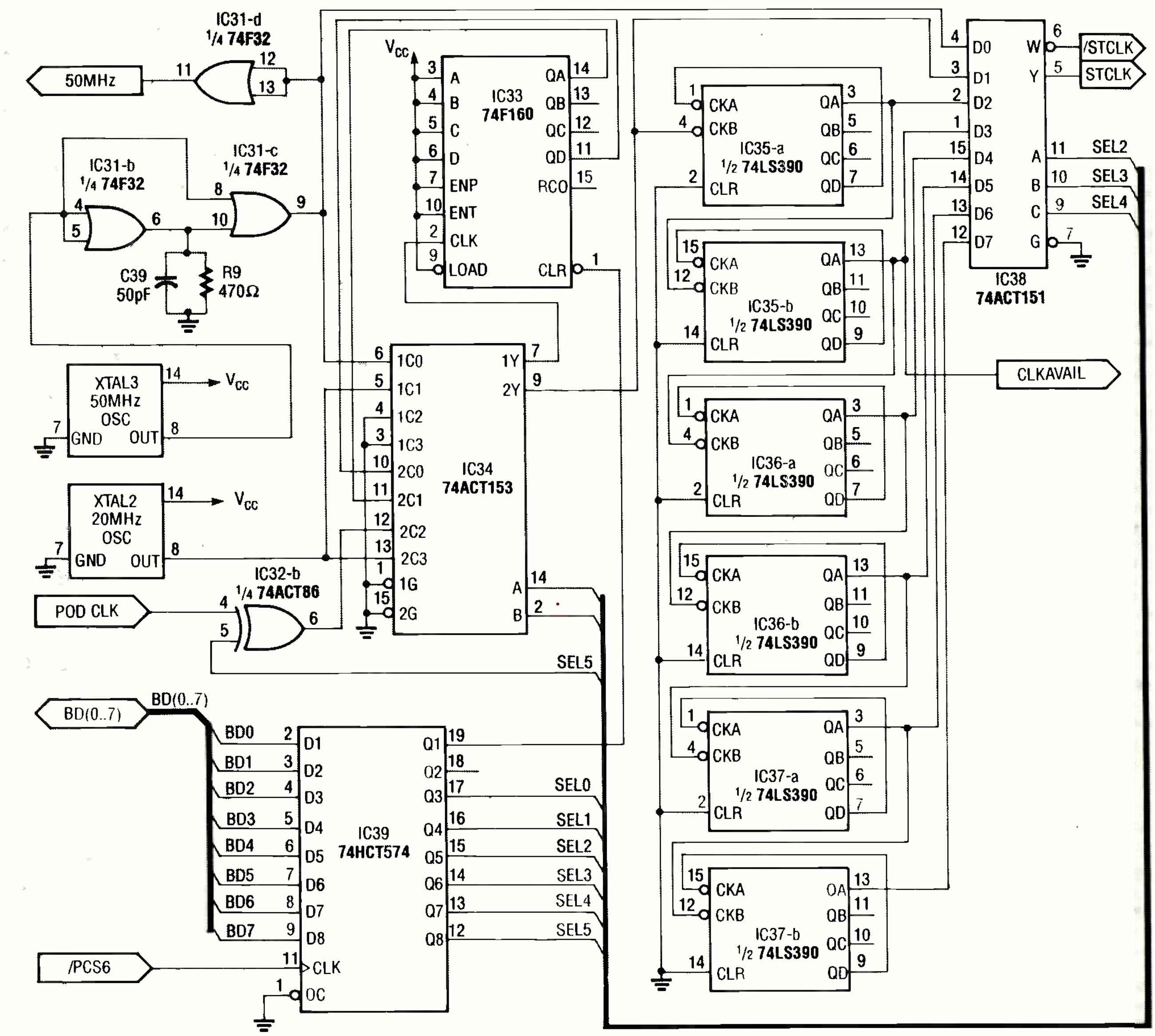


FIG. 4—CLOCK GENERATOR AND TIMING LOGIC. The logic analyzer can generate 22 internal frequencies, ranging from 50 MHz to 5 Hz.

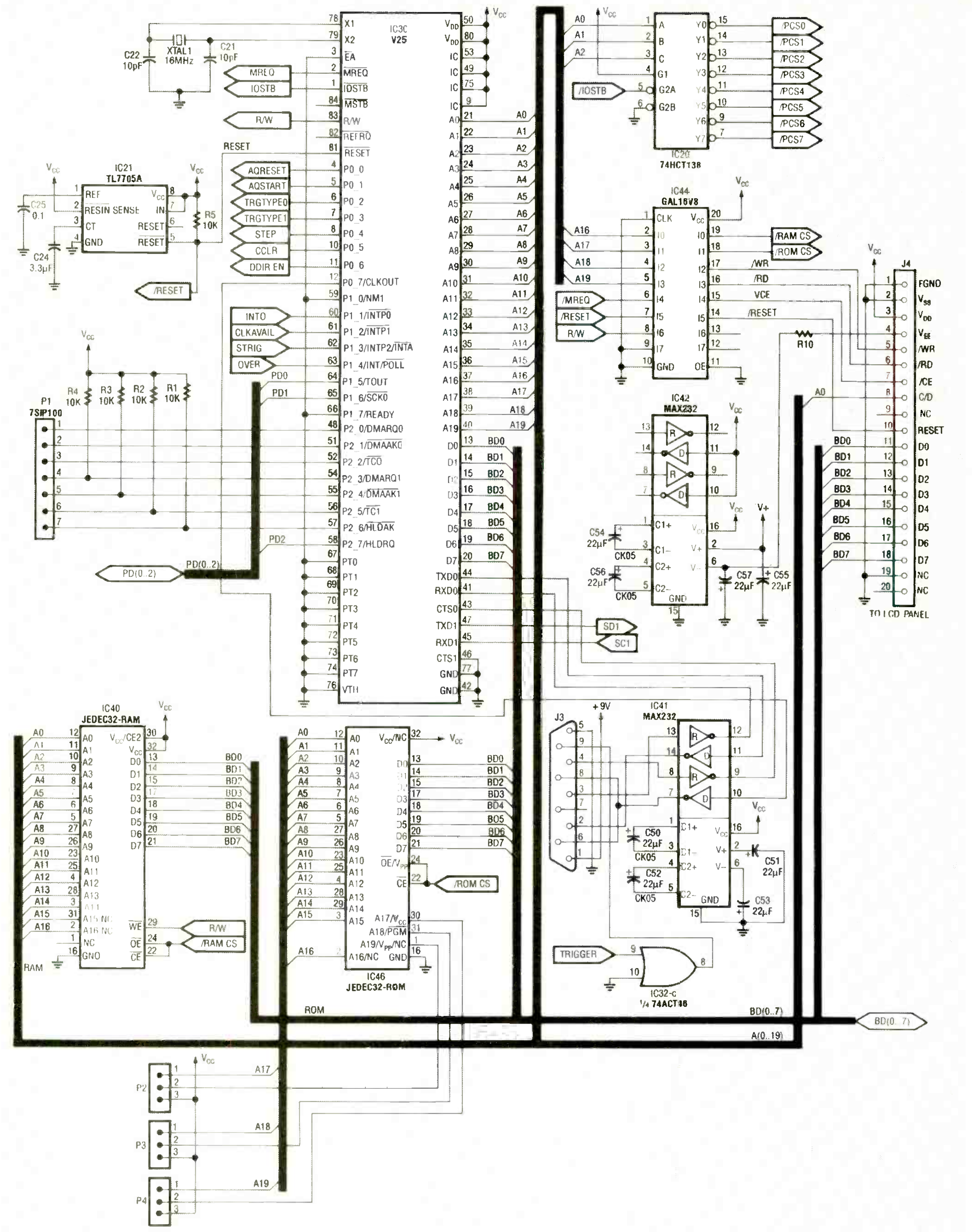


FIG. 5—THE PROCESSOR SECTION contains the microprocessor, keyboard interface, LCD panel interface, serial interface, RAM, and ROM.

signals are used by the microprocessor to copy the contents of the acquisition buffer into the microprocessor's own RAM for further manipulation. Data from the high speed acquisition RAM is read by IC6 and IC16.

Figure 4 shows the clock generator and timing logic for the analyzer. The unit can generate 22 internal frequencies arranged in a 5-2-1 sequence (50 MHz, 20 MHz, 10 MHz, and so on). The highest frequency is 50 MHz (20-ns period) and the lowest is 5 Hz (0.2-s period).

Self-contained TTL oscillators, XTAL2 and XTAL3, generate the base 50-MHz and 20-MHz square waves. The duty cycle of the 50-MHz waveform is adjusted by IC31-b, IC31c and the associated R-C network. The timing requirements of the high speed RAM IC's require that the write-enable pulse width be at least 13 ns long. The 50-MHz oscillator produces a square wave with a 50% duty cycle (10 ns low, 10 ns high). The circuit is therefore used to adjust the duty cycle to 35% (13 ns low, 7 ns high).

ORDERING INFORMATION

Note: The following items are available from Convention Systems, 1214-315 Southampton Dr. SW, Calgary AB, Canada T2W 2T6, (403) 253-4427. Send check or money order. Shipping is by ground delivery. Contact Convention Systems for additional charges if overnight delivery is desired. All items are postpaid, except as noted.

- **Etched, drilled and plated main and keyboard PC boards—$99.00.**
- **Preprogrammed EPROM, GAL16V8-15LP, and GAL16V8-10LP (IC44–IC46)—$99.00**
- **Milled-out case with plastic overlay—$79.00.**
- **Probe assembly—$99.00**
- **AC adapter—$15.00**
- **LCD panel—$150.00**
- **IC30 V25 microprocessor—$29.00**
- **Manual—$32.00**
- **Complete kit, including probe assembly and AC adapter—$695.00 plus $20.00 S & H.**
- **A complete assembled unit, including probe assembly and AC adapter—$695.00 plus $20.00 shipping and handling.**

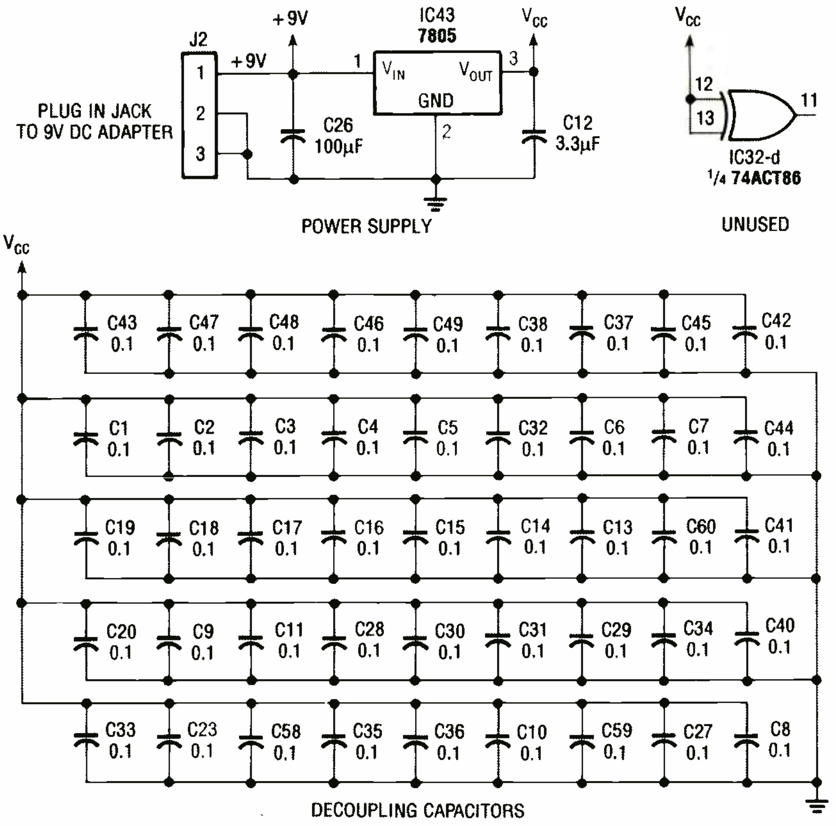


FIG. 6—POWER CIRCUIT AND DECOUPLING CAPACITORS. Each IC is decoupled by a 0.1 µF capacitor.

A divider chain, which produces the 22 clock frequencies, is formed by IC33, IC34, IC35, IC36, and IC37. Multiplexer IC34 selects the 50-MHz or 20-MHz oscillators, the 25-MHz or 5-MHz signals from IC33, or the external K line. A bi-quinary divider chain is formed by IC33, IC35, IC36, and IC37. IC33, a 74ACT160, is similar in function to IC35-IC37, which are 74LS390 dual-decade counters. It is used at the beginning of the chain because the 74LS390 can handle a maximum frequency of only 20 MHz.

The various clock sources are multiplexed into IC38, an 8-to-1 multiplexer. The STCLK (state clock) signal is produced by IC38. That signal is used to drive the acquisition state machine and to sample the input data lines. Eight-bit latch, IC39, is used to select the source and/or frequency of the STCLK signal.

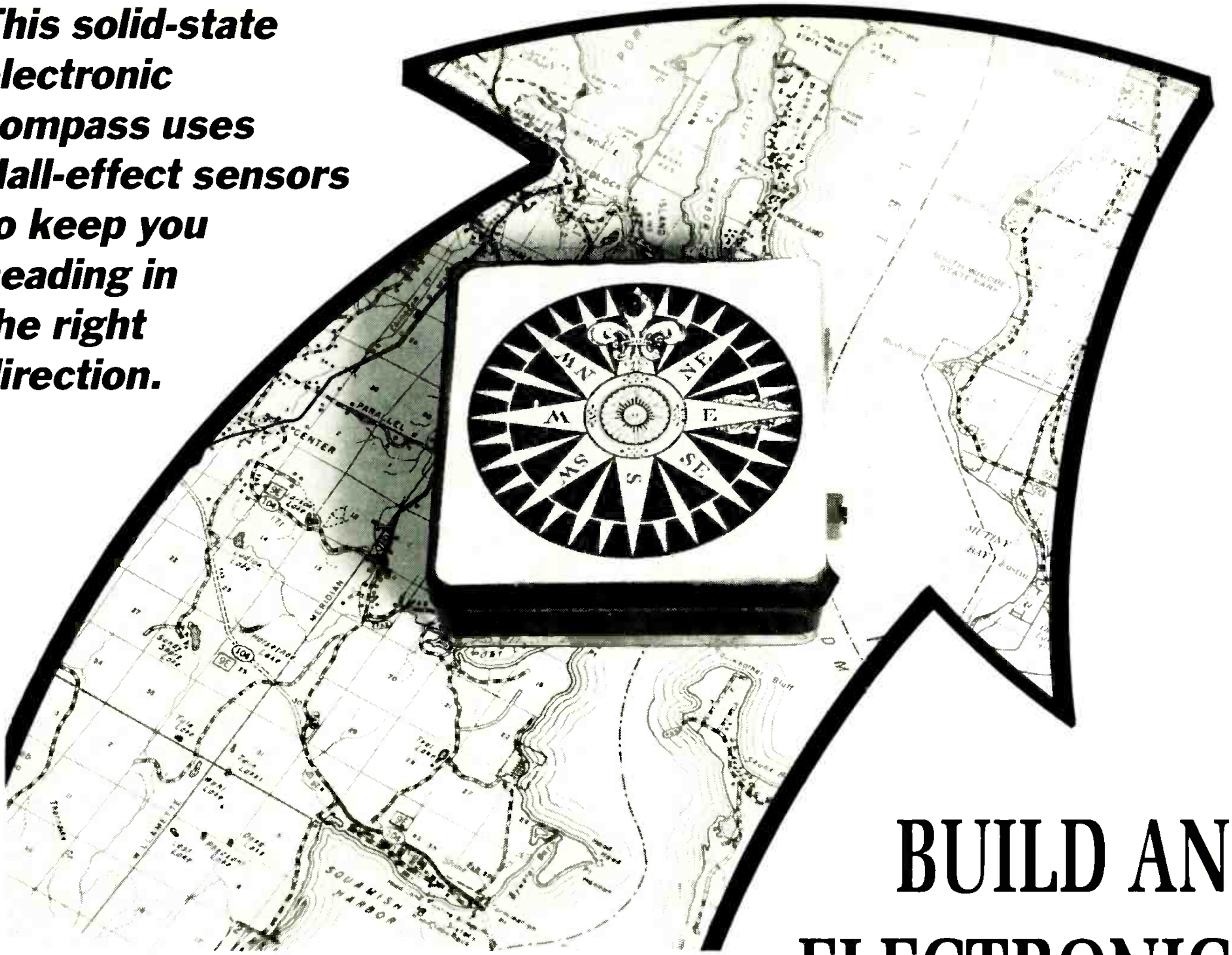
The external clock enters pin 4 of IC32-b, an XOR gate. By setting pin 5 to a high level, the clock signal can be inverted before being presented to the multiplexers. To sample on the rising edge of the external clock, pin 5 is set to 0. To sample on the falling edge, pin 5 is set to 1.

The microprocessor, keyboard interface, LCD panel interface, serial interface, RAM and ROM is shown in Fig. 5. The microprocessor used is the V25 (IC30) from NEC electronics, which is 100% code compatible with the Intel 8088 microprocessor (used in the IBM XT class of computers). The V25 includes two serial channels, a DMA controller, and parallel I/O ports. Using this part allowed us to implement the entire microprocessor section using only seven IC's!

There is one ROM site, IC46, and one RAM site, IC40. The ROM site is a 32-pin JEDEC socket which will accept 1-, 2-, or 4-Mbit EPROMS. The logic analyzer software currently fits in a 1 Mbit part (128K × 8). The RAM site accepts either 32K or 128K static RAM IC's. In order to permanently store the configuration of the logic analyzer, the RAM site uses a Dallas semiconductor component called a SmartSocket. That device consists of a standard socket, along with a 3-volt lithium battery, and

continued on page 87

This solid-state electronic compass uses Hall-effect sensors to keep you heading in the right direction.



BUILD AN ELECTRONIC COMPASS

ANTHONY J. CARISTI

MOST OF US HAVE AT ONE TIME OR another used a common magnetic compass, which often consists of a light-weight balanced magnet suspended on a pivot. The magnet, free to rotate, is affected by Earth's magnetic field, and assumes a position in which its north-seeking pole points to Earth's magnetic north pole. The geographical north pole of Earth is offset from the magnetic north pole by about 10 or 15 degrees in most areas of the United States.

Many low-cost compasses leave something to be desired in their performance, which can be affected by any tilt of the case or friction in the pivot. However, with the development of solid-state magnetic detecting devices, called Hall-effect generators, it is possible to construct a low-cost, reliable magnetic compass which has no moving parts and eliminates the disadvantages of inexpensive mechanical types. Because the project contains no moving or mechanically sensitive parts, it is an extremely rugged device that can tolerate all potential stresses encountered when hiking or traveling through rough terrain. Taking a reading on the compass is quick, easy, and very reliable.

This solid-state compass uses a unique detection system that produces two sharply defined points centered on the direction of magnetic north, as indicated by an LED. That permits a quick, accurate reading. The project, housed in a plastic enclosure, is small and lightweight, and is powered by a common 9-volt battery. Since the compass circuit is energized only when it is used to take a reading, the battery's useful life approaches that of its shelf life.

About the circuit

Development of a magnetically sensitive solid-state compass is made possible through a phenomenon called Hall effect, which was discovered in 1879 by Edwin Hall; he observed that a small voltage was developed at the edges of a current-carrying gold foil when the foil was exposed to a magnetic field. Solid-state technology now provides small, low-cost Hall-effect devices, which are very sensitive and able to detect Earth's extremely weak magnetic field.

The basic Hall-effect sensor, shown in Fig. 1, is a small sheet of semiconductor material in which a bias current flows. The Hall-effect output of the sensor takes the form of a voltage measured across the width of the conducting material, and will be negligible in the absence of a magnetic field. If the biased Hall sensor is placed in a magnetic field with the flux at right angles to the flow of current, a voltage output directly proportional to the intensity of the magnetic field is produced. Additionally, the voltage will be a function of the angle between the lines of force and the plane of the sensor. Maximum Hall-effect output voltage occurs when the face of the sensor is at right angles to the lines of force, and zero voltage is produced when the lines of force are parallel to the face of the sensor.

The Hall-effect sensor is further enhanced by using integrated-circuit technology to add a stable high-quality DC amplifier to the device. It then provides a usable linear output voltage which is sensitive enough to react to Earth's magnetic field (about ½ Gauss).

Referring to the schematic in Fig. 2, The Hall-effect generators (IC3 and IC4) are three-terminal linear devices which are driven by a regulated 5-volt supply provided by fixed-voltage regulator IC1. The output of each of the sensors is a DC voltage that varies linearly from a quiescent value of 2.5 volts as their position with respect to the lines of force of the magnetic field changes. A typical sensor has an output-voltage sensitivity of about 1.3 millivolts per Gauss.

Two Hall-effect generators are used in the circuit to provide twice the sensitivity of a single sensor. The two devices are oriented in opposite directions so that the change in output voltage of one sensor will be positive while the change in the other will be negative as the compass is rotated.

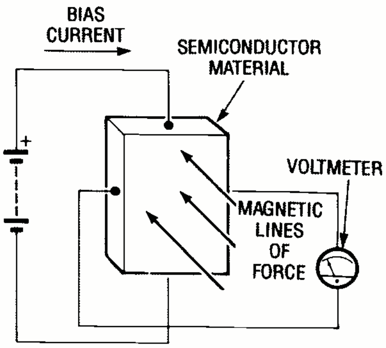


FIG. 1—THE BASIC HALL-EFFECT sensor is a small sheet of semiconductor material in which a bias current flows. The output voltage, measured across the width of the conducting material, is negligible in the absence of a magnetic field. If placed in a magnetic field, the output is directly proportional to the intensity of the magnetic field.

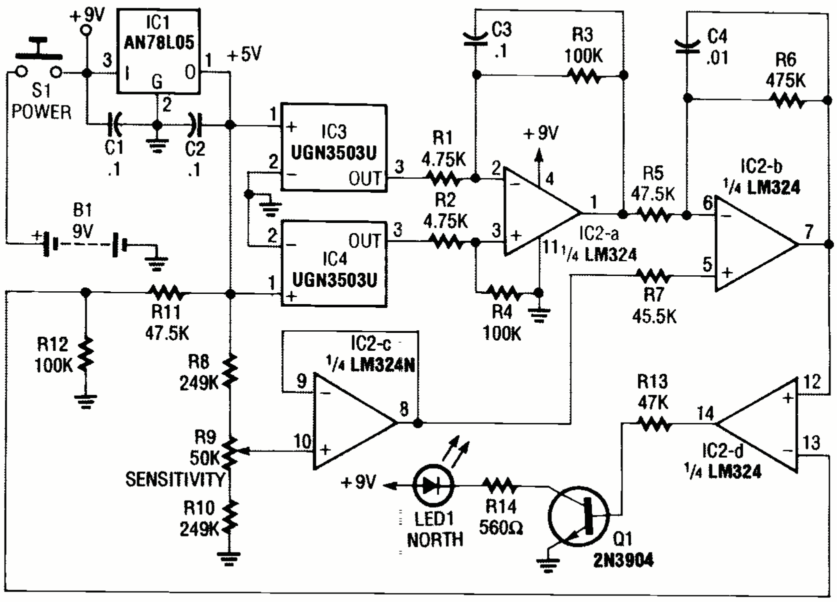


FIG. 2—TWO HALL-EFFECT GENERATORS provide twice the sensitivity of a single sensor. The two devices are physically oriented in opposite directions so that the change in output voltage of one sensor will be positive while that of the other will be negative as the compass is rotated.

The voltage differential between the two output terminals of the sensors is a representation of the magnetic field intensity and direction. The voltage differential produced by the Hall generators is fed to a differential amplifier, IC2-a. As a result, the output of IC2-a (pin 1) will be a minimum (null) when the compass is facing the magnetic north pole, and a maximum when it faces the south pole.

The change in output voltage of IC2-a is too small to allow a simple method of determining the null voltage as the compass is rotated. Therefore, IC2-b is used as an inverting amplifier with a gain of 100 to further increase the change in voltage. A DC offset, provided by sensitivity-adjust potentiometer R9 and voltage follower IC2-c, permits the DC output voltage of IC2-b to be set to a usable level to drive the next stage.

Op-amp IC2-d is used as a voltage comparator with a fixed reference of about 3.4 volts fed to its negative input. Thus, when the output of IC2-b fed to the positive input of the comparator exceeds the 3.4-volt reference level, the output of IC2-d (pin 14) goes high, applying forward bias to Q1. That in turn illuminates LED1 to indicate that a voltage exceeding the reference exists at IC2-b pin 7. The use of a voltage comparator to detect the change in output voltage of IC2-b (pin 7) produces two sharply defined points and allows a more accurate determination of the magnetic north pole.

As shown in Fig. 3, the LED will be illuminated over a small arc as the compass is rotated full circle, and will remain off over the rest of the 360-degree span. The sensitivity control (R9) allows adjustment of the width of

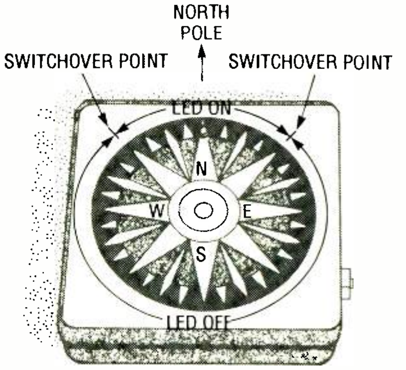


FIG. 3—THE LED WILL BE ILLUMINATED over a small arc as the compass is rotated full circle. True magnetic north is the position at the center of the arc.

the arc. Once the two LED switching points are determined, true magnetic north is then the position at the center of the arc.

Power is provided by a common 9-volt battery. The circuit draws about 25 mA and, since it's usually powered for only a few seconds at a time, battery life is extremely long; several hours of continuous compass operation is also possible. Circuit stability with a falling battery voltage is ensured by the 5-volt regulator, IC5. When the battery is exhausted and cannot deliver sufficient current to operate the circuit, the LED will appear dim or will not illuminate at all.

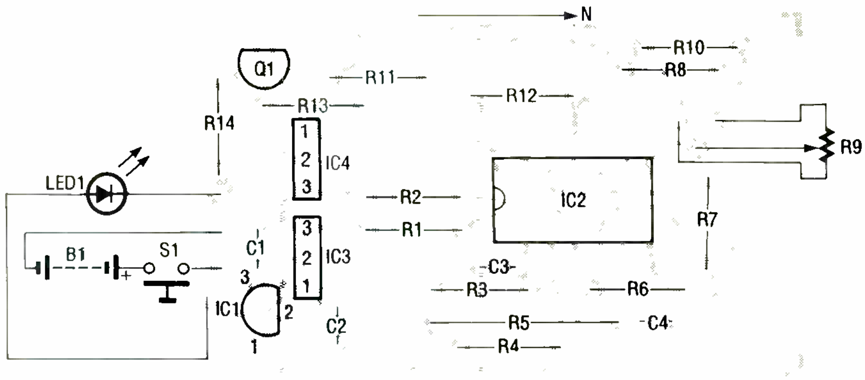


FIG. 4—PARTS PLACEMENT DIAGRAM. The Hall generators must be placed in opposite directions and exactly parallel as shown. Pin 1 of the Hall sensors is on the left side when looking at the markings on the face of the device.

Construction

The circuit, when built on the printed circuit board (for which we have provided the foil pattern), is very compact; the prototype is housed in a 2½-inch square by 1-inch high plastic enclosure, that has sufficient room to accommodate both the board and the 9-volt battery. A metal enclosure must *not* be used for this project—it can attenuate or distort Earth's weak magnetic field. The power switch and sensitivity control are mounted on the side of the enclosure to allow easy operation of the compass.

Figure 4 shows the parts layout. The position of all polarized components (especially the Hall sensors) must be followed exactly as shown. The operation of the project depends upon the Hall generators being placed in opposite directions and exactly parallel as indicated in Fig. 4. Note that the orientation of the sensors is determined by the marked face of the device, with pin 1 being on the left side when looking at the markings. The sensors must be positioned so that they are aligned square with the rectangular shape of the printed circuit board. That way the compass direction will be accurate when the project is assembled into the enclosure. (Use the "north" indication of Fig. 4 to determine the relationship between the PC board and compass scale when final assembly is done.)

Many of the resistors specified in the parts list are metal-film types. The use of such components ensures maximum stability of the circuit with varying ambient temperature changes, and reduces the need to periodically adjust the sensitivity control. Ordinary carbon resistors are not temperature-stable and should not be used in place of metal-film types. Also, it's a good idea to use a socket for IC2.

It is recommended that you use a miniature momentary pushbutton switch for S1. That will ensure that battery power will never be inadvertently left on when the project is not in use. The sensitivity control, R9, may be placed on the side of the enclosure to allow circuit adjustment when necessary. You should use a battery clip for B1. If desired, a suitable clip can be obtained from a discarded 9-volt battery (just peel away the metal case and rip the top off). Be very careful to wire the battery clip with the correct polarity.

When the circuit board is completed, examine it very carefully for shorts, opens, and cold solder joints. It is much easier to correct problems at this stage rather than later on if you discover that your project does not operate. A photo of the finished board is shown in Fig. 5.

Use a photocopy of the artwork in Fig. 6 for the top of the compass; you can simply glue it in place. Indicator LED1 is placed at the north indication of the compass by drilling a suitable size hole in the plastic top where the letter N would be. Be very careful when drilling; some plastics will shatter if subjected to excessive stress. Be sure to properly orient the top of the enclosure in accordance with the final position of the PC board.

PARTS LIST

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

R1, R2—4750 ohms, 1% metal film
R3, R4, R12—100,000 ohms, 1% metal film
R5, R7, R11—47,500 ohms, 1% metal film
R6—475,000 ohms, 1% metal film
R8, R10—249,000 ohms, 1% metal film
R9—50,000-ohm, potentiometer
R13—47,000 ohms
R14—560 ohms

Capacitors

C1–C3—0.1 µF, 50 volts, ceramic disc
C4—0.01 µF, 50 volts, ceramic disc

Semiconductors

IC1—AN78L05 5-volt regulator
IC2, IC3—Sprague UGN3503U Hall generator
IC4—LM324N quad op-amp
LED1—red light-emitting diode
Q1—2N3904 NPN transistor

Other components

B1—9-volt alkaline battery
S1—SPST pushbutton switch, normally open

Miscellaneous: Plastic enclosure, battery clip, control knob, IC socket, wire, solder, etc.

Note: The following items are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463: An etched and drilled PC board, $9.95; set of two Hall sensors, $9.75; IC1, $2.00; IC2, $2.00; set of 11 metal-film resistors, $4.95. Please add $2.50 postage/handling.

Checkout

When you are satisfied that all wiring is complete and correct, the checkout procedure must be performed, and be sure to use a fresh 9-volt battery. Checkout requires a DC voltmeter connected to ground and the output terminal of IC1. Apply power to the circuit check for +4.75 to +5.25 volts. Measure the resistance between the 5-volt bus and ground; a normal reading is about 600 ohms. Measure the terminal voltage of the battery to be sure that it is delivering at least 7 volts under load to IC1. Replace a weak battery if necessary.

Next, measure the output voltage of IC2 pin 1, and verify the voltage range of potentiometer R9. (Compass orientation is not important at this time.) The voltage should be about 2 to 3 volts DC. Measure and record the DC voltage that you observe at IC2-a pin 1.

Measure the voltage change at IC2-c pin 8 as the sensitivity control is rotated over its entire range. The difference between the highest and lowest readings should be about 0.45 volts. Ideally, the center of the measured voltage range should be close to the voltage recorded earlier at IC2 pin 1.

If necessary, change the value of R8 and/or R10 so that the voltage range obtained at IC2-c pin 8 is somewhat centered about the voltage reading at IC2-a pin 1. This ensures proper adjustment range of the sensitivity control for the particular pair of Hall generators that are used in your compass project.

Once the sensitivity range is correct, rotate R9 over its range while observing the LED. At one end of the setting, the LED should be extinguished, and at the other end it should be illuminated; if not, check the polarity of LED1 and the orientation of Q1. Check pin 14 of IC2-d to be certain it swings from about zero to battery voltage as R9 is rotated over its range. Check pin 13 of IC2-d for a voltage of about 3.4 volts as set by R11 and R12. Problems in this area may warrant replacing IC2 if everything else checks out alright—check your soldering before changing the IC.

When the LED operates as described, the project is ready to be tested under actual operating conditions. Before you start, make sure that there are no magnetic fields nearby, and the project is not shielded by a large mass of iron or steel.

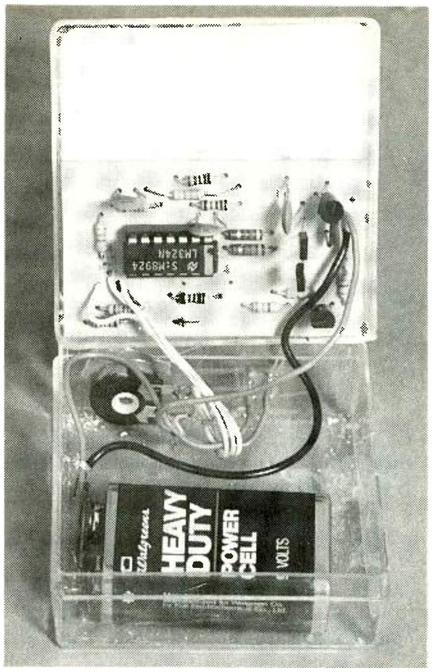
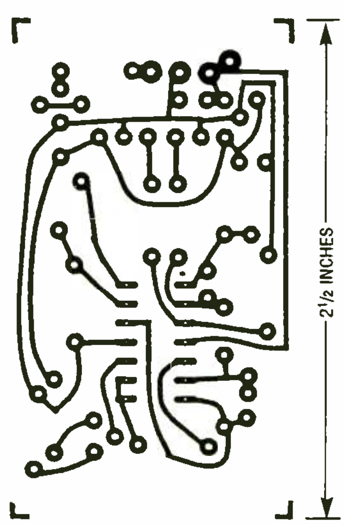


FIG. 5—EXAMINE THE COMPLETED board for shorts, opens, and cold solder joints before installing it in a plastic case.

FIG. 6—USE A PHOTOCOPY of this artwork for the top of the compass, and glue it in place on top of the case.



FOIL PATTERN for the electronic compass, shown actual size.

While holding the unit horizontally in any direction, apply power and carefully adjust R9 so that the LED is at the switch-over point between on and off; allow at least 10 seconds for the circuit to stabilize. Flicker of the LED is normal as the circuit switches back and forth. Once R9 is set, rotate the compass over a 360-degree arc (full circle) and note that the LED will be on over part of the arc, and off over the rest. If necessary, readjust potentiometer R9 very slightly to obtain this result. The optimum setting for R9 will be at the point where the arc of illumination is as small as possible.

As the compass is rotated over the illuminated arc, note the two on/off points. When the compass is positioned halfway between those points, it is facing the magnetic north pole, and the scale indications on its face indicate all other directions.

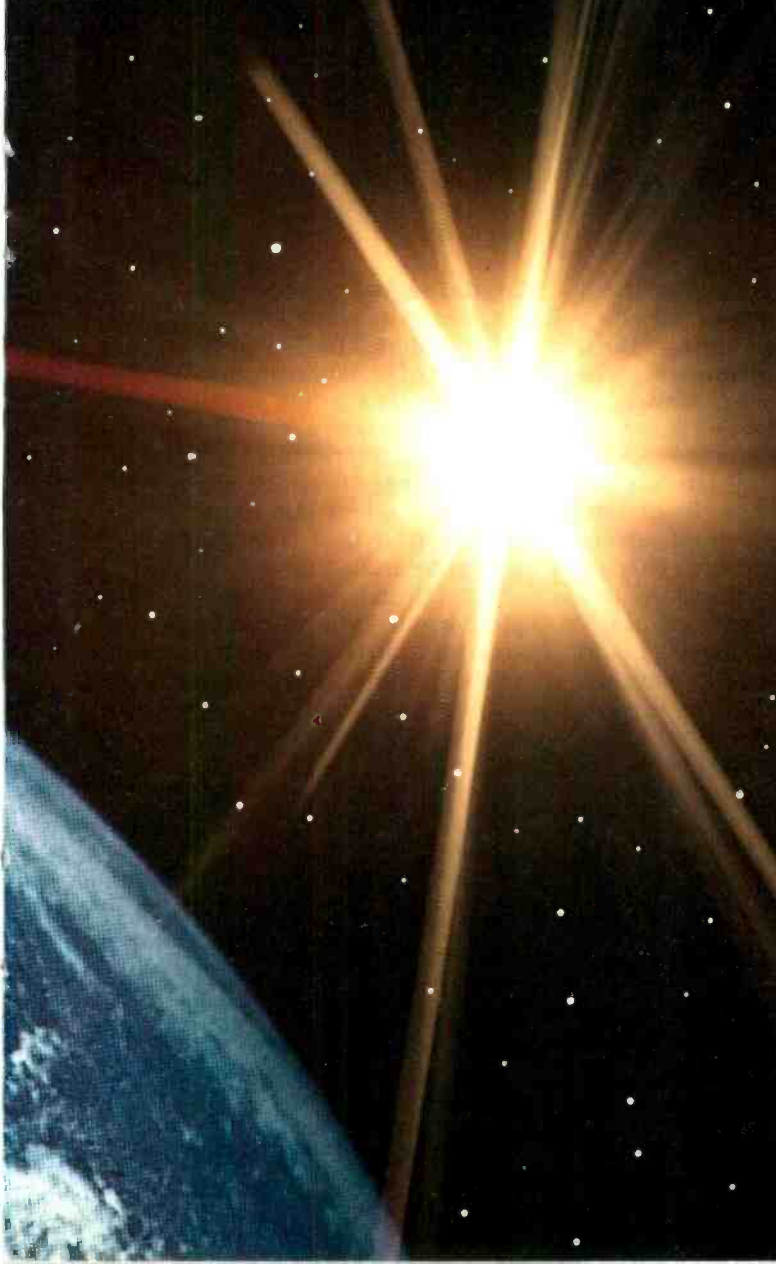
Using the compass

Always be sure that the battery is reasonably fresh, and take along an extra one before starting out on an excursion with the compass. (A weak battery will be indicated by a dim or totally unlit LED.) Avoid taking a compass reading in any area where there may be a magnetic field from a nearby device, or where Earth's magnetic field is shielded by a large mass of metal.

Hold the compass in a horizontal position and rotate it full circle while observing the LED. Adjustment of the sensitivity control is indicated if the LED is totally on or totally off as the compass is rotated. Always allow at least 10 seconds operating time for the circuit to stabilize. Once the sensitivity control is adjusted, it should not require readjustment unless the project is subjected to an extreme change in temperature.

Don't forget that the electronic-compass circuit can be used for things other than a simple direction finder. It provides an electronic means of finding north, so it should be easy to interface the compass to other devices that may need to know where north is—a robot, for example. **R-E**

THE NEW WORLD OF DSP



JOSEF BERNARD

WHAT MICROPROCESSORS WERE IN the 1980's, digital signal processing (DSP) will be in the '90s. It is already being used in consumer audio, video, and communications equipment, and will show up in many more products within the next few years. With the ability to design and manufacture fast and accurate analog-to-digital (A/D) and digital-to-analog (D/A) converters, and to process and manipulate digital information at blinding speed, today's technology has made it as cost-effective to manipulate signals in the digital realm as it is to do so in the analog, and the results are better, and more spectacular.

Before we can appreciate some of the devices in which DSP is being, and will be used, we should have an understanding of what it is, and how it works.

Analog signal processing

Signal processing can take many forms. Sometimes it involves changes in signal levels such as the type used in an audio graphic equalizer. In that type of device, the audio-frequency spectrum is divided into frequency bands by a series of analog filter networks. The gain of each filter circuit can be adjusted upward or downward around a center point to emphasize or de-emphasize the audio frequencies for which it is responsible, and therefore tailor the sound of an audio system to fit the requirements of a room or the ear of a listener. We'll return to the example of an audio equalizer later to show some of the effects that can be accomplished with DSP.

Analog filters—either in the form of L-C networks (Fig. 1-*a*) or simple op-amp circuits (Fig. 1-*b*)—are used in other numerous signal processing applications. They can, for example, be used to "peak up" audio or RF signals at certain frequencies or, in the form of high-pass, low-pass, and bandpass or notch filters, to allow the passage of signals of certain frequencies while blocking those of others.

Signal processing can also be used to modify the phase relationships in a complex signal, as is the case in the TINT control found on NTSC TV receivers—although that's not being done digitally, at least not yet. In audio, on a gross scale, phase shifting shows up in the form of "phlanging," a technique used in recording studios to add a rather weird-sounding effect to material. (The technique got its name from the fact that, initially, it was produced by playing two identical tapes and varying their speeds ever so slightly by applying pressure to the flanges of the tape reels. Now, of course, it's done digitally.) And, since the ear is extremely sensitive to the phase relationships of the sounds reaching it and uses them to help establish the location of sound sources, changing those relationships in recorded material can greatly affect the way the sound is perceived (see All About Surround Sound, June 1990 **Radio Electronics**).

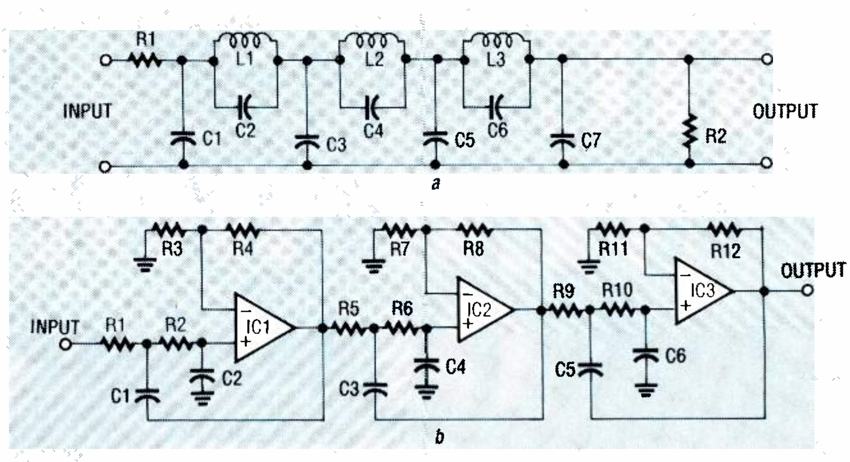


FIG. 1—TWO FILTERS; a passive L-C (*a*) and an active op-amp (*b*). Neither of these types can be as flexible or reliable as one using DSP.

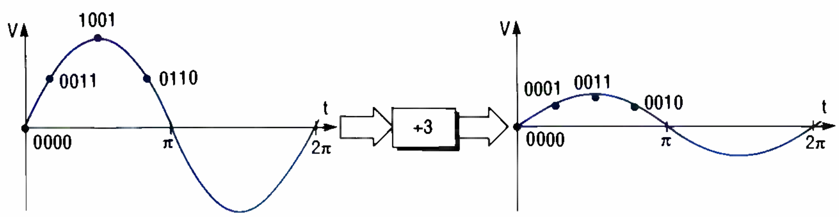


FIG. 2—A HYPOTHETICAL DSP VOLUME CONTROL would divide each signal sample by the same number to reduce it in strength.

Signals can also be summed, or subtracted from one other, to achieve particular results. Both summing and subtractive techniques are used, for instance, in various audio and video noise-reduction schemes.

Until recently, all the signal processing schemes described above, and a number of others not mentioned here, were carried out in the analog domain. Depending on the degree of precision required, the circuits could get very complex and very expensive. Also, a particular circuit could generally serve only a single purpose; if you wanted both frequency-selective processing, for example, and noise reduction, you had to design and build two completely different processing stages. Also adding to its inconvenience was analog signal-processing's dependence on analog components. As analog components heated and cooled, and as they aged, their values drifted and the characteristics of the circuits in which they were used changed. Precision in the analog world can be extremely difficult and costly to come by. Digital signal processing, however, is entirely different.

Digital signal processing

Once you have converted an analog signal to digital form—to a string of binary numbers representing the voltage levels of the signal as it varies over time—you can very easily perform all sorts of operations on those numbers that will affect the signal they represent when they're reconverted to analog form.

Let's take a very simple example. Suppose you wanted a digital volume control, which might, under certain primitive circumstances, be construed as a kind of DSP. To cut the volume of a signal in one third, all you would have to do would be to divide every binary number in its digital representation by three (Fig. 2). The voltages represented by the resulting numbers would be one third their original value, and the amplitude of the reconstructed analog signal would be one third that of what you started with. By changing the divisor, you could vary the amplitude accordingly in either direction.

Taking the process a step further, if you were to multiply all the

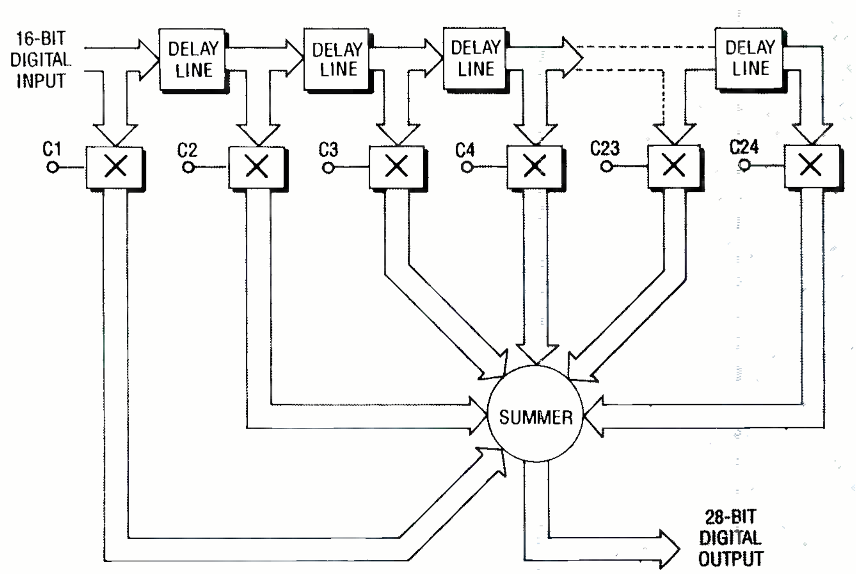


FIG. 3—A CD PLAYER'S DIGITAL FILTER is an example of a dedicated DSP IC. Within it, each sample is multiplied by a fixed coefficient; this is the basis for oversampling.

numbers by one (the equivalent of a unity-gain amplifier) *except* for those representing frequencies between X and Y, which it would divide by, say, 8, you would have a notch filter. That particular filter would, admittedly, have extremely steep sides, but its slope could be modified by using an expression of some complexity to determine the divisor at each point.

As another example of digital signal processing, consider a signal that's stored briefly in RAM as it passes through a system. By reading out that signal a couple of milliseconds after it's been read in, or by shifting it slowly through the RAM's addresses, and then adding it back at a lower level (smaller numbers) than the original as *it* was read out, you'd develop a reverberation effect. Note, by the way, that in that application there are two DSP processes going on at once; time delay and level control.

Digital signal processing of the sort we've just described has been with us for a few years, at least in simple form. For example, digital delay lines have long been used in recording studios. Perhaps the most sophisticated "non-DSP" DSP circuitry is that found in the oversampling digital filters used in CD players (Fig. 3), where every binary number passing through is multiplied by a fixed coefficient. The problem with such DSP devices to date—both single-chip ones and the ones requiring an entire boxful of components—is that they have been dedicated to a single-purpose. They've not been very flexible, which has limited their usefulness. Speed, too, has frequently been a limiting factor. The DSP processes used to enhance satellite photographs, for example, do not take place in real time; it is sometimes weeks before the results are available. (Although much of that delay is no doubt due to the bureaucratic process and long periods of "standing on line.")

Even so, as you've read this description of the principles of DSP, you may have said to yourself, "Hey, I'll bet I could teach my *computer* to do that! Then I could do *anything* I wanted!" And you could, but there would be a hitch. Even today's '386 and '486 desktop systems operating at 30 MHz or more are not fast enough to keep up with the heavy computational overhead demanded by good DSP. DSP, as the term is generally used today, requires that information appear at the output at the same rate it is supplied to the input. Today's small computers would need a lot of help to meet that criterion.

50 megaflops

Fortunately, that sort of help is available. Just as numeric coprocessors, such as the 80387, have lifted a lot of the number-crunching burden from their associated microprocessors (and speeded things up enormously in the process) there are now special number-crunching processors for DSP. Those processors make DSP a real-time process—the modified signal comes out as quickly as it goes in. The difference between the "old" DSP and the new is rather like that between taking your pictures down to the drugstore to be developed and picking them up a week later, and owning a Polaroid 60-second camera.

What makes real-time DSP possible is a new class of IC's from companies such as Intel, Motorola, and Texas Instruments, not to mention a number

MIPS, MOPS, FLOPS

Clock speed is not necessarily an accurate indicator of how rapidly or efficiently a device performs. One processor running at, say, 20 MHz, may not have the throughput of another operating at only 12 MHz. The difference is largely that of the device's internal architecture, instruction set, and other built-in programming. For that reason, performance is often more accurately measured in terms of the number of instructions or math operations of which a device is capable in a given period of time.

The term "MIPS" stands for million instructions per second, and refers to the number of commands that can be executed in that time. A 27-MHz Motorola DSP56001 runs at the rate of about 13.5 MIPS, a 33.3-MHz DSP96002 at 16.65 MIPS.

"MOPS," which stands for million operations per second, is a more accurate measure of a processor's abilities, since a single instruction can be responsible for the simultaneous execution of several (six in the case of the 56001, up to ten for the 96002) operations at once. Such operations can include those for math (add, multiply, subtract), for moving data internally and to and from memory, for carrying out program instructions, and so forth. The 56001 can perform at the rate of 81 MOPS and the 96002, 165 MOPS.

Finally, "megaFLOPS," or MFLOPS, stands for millions-of-FLOPS, or millions of floating-point math operations per second. Floating-point math, which uses exponential notation, is used extensively in the complex calculations required by such applications as 3-D graphics and image processing. Fixed-point math, which is like the "integer math" used in early Apple computers, is much simpler, and cheaper, than floating point to implement and perform and is what the 56001 uses. It is well suited, though, to audio processing where the calculations are not as involved as they can be for graphics.

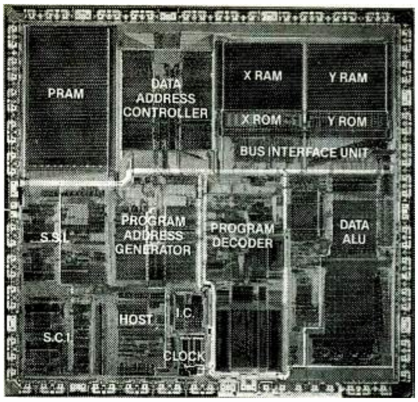
of offshore manufacturers. Just as the architecture and instruction sets of math coprocessors are created with a specific purpose in mind, these special purpose devices are tailored to the high-speed processing of the digital equivalents of audible and visible information. While each manufacturer has his own idea of what a DSP device should do, and how it should do it, the general principles are the same—real-time manipulation of digital data representing analog phenomena. We'll look at two DSP IC's from Motorola representing the group.

Motorola's DSP56001 is a "general purpose" fixed-point-math DSP IC that's found applications in a number of different types of devices. For example, it is an integral part of Steve Jobs' NeXT computer, that literal "black box," serving to provide on-board data communications (modem and fax) and sound synthesis for such purposes as voice mail, voice-interactive programs, and high-fidelity, CD-quality audio. The 56001 is also incorporated in Cincinnati Microwave's Escort radar detector where it differentiates between radar signals and other, unwanted, types of noise. At a price of $56, even in single-unit evaluation quantities, and maybe less by the time you read this, the DSP56001 is affordable enough to show up in a number of mass-produced general-market devices.

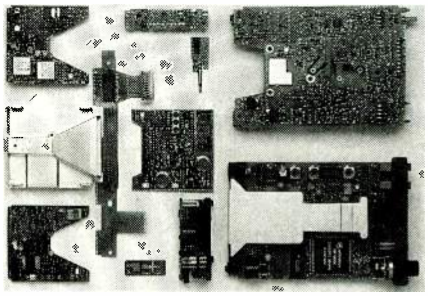
Speed is essential to real-time signal processing, and the DSP56001's specifications demonstrate how it performs in that area. For instance, the processor runs at a speed of 27 MHz, with an instruction-cycle time of 74.1 nanoseconds (0.0000000741 seconds). In the time it takes to execute one of those cycles, a beam of light would travel about 73 feet!

Other 56001 specs include

- Word length of 24 bits, providing a 144-dB dynamic range.
- Capability to execute at 94.5 million instructions per second (MIPS).
- Three complete and independent execution units capable of operating simultaneously and in parallel.
- Triple-bus Harvard architecture. (Harvard architecture, used in some RISC processors, involves two separate buses; the 65001 has three.)
- The ability to perform six separate operations simultaneously.



MOTOROLA'S DSP56001 digital signal processor contains three separate execution units and uses a triple-bus architecture to facilitate data handling.



THE DSP56001 at the heart of Cincinnati Microwave's *Escort* radar detector increases its sensitivity by differentiating between radar signals and other types of microwave "noise."

The physical and electrical specifications of this Motorola DSP device are impressive, both in terms of large and small numbers as well. The DSP56001

- Comes in an 88-pin package.
- Operates from a single 5-volt supply.
- Has five 5-volt and seven ground pins to ensure even power distribution and glitch-free operation.
- Consumes less than half a watt of power.

An even more powerful, although somewhat more specialized, DSP device is Motorola's DSP96002 "Media Engine." This 32-bit device, whose internal accumulators can store numbers 96 bits long, comes in a 223-pin PGA (pin grid array) package 1.845 inches square, and uses a one-micron architecture to accommodate some 850,000 transistors. It operates at a clock speed of 33.3 MHz, although a "slow" 27-MHz version is also available. The processor can perform at the rate of 50 megaFLOP's (see box copy), and even has tables of sine and cosine values built into it, which can be used in areas such as graphics generation and manipulation. The 96002 processor is capable of addressing an incredible 12 gigabytes (12 trillion bytes) of memory.

The DSP96002 is expected to find use in the new generation of entertainment and information-processing systems to provide high-resolution graphics and synthesized stereo sound. It has the capability to do both at the same time (hence the reference to it as a "multi media" product), switching back and forth between the two tasks so quickly that no interruption is apparent. In medical, and other, imaging technologies DSP will prove itself invaluable in enhancing and manipulating visual data. The Motorola IC is also expected to find application in color laser printers where it will convert page-description-language commands into the fonts and graphics that appear as output, and as controllers in huge high-end computer disk drives that require constant compensation for the effects of thermal expansion and vibration. The science of robotics, too, will benefit from the ability of a processor such as the 96002 to perform powerful floating-point calculations in real time. For large and complex tasks, several 96002's can easily be configured to operate in tandem and divide the work into more manageable slices, apportioning it among them.

Motorola has plans to introduce an entire family of DSP products. One of the first is the 56ADC single-chip analog-to-digital converter. It can process signals at the rate of 6.4 *million* samples per second (Ms/s) (CD's, in comparison, use a sampling rate of 44.1 *thousand* samples per second), eliminating the need for complex sample-and-hold circuitry. Also in the works is a "sawed off" 16-bit DSP device, as well as a 40-MHz version of the 32-bit 96002.

Some real DSP products

A very good example of some of the ways DSP will be showing up in consumer electronics equipment is Sony's STR-D2010 stereo receiver. In it, many analog functions have been replaced by their digital equivalents, and in implementing those Sony has added an extra degree of flexibility to the features available to the user. A proprietary DSP IC, coupled with 16-bit A/D and 18-bit D/A circuitry and an 8× oversampling digital filter (which, as we've pointed out, in itself provides a form of DSP) is firmware-programmed for a number of useful operations.

The receiver has no treble or bass controls. Instead, it contains a parametric equalizer to tailor frequency response. Parametric equalizers used to be pretty tricky to design and use. They differ from "ordinary" graphic-style equalizers in that the frequency bands on which they operate, and their response curves within those bands, are adjustable to suit the needs of the user. The device's parameters of operation can be changed by the user. With its DSP IC (and 256K of on-chip RAM) the STR-D2010 allows you to define three separate frequency bands (a vacuum-fluorescent display allows you see the response curves, and also functions as a spectrum-monitor display), each with its own degree of boost or cut, and with one of several slopes. There's no "loudness" control either. Instead, a digital signal-compression technique is used to compensate for the way the ear perceives sound at low volume levels.

The Sony unit also has surround-sound capabilities, and uses DSP techniques to provide the various signal delays used to manufacture ambience through artificial echo and reverberation. There's Dolby Surround processing too, using digital techniques to extract the matrixed surround information from the left and right-channel audio signals.

An autosound receiver from Eclipse includes DSP technology to provide ambience and other effects. Video, too, can benefit from DSP, although the term is generally not yet applied to the processes being used. Video noise reduction, for example, can be accomplished by digitizing the video and comparing successive pixels or adjacent lines. By pixel or line averaging, or even replacing a "bad" pixel with a "good" one, picture quality can be improved. It is even possible to average two or more successive *fields* of video to smooth things out.

Amateur radio is getting into the DSP act, too. Kenwood's top-of-the-line amateur transceiver, the TS-950SD, uses DSP in a number of ways to enhance incoming and outgoing signals. The receiver section, for instance, includes such DSP features as a digital AF filter with user-variable characteristics. The transmitter uses digital techniques for speech compression that increase average output power while keeping peak power output the same. It is also possible for the waveshape of the signal to be manipulated using DSP techniques to increase intelligibility.

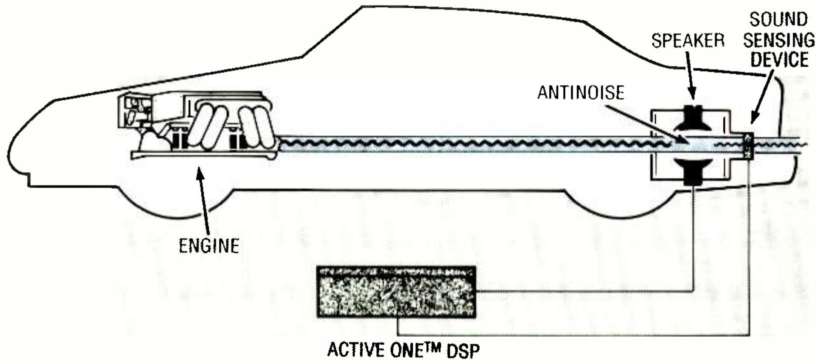


FIG. 5—USING DSP NOISE-CANCELLATION, this "stealth" muffler not only quiets engine noise, but improves performance up to fifteen percent by doing away with conventional baffle systems.

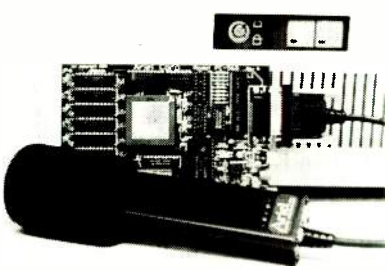


FIG. 4—A DIGITAL MICROPHONE, known as the DM-N from Ariel Corporation uses two Motorola A/D converters to provide two channels of digital input to the NeXT computer system. It operates at the rate of 6.5 Ms/s, eliminating the need for sample-and-hold and anti-aliasing-filter functions.

IC SOURCES

The Motorola DSP96002 digital signal processing IC currently sells for about $750 in single-unit evaluation quantities, $650 for the "slow" 27-MHz version. More information on this and the company's other DSP products is available from:

Motorola Microprocessor Products Group
DSP Marketing
6501 William Cannon Drive West
Austin, TX 78735-8598

One supplier of complete sets of pre-programmed DSP IC's is:

The DSP Group, Inc.
1900 Powell Street, Suite 1120
Emeryville, CA 94608

The manufacturer of the DM-N digital microphone and MM-96 multimedia board for MS-DOS computers, can be reached at:

Ariel Corporation
433 River Road
Highland Park, NJ 08904

Finally, the company that has developed the DSP "stealth" muffler is:

Active Noise & Vibration Technology
3811 E. Wier Avenue
Phoenix, AZ 85040

On the cutting edge

Besides the applications we've already mentioned, DSP is now being used commercially in such devices as cellular telephones for compansion; in phone-answering and cordless-phone equipment for speech digitization, synthesis, and storage; in transcription and dictation units for variable-speed playback; and in facsimile machines and other de-

continued on page 53

We are in the process of building an automated component inspection system (CIS). Last time we built a PC-based capacitance meter. Now we will combine the capacitance meter with a volt/ohmmeter on a single PC board. The result will be an accurate, low cost, computer-assisted test instrument that interfaces through a standard PC parallel port.

Our CIS meter measures three basic quantities: resistance, voltage, and capacitance. Resistance may vary from 0 to 20 megohms. Voltage may vary from 0 to 2 volts DC, but simple peripheral circuitry can be added to increase range. Capacitance may vary from 20 pF to 20 µF.

Multimeter basics

The preferred instrument for measuring resistance and voltage is a digital multimeter, or DMM. All DMM's are based on a simple, single-range voltmeter. The nice thing is that converting a humble DMM into a measurement powerhouse requires only a handful of resistors and some switches.

Intersil's 7106 is the basic building block of many meters. The 7106 contains an analog-to-digital converter (ADC) and it provides a three-digit output capable of driving an LCD directly.

A basic 7106 voltmeter that requires only three resistors and five capacitors is shown in Fig. 1. To calibrate the circuit, you must set the reference voltage at the wiper of R2 to 1.000 volt. That setting results in an overall range of 0.0 to 2.000 volts.

Increasing range

What if we want to measure a voltage greater than 2.000? To do so, we use a simple voltage divider, as shown in Fig. 2. With that simple addition, the incoming voltage is divided by the ratio of the two resistors to produce a voltage with a corresponding value. In this case, the resistance ratio is 10:1, so the maximum voltage increases by a factor of ten, giving a total range of 0–20 volts.

Measuring resistance

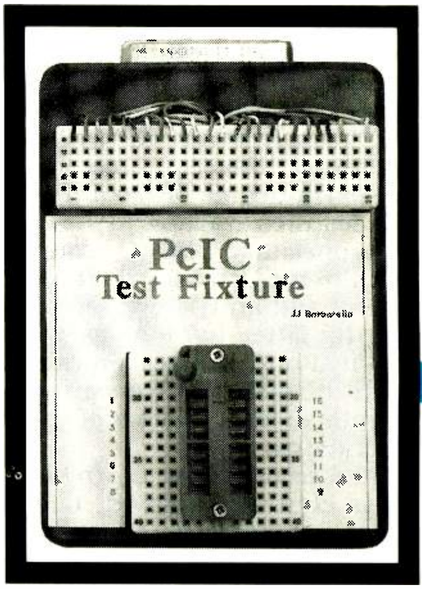
The 7106 compares the incoming voltage to the reference voltage between pins 35 and 36. By altering the circuit slightly, we can create an ohmmeter, as shown in Fig. 3. That circuit gives us another voltage divider. If the unknown resistance (R_{IN}) equals R_{REF}, the same voltage will appear across both the reference and the measurement inputs, resulting in a reading of 1.000. As the value of R_{IN} varies, the reading will vary accordingly. As for range, if the value of R_{REF} were 1K, the range would be 0 to 2K. For a range of 200K, R_{REF} should have a value of 100K.

Computer interfacing

By now you're probably thinking, "That's all well and good, but how do you hook up a 7106 to a PC? The output lines only drive an LCD!" Actually, what may at first seem like an odd approach is both simple and practical. To see why, let's look at a standard LCD readout.

As shown in Fig. 4-*a*, the LCD consists of three seven-segment digits and a single leading "1," making a total of 22 segments. Figure 4-*b* shows which segments are used to display each integer from zero to nine; Fig. 4-*c* shows the same values, but without the use of segments c and d. The 4-*c* versions aren't pretty, but each one is unique, so a computer could read the 7106 segment outputs and translate the values into a more comprehensible form. By ignoring two segments from each digit, sixteen lines are required: five for each digit plus one for the leading digit. Reducing the number of lines in that way is significant because it allows us to use a simple scheme to read each display segment into the computer and then determine what the composite reading was.

A pair of 4051 analog multiplexers does the trick. The 4051 connects one of eight inputs to a single output according to the binary value at three control inputs (A, B, and C). Using two 4051's with common control lines, we can monitor the status of sixteen inputs using only three output and two input lines from the computer. As shown in Table 1, when A, B, and C are all low, input 0 is connected to the output; when A, B, and C are all high, input 7 is connected to the output.



In our circuit, we connect the sixteen signal inputs of the two 4051's to the segment-drive outputs of the 7106, and use the computer to control the A, B, and C control inputs. We also use the computer to monitor the pin-3 outputs of the 4051's.

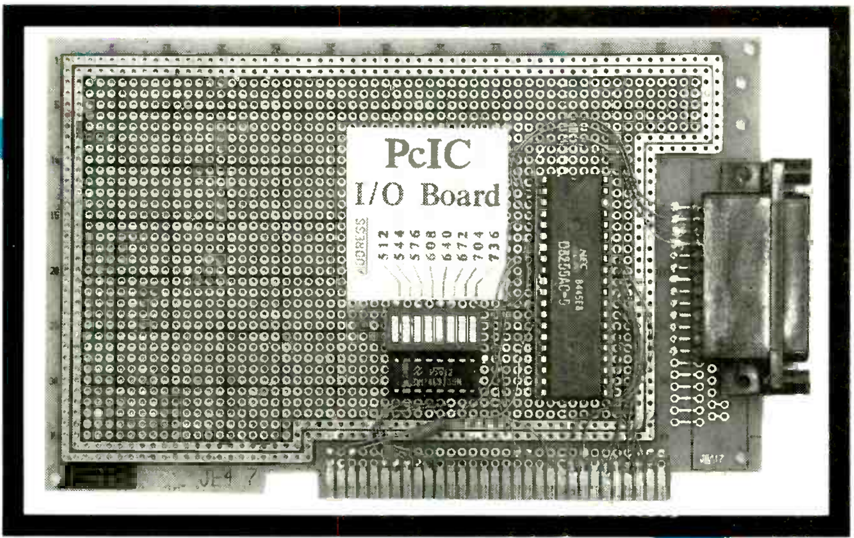
The circuit

The complete circuit is shown in Fig. 5. The circuit is slightly different from the basic circuit in that the reference and voltage inputs are routed to a three-pole, double-throw switch (S1), which selects ohms or volts. In the "volts" position, the CALIBRATE potentiometer (R10) is connected to the reference inputs of the 7106. In the "ohms" position, the reference inputs are connected to one of several reference resistors, as selected by analog-switch IC7.

A 4030 EXCLUSIVE-OR gate (IC2) converts the segment-drive signals to DC levels. The 7106 provides segment drive and BP (backplane) signals, both of which are square waves. When a segment is to be illuminated, the phase of the segment output is shifted 180 degrees with respect to BP. By sending the BP and segment signals through an EXCLUSIVE-OR gate, a steady low is obtained when a segment is off, and a high when it is on. That steady-state level can then be read by the PC through the PE and SLCT inputs.

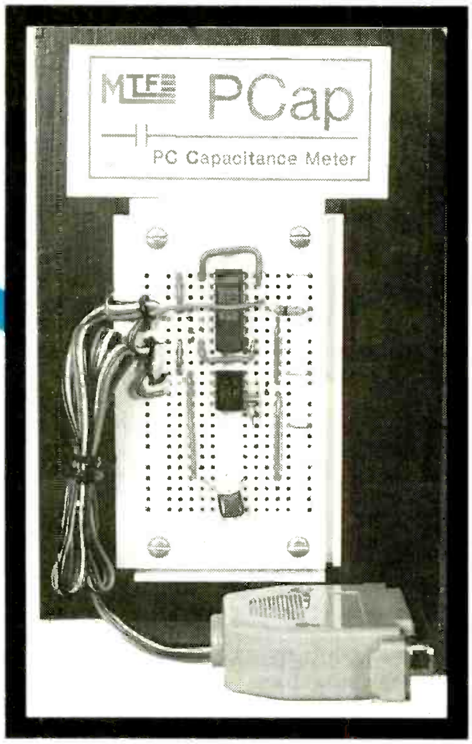
A normally-open pushbutton switch (S2) allows a diode or

EXPERIMENTING WITH PC-BASED TEST EQUIPMENT



This time we build a low-cost PC-based voltage, resistance, and capacitance meter.

JAMES J. BARBARELLO



transistor junction to be forward-biased, thereby allowing measurement of the voltage drop across the junction. We incorporated the capacitance meter (discussed in the May 1991 issue of **Radio-Electronics**) in IC4 and IC6.

In the schematic, note that there are two ground circuits. The reason is that the 7106 requires a supply greater than 6.5 volts, but the PC needs standard TTL levels. In addition, the meter inputs are referenced to the 7106's INLO input, which differs from the digital ground. We use a 9-volt DC wall transformer to power the 7106 and associated IC's, and Zener diode D1 to generate the required TTL levels for the PC interface.

Construction

We recommend PC-board construction for this project. Foil patterns are provided if you wish to make your own board.

Begin construction by installing the 12 jumpers, as shown in Fig. 6. Next, install sockets for all seven IC's. Except for IC4, all IC's are static-sensitive—especially IC1—so use standard precautions when handling those devices. Install the remaining components.

There are 13 connections to P1, two connections for power, and 11 other connections. Prepare 24 lengths of wire, stripping ⅛" of insulation from both ends of each wire. Connect the designated wires to P1 and S1.

If there is a plug on the lead from the power cube, remove it and strip ⅛" of insulation from the two leads. Using a voltmeter, determine which is positive and which is negative, and attach each to the appropriate pad on the PC board. Don't mix them up!

You can use whatever you like for input terminals. The author found it convenient to use a solderless breadboard strip with four rows of connection points. He ran leads from the ± resistance/voltage inputs to one pair of rows, and from the ± capacitor inputs to the other. That scheme allows quick insertion and removal of test components. A separate set of terminals provides a quick connection for diode/transistor testing.

Check your work carefully, making sure all semiconductors and the power leads were installed correctly, and that there are no solder bridges or opens on the PC board. If you have an oscilloscope handy, apply power and check for a square wave between pins 38 and 40 of IC1; the frequency should be between 40

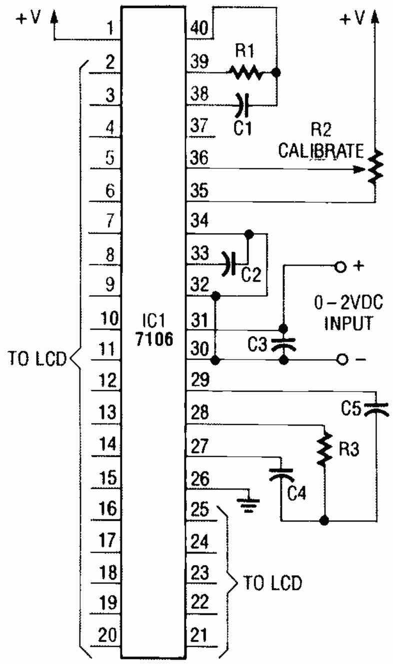


FIG. 1—A BASIC DMM can be built around Intersil's versatile 7106 and a few resistors and capacitors.

TABLE 1—4051 DECODING

A	B	C	"0"	"1"	"2"	"3"	"4"	"5"	"6"	"7"
0	0	0	X							
0	0	1		X						
0	1	0			X					
0	1	1				X				
1	0	0					X			
1	0	1						X		
1	1	0							X	
1	1	1								X

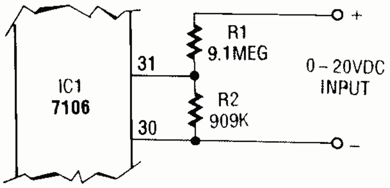


FIG. 2—INCREASE INPUT-VOLTAGE range by adding a voltage divider. In this circuit, range increases by a factor of ten.

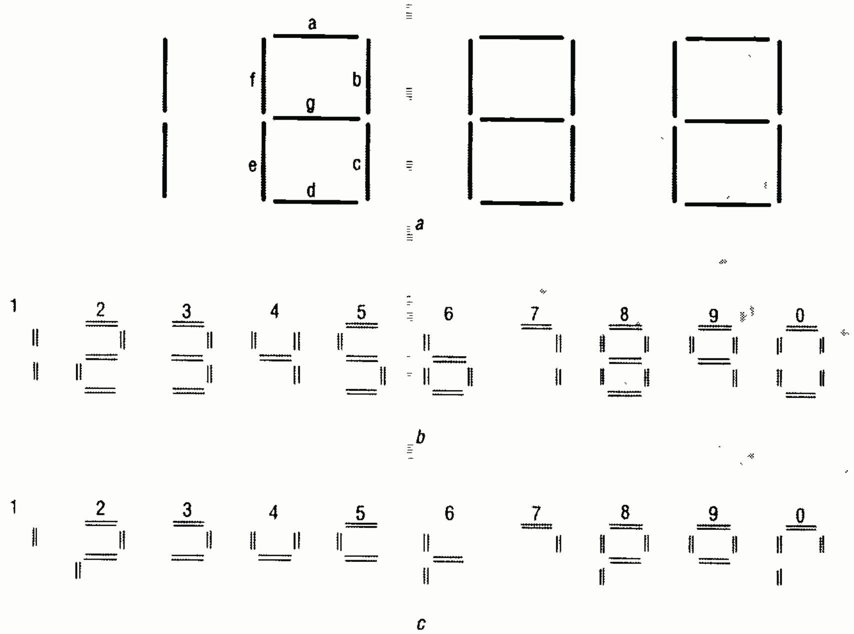


FIG. 4—THE 7106 DRIVES A 3½-DIGIT LCD DISPLAY (*a*). Each integer from 0–9 is formed from a unique combination of segments (*b*); by ignoring segments c and d, each digit remains unique, but fewer lines allow a cleaner PC interface.

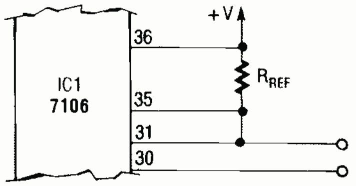


FIG. 3—MEASURE RESISTANCE with the 7106 as shown here.

and 50 kHz. That measurement is not strictly necessary, but making it confirms that the circuit is operating.

Software

The software consists of several independent QuickBASIC programs for calibrating the device and making different measurements. Unfortunately, there is not enough space to publish all of the programs. However, the software is available from the RE-BBS (file: PCTEST2.ZIP, 516-293-2283, 1200/2400, 8N1)

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1, R4, R7—100,000 ohms
R2—470,000 ohms
R3, R9—10 megohms
R5, R11, R12—1000 ohms
R6—1 megohm
R8—10,000 ohms
R10—100,000 ohms
Capacitors
C1—100 pF, 5%
C2, C3—0.1 µF, 10%
C4—0.047 µF, 10%
C5—0.47 µF, 10%
Semiconductors
IC1—7106CPL 3½-digit LCD A/D converter
IC2—CD4030 quad XOR gate
IC3, IC5—CD4051 8-channel multiplexer
IC4—555 timer
IC6, IC7—CD4066 quad bilateral switch
D1—1N4734 5.6-volt Zener diode
Other components
P1—DB25 male connector
S1—3-pole, double-throw slide switch
S2—normally-open SPST pushbutton switch

Miscellaneous: 9-volt DC, ½-amp wall transformer; case; solderless breadboard strip; PC board.

Note: A compiled version of the software that also contains data-logging capability is available on 5¼" double-density PC diskette for $12.00 from JJ Barbarello, RD#3, Box 241H, Tennent Road, Manalapan, NJ 07726. The author will be happy to answer any questions. Please include a self-addressed stamped envelope for reply.

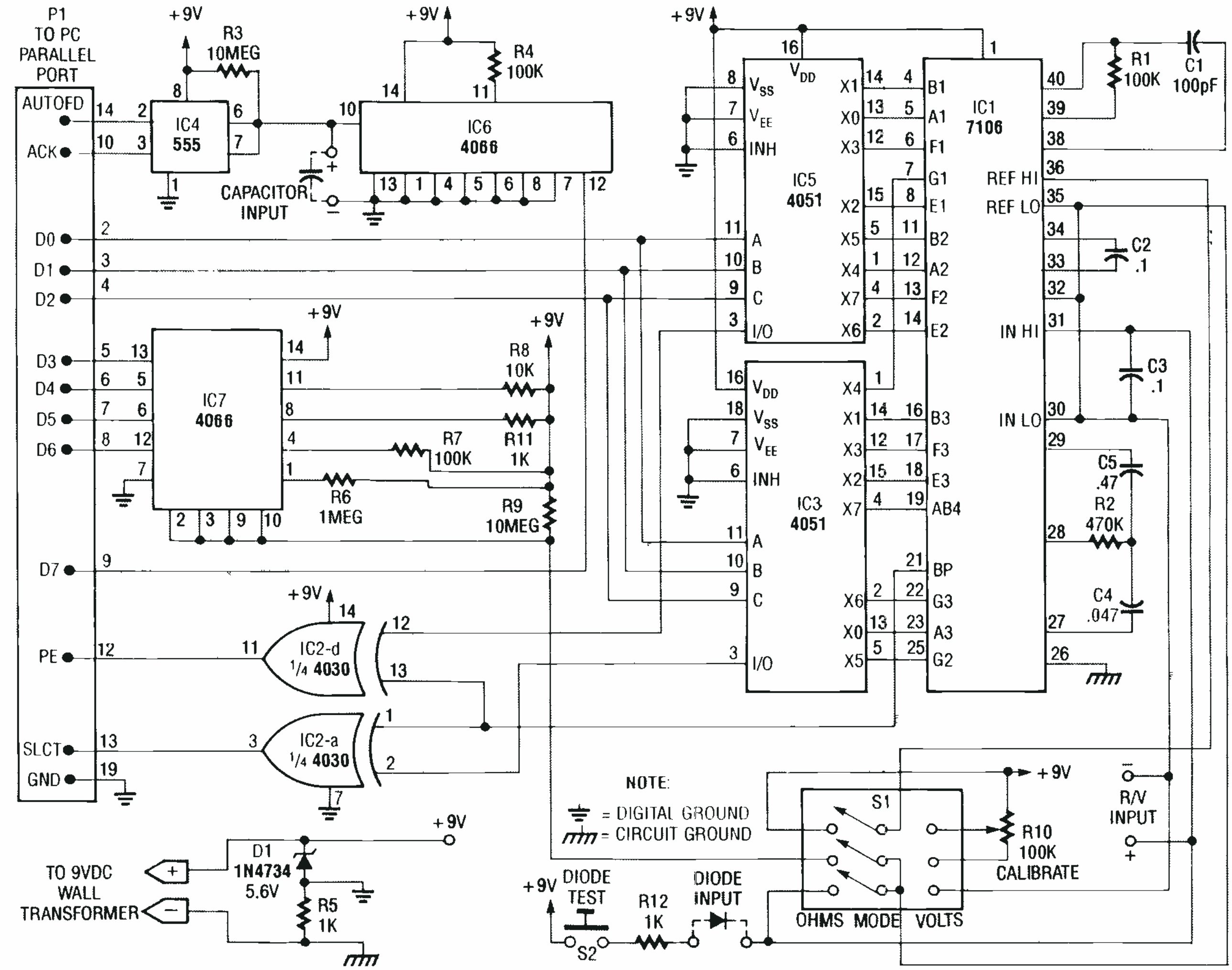


FIG. 5—COMPLETE SCHEMATIC. Data lines D0–D3 select one of eight segment-output lines through the 4051's (IC5, IC6). Range selection is accomplished by data lines D3–D6, which select one of four resistors through analog-switch IC7. The selected resistor, if any, is paralleled with R9, thereby decreasing effective resistance.

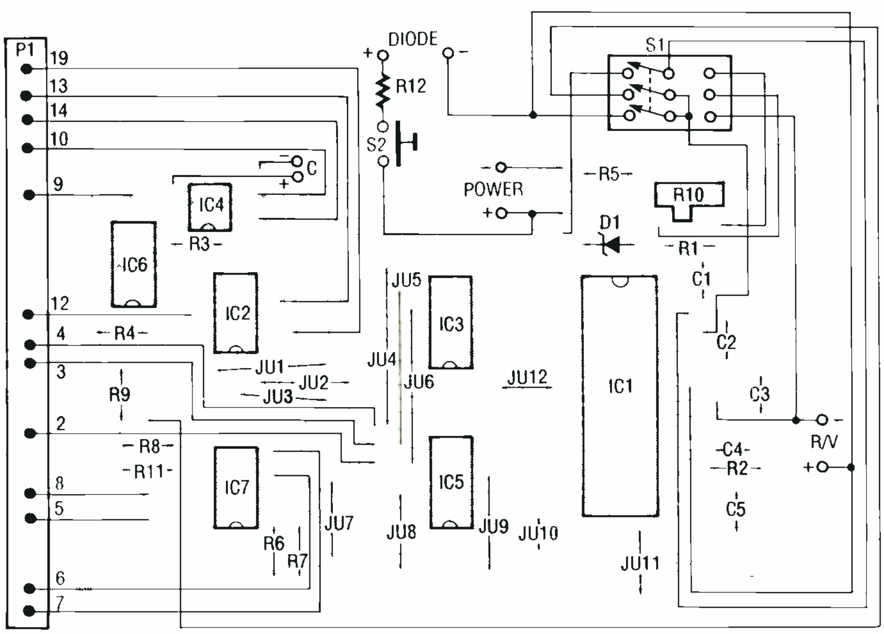


FIG. 6—MOUNT ALL COMPONENTS as shown here, installing the twelve jumpers first.

and from the author, as mentioned in the parts list. Listing 1 shows the resistance-measurement program.

Calibration and use

Both the hardware and the software must be calibrated. Begin hardware calibration by connecting a DMM across the wiper and the lower end of R10, and set S1 to the "volts" position. Apply power and adjust R10 until the DMM reads 1.000 volt.

Begin software calibration by executing the OHMFAX program. The screen will initially show null calibration factors for the five resistance ranges, R1–R5. The program asks whether you want to revise those values; press Y and enter the following initial values: R1, 10000; R2, 1000; R3, 100; R4, 10; R5, 1. The Revise question will appear again; press N this time. Then the program asks whether to save the values you just entered; press Y. Now the

LISTING 1

```
REM************************
REM**     OHMS.BAS        *
REM**      V900518        *
REM************************
DEF SEG = 64: DEFINT A-C, I-K: DEFDBL R, V, X
DIM a(9), j(7), k(7), r(5), r$(5), m(5), f$(6), ft$(6)
OPEN "r", 1, "ohmfax.dat", 50
 FIELD 1, 10 AS r1$, 10 AS r2$, 10 AS r3$, 10 AS r4$, 10 AS r5$
 GET 1, 1
 r(1) = VAL(r1$): r(2) = VAL(r2$): r(3) = VAL(r3$)
 r(4) = VAL(r4$): r(5) = VAL(r5$)
CLOSE
a(0) = 15: a(1) = 2: a(2) = 23: a(3) = 19: a(4) = 26
a(5) = 25: a(6) = 29: a(7) = 3: a(8) = 31: a(9) = 27
m(1) = 0: m(2) = 8· m(3) = 16: m(4) = 32: m(5) = 64
r$(1) = "20Meg": r$(2) = "2 Meg": r$(3) = "200 K"
r$(4) = "20 K ": r$(5) = "2 K  "
comma$ = CHR$(34) + ","
GOSUB S1: C = PEEK(8) + 256 * (PEEK(9)) + 2: B = C - 1: a = B - 1
imsk = 5: imskold = imsk: readingold = -999: OUT a, m(imsk)
LOCATE 20, 4
COLOR 0, 7: PRINT " M "; : COLOR 7, 0: PRINT "easure, ";
COLOR 0, 7: PRINT " D "; : COLOR 7, 0: PRINT "atalog, ";
COLOR 0, 7: PRINT " E "; : COLOR 7, 0: PRINT "nd, or ";
PRINT "Range: ": LOCATE 21, 43
PRINT " 1      2      3      4     "; : COLOR 0, 7: PRINT " 5 ";
: COLOR 7, 0
FOR i = 1 TO 5: LOCATE 20, 43 + (i - 1) * 7: PRINT r$(i): NEXT
LOCATE 20, 71: COLOR 0, 7: PRINT r$(5): COLOR 7, 0
GOTO tryagain:
 REM
 REM**** SETUP COMPLETED - MEASUREMENT LOOP BEGINS
 REM
begin:
OUT a, m(imsk): LOCATE 9, 35: PRINT "Measuring... "
FOR i = 0 TO 7
  ii = i + m(imsk)
  OUT a, ii
    FOR rr = 1 TO 150: NEXT rr
  j(i) = INP(889) AND 16: j(i) = j(i) / 16
  k(i) = INP(889) AND 32: k(i) = k(i) / 32
NEXT
  REM
  REM**** MEASUREMENT LOOP ENDS - CALCULATE VALUE
  REM
ones = k(0) + k(1) * 2 + k(2) * 4 + k(3) * 8 + j(4) * 16
tens = k(4) + k(5) * 2 + k(6) * 4 + k(7) * 8 + j(5) * 16
huns = j(0) + j(1) * 2 + j(2) * 4 + j(3) * 8 + j(6) * 16
thos = j(7): IF huns = 0 THEN huns = 99
FOR i = 0 TO 9
  IF ones = a(i) THEN ones = i: GOTO JUMP1
NEXT
JUMP1:
FOR i = 0 TO 9
  IF tens = a(i) THEN tens = i: GOTO jump2
NEXT
jump2:
FOR i = 0 TO 9
  IF huns = a(i) THEN huns = i: GOTO JUMP3
NEXT
JUMP3:
reading = thos * 1000 + huns * 100 + tens * 10 + ones
  REM
  REM**** VALUE CALCULATED - DETERMINE IF STEADY STATE READING
  REM
IF reading <> readingold THEN readingold = reading: GOTO begin
  REM
  REM**** STEADY STATE READING - DISPLAY
  REM
LOCATE 9, 35
IF imsk = 1 THEN PRINT USING " ##.## Mohms"; reading * r(imsk) /
1000000: measuredvalue = reading * r(imsk) / 1000000
IF imsk = 2 THEN PRINT USING " #### Kohms "; reading * r(imsk) /
1000: measuredvalue = reading * r(imsk) / 1000
IF imsk = 3 THEN PRINT USING "###.# Kohms "; reading * r(imsk) /
1000: measuredvalue = reading * r(imsk) / 1000
IF imsk = 4 THEN PRINT USING " ##.# Kohms "; reading * r(imsk) /
1000: measuredvalue = reading * r(imsk) / 1000
IF imsk = 5 THEN PRINT USING " #### ohms  "; reading * r(imsk):
measuredvalue = reading * r(imsk)
IF huns = 99 AND thos = 1 THEN LOCATE 9, 35: PRINT "OVERRANGE !!
"
BEEP
LOCATE 12, 37
tryagain:
reply$ = UCASE$(INPUT$(1))
IF VAL(reply$) < 1 OR VAL(reply$) > 5 THEN GOTO tryagain2
imsk = VAL(reply$)
LOCATE 21, 43 + (imskold - 1) * 7: COLOR 7, 0: PRINT
STR$(imskold); " ";
LOCATE 20, 43 + (imskold - 1) * 7: PRINT r$(imskold)
LOCATE 21, 43 + (imsk - 1) * 7: COLOR 0, 7: PRINT " "; reply$; "
";
LOCATE 20, 43 + (imsk - 1) * 7: PRINT r$(imsk)
COLOR 7, 0: imskold = imsk: OUT a, m(imsk): GOTO tryagain
tryagain2:
SELECT CASE reply$
  CASE "M"
   GOTO begin
  CASE "E"
   CLOSE : END
  CASE ELSE
   SOUND 100, 4
   GOTO tryagain
  END SELECT
GOTO begin
END
S1:
CLS : LOCATE 1, 23: COLOR 0, 7: PRINT SPACE$(35)
LOCATE 2, 23: PRINT " MANUFACTURING TECHNOLOGY FACILITY "
LOCATE 3, 23: PRINT "           PC OHM METER            ":
LOCATE 4, 23: PRINT SPACE$(35): COLOR 7, 0
LOCATE 8, 30: PRINT CHR$(222); STRING$(19, 223); CHR$(221)
LOCATE 9, 30: PRINT CHR$(222): LOCATE 9, 50: PRINT CHR$(221)
LOCATE 10, 30: PRINT CHR$(222); STRING$(19, 220); CHR$(221)
RETURN
```

program ends. You will repeat the procedure later, after the meter is up and running, to refine the calibration factors.

To measure resistance, power up your computer and connect P1 to your computer's LPT1 port. Plug in the power cube and execute the OHMS program. Note that you have five ranges (Range 1–Range 5) to choose from; Range 5 is the default. To change ranges, simply press the corresponding number on the keyboard, and the selected range will be highlighted on the screen. Place S1 in the "ohms" position, and connect a test resistor to the R+ and R− terminals. Press M on the keyboard to make a measurement. As with many DMM's, readings on the higher resistance ranges take somewhat longer than on the lower ranges.

To refine calibration you'll need a DMM. Select Range 5 and measure a 1K resistor. Remove the resistor and measure it with the digital multimeter. If the readings are not the same, use the following formula to calculate a new calibration factor for Range 5:

$$R5 = 1 + (R_{DMM} - R_{CIS}) \times 2$$

where R_{DMM} is the DMM reading and R_{CIS} is the reading with our meter.

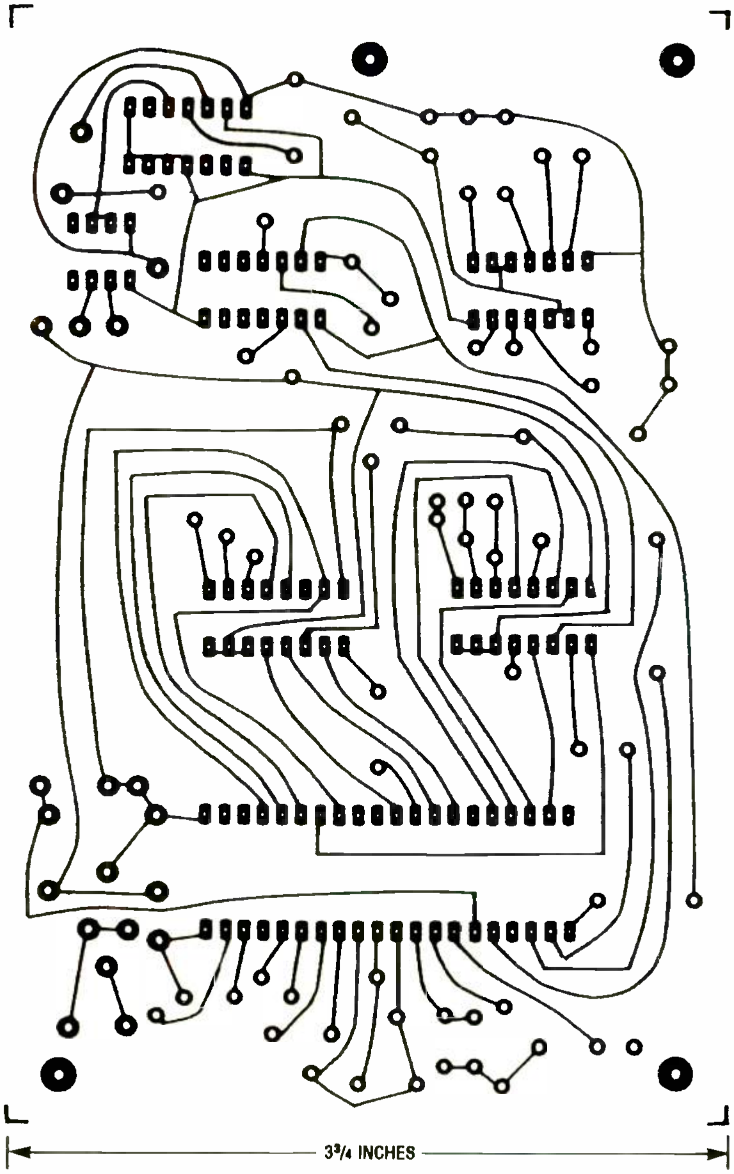
Repeat that procedure with a 10K resistor for Range 4, a 100K resistor for Range 3, a 1 megohm-resistor for Range 2, and a 10-megohm resistor for Range 1. Calculate approximate new factors using the following formulas:

$$R4 = 10 + (R_{DMM} - R_{CIS}) \times 2$$
$$R3 = 100 + (R_{DMM} - R_{CIS}) \times 2$$
$$R2 = 1000 + (R_{DMM} - R_{CIS}) \times 2$$
$$R1 = 10000 + (R_{DMM} - R_{CIS}) \times 2$$

End the program by pressing E on the keyboard. Recalibrate using OHMFAX, entering the calculated factors. Repeat the entire process several times until the CIS and DMM readings match each other.

As for voltage, you can measure an input between 0 and 1.999 volts DC. To extend the range, use a simple voltage divider, as shown back in Fig. 2.

To measure voltage, place S1 in the "volts" position and execute the DIODE program. When ready to measure, press M on the keyboard. To measure the forward voltage drop across a diode or the



FOIL PATTERN shown actual size.

base-emitter junction of a transistor, insert the device into the appropriate terminals and press S2; doing so forward biases the junction and thereby allows you to measure the voltage drop across it.

Capacitance measurement works as described in May. Place the capacitor to be measured in the C+ and C− terminals; the position of S1 is irrelevant. Execute the CAP program. When ready to measure, press M on the keyboard. Note: The capacitance meter described last time used parallel port line D6 to switch the low range resistor in, but the current version uses line D7. Hence there is a minor change to the CAP program. The line immediately below the RESTART: label must be changed from OUT A,64 to OUT A,128.

Conclusion

This project is a versatile computer-assisted test instrument. You can increase its versatility by modifying the software. For example, you could include data logging or the ability to specify pass/fail criteria for different components. In that way data could be analyzed to determine the quality of components supplied by different vendors. In the final installment of this three-part series, we'll build an IC tester to round out our computer-controlled component inspection system. R-E

NEW WORLD OF DSP

continued from page 47

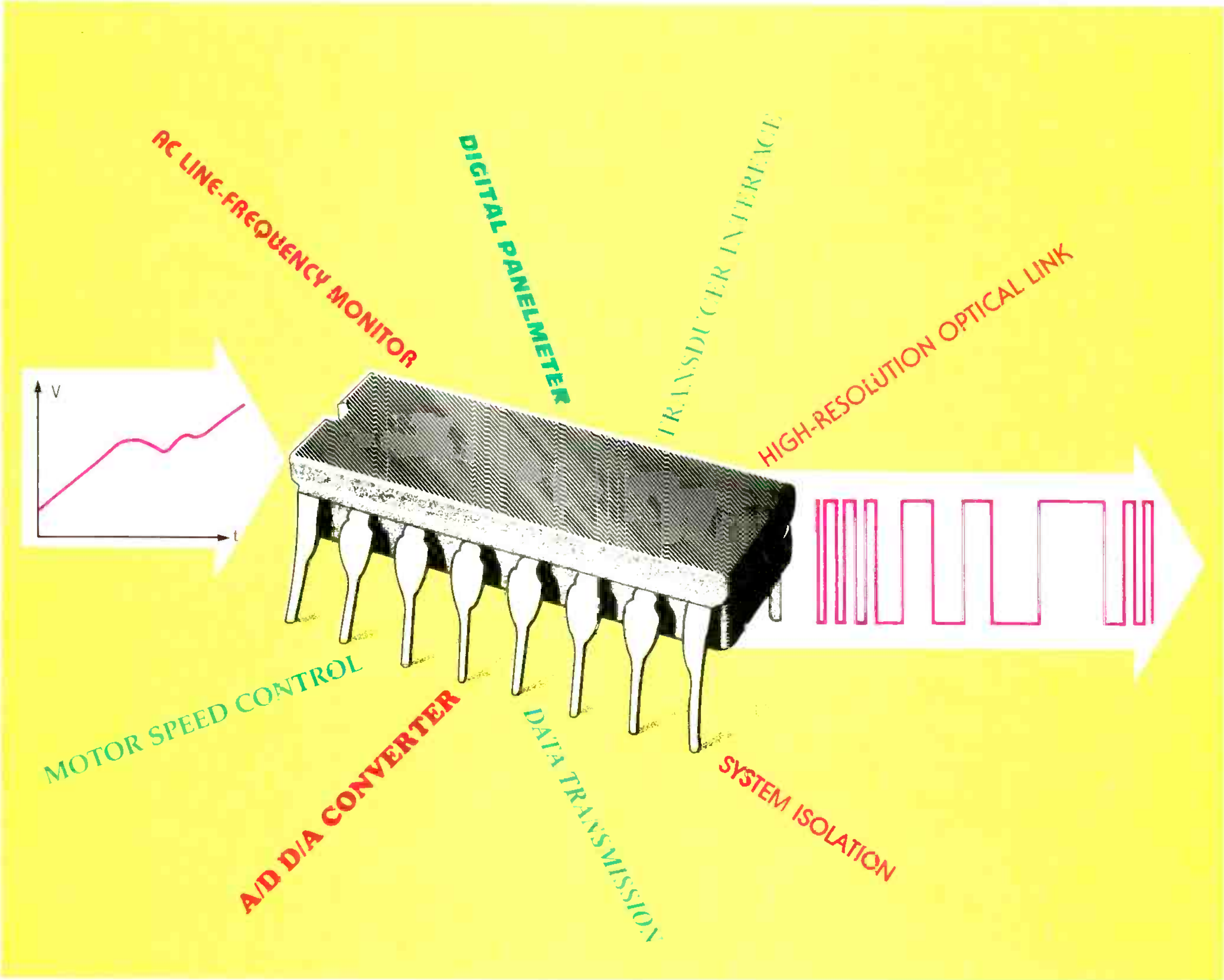
vices with modems for data compression. At least one company specializes in the preparation of entire sets of DSP IC's to meet particular signal-processing requirements.

Two Motorola 56ADC's are at the heart of Ariel Corp.'s DM-N digital microphone (Fig. 4), which is designed for direct connection to the NeXT computer system, and the same company already has designed an IBM/AT-compatible plug-in board that contains a pair of DSP96002's. This board, the MM-96, can provide a microcomputer with mainframe-class multimedia performance for scientific, industrial or artistic applications.

And a company in Phoenix is working on a DSP-controlled muffler that is said to improve automobile performance by between eight and fifteen percent! Using electronic noise cancellation techniques, this "stealth" muffler (Fig. 5) does away with baffles and other obstructions, allowing exhaust gases, but not the noise that usually accompanies them, to pass straight through. A fringe benefit of a DSP muffler would allow you not only to silence your engine, but perhaps also to tailor the muffler's output to make your Chevy Nova sound like a Ferrari. Work is also being done on silencers for such notorious noisemakers as helicopters. Shades of Blue Thunder!

The DSP technology and applications we are seeing now are just the beginning of what will prove to be a significant era in electronics. Consumer products that include DSP circuits are soon going to be popping up like flowers blossoming after a desert rain. Some applications are ripe for DSP now, but some of the devices that we will soon see will perform functions of which we have not yet even conceived. Some of the uses to which DSP will be put will be ingenious, and some of them absurd. And a few of the applications will have a significant and long-term effect on the way we conceive of and use electronics. R-E

V/F CONVERTERS



Voltage-to-frequency converters can often be an inexpensive alternative to A/D and D/A converters.

HARRY L. TRIETLEY

IN TODAY'S WORLD OF HIGH-PERFORMANCE single-chip analog-to-digital converters, the simple voltage-to-frequency (V/F) converter is sometimes overlooked. However, V/F converters offer the best combination of resolution, performance, simplicity, and cost in analog-to-digital (A/D) conversion when speed is not important. They can be used for isolation, and to eliminate ground loops and shock hazards, especially in patient-attached medical instruments. Their serial outputs make them ideal for two-wire or fiberoptic data transmission. Long-term data (flow, kilowatt hours, and so on) may be totaled or integrated by counting their output pulses.

The performance and features available in today's V/F converter IC's make it easy for you to design your own applications. V/F converter IC's may also be used to build frequency-to-voltage (F/V) converters, which can act as an interface with TTL logic. In this article we'll look at a number of IC's used in several applications.

Charge-balance conversion

Figure 1 shows a basic V/F converter using Burr-Brown's VFC32 IC, along with typical circuit values. The VFC32 operates up to 500 kHz. Typical linearity is 0.005% to 10 kHz, 0.025% to 100 kHz, and 0.05% to 500 kHz. Linearity is a measure of the V/F converter's performance, and is a function of the full-scale frequency, f_{FS}. It is the maximum deviation of the actual transfer function from a straight line drawn between 90% and 0.1% of f_{FS}. For a particular f_{FS}, the linearity error decreases with decreasing operating frequency.

The input amplifier is connected as an inverting integrator. Negative feedback holds pin 1 to zero volts. Optional components

R3 and R4 allow the offset to be precisely adjusted so that C2 neither charges nor discharges when V_{IN} is zero.

If V_{IN} is zero, C2's charge holds steady and nothing happens. When a positive input is applied, the input current

$$I = V_{IN}/(R1 + R2)$$

charges C2 so that pin 13 ramps downward. When C2's voltage crosses zero, the comparator triggers the one-shot, closing S1 and momentarily applying the 1-mA reference current to the integrator's input. That charges C2 in the opposite direction, resetting the voltage on pin 13 positive and allowing the cycle to start over.

If V_{IN} is increased, the downward ramp occurs faster, raising the pulse frequency proportionally. The full-scale input current must be less than 1 mA; the specification sheets recommend 0.25 mA full scale for best linearity. (Above 200 kHz the input may be increased to 0.5 mA for improved temperature stability.) If the input voltage drops to zero, the capacitor's charge once again holds steady and the pulses stop.

That operation is known as "charge balance" conversion—the positive charge from the 1-mA source balances the negative charge from the input. Over one complete cycle the net charge on C2 does not change. The charge

$$Q = I \times T$$

removed by the input current during a complete cycle is equal to the charge added by the timed 1-mA reference. If T is the period of one cycle, and T_{OS} is the one-shot period, then

$$Q = [V_{IN}/(R1 + R2)] \times T = 1\ mA \times T_{OS}$$

or,

$$T = [1\ mA(R1 + R2)/V_{IN}] \times T_{OS}$$

The frequency is therefore

$$f = 1/T = V_{IN}/[1\ mA \times (R1 + R2) \times T_{OS}].$$

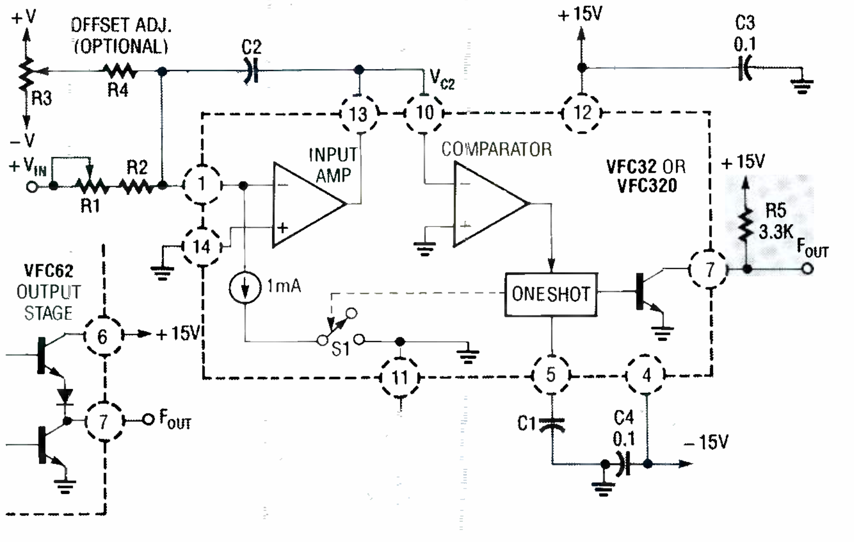
T_{OS} is equal to

$$7.5\ V \times (C1 + 30\ pF)/1\ mA$$

where 30 pF represents the internal capacitance of the IC, and 7.5 V is the internal voltage reference. A 25% duty cycle or less is recommended to achieve best linearity. That corresponds to a maximum input current of 0.25 mA.

The external one-shot capacitor C1 determines the duration of the output pulse, and is dependent on the full-scale frequency, f_{FS}, according to the equation

$$C1\ (pF) = 33 \times 10^6/(f_{MAX} - 30)$$



CIRCUIT VALUES

Full-Scale Input	Full-Scale Frequency	C1	C2	R1 (ohms)	R2 (ohms)
1 V	10 kHz	3300 pF	0.01 µF	1K	3K
10 V	10 kHz	3300 pF	0.01 µF	10K	30K
1 V	100 kHz	300 pF	0.001 µF	1K	3K
10 V	100 kHz	300 pF	0.001 µF	10K	30K

FIG. 1—A CHARGE-BALANCE V/F CONVERTER using a VFC32 IC. The positive charge from the 1-mA balances the negative charge from the input.

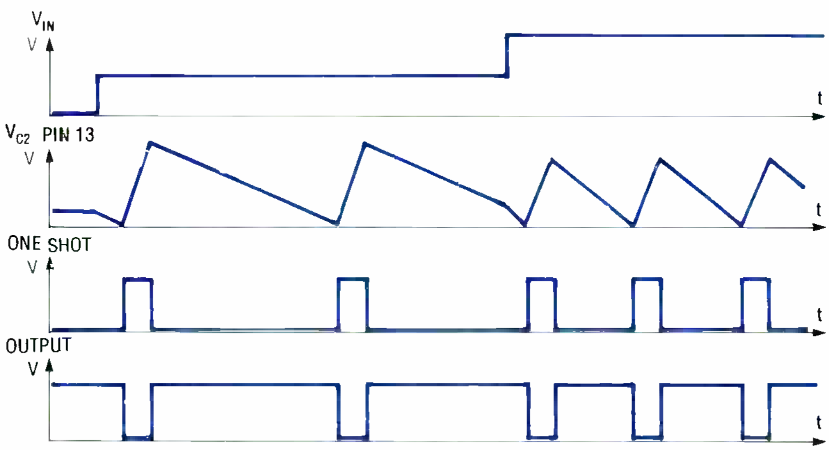
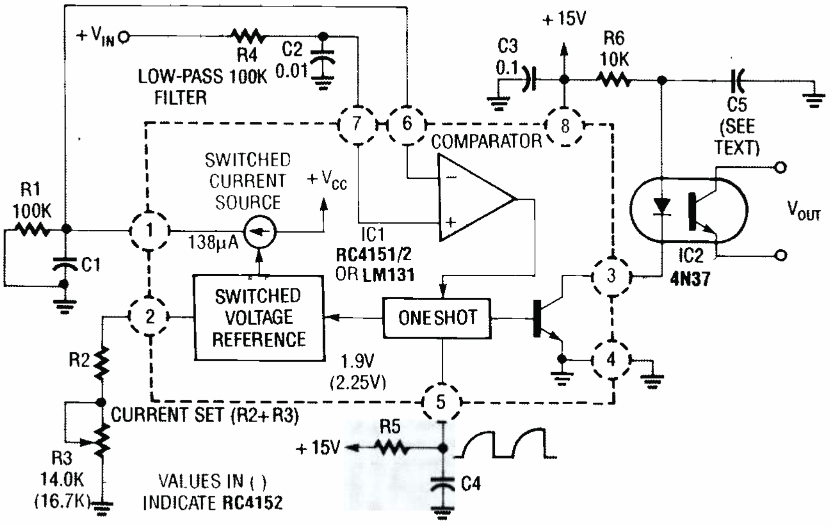


FIG. 2—V/F CONVERTER WAVEFORMS for Fig. 1.

Resistor R1 is used to trim the tolerances of C1 and IC1. A low-temperature type capacitor should be used for C1, an NPO ceramic is best for this type of application.

Notice that C2's value does not affect the frequency. The only requirement is that it be large enough to keep the voltage swing at pin 13 within the limits of the input amplifier. The manufacturer's recommendation is $(100/f_{MAX})$ microfarads below 100 kHz, or 0.001 µF above 100 kHz. Low-leakage is important, therefore, a mylar capacitor is recommended. Waveforms of the Fig. 1 circuit are shown in Fig. 2.

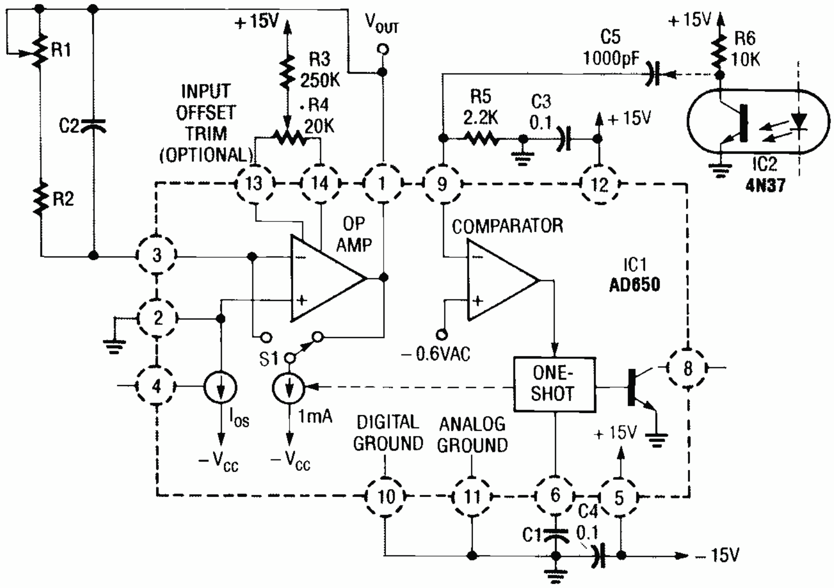
Before moving on, let's briefly mention two upgraded versions of this IC from Burr-Brown: VFC62 and VFC320. VFC62 is pin-compatible with VFC32, but it adds an active-pullup transistor, as shown in Fig. 1. It also operates up to 1 MHz, has better temperature stability, and slightly better linearity. To use the active pullup, pin 6 must be tied to the +15-volt supply. In a VFC32 circuit (pin 6 unused) the external pullup resistor, R5, will still work. The MVFC320 has improved specifications, and is similar to the VFC62 but has pinouts and output circuitry identical to the VFC32.



CIRCUIT VALUES

Full-Scale Input	Full-Scale Frequency	C1	C4	R5 (ohms)
10 V	1 kHz	10 μF	0.1 μF	6.8K
10 V	10 kHz	1 μF	0.01 μF	6.8K
10 V	100 kHz	0.1 μF	0.001 μF	6.8K

FIG. 3—A LOW-COST V/F CONVERTER WITH OPTOCOUPLER output. The output is fed to an optocoupler for input/output isolation. The circuit can be used to pulse an LED input into a fiberoptic cable.



CIRCUIT VALUES

Full-Scale Frequency	Full-Scale Output	C1	C2	R1 (ohms)	R2 (ohms)
10 kHz	1 V	3300 pF	3.3 μF	1K	3.8K
10 kHz	10 V	3300 pF	0.33 μF	10K	38.3K
100 kHz	1 V	680 pF	0.33 μF	500	1.82K
100 kHz	10 V	680 pF	3300 pF	5K	18.2K
1 MHz	1 V	47 pF	3300 pF	500	1.33K
1 MHz	10 V	47 pF	1000 pF	5K	13.3K

FIG. 4—A V/F CONVERTER CAN BE MADE INTO AN F/V converter using an AD650 IC.

A low-cost optocoupled output

Raytheon introduced the first V/F converter IC, the RC4151, now also second-sourced by Exar as the XR4151. Also available are the RC4152 with better specifications and National Semiconductor's pin-compatible LM131. The LM131 is similar to the VFC32 except that it lacks the input op-amp. By using an external op-amp it can be applied similarly to the VFC32. In fact, in low-level applications it may be advantageous to choose a high-grade external amplifier.

Figure 3 shows the RC4151's basic operation. Typical circuit values are also shown in this figure. The current source is pulsed by the one-shot, which applies a fixed charge ($Q = I \times T$) on C1. Between pulses, C1 discharges through R1. Each time C1's voltage drops below V_{IN}, the one-shot is retriggered. As V_{IN} goes higher, to so does the retrigger point and, therefore, the voltage on C1. As C1's voltage doubles so does the rate of discharge through R1. It takes twice the pulse rate to keep C1 charged. The output pulse rate, therefore, increases in proportion to V_{IN}.

In this application, the output is fed to an optocoupler for input/output isolation. The same circuit can be used to pulse an LED input to a fiberoptic cable. When the one-shot fires, pin 3 is pulled low. Capacitor C5 charges between pulses, providing a short high-current pulse to the LED. (The same effect could be obtained by omitting C5 and making R6 smaller, but the power supply pulses would be higher.)

This circuit is less linear than those using op-amp integrators and is recommended for limited input ranges which do not go to zero. For an input range of 0.01–10 V, and a full-scale output of 10 kHz, linearity will be better than 1%.

F/V conversion

Figure 4 shows how a V/F converter IC may be used to create a frequency-to-voltage (F/V) converter. The high-performance AD650, available from Analog Devices and Maxim, is similar to the VFC32 but it offers guaranteed linearity of 0.1% up to 1 MHz. Typical linearity is 0.002% to 10 kHz, 0.005% to 100 kHz and 0.07% to 1 MHz. An added offset current source simplifies the design of offset or bipolar input ranges, but we will not make use of that in our application.

In Fig. 4, the AC or pulsed input is applied to the comparator. Each time it drops below −0.6 volts, the one-shot is triggered, switching S1 to the op-amp's in-

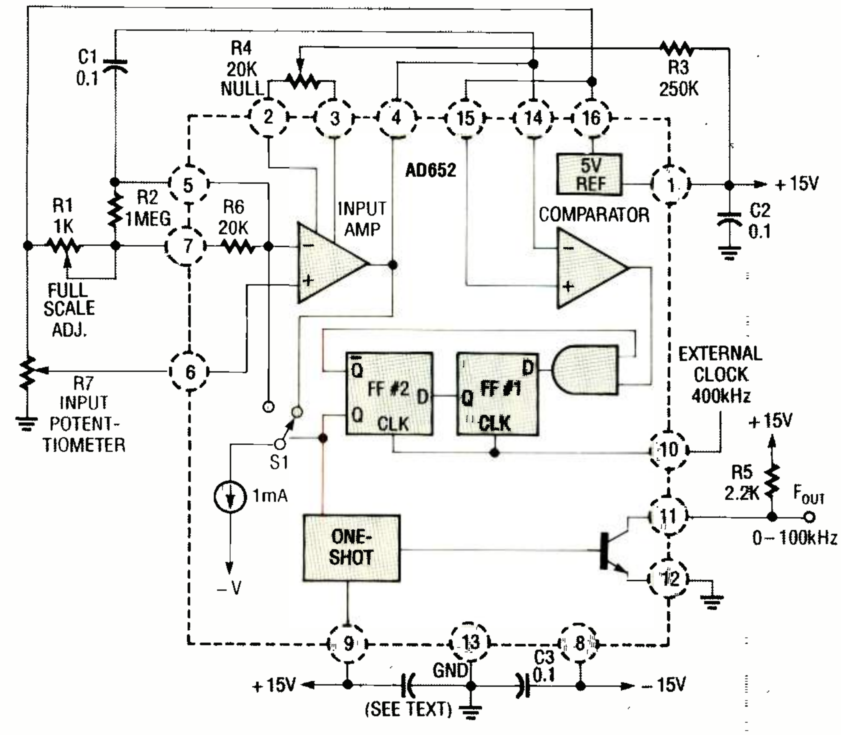


FIG. 5—AN A/D POTENTIOMETER INPUT APPLICATION. This circuit shows an AD652 IC used to convert from potentiometer position to frequency

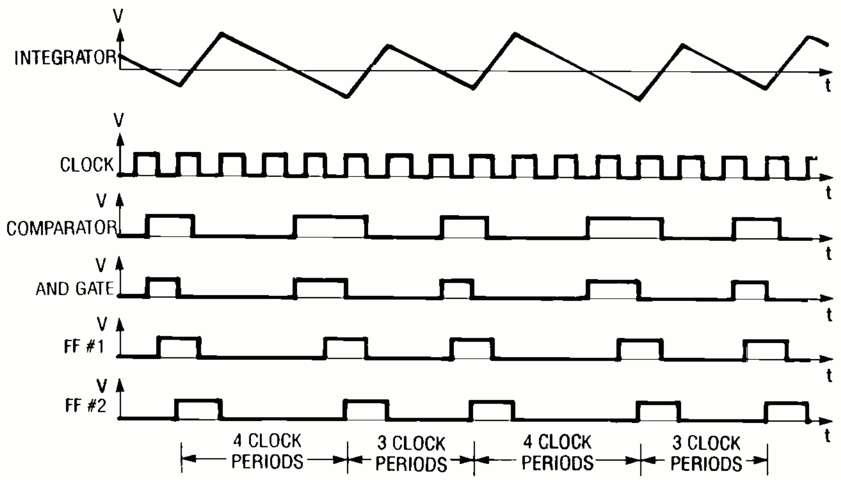


FIG. 6—TYPICAL WAVEFORMS for Fig. 5.

put and drawing a timed current pulse. Between pulses, the 1-mA current is connected to the op-amp output. (That has no effect on the overall circuit operation since the op-amp's output simply supplies an extra milliamp to the current source.)

The average current represented by the on-off pulses is

$$1 \text{ mA} \times T1/T, \text{ or}$$
$$1 \text{ mA} \times T1 \times f_{IN}$$

where T1 is the one-shot's pulse width, and T is the input period ($f_{IN} = 1/T$). The op-amp is connected as a low-pass filter. Each current pulse raises C2's output; capacitor C2 discharges through R1 and R2 between pulses. The DC output is

$$V_{OUT} = I_{AVG} \times (R1 + R2), \text{ or}$$
$$V_{OUT} = 1 \text{ mA} \times (R1 + R2) \times T1 \times f_{IN}.$$

The output is proportional to frequency, with the conversion factor determined by the value of R1 + R2 and by T1 which, in turn, is determined by C1. Capacitor C2 does not affect the conversion, it only filters the ripple.

T1 can be found by

$$T1 \text{ (ms)} = 6.8 \times C1 \text{ (}\mu\text{F)} + 0.0003.$$

The output becomes

$$V_{OUT} = [R1 + R2 \text{ (Kohms)} \times 6.8C1 \text{ (}\mu\text{F)}] + [0.0003 \times f_{IN} \text{ (kHz)}].$$

Typical component values are shown in Fig. 4.

The values of C5 and R5 are for TTL or other fast-risetime inputs, such as the optional optocoupler shown. Sine waves or other slow waveforms may need to be "squared up" by a comparator or amplifier before being fed to this circuit. The input pulse is differentiated by the high-pass R-C filter so that it does not spend much time below −0.6 volts. If pin 9 were below −0.6 volts at the end of T1, the one-shot would retrigger, producing an incorrect output.

Synchronized V/F conversion

The circuits we have seen so far depend on a one-shot circuit and capacitor for the charge-balance pulse width. If the one-shot period changes with temperature, time, or line voltage, so will the conversion factor.

Let's now look at an IC that's synchronized to an external clock. If the clock is crystal-controlled, the circuit's drift will be determined by the input resistor and the 1-mA source. Figure 5 shows Analog Devices' AD652 in a potentiometer input application. Figure 6 shows the waveforms. (Burr-Brown makes a similar IC, the VFC-100, lacking only in the optional offset trim capability.) The best grade of AD652 provides guaranteed temperature stability of 25 ppm per °C at 1 MHz, 50 ppm per °C at 4 MHz, with linearity of 0.02% or better at 4 MHz.

The IC's circuitry looks much like the others we've seen, but with added logic circuitry between the comparator and the one-shot. If the comparator's output goes high and flip-flop #2's Q output is high, the AND gate's output also goes high. Flip-flop #1's output will be clocked high by the next negative clock transition.

On the following positive clock transition, flip-flop #1's output will be clocked through flip-flop #2, bringing both Q and the AND gate output low. The following two clock transitions transfer this low data first to flip-flop #1's output, then to flip-flop #2. The end result is that each time the comparator goes low, a one-clock-period pulse will be produced. That pulse determines the amount of time that the 1-mA source is connected to the input.

The one-shot is used only to control the length of the output transistor's pulse. It has nothing to do with the conversion factor. Bringing pin 9 high disables the one-shot, in which case the output pulse width will equal the clock's period.

The input from potentiometer R7 is useful for many types of measurements. In addition to rotary or linear position, the potentiometer can be attached to mechanisms such as floats, pressure, or weight gauges.

The inverting input and R7 are both connected to the IC's built-in 5-volt reference. As the wiper goes clockwise, the input amplifier integrates the difference between the 5-volt reference and the wiper voltage, so decreasing the wiper voltage increases the output frequency.

The AD652 is scaled so that, at 10 volts, the output is half the clock frequency. In fact, both the conversion rate and the 5-volt reference are laser-trimmed to better than 1%, so that it can be used without trimmer potentiometers if ultimate accuracy is not needed. In that circuit, R4 (null) and R1 (full scale) allow fine calibration to better than 0.1%. Since the input is 0–5 volts, full-scale output will be ¼ the clock frequency.

Synchronized conversion is great for long-count accuracy but poor for pulse-to-pulse stability. That's because the 1-mA "reset" is not synchronized with the integrator's zero crossing, but is tied to the clock. Notice in Fig. 6 the first reset begins ¾ clock period after the integrator crosses zero and lasts one clock cycle. On the next cycle, because of the relative timing of the zero crossing, reset does not begin until 1-1/4 periods later. That means the integrator has time to go further negative before reset begins and it will be less positive after reset.

The third discharge gets to zero faster. In this example it also requires only ¾ period before reset begins. Overall, the output period jitters back and forth between three and four clock pulses. If you count the average period or frequency over 1000 pulses, for example, you will get a very accurate result. But if you try to measure individual pulses, the results will be meaningless. Use synchronized conversion for high-resolution (long-term counting) A/D conversion, or

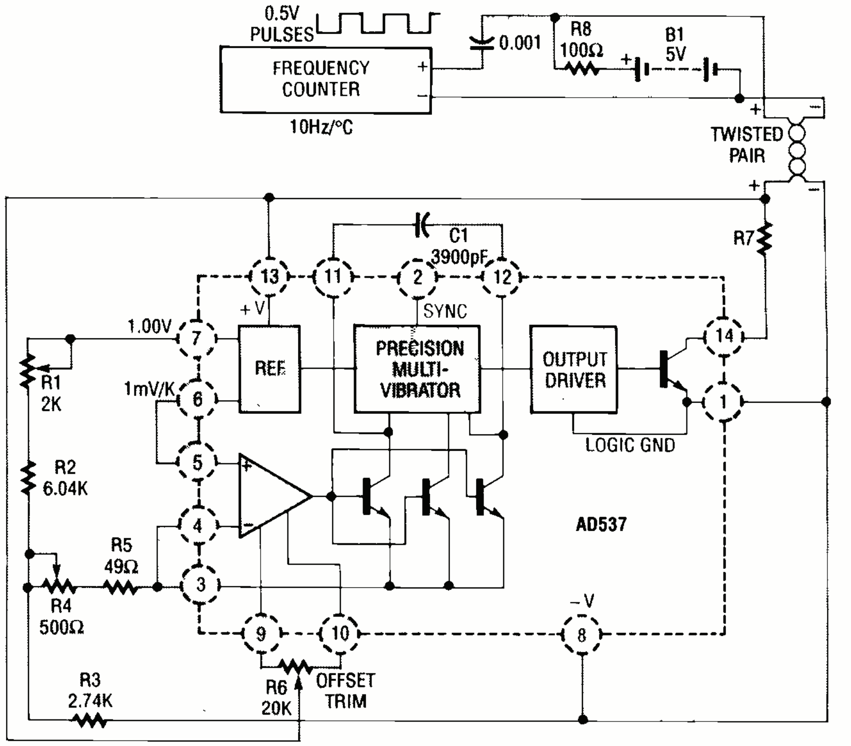


FIG. 7—A TEMPERATURE SENSOR AND V/F CONVERTER can be made from an AD537 IC. Here it is used for two-wire temperature data transmission.

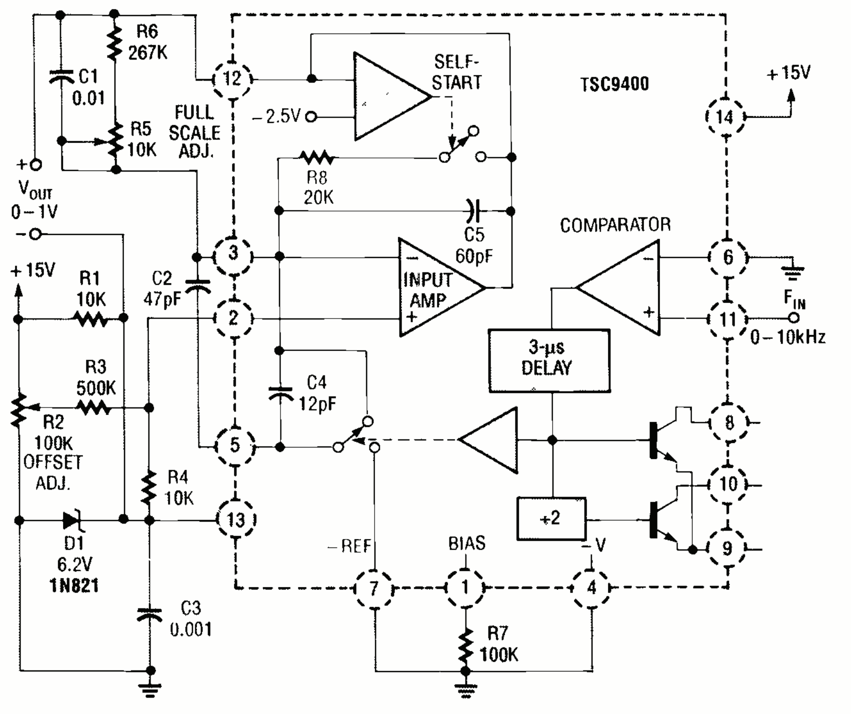


FIG. 8—A TSC9400 USED IN A SINGLE-SUPPLY F/V converter. A Zener diode offsets the IC's ground terminal. This circuit converts 0–10 kHz to 0–1 V.

data telemetry, but not for applications which count the time between individual pulses.

Multivibrator application

We'll now examine Analog Devices' AD537, which operates on a different principle. Figure 7 shows a unique two-wire temperature transmission system.

Let's look at how conversion is accomplished first, then we'll examine the temperature input and two-wire output. Conversion is provided by a precision multivibrator. The input amplifier controls three transistors in a "current-mirror" circuit. Two of the transistors provide charging current to the multivibrator's capacitor while the third controls bias levels in its circuitry. The result is linear current-to-frequency conversion from 0.1 μA to 2 mA. Best performance is achieved when the circuit is scaled for 1 mA full scale. The IC is specified to 100 kHz with worst-case nonlinearity of 0.25% or 0.1%, depending on the grade ordered.

Because the circuit is a multivibrator instead of a charge-discharge integrator, its output is automatically a square wave (50% duty cycle). At 1 mA the output is $f = 0.1/C$, where f is in kilohertz and C is in microfarads.

The AD537 provides two reference outputs; one fixed at 1 volt and a second which varies with temperature (1 mV per K, where K = Kelvins, which is equal to °C + 273.15). The circuit in Fig. 7 makes use of both references to scale the output to 10 Hz per °C. At 0°C, the divided-down voltage from the 1-volt reference will balance the 273-mV temperature signal. The current in R4 and R5 will be zero, resulting in zero output. As temperature rises, the current increases about 0.4 mA per °C, producing a frequency output of 10 Hz per °C.

The "two-wire" output indicates that only two wires are needed to carry both the power and the output. Each output pulse modulates the supply current by drawing 5 mA through R7. The pulses are received at the other end of the twisted pair as 0.5 volts pulses across R8. The pulses are coupled through C2 to a frequency counter, or perhaps an F/V converter similar to the circuit in Fig. 4. The two-wire principle can be used with any V/F converter, not just the AD537.

Now we'll show you how to calibrate the circuit. Measure the room temperature (T) and the voltage at pin 6 (V_6). The offset voltage (V_{OS}) can be computed by

$$V_{OS} = V_6 \times \frac{273.15}{T(°C) + 273.15}$$

Temporarily disconnect R5 and adjust R1 until the voltage across R3 equals V_{OS}. Reconnect R5 and adjust R4 for the correct output

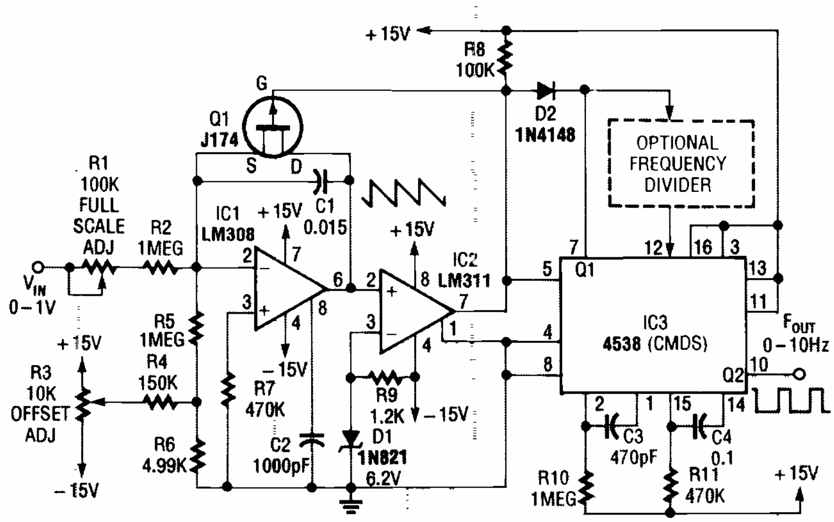


FIG. 9—A SIMPLE, LOW-FREQUENCY V/F CONVERTER built from standard IC's.

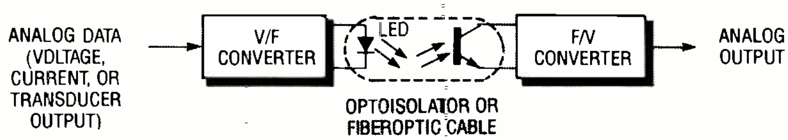


FIG. 10—ANALOG DATA CAN BE OPTICALLY COUPLED using two IC's, one as a V/F converter, the other as an F/V converter.

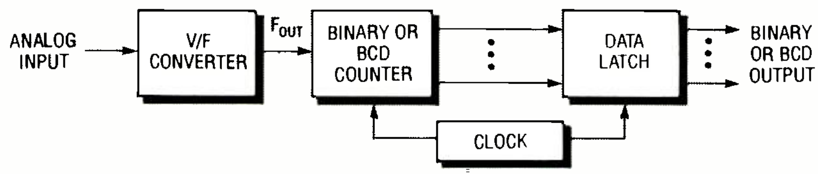


FIG. 11—A HIGH-RESOLUTION A/D CONVERTER can be made from a V/F converter and a counter.

frequency at 10 Hz/°C (for example, 250 Hz at 25°C).

Charge-balance

Teledyne's TSC9400 family of IC's illustrates a different type of charge-balance circuit using capacitance discharge. Instead of gating a current for a fixed period of time, reset is accomplished by charging a small capacitance via the input amplifier's summing junction.

Figure 8 shows the TSC9402 in a single-supply F/V converter. Other than its reset, operation is similar to the F/V converter of Fig. 4. We will not analyze Fig. 8 in detail but will just point out the differences.

The SPDT switch inside the IC normally shorts C2 and the internal 12 pF capacitance. When the comparator trips, the switch connects C2 to –REF for at least 3 μs. Capacitor C2 charges to the reference voltage of –6.2 V, causing a net charge flow of Q = C × V. That charge is transferred to C1 (plus its internal 60 pF shunt), raising the output. Between pulses the output decays through R5. The faster the pulses, the higher the average output. As with Fig. 4, C1 does not affect the output scaling but simply determines the amount of filtering.

The TSC9402's self-start circuit insures proper startup. Depending on how power comes up it's possible that C1 may begin with a negative charge. If the IC is used in a V/F converter similar to the circuit in Fig. 1, the comparator will already have switched and no further reset pulse will occur. If C1's output ramps below –2.5 V, the self-start comparator momentarily closes the switch, discharging C1 and resetting the output to zero.

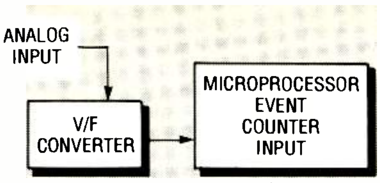


FIG. 12—EVENT COUNTER CAPABILITY is included in some microprocessors. They can be programmed to count pulses in a manner similar to Fig. 11.

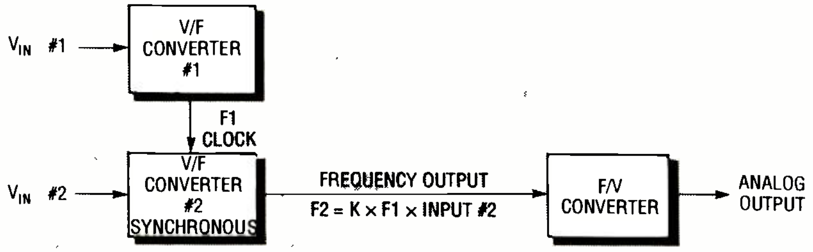


FIG. 13—A SYNCHRONOUS V/F CONVERTER produces an output proportional to both its input and its clock frequency. Shown here is the heart of an analog multiplier.

The lowest-cost version TSC9402 guarantees 0.25% linearity to 10 kHz (0.05% typical) and 0.5% to 100 kHz (0.25% typical). The best grade, TSC9401, guarantees 0.01% linearity to 10 kHz and 0.08% to 100 kHz.

A do-it-yourself circuit

Let's look at a simple circuit that you can build yourself without any specialized IC's. Although lower in performance than the IC's we've seen, it works well in low-speed applications.

The circuit of Fig. 9 charges C1 to a fixed reference level, instantly discharges it and then repeats the cycle. Op-amp IC1 is configured as an integrator. With a positive input, C1 charges until IC1's output reaches −6.2 V, at which point comparator IC2's output goes low. That turns on Q1, a P-channel JFET, and triggers the input half of IC3, a dual monostable multivibrator.

Pin 7 of IC3 is pulled low for 470 μs, keeping Q1 on long enough to insure that C1 is completely discharged. Once Q1 turns off, the cycle starts over. The output section of IC3 produces a longer output pulse, 47 ms in this circuit.

Component values for R1, R2, and C1 are chosen so that, at 1 V input, it takes 100 ms for C1 to charge to −6.2 V. The cycle repeats at a rate proportional to the input, 10 Hz at full scale. For lower output pulse rates a counter or frequency divider IC may be inserted between the two sections of IC3.

Low output frequencies are useful when totaling measurements over long periods of time. For instance, if the input comes from a circuit which measures kilowatts the output pulses can drive a mechanical or electronic counter to indicate kilowatt-hours. Or, the input could come from a flowrate meter, in which case the totaled count would represent total flow (gallons, liters, barrels, and so on). Another application involves measuring conveyer belt feed. If the belt moves at a constant speed, a signal from a weight transducer may be totaled to give the quantity of mass delivered over a period of time.

We should point out that C1 does not integrate while Q1 is on. That represents an error in the output period, and must be kept short. Because of that, this type of circuit is not suitable for high output frequencies.

Other applications

We'll finish this article with four application ideas. In Fig. 10 a V/F and F/V converter are optically coupled to provide analog signal isolation. That system isolates ground loops and provides noise immunity in industrial measurement applications. Fiberoptic communication also provides inherently safe data transmission through areas containing explosive gases.

In patient monitoring systems, optical isolation eliminates the shock hazard, especially if the front end is battery-powered. Operation up to 100 kHz and beyond allows transient signals such as electrocardiograms to be isolated as well as steady signals such as temperature.

Figure 11 shows how a V/F converter can be used to create a high-resolution A/D converter. Its output pulses are counted for a period of time determined by the clock. The longer the count, the higher the resolution.

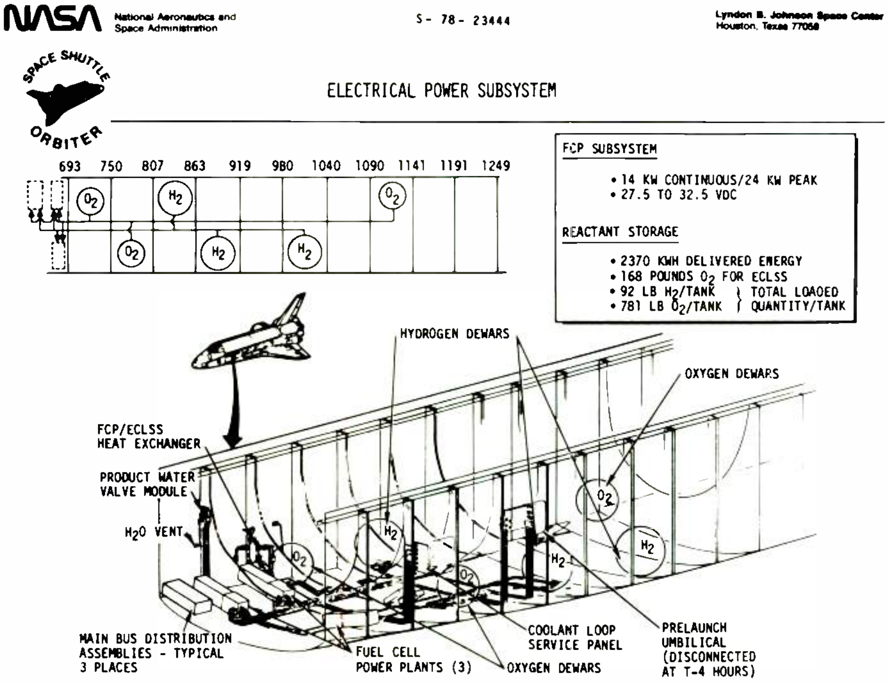
The tradeoff, however, is conversion speed. Successive-approximation and "flash" converters (see **Radio Electronics** February 1987) require extremely precise (and expensive) components as resolution increases, but they can convert in microseconds. Counter-based converters are great for high-resolution conversion of DC data, but you wouldn't use one to digitize audio or video!

In some systems the counter and latch can be replaced by microprocessor software. Some microprocessors include an event counter, making the electrical interconnection very simple (Fig. 12). Others may require the use of an interrupt port and carefully thought out software. Keep the microprocessor's clock speed and instruction set in mind when setting the V/F converter's output frequency range. Maximum pulse rates of 100 kHz are probably safe with most systems.

Once again, the tradeoff is speed. Counting ties up the microprocessor's central processing unit (CPU), limiting its availability for other functions. Such systems are best for simple, low-speed applications where resolution and low cost are important parameters.

Finally, Fig. 13 uses two V/F converters to perform analog multiplication. Converter number 1 produces an output, F1, proportional to input number 1. A synchronous converter is used to convert input number 2. Since the synchronous converter's full-scale output is set by its clock (F1), frequency F2 is proportional to input number 2 multiplied by F1. If a DC output is required, an F/V converter performs the conversion.

One of the things that makes electronics fun is the ability to use basic circuits to solve unique problems. Now that we've gotten you started, let's see how many V/F converter applications you can think up! **R-E**



FUEL CELLS

Could fuel cells be the ideal energy source of tomorrow?

RALPH HUBSCHER

FUEL CELLS COULD POTENTIALLY BE the most efficient and environmentally clean source of power ever developed. Fuel cells are an attractive alternative to conventional power generation because they are highly efficient, and produce drinking water as an added by-product. What more could you ask for in an energy source? The principle of fuel cell operation was discovered by Sir William Grove in 1839. He found that electricity could be generated by supplying hydrogen and oxygen to two separate electrodes immersed in sulfuric acid. For more than a century, however, fuel cells remained a mere curiosity.

The theory of fuel cell operation defied commercial applications for so long because of technical and financial obstacles. It wasn't until the 1960's, during the growth of the space program, that there was a renewed interest in developing fuel cell technology into a viable energy alternative to standard power generation.

There are two important concerns in conventional power generation: efficiency and pollution. Most of the power in the world is generated from heat engines using the heat from combustion of fossil fuels. Mechanical systems involve many energy conversion steps, and their efficiencies are limited by the laws of thermodynamics. That results in considerable power losses.

A fuel cell, on the other hand, converts potential chemical energy of fuel into electricity. It operates at a constant-temperature during the electrochemical process, therefore it's efficiency is not limited by thermodynamic laws governing heat engines.

Pollution is a result of combustion, industrial processing, and vehicle exhaust. Those pollutants consist of unburned fuel, partially burned fuel, carbon, carbon monoxide, carbon dioxide, dust, sulfur dioxide, nitrous oxides and so on. Waste heat from power plants warms up the rivers, causing havoc to the natural balance of fish and wildlife. And we all know of the devastating effects of acid rain, which results from man-made emissions of sulfur and nitrogen in the air. The by-product of a fuel-cell reaction, however, is water. Who would object to that?

Fuel-cell chemistry

Fuel cells operate by converting the potential energy of certain chemical reactions directly into electrical current in a flameless, catalyzed reaction. Some types of fuel cells work very well at room temperature.

A basic fuel cell consists of an anode (+) and cathode (−) separated by a conducting electrolyte such as a solution of potassium hydroxide. A fuel, such as hydrogen gas, or hydrazine, is introduced to the negative electrode where it is oxidized, releasing electrons to the load. Oxidation is the process of removing one or more electrons from an ion or molecule. In fuel cells, hydrogen ions are formed at the electrode by electrochemical oxidation of the fuel. If the fuel is hydrogen, hydrogen ions are created by the following ionization reaction:

$$H_2 \rightarrow 2H^+ + 2e$$

Oxygen, air, or hydrogen peroxide (a source of oxygen) is fed to the cathode, where it is reduced, whereby the O_2 oxygen molecule splits apart. Ionic conduction completes the circuit through the electrolyte. Hydrogen and oxygen react to form water, as this chemical equation shows:

$$2\ H_2 + O_2 \rightarrow 2H_2O, \text{ or}$$

Hydrogen + Oxygen → water

If hydrazine is oxidized, additional nitrogen is formed which is a normal constituent of air, and also safe:

$N_2H_4 + O_2 \rightarrow 2H_2O + N_2$, or
Hydrazine + Oxygen → Water + Nitrogen

You may be tempted to say that if hydrogen is such a "clean" fuel, we can just burn hydrogen in air and get pure water as the combustion product plus power. Burning hydrogen would indeed be a considerable improvement over burning coal, oil, or gasoline. However, when air is burned, a large amount of nitrogen is drawn into the combustion chamber and heated to roughly 1000°C. At that temperature, it partially reacts with oxygen and forms oxides of nitrogen. So, even though the reaction product of the main reaction is pure drinking water, the side reaction spoils it all by making the resulting water unsuitable to drink. If hydrogen and oxygen react in a fuel cell at room temperature, that problem is eliminated.

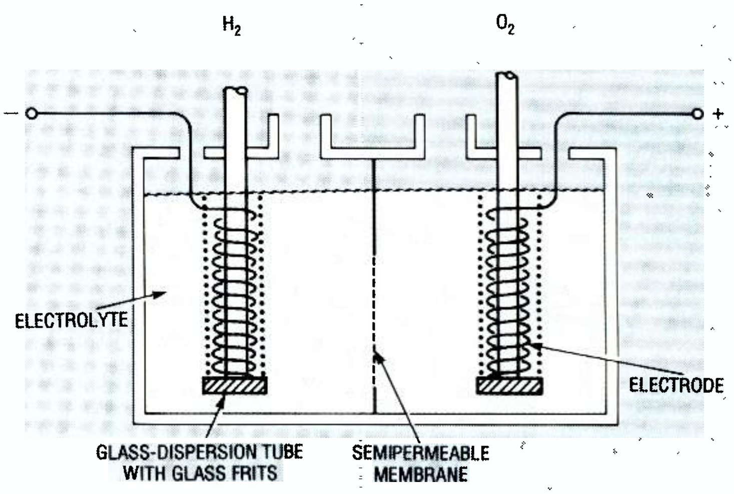


FIG. 1—THE AUTHOR'S FUEL CELL uses two adjoining chambers separated by a semi-permeable membrane. The chambers are filled with an electrolyte. Hydrogen is directed to one electrode, oxygen to the other.

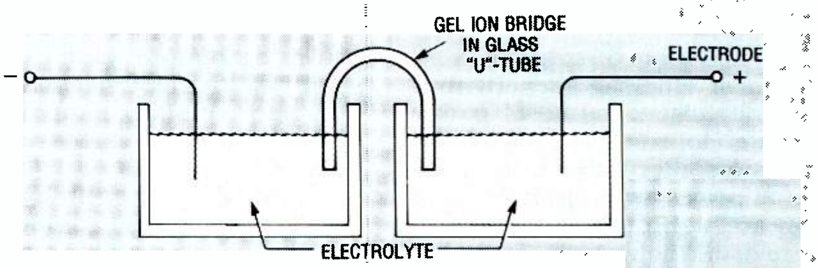


FIG. 2—IONS TRAVEL ALONG a gel-on bridge in a glass tube placed in the electrolyte solution.

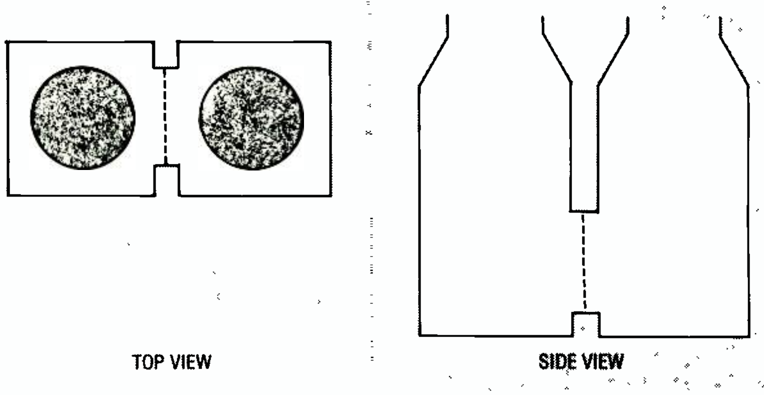


FIG. 3—THE CONTAINER used for the fuel cell consists of square-based 250-ml polyethylene bottles with holes cut in their sides. A round piece of fine glass was cemented in with sealing wax and an additional layer of beeswax.

Space-age power

The desirable characteristics of fuel cells led to the development of various systems ranging in size from 5-watt portable units, to the kilowatt (kW) power level for military applications, on up to large stationary plants delivering megawatts of power. The lower-power fuel cells were designed primarily for the space program and front-line military use where ease of operation, low maintenance, and low noise are important.

Fuel cells are used solely for power generation of space crafts because of one chief advantage: when power is required for more than a few hours, the battery weight per kilowatt-hour as a function of its operational life is far superior to that of conventional battery cells. A relatively light-weight fuel cell can have a lifespan of five to ten times that of a primary battery.

Fuel cells built between 1960 and 1970 for the Gemini and Apollo space missions and in 1980 for the Space Shuttle Orbiter are among the most successful fuel cells to date. They were needed because of their chief advantages over batteries—weight and lifespan. Those fuel cells used cryogenic reactants of hydrogen and oxygen.

Some space-craft power generation systems use solid polymer electrolyte (SPE) technology in the construction of their fuel cells. That type of fuel-cell assembly consists of an ion-exchange membrane-electrode system with gas distribution, current collection, heat removal, and water management. Many of those assemblies are bolted together between end plates to form an SPE stack assembly.

The Gemini system used three 1-kW SPE fuel-cell stacks. The Apollo system used a larger 1.5-kW fuel-cell stack based on a concentrated 45% potassium-hydroxide electrolyte. The Apollo power plant was designed to operate for over 400 hours. The fuel cell in Apollo 8 lasted for 440 hours, the system produced 292 kWh of power, and 100 liters of water.

The Space Shuttle system was more advanced in design than either the Gemini or Apollo fuel cells. The Space Shuttle fuel cells are 20 kilograms lighter and deliver six to eight times as much power. Each fuel cell power plant consists of a power section where the chemical reaction occurs, and a compact accessory section connected to the power section, which controls and monitors the power section's performance. The three fuel-cell power plants are coupled to the hydrogen and oxygen reactant subsystem and the power distribution subsystem. The fuel cells generate heat and water as by-products of electrical power generation. The excess heat is directed to Freon coolant loops, and the water to a potable water storage subsystem.

Some power specifications of each fuel-cell power plant are:

- 2 kilowatts at 32.5 VDC.
- 12 kilowatts at 27.5 VDC.
- 7 kilowatts continuous power.
- 12 kilowatts peak.
- All three fuel cell power plants are capable of supplying a maximum continuous output of 21,000 watts with 15 minute peaks of 36,000 watts.

Some experimental fuel cells have been considered for use with vehicles. The major prohibiting factor in their use is the difficulty in reliably containing hydrogen gas, and the possibility of an explosion. Also, special fuels such as hydrogen, methanol, and hydrazine are more expensive than hydrocarbon fuels.

Many advanced fuel-cell designs have been developed for power utility applications, but because of the typical problems of fuel storage and cost effectiveness, they have not been widely used.

An experimental fuel cell

The author was able to build a successful experimental fuel cell by the technique described below. We must, however, issue this word of caution: This product should *NOT* be built or experimented with in any way except under the direct supervision of someone who is highly qualified in the fields of chemistry or chemical engineering. Some chemicals and gaseous by-products in a fuel cell could be toxic and/or explosive! All dangerous chemicals are listed in the sidebar. You must be familiar with proper handling and disposal of any chemicals used.

The author's experimental fuel cell uses two adjoining chambers separated by a membrane, as shown in Fig. 1. An electrode with catalytic properties is placed into each chamber. Both chambers are filled with a liquid electrolyte. One electrode is then purged with hydrogen gas, the other with oxygen or air, and a voltmeter is connected across the electrodes.

In order to be able to build a fuel cell you should be familiar with semipermeable membranes and catalysts. Semipermeable means that only some ions can pass through it but other matter is retained. In actual applications, separation of ions is not perfect, and some leakage usually occurs, and is permissible. Total blockage on the other hand would inhibit a reaction. The following materials could be used as semipermeable membranes:

- Unglazed discs of baked clay (an old clay flower pot).
- Fine glass frits (the partly fused mixture of sand and fluxes which glass is made of).
- Cellophane.
- Wet plaster.
- Moist, or hardened cement.
- Zinc oxide or zinc chloride cement.
- Certain types of plastic foam.
- Silicic acid gel, prepared by slowly acidifying sodium silicate solution.
- Gelatin saturated with salt.

Clay, cement or plaster discs should be as thin as possible. The gels should be used to build ion bridges according to Fig. 2. Glass frits can be bought at lab supply houses and are best for this use. If glass frits are used, the gases move upward, and stay in the proper place. Any fair separation will do. The author used two square polyethylene bottles and a large fine glass frit which was glued into holes cut in the sides of the bottles (Fig. 3).

In order to get hydrogen and oxygen to react at room temperature they must be coaxed a little. Without the proper catalyst, nothing at all happens.

A catalyst is a compound that hastens reactions without actually taking part in the reaction. If you set up a H_2/O_2 fuel cell with sulfuric acid and carbon electrodes for instance, there will be no electrical energy generated. If platinum- or palladium-coated carbon electrodes are used, the reaction gets going. Union Carbide has used this method and supply such electrodes.

The method the author used to plate carbon was to wrap platinum wire and a platinum net around the carbon rods, which works very well. An easy and low-priced way of producing a large surface of palladium is to coat nickel netting with palladium. That can be done by immersing a

CHEMICALS USED IN FUEL CELLS

• Hydrogen—A colorless and odorless gas which is sold compressed in steel bottles. Small lab-size bottles are available together with simple low-priced reducing valves. Hydrogen is not poisonous, but extremely flammable and forms explosive mixtures with air.

• Oxygen—Also is sold in compressed form in lab-sized bottles. It is not toxic but must be kept from fire or flame since it will support combustion and can make a four alarm fire out of a glowing match.

• Hydrazine—Anyone not used to working with dangerous chemicals should not handle this compound. It is carcinogenic and should be dispensed in a hood only. Hydrazine should be handled with rubber gloves.

• Hydrogen peroxide 30%—Most everyone knows this chemical as a 3% solution for bleaching or wound treatment. The 30% concentration will bleach the skin and is dangerous when swallowed. Handle with rubber gloves.

• Sulfuric acid—It is poisonous when swallowed. It can blind you if splashed in the eye. It will burn holes in your clothes. A solution in water should be prepared by slowly pouring small amounts into plenty of cold water while stirring with a glass rod. Handle with rubber gloves.

• Potassium hydroxide solution 30%—Potassium hydroxide is a strong base and is poisonous. 300 grams are dissolved in 900 milliliters of cold water. Let it stand and cool off. Store in a plastic bottle with cap. Handle with gloves, it can damage the skin.

• Palladium dichloride—Dark brown crystals soluble in water. Moderately poisonous when swallowed. Dissolve 2 grams in 100 milliliters of water.

nickel net in a 2% solution of palladium dichloride over night. The coating looks black. Palladium coated nickel acts like pure palladium. The author had a supply of platinum on hand or he would have used the approach just mentioned.

The amount of palladium dichlorides you need costs about $20.00. Platinum, palladium, silver, nickel (especially Raney nickel) have been used as catalysts in different fuel cells. Platinum-group metals work so well because they have an affinity to hydrogen and will pick up considerable amounts of it for storage in their crystal lattices. A platinum electrode saturated with hydrogen, therefore, is practically an electrode of solidified hydrogen. The pure metal is too expensive, so palladinized nickel, platinized carbon or Raney nickel on a carrier matrix are the first choice.

Impinger-type glass tubes with frits or aquarium-type dispersion tubes are used as gas inlet tubes. The electrodes are wound around the tube in a coil. Copper wire leads are connected. The electrolyte is a 30% potassium hydroxide solution. Oxygen and hydrogen can be bought in small laboratory bottles with reasonably priced lab-reduction valves.

Hydrogen can also be produced from zinc and diluted hydrochloric acid. That leaves you with a solution of zinc chloride which is hazardous to the environment and must be disposed of in a manner prescribed by law.

The entire experiment was conducted in the open air in order to allow the flammable hydrogen to disperse. Rotameters were used to check gas flow. They can be replaced by bubble indicators if you prefer. Gas flow was 10-20 liters per hour (l/h) but can be varied. Oxygen flow should be about ½ that of hydrogen flow. The reaction is sluggish at the beginning as hydrogen has to saturate the platinum metal surface.

An indication of about 10 mV may occur for several minutes, which will then rise. There may be steps in this rise, therefore it may be necessary to put a little drain on the system by using a 100-ohm resistor connected across the 2 chambers. It can be removed again after a few minutes. That helps overcome polarization effects. The author measured 998 mV after about 10 minutes. To compensate for the slow start, the cell will generate a voltage for some time after the hydrogen is turned off.

After you finish, the potassium hydroxide solution should be poured into a well-capped plastic bottle. It can be used over again, but it will accumulate carbonate which makes it less effective. Some prefer diluted sulfuric acid for the same purpose because it keeps longer. Air can, in most cases, be substituted for oxygen. The amount must be raised, however, since only ⅕ of air is oxygen. Hydrogen peroxide can be used in place of oxygen but it dilutes the electrolyte.

Hydrogen can be replaced with hydrogen-containing gases such as "city gas" produced from coal, containing hydrogen, methane, and carbon monoxide. Several variations of fuel cell components that react at room temperature are shown in Table 1. The fuel cell can also be used as a one-shot unit for liquid fuel, namely hydrazine, and 30% hydrogen peroxide. Both compounds are rocket fuels but can be controlled very well. They are, however, highly toxic and poisonous. Because hydrazine is known to be a carcinogen, one should not work with it unless you are familiar with handling very poisonous substances. Hydrogen peroxide at 30% concentration will bleach your hands and should also be handled very carefully.

TABLE 1
FUEL-CELL COMPONENTS THAT REACT AT ROOM TEMPERATURE

Fuel	Oxidant	Electrode Material	Electrolyte	Catalyst	Recorded Voltage (mV)
hydrogen 20 l/h	oxygen 10 l/h	carbon	5% sulfuric acid	none	No reaction
hydrogen 20 l/h	oxygen 10 l/h	carbon/platinum	5% sulfuric acid	platinum	533
hydrogen 20 l/h	air 40 l/h	carbon/platinum	5% sulfuric acid	platinum	469
hydrogen 20 l/h	oxygen 10 l/h	platinum	30% potassium hydroxide	platinum	988
hydrogen 20 l/h	oxygen 10 l/h	palladium on nickel	30% potassium hydroxide	palladium	*
2 ml 24% hydrazine hydrate	10 drops 30% hydrogen peroxide	palladium on nickel	30% potassium hydroxide	palladium	*

*This reaction was not tried by the author, but works according to literature on the subject.

Fuel cells have been run with "steam reformed" methyl alcohol. At 200°C, methyl alcohol reacts with water to form hydrogen and carbon dioxide as shown in the following equation:

$$CH_3OH + H_2O \rightarrow 3H_2 + CO_2, \text{ or}$$
methyl alcohol + water→hydrogen + carbon dioxide

At temperatures higher than room temperature many other reactions are possible. Some of them allow a separation and collection of the water formed.

You're probably wondering why fuel cells are not more widely used. The first big drawback is cost, which is always a primary consideration in power generation. Hydrogen is an expensive fuel compared to other types of fuels, and the storage of hydrogen is still a problem. Perhaps in the future, we'll use solar energy on a large scale to decompose water into hydrogen and oxygen, which can then be stored. When energy is needed, the two gases can be recombined to water in a fuel cell. R-E

HARDWARE HACKER

Let's look at electronic tuning diodes, some unusual newsletters, parametric amplification, association book resources, and preventing modem dropouts.

DON LANCASTER

We might start off with the reminder that we do have our technical helpline available for your use per the box below. That's where you can go for tech help, referral to highly qualified consultants, for book and software purchases, and for general off-the-wall networking.

Your best calling times are weekdays 8–5, *Mountain Standard time*. Before you call, please re-read the *entire* column and especially the *Names and Numbers* and *Resource* boxes. Hardware Hackers calling without a pencil or pen handy will get chopped up and fed to the cows.

You could also reach me via my personal BBS, otherwise known as *GEnie* PSRT. Call (800) 638-9636 for voice connect info.

But, please do note that I am an independent developer and author sitting here on my sand dune in the middle of the Upper Sonoran desert. I have very little input to any **Radio-Electronics** editorial policy and know next to nothing about projects by other authors. To leave comments for the editors, you may want to use the RE-BBS at (516) 293-2283.

Yeah, I sometimes do welcome any visitors that call in advance. But do note that Gurus are supposed to be hard to reach, because (A) it adds to the mystique, and (B) the Guru's and Swami's Union Local #415 rules demand it. At any rate, there is a seven-hour drive involved in reaching the nearest airport from here. I won't even mention the deadly Gila Monsters or hostile Indians.

Every once in a while I'll get a call that sounds reasonable at the time, but after thinking things over... For instance, one Hardware Hacker wanted to crystal control that low-cost BA1404 FM stereo broadcaster we've looked at in past issues. He wanted to do this so that several actors in a play could be on the same frequency.

Uh, whoops. You can't get there from here. Sure, you can crystal control your BA1404. And you certainly can put as many of them as you want on the same frequency. But one of the key properties of FM reception is that you will receive only your *strongest* station, with virtually zero pickup of any of those others. That normally desirable action is known as the *FM capture effect* and is caused by the hard limiting present in virtually all FM receivers. As little as a fraction of a decibel can cause any one signal to utterly and totally dominate. Sorry about that. We return you to our column already in progress...

Electronic tuning

The traditional method of tuning a resonant circuit to your desired frequency is to use some adjustable or variable capacitor. While obvious and cheap, those capacitors are often large and sometimes expensive, could be sensitive to fields and vibration, and usually require human intervention for their use. These days, it is much better to go to one or more *electronic tuning* methods.

The simplest method of electronic tuning is to never do it. As much as possible, you purposely design out any need for a variable capacitor or a direct replacement. For instance, you use digitally synthesized frequencies instead of a local oscillator or BFO. You use switched-capacitor filters or active filters that are tunable by an input frequency or voltage. Or you use ceramic or SAW filters that are so precise and so repeatable that no adjustment is needed. You also tend to use a few higher-quality filters, rather than lots of individually tuned and cascaded LC circuits.

But after all of that, there remain times and places where you'll still need a few electronically variable capacitors. Selecting a station on a radio or TV are obvious examples.

One very popular, well performing, and ultra-low-cost electronic tuning method is called a *varactor diode*, sometimes known by the trademarked name *Varicap*. Varactor diodes are diodes that have been optimized to look and behave like a high-quality electrically variable capacitor.

Most any diode conducts current in the forward direction and blocks it in the reverse direction. Specifically, when you reverse bias a diode, you create a *depletion region* containing neither electrons nor holes. As you increase your reverse bias, the depletion region gets thicker, and vice versa. Thus, *any* diode will behave as an electrically variable capacitance as you vary its reverse bias voltage.

For most diodes, this unavoidable depletion region capacitance is a flaw that restricts your maximum speed of operation. But in a varactor diode, the depletion-region capacitance is purposely made rather large, quite high quality, and very controllable.

Figure 1 shows you a typical circuit. From the electrical control side, you simply reverse bias your diode by way of a large series resistance or some other method that has a very high RF impedance. When you change the value of the voltage, you electrically change the capacitance of the varactor's depletion region, and thus tune your circuit. Typically, you change your tuning voltage over a 3- to 30-volt reverse-bias range.

On the resonant circuit side, you do have to provide a DC return path to ground for the tuning voltage bias. You also have to provide a series blocking capacitor to keep any other

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DC path from shorting out your diode. Normally the series capacitor is very much larger than the varactor's capacitance, so it does not significantly alter any of your resonance calculations.

Sadly, the varactor's capacitance changes nonlinearly with the reverse voltage. Depending on the varactor, you might have 60 pF at 1 volt reverse bias, 45 pF at 2 volts, and 18 pF at 20 volts. Thus, your first couple of volts of reverse bias will by far give you the most variation. The plot of capacitance versus reverse voltage is roughly linear when plotted on semi-log paper.

Varactor capacitances can go from a fraction of a picofarad with exotic microwave devices on up to several hundred or more picofarads for use in audio filters or AM tuning. You can sometimes use giant silicon power diodes for lower frequency varactor experiments. But the Q will often be low when you try that, and the tuning range will be limited.

The *capacitance range* of a varactor is usually defined as the ratio between your 3- and 30-volt bias settings. An ordinary varactor will often have a capacitance range of

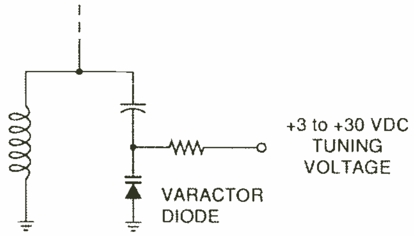

FIG. 1—ELECTRONIC TUNING using a varactor diode. The diode depletion-layer capacitance varies with the applied reverse bias. The large series capacitor serves as a DC block to prevent shorting out the tuning voltage.

3:1.

But note that a frequency change varies with the *square root* of your capacitance change in any resonant circuit. So, this type of 3:1 varactor can shift a resonant frequency only by 1.73 or so.

One way to increase the range of a Varactor is to cheat and use a lower bias voltage. Your capacitance will increase dramatically for very low values of reverse bias. But at that point the diode will start to conduct and very much reduce the available Q or selectivity for your tuned circuit. Linearity will also be awful.

For wider tuning ranges, special varactors are obtainable which have different doping profiles. Varactors with a medium tuning range have an *abrupt* doping profile, while those with very high tuning ranges use a *hyperabrupt* profile.

The tradeoffs for a wider tuning range are more nonlinearity, somewhat higher cost, lower circuit Q, and harder tuning. It will also become vastly more sensitive to noise and the precision of your tuning voltage.

The AM broadcast frequencies of 550 to 1650 kilohertz have a 3:1 range. Thus, you should use a hyperabrupt varactor having at least a 9:1 and preferably a 10:1 tuning range here. The hyperabrupt *Motorola MVAM108* is one good choice here, having an extreme 15:1 range.

Those television frequencies are spread out over a very wide range. To prevent having to tune them all at once, three varactor tuners are separately used in several individually selected circuits. One for the lower VHF channels 2–6, a second for the high VHF channels 7–13, and a third for the remaining UHF channels. And sometimes a fourth for special cable channels. Note that there is a rather large frequency gap between channel 6 and channel 7 that holds both the FM broadcast band and emergency services.

Should you instead want to restrict the tuning range of a varactor, you can either put a fixed capacitor in parallel with it or else use a narrower voltage control range. The fixed parallel capacitor is often the better choice.

Varactors work best with tuned signals in the microvolt range. Should your signals being tuned get above several millivolts, the signals themselves can add to or subtract from the tuning voltage. Thus, your positive signal excursions will increase the resonant frequency and vice versa—which can introduce moderate to severe second-harmonic distortion.

You might resolve that possible distortion problem by using a pair of varactor diodes as shown in Fig. 2. The two varactors are in parallel as far as the DC tuning voltage goes, but are in series with any signals being tuned. Thus, on a positive peak, the capacitance of one Varicap will increase as the other decreases, and largely cancel each other out.

Dual varactors in a single package are rather popular. The *Motorola MV104* is one example. Note that two capacitors in series give you *one half* the total capacitance. Be sure to allow for that in your designs.

It is extremely important to have a *very* stable reference for your tuning voltage, since any drift at all could detune your circuit. If possible, you will also want to use some sort of feedback to keep your tuning locked on channel. Various types of automatic frequency control (AFC) can sometimes do that for you.

Sadly, varactors drift over temperature. Their values will increase with increasing temperature. One typical value is in the 200-parts-per-million range. On the other hand, a regular diode that is *forward* biased will have

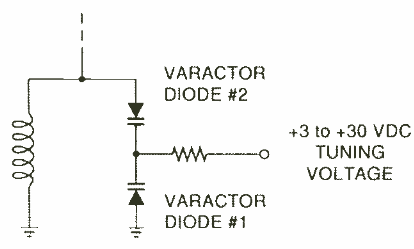

FIG. 2—A PAIR OF BACK-TO-BACK varactor diodes can be used to prevent larger signals from detuning themselves. A positive signal swing raises the capacity of one varactor and lowers that of the other. The changes largely cancel out.

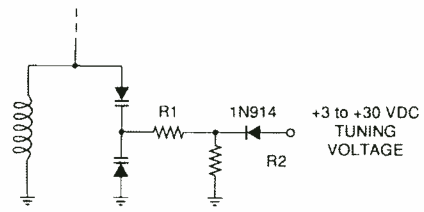

FIG. 3—A TEMPERATURE compensated varactor tuner. The forward drop temperature drift of the ordinary diode can be used to offset the capacitance drift of the reverse-biased tuning varactors. Resistor R1 has to be large enough to not load the tank circuit. Resistor R2 adjusts the temperature coefficient.

a current-dependent drift with a negative temperature coefficient.

Figure 3 shows how to add an ordinary diode in series with your tuning voltage to temperature-compensate a varactor diode. The load resistor of the diode is adjusted to give a minimum overall drift. Sometimes a parallel capacitor can also be added to the circuit having a chosen temperature coefficient.

A precise temperature compensation over a wide range could get tricky. At the least, everything has to be tightly heatsinked together. More details appear in the *Motorola* ap note *AN551*.

As we've just seen, *Motorola* is one leading supplier of a wide variety of low-cost and easy-to-get varactor diodes. Some cost under a dollar. See their *RF Device Data II* handbook for data sheets and ap notes.

Parametric amplifiers

Surprisingly, varactor diodes were not initially designed for electronic tuning. Instead, they were created for a unique beastie once known as a *parametric amplifier*. Back in the days of tube-style UHF TV tuners with 35 decibel noise figures, the idea of an ultra-low-noise, high-gain, high-frequency amplifier that used nothing but a diode sounded like a great idea.

Today, low-noise and high-gain microwave transistors are a buck each from such outfits as *Mini-Circuits Lab* and *Avantek*. Paramps are largely limited to esoteric ultra-microwave lab uses and for optical and infrared experiments. Although I do strongly suspect you'll soon see a stunning resurgence of paramps in a brand-new application area.

Figure 4 shows you how the parametric amplifier works. This is exactly the same idea as pumping a swing on the playground. The local oscillator called the *pump frequency* causes the capacitance of a varactor to change in a time-varying manner. The "parameter" we are varying is the diode capacitance. A low-level input signal known as the *input frequency* is also routed to the same time-varying capacitor. A filter extracts an output signal that is called the *idler frequency*.

The net result can be a very strong and low-noise amplification and a possible frequency conversion for your input signals. Since a purely reactive capacitor is in use, there are theoretically none of those noise problems associated with resistance or traditional tube or semiconductor amplifier circuits. I once used a plain old three-cent 1N914 computer diode

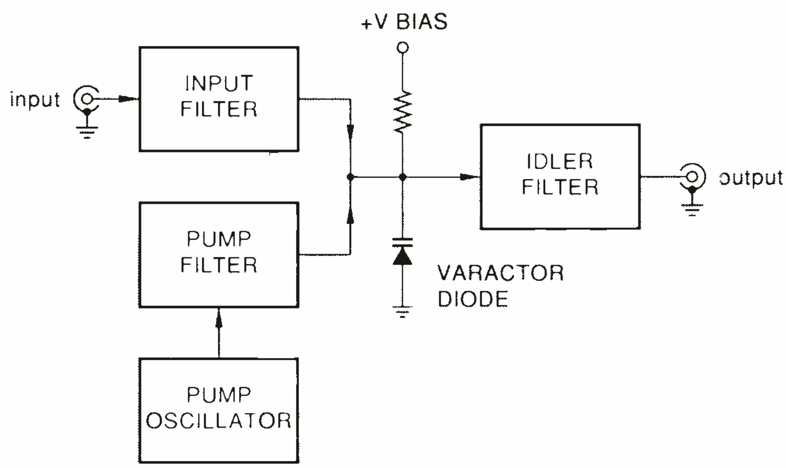

FIG. 4—A VARACTOR DIODE PARAMETRIC AMPLIFIER in which a diode provides low-noise amplification. The pump frequency causes the varactor capacitance to vary in such a time-dependent "parametric" way that its interaction with the input frequency produces an amplified output at the idler frequency.

to produce 20 decibels of gain and a 2-decibel noise figure at 600 MHz. The diode was DC back-biased to −3 volts or so and a suitable pump frequency was capacitively superimposed. Long ago and far away.

Paramps can be designed as upconverters with gain, as downconverters with loss, or as negative-resistance devices with potentially high gain but possible instabilities.

The key math behind paramps is known as the *Manley-Rowe* relations. One horse's mouth classic on the subject is Blackwell and Kotzebue's *Semiconductor Diode Parametric Amplifiers*, published by Prentice Hall, way back in 1961. Included is a good summary of Manley-Rowe and an extensive bibliography. For more modern info on paramps, check out the *Dialog Information Service*.

Professional society libraries

As we've seen a number of times in the past, that *Uhlricht's Periodicals Dictionary* on the reference shelf at your local library is overwhelmingly your single most important hardware hacking resource, bar none. But there's another set of books on the same shelf titled the *Encyclopedia of Associations*, that you might also find quite useful.

There are zillions of professional societies, most of which seem outrageously expensive and who simply do not deliver what they think they do. On the other hand, many of these groups have association bookstores that have outstanding tutorials, reprints, and information real hard to find elsewhere.

To get you started, our resource sidebar for this month lists a few of the professional organizations. Here is a brief rundown...

The *American Association for the Advancement of Science* publishes the "must have" *Science* magazine and provides outstanding book reviews. The *Association of Energy Engineers* carries dozens of books including a *Small Power Production Manual* and *Efficient Electrical Systems Design*.

That *Institute of Electrical and Electronic Engineers* is a very poor performer that is way overblown and far overrated to the point of being a ripoff. But their reference books do include *Visual Communication Systems* and *Navigation: Land, Sea, Air, and Space*.

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The *American Society of Materials* has hundreds of books on just about anything mechanical. Their *Metals Handbook* series are classics.

The *Society of Motion Picture and Television Engineers* is big on time codes, on video production, and other hard-to-find resources. The *Journal of the Audio Engineering Society* is your foremost resource for any music synthesizer theory, and just about all other audio.

And we've already seen that the *Society of Automotive Engineers* has lots of great automotive electronics books. And finally, one real sleeper, that *Society of Photo-Optical Instrumentation Engineers* which publish a Milestone Series that includes such gems as *Fiber Optic Gyroscopes*, *Digital Image Processing*, and *Ultrahigh Speed Photography*.

Naturally, there are bunches more where those come from. For the first of our two contests this month, just tell me about any professional organization in any field that has book or publication resources of possible interest to hardware hackers. There will be all the usual *Incredible Secret Money Machine* book prizes, with an all-expense-paid (FOB Thatcher, AZ) *tinaja quest* for two going to the very best of all. As usual, send all your written entries directly to me at *Synergetics*, rather than on to **Radio-Electronics** editorial.

Teleprotection surprises

One of the ruder surprises you'll discover when you first start using a modem extensively is that anyone picking up an extension phone can blast you off the air. That can get especially frustrating and infuriating just before the end of a long and costly upload or download.

Radio Shack offers a product called their 43-107 *Teleprotector*. It costs eight bucks and its only tiny problem is that it may end up working *too* good for you.

Any unused telephone line has around 48 volts of direct current on it. When the first phone is picked up, the working voltage drops down into the 6- to 8-volt range. So, if you simply put a plain old voltmeter right across the red and green wires on your extension phone, you can quickly tell if the phone line is in use by another extension.

Figure 5 shows you the circuit for their teleprotector, along with some possible modifications. An extension phone normally uses only the red and green wires. The teleprotector breaks the green wire and inserts a full-wave diode bridge. The purpose of the bridge is to make the current in the use-sensing circuit always go in

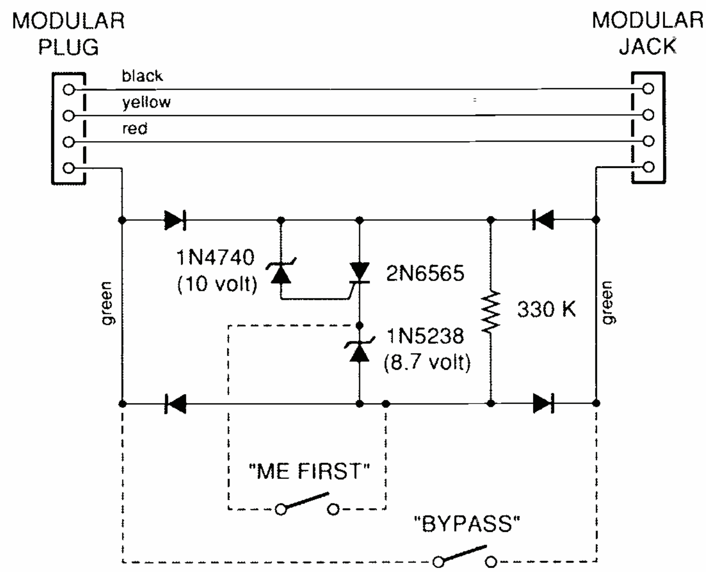

FIG. 5—CIRCUIT DIAGRAM for the Radio Shack 43-107 teleprotector, along with two possible modifications. Unmodified, the extension phone is allowed on the line only when no other phone or modem is in use. The bypass switch will defeat the teleprotector entirely; the me-first switch lets your extension remain active if another phone gets picked up during a call.

the same direction, even during the ringing or if the phone polarity somehow ends up backwards.

Initially, there is only a very high value 390K resistor inside the bridge. That is much too large a series value to let the phone work. When you pick up the phone, the full available line voltage initially appears across that resistor. Should you have at least 18.7 volts available (meaning that there is no other extension in use), the silicon controlled rectifier (SCR) turns on, stays on, and lets the extension operate. If another phone is being used, there will not be enough voltage to turn on the gate of the SCR, and the extension will remain off.

So far so good. Any SCR will stay on only so long as its main anode to cathode current drops to zero. This particular SCR can get turned off one of two ways. If you hang up your protected extension, the current in the green wire obviously drops to zero and resets you for the next call.

But there's also that mysterious 8.7-volt Zener diode *in series* with the SCR. Should some other phone get picked up, there won't be enough voltage left on the line to keep the Zener conducting, so the SCR turns off, as does the extension phone.

Thus, your protected extension phone will never turn on if another phone is off hook. Should you be using your protected extension phone and should another one get picked up, you will get unceremoniously cut off the line!

All of which means that their teleprotector works *exactly* as they advertise. There is no way to eavesdrop with a teleprotected extension phone. There is also no way to let the teleprotected extension blast your modem off the air. Or a FAX machine for that matter.

Another trick is to hook up their teleprotector up to your answering machine. When you pick up your remote extension, your answering machine drops off the line, stopping the now unwanted message. Which also can be handy.

One key point: Your teleprotector does *not* go on the modem phone. It goes on the interfering extension.

Now for the big problems. Your teleprotected extension can *not* be used for any conferencing! You also cannot have a receptionist answer by picking up with their teleprotected extension and then listening in long enough to verify the correct person picked up the call.

Two possible circuit modifications are also shown in Fig. 5 that might be more suited to you should you need conferencing, but your main goal is to eliminate any modem blasting. The BYPASS switch completely defeats the teleprotecting. Whenever any two phone conversations are wanted, you slide that switch into its "bypass" position, shorting the works out. You

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do, of course, have to remember to flip the switch back after any two-phone conversations.

Closing the ME FIRST switch lets the protected phone initiate or receive a call so long as it is the first phone picked up. It will stay active should additional phones be picked up, so two-phone conferencing can still be done. But the protected phone still can no longer break in on a modem or fax in progress.

If you really want to get hairy, you can even let your protected phone purposely break in on an ongoing voice conversation when in the "me first" position. Just shout at the other person to pick up their phone. Once you are sure their phone is picked up, hang your phone up for half a second, and pick it up again. Both of you should now be in conference.

But my particular setup requires *three* phones, any-way conferencing, and no modem blasting. As a second contest for this month, let's have your thoughts on how to elegantly handle this problem.

The *Radio Shack* teleprotector unit is cheap enough that you probably would not want to build one up from scratch. But should you decide to experiment completely on your own, that oddball 2N6565 sensitive-gate SCR is a *Teccor* product available by way of *Mouser Electronics*.

New tech literature

From *Signetics/Phillips*, you should look into their outstanding new *RF Communications* data handbook. Included are full use details of their hot new NE602 active VHF mixers, info on cellular phone chips, and frequency synthesizers.

Also from *Signetics/Phillips*, a new *Telecom IC* shortform catalog. And from *Brooktree*, a *Product Databook* on all their A/D, D/A, color palette, and video chips.

Our featured free software deal for this month is the *High Performance Electronics Selection Guide* offered by *Burr-Brown*.

One marketing firm aggressively seeking *tested* and *developed* low-end consumer electronics items for use on an ongoing royalty basis is Mark Gottleib's *DesignTech*.

Two rather impressive "labor of love" high-quality newsletters are Don Parham's *Homebuilt Rotorcraft* for the Gyro Gearloose crowd; and Ed Zimmer's *Inventor-Entrepreneur Network Newsletter*, that's intended mostly for Michigan hackers.

A pair of interesting trade journals include *Medical Electronic Products* and *Medical Equipment Designer*. Yes, they have info on brain-wave electrodes. But do make certain you know what you are doing before you make a decision to hotwire your neighbor's cat.

Turning to my own products, for the fundamentals of microprocessors and microcomputers, check into my *Micro Cookbook I* and *Micro Cookbook II*. Or to pick up all the "oldies but goodies" at once, do try out my *Lancaster Classics Library*.

We also now have the *Hardware Hacker III* reprints available, which have the latest and best of all these columns in them. All edited, revised, corrected, and indexed.

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

Our usual reminder here that most of the items mentioned appear either in the *Names and Numbers* or in the *Association Bookstore Resources* sidebars.

As always, this is your column and you can get technical help and off-the-wall networking per that *Need Help?* box. The best calling times are weekdays 8–5, *Mountain Standard Time*. Let's hear from you. **R-E**

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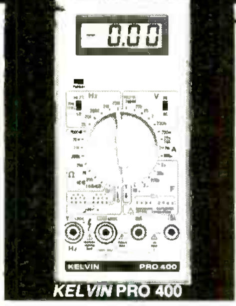

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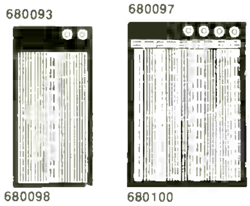

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WALL TRANSFORMER

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AUDIO UPDATE

A Distortion Primer—Part 1

LARRY KLEIN

In any compilation of the real (and imaginary) problems troubling audio reproduction, distortion would rank right up there near the top of the list. Almost everyone agrees that distortion is *not* a good thing. But beyond that basic point, arguments start. Exactly what's the problem? Simply this: Electronic audio distortion, while easy to measure in its various manifestations, is devilishly difficult to correlate with the perceptions of the human ear/brain apparatus. The situation is further complicated by some manufacturers of expensive audio equipment, accessories, and connecting wires, who are pleased to invent wonderfully esoteric distortion problems (with accompanying voodoo solutions) to satisfy the needs of the devout tweaks and techno-crazies.

Terminological confusion

My *Illustrated Encyclopedia of Electronics* tells me that "Distortion is any change in a signal that alters its basic waveform or the relationship between its various frequency components." Some of the misunderstanding about standard distortions and their audibility arises from ambiguities in terminology. For example, sometimes the technical name for a distortion describes the way the afflicted waveform looks on a scope (e.g., clipping distortion when the tops and/or bottoms of a waveform are decapitated); other times the name refers to the electronic flaw in the amplifier that produces the problem (e.g., crossover distortion).

The terms *harmonic distortion* (HD) and *intermodulation distortion* (IMD) in effect describe kinds of test procedures rather than specific flaws in the equipment under test. If an amplifier has a problem, the same condition should show up on both HD and IMD distortion tests—and provide entirely different measurement numbers. Keep in mind that the numbers provided by distortion-testing instruments are somewhat arbitrary; they depend as much on the type of test and the specifics of the test signal used as on the magnitude of the flaw in the amplifier. And for perhaps the same reason, none of the distortion-measurement numbers correlate directly with audible unpleasantness—or with each other. In other words, 2% distortion does not necessarily sound twice as bad as 1%, or even necessarily worse than 0.5%.

Harmonic distortion

In any discussion of harmonic distortion, keep in mind the distinction between the natural harmonics that are a part of all tones produced by musical instruments and the undesired spurious harmonics that result from flawed amplification. It is the natural harmonic content that causes the same musical note played on a clarinet, a piano, and a flute to sound different—and to look different on an oscilloscope. Any complex waveform can be "discussed" by a mathematical process known as a Fourier analysis and shown to be composed of a large number of odd and even harmonics. Figure 1 shows a violin note and its second, third, fourth, fifth, sixth, and eighth harmonic components. With the proper instrumentation, it is possible to detect harmonics as high as the twentieth.

HD comes about *not* through distortion of the harmonics of a signal, nor does it result from spurious harmonic frequencies generated by an oscillating amplifier. What happens is that the amplifier, because of some technical inadequacy, changes (distorts) the original shape of the signal waveform. That change can be quantified by analyzing it in terms of the spurious harmonics added to the fundamental test signal—which is, in general, the way the ear hears it.

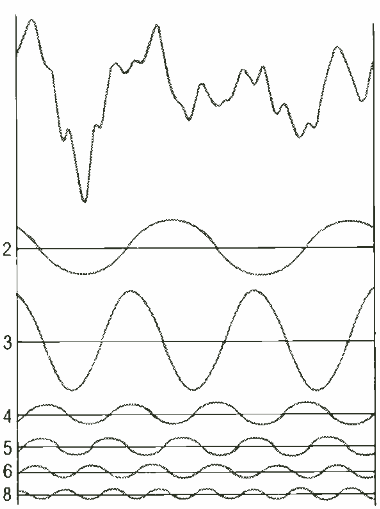

FIG. 1—FOURIER ANALYSIS of a violin note showing the relative strengths of the strongest natural harmonics.

When testing an amplifier's HD performance, you feed in as distortionless a sine wave as can be generated. The HD analyzer, which is connected across the amplifier's output test load, operates by nulling out the input test signal and reading (as a percentage of it) whatever harmonics and noise are introduced by the amplifier. If, say, a 3-kHz test signal was used, amplifier nonlinearity might produce spurious harmonics at 6 kHz, 9 kHz, and so forth. The term *THD* indicates that the lumped *total* of all the harmonic components is included in the measurement. A more sophisticated instrument, called a spectrum analyzer, is capable of indicating the relative strengths of *each* of the spurious harmonics. It is recommended by the EIA Amplifier standard (RS-490) and is used by many test labs.

To illustrate the mechanisms involved, an exaggerated example of distortion is shown in Fig. 2. Let us say that a malfunction of the amplifier causes third-harmonic distortion of waveform (*a*), a 1000-Hz sine-wave input signal. The distorted output signal (*c*) would look as though a 3000-Hz tone (*b*) were combined with the 1000-Hz tone. Keep in mind that a distorting amplifier does not actually generate spurious harmonic waveforms and mix them with the original wave; what it does is distort the original waveform in such a way that the output waveform looks as it would if specific spurious harmonics were added. Of course, in real life we would have not only third-harmonic distortion but also an assortment of various odd and even harmonics of various strengths.

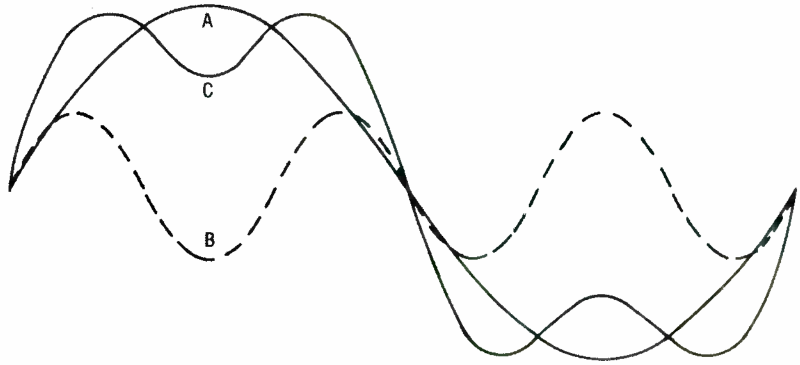

FIG. 2—SIMPLIFIED ILLUSTRATIONS of how a spurious third harmonic (*b*) combined with the input signal (*a*) produces a distorted signal (*c*).

There's some evidence that the specific HD content of a distorted signal (meaning the relative strengths of the distortion components extending up to the tenth harmonic or higher) is more audibly significant than the absolute THD figure. In other words, depending upon the ways that two amplifiers are distorting a piece of music, a measured 3% THD from one might sound a lot worse than 3% from the other.

Intermodulation distortion

The same amplifier nonlinearities that produce THD also produce intermodulation distortion (IMD), but through a somewhat different mechanism. When two (or more) signals are fed through a nonlinear amplifier, the signals tend to *intermodulate*, meaning that they interact in a specific and undesirable way. If, for example, a low-frequency signal of 40 Hz was traveling through a nonlinear amplifier along with a higher frequency of, say, 2 kHz, spurious sum and difference frequencies that are known as IM products would be produced at 1920, 1960, 2040, 2080 Hz, and so on and so forth.

There are two different IMD test techniques in current use, both employing a pair of test tones applied simultaneously. The older SMPTE (Society of Motion Picture and Television Engineers) IMD test uses a composite 60- and 7000-Hz test signal in a 4:1 ratio, while the IHF-IM test uses two equal-amplitude high-frequency tones. The description of the IHF test incorporated in the current EIA Standard (formerly IHF-A-201 1966) reads as follows: "The percentage of IHF intermodulation distortion (IHF-IM) of a composite signal composed primarily of two relatively high-frequency sinusoidal signals, one having a frequency of f_1 and the other having a frequency of f_2, of equal amplitude, is numerically equal to 100 times the square root of the sum of the squares of the second- through fifth-order distortion components divided by the square root of the sums of the squares of the amplitudes of the sums of the components at frequencies f_1 and f_2." All of which, I think, helps explain the relative popularity of the SMPTE method over the IHF-IM method.

Unlike THD, IMD distortion components do not have a harmonic relationship with the music and, therefore, can't be heard as part of the music. For that reason, IMD is generally thought of as more audibly unpleasant. However, I would say that, given the very low distortion figures of *all* of today's better standard-brand audio amplifiers, neither THD nor IMD are likely to be audible, *assuming* that the amplifier is working properly and is never driven into overload. And, even under overload clipping conditions, with complex program material such as a loud symphonic work, it is well documented that distortion (of any flavor) has to reach approximately 6% before it becomes audible. That is true because the spurious distortion frequencies are overwhelmed (technically, "psychoacoustically masked") by music occurring at the same frequencies. However, when the test signal is a pure tone, distortion as low as 0.15% can be heard. Probably for all of the above reasons, it seems that few professional testers will bother with IM measurements.

In next month's wrap up on our distortion discussion, we will look at some of the popular "new" distortions and try to place the entire topic in a real-world context. **R-E**

DRAWING BOARD

Let's add an audible indicator to our logic probe.

ROBERT GROSSBLATT

The probe we've been designing can indicate circuit highs and lows but there are things we can do to make it better. One of the first things that comes to mind is to work out some way for us to have an audible indication from the logic probe.

Doing something like this is a good exercise. Remember that we currently have points in the circuit (the comparator outputs) that indicate whether a high or low is detected in the circuit.

There are a few ways you could use the extra pair of comparators we have for the audible indicator, but the easiest thing to do is just piggyback their inputs on the inputs of the first pair. That is shown in Fig. 1.

By adding some extra wire to our design, we now have two independent outputs that signal high and low levels in the circuit under test. Our next job is to figure out a way to make them work as triggers for an audio circuit.

The first thing we have to do is add some resistors to the outputs of the second set of comparators. That has to be done because, if you go through the data sheet for the 339 (or any member of that family), you'll see that the comparator output is an uncommitted open collector of an internal transistor. The resistors have to be added in this case just as you would for any transistor-based design.

All that's left for us to do so we can add an audio indicator to the circuit is figure out how we're going to actually generate the audio.

It's no big deal to build a tone generator out of a 555 but this application adds a new wrinkle. We want it to generate two different sounds—one to indicate that a low has been detected and the other to indicate a high.

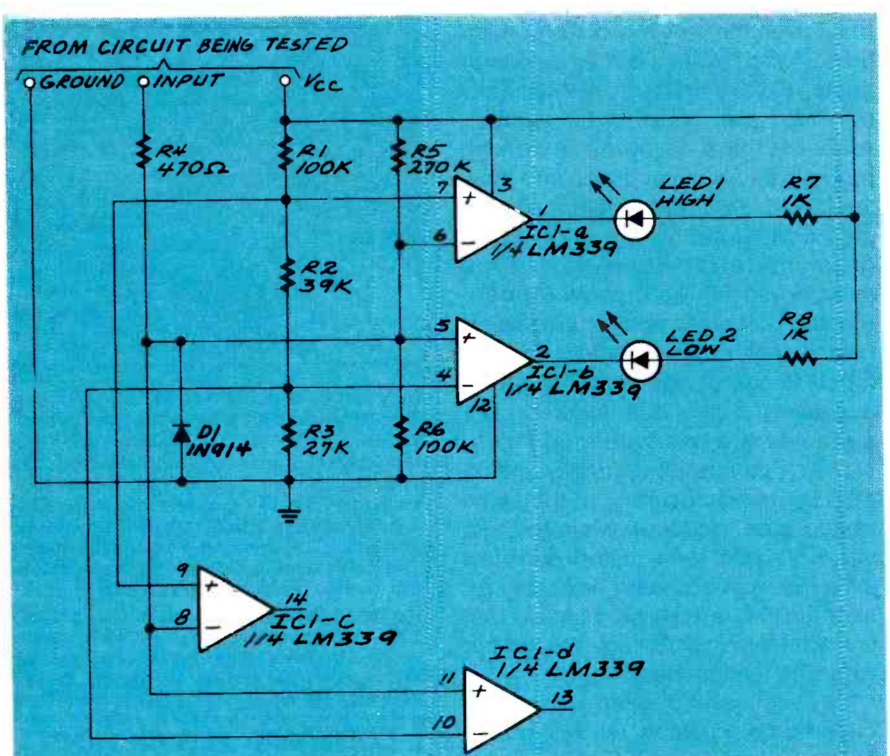

FIG. 1—YOU CAN ADD an audible indication to the logic probe without adding any extra silicon to the board; we'll use the other pair of comparators in the LM339.

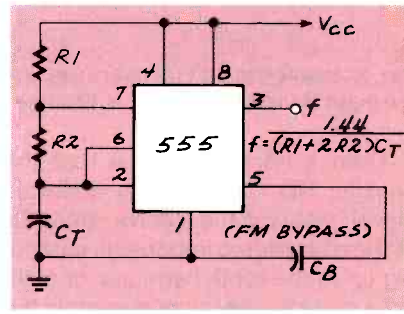

FIG. 2—THE FREQUENCY of the tone generator built from a 555 can be controlled by having the high outputs of the comparators supply the charging current for the 555's internal timing capacitor.

The frequency of a tone generator built from a 555 depends on three separate components as shown in Fig. 2. The trick to having the output frequency controlled by the two comparators is to have the high outputs of the comparators supply the charging current for the 555's internal timing capacitor. In normal 555 circuits, that current comes directly from the power supply, but in this case we can use a couple of steering diodes to put different resistors into the 555's timing chain and cause it to output two different frequencies.

The final version of the circuit is shown in Fig. 3. With the values shown in the schematic, the high frequency will be about 4 kHz and the low frequency will be about 500 Hz.

Since we've now got a circuit that can generate two different tones depending on whether a high or low is presented to the input, it would be a shame not to be able to set things up so the probe could be used as a tone source as well.

If you study the switch arrangement shown in Fig. 4, you'll see that S1 switches the circuit from a logic probe to a tone generator by force feeding either a high or low voltage (via S2) to the input and routing the speaker output to the probe tip. When you use the circuit as a tone generator, the speaker will be disconnected, but you'll be able to see which frequency you've selected because the LED's still work.

The logic probe/tone generator we've been designing is a really good addition to your collection of test gear. I've been using it for years and have gone so far as to lay out a PC board for it. I'll clean up the artwork and put it in next month's column.

It's well worth building because, when you get familiar with the circuit, you'll find that it even gives you useful information when you connect the probe to clock lines. There's no way you'll be able to measure the frequency but the audio from the probe will bear a proportional relationship to the frequency and duty cycle. **R-E**

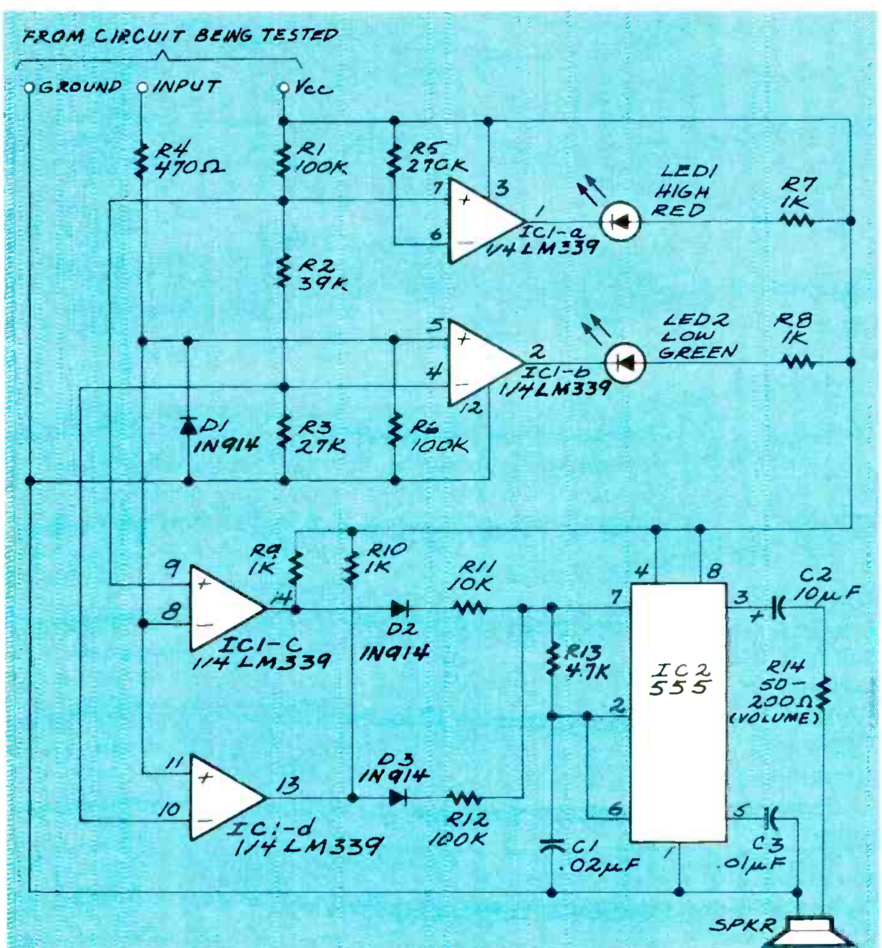

FIG. 3—IN THE FINAL VERSION OF THE CIRCUIT, the high frequency will be about 4 kHz and the low frequency will be about 500 Hz.

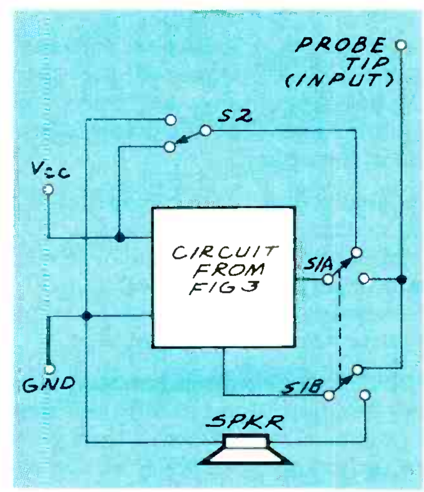

FIG. 4—WE CAN SET UP THE PROBE so that it can also be used as a tone generator; S1 switches the circuit from a logic probe to a tone generator by force feeding either a high or low voltage (via S2) to the input and routing the speaker output to the probe tip.

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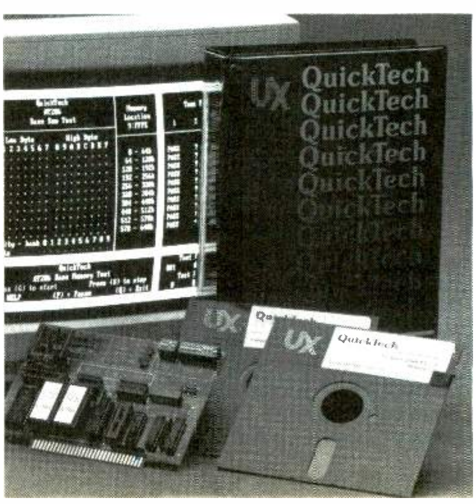

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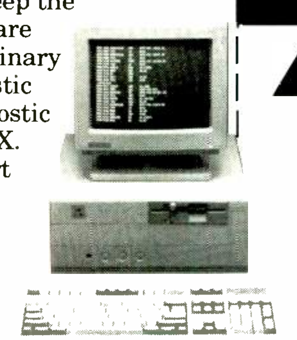

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Windows watch

JEFF HOLTZMAN

Windows is really taking the PC world by storm. By the time you read this, it will have been a year since Windows 3.0 was released. What's happened in the interim? Where are things going?

Virtually all interesting software development is now focused on the Windows environment. The major computer magazines have sponsored special sections on Windows products, and the technical columns formerly associated with OS/2 now grudgingly include Windows information as well.

Hardly a day passes when a new, upgraded, or converted product does not appear for the Windows environment. In some cases, these new products are spectacular; in others, disastrous. The latter remind me of the early 80's, when the industry made the transition from CP/M to MS-DOS. The first applications were straight ports that worked worse under DOS than they did under CP/M. But gradually, the old applications improved, and new ones were introduced. In some cases, the old apps (e.g., WordStar, dBASE) remained mired in the bog of the past and, though they're still hanging on, have yet to capitalize on the unique strengths of the new environment. Of course new apps (e.g., 1-2-3) learned to stretch that environment to the limit—and beyond. For example, Lotus was a driving force behind Hercules graphics adapters and the EMS specification.

Now the industry is going through another tectonic shift. Highly influential companies (Borland, Lotus, Word Perfect, Software Publishing) that heretofore have ignored Windows are now scrambling to get something to market as soon as possible. And some companies (WordStar, Lotus again) are trying to buy their way in. Meanwhile, with control of the operating system (DOS) and the operating environment (Windows), serious applications (Word, Excel, PowerPoint, Project) in all major categories except database and telecommunications, and a LAN operating system (LAN Manager) worthy of being taken seriously, Microsoft's dominance of the industry continues to increase.

Windows and OS/2

Why has Windows usurped the position many people once expected OS/2 to occupy? There's no good reason on technical grounds. Windows requires just as much in the way of system resources (CPU, RAM, hard disk) as OS/2. And with that same set of resources, Windows provides a less-stable, less-powerful environment for running programs than OS/2.

There's lots of grumbling in the developer community about Microsoft's seeming desertion of OS/2. People working in that environment have invested lots of time and effort learning the OS/2 API (Application Programming Interface). And now they're finding that the expected market for their products seems to have disappeared. Further, due to the large differences in API's, converting their OS/2 work to Windows is difficult.

For a while last fall, Microsoft was touting a so-called binary-compatibility layer (BCL) that would allow Windows programs to run unmodified under OS/2 2.0, the still-unreleased 386-specific version of the operating system. In practical terms, that amounts to adding a layer of software to translate Windows calls to OS/2 format. However, there were lots of questions about whether that type of kludge was even possible. In addition, given the lackluster performance of both environments on anything less than a 25-MHz 386, it's hard to believe that users would accept that type of performance-degrading solution.

Recently emphasis has shifted to OS/2 3.0, a "portable" operating system that will run on multiple hardware platforms, and will allow mixing and matching multiple API's (DOS, Windows, OS/2, POSIX), file systems (DOS, HPFS, POSIX), and graphical user interfaces (Windows, OS/2 PM, X Windows). However, OS/2 3.0 probably won't be seen before 1992. And when it does appear, it just might go by another name—Windows-32, perhaps. But will the industry become mired in the present API by then? According to some rumors, OS/2 3.0 will be able to run Windows, OS/2, and POSIX applications on screen in separate windows simultaneously. But what sort of system resources will be required to do so? Will we have 50-MHz CPU's and 16Mb DRAM's by then? If so, maybe performance won't matter, but if not...

Windows 3.1

A more immediate topic of speculation has been Windows 3.1, originally due around mid-year, but now third or fourth quarter. Expected features include smaller size and better speed, a built-in type-scaling/font-management system called TrueType, multimedia extensions, an improved File Manager, support for stylus-based input, and a Windows-specific version of BASIC. To get a taste for the latter, check out WordBASIC, the amazingly powerful "macro" language in Word for Windows. Borland should release a version of Turbo Pascal for Windows sometime this year as well.

Windows now

When Windows 3.0 first came out, I found it interesting and enjoyable—but somewhat impractical. However, gradually throughout the past year, I have migrated more and more of my activity there, so that now I spend 90% of my computer time running Windows. The other 10% is used almost entirely for two things: system backup (to an Irwin tape drive) and file management (with Lotus' Magellan).

In the past I've mentioned my big three Windows applications: Word for Windows, Corel Draw, and CrossTalk for Windows. Now I'd like to discuss some of the other applications and utilities, large and small, that have allowed me to make this migration.

Best spreadsheet: Excel 3.0 was built specifically for Win3, hence is better integrated than the current versions of Word For Windows and Project. Excel 3.0 has several irresistible new features including spreadsheet outlining, powerful drawing tools (something I expect to see in the next version of WinWord), much-improved charting (including 3D graphs), an autosum function that intelligently figures out the correct horizontal or vertical sum function, and full support for different type faces, styles, and sizes. The program includes several add-on packages, including a goal-seeking function that works backward from results to modify an equation that generates said results, and a database query tool that allows you to query a local or networked database.

Most useful utility: I've mentioned it before, but Adobe's ATM (Adobe Type Manager) neatly and cleanly solves one of Windows' biggest problems: font management. ATM brings the ideal of WYSIWYG (what you see is what you get) closer to reality by an order of magnitude. With ATM, you can print text in any PostScript font on any dot-matrix, ink-jet, or laser printer and, regardless of the printer, see an accurate representation on-screen.

You can develop your document in your office with a PostScript laser printer, take the document on the road and print it on a portable ink-jet, work on it at home with a dot-matrix, and produce final copy on a Linotronic typesetting machine. In all cases, you can simply switch drivers and not worry about font availability on the target printer. And regardless of the output device, the document will print identically, within the physical limits of the device. For example, if you call for a 30-point headline in Helvetica, whether you print it on a 9-pin Epson or a 2540 dpi Linotronic, you'll get 30-point Helvetica. Microsoft's own TrueType, developed in conjunction with Apple, will incorporate ATM-like features directly in Windows. ATM lists for $99 and is available through mail-order distributors for about $60. Highest recommendation.

Best file manager: BeckerTools 2.0 is the best I've found. It's crammed with useful utilities (copy, delete, move, format, edit, etc.) and customization options (see Fig. 1). BT2 works better than Windows' own File manager, and it does so in a manner familiar to users of MS-DOS file managers. The program does not always follow Windows' user-interface guidelines, and is simply awkward in others. It has a "pack" function for compressing files, but does not use a standard format; the program should allow optional use of an external program (PKZIP or your favorite), and better control over compressed files. $129.95 from Abacus, 5370 52nd Street SE, Grand Rapids, MI 49502-8107. (800) 451-4319; (616) 698-0330.

Tutorial/games: Microsoft has released a Productivity Pack for Windows that contains a tutorial on using Windows. Novices to whom I've recommended it say that it's a big help. Microsoft has also released an Entertainment Pack that contains several games and one of the better screen blankers on the market.

XGA UPDATE

Last time I made some off-the-cuff remarks about IBM's XGA video adapter. It turns out that IBM really is serious about making XGA a new standard. Last month the company made two important announcements on this subject. (1) In addition to the Micro Channel (PS/2) bus version, there will be an AT-bus version of the XGA adapter. (2) IBM will sell XGA chip sets to OEM's who can then build it on their own boards and sell it. These are significant changes in IBM's marketing direction, and will ensure that XGA assumes VGA's current role as standard bearer. Look for XGA boards to appear in late 1991 or early 1992. **R-E**

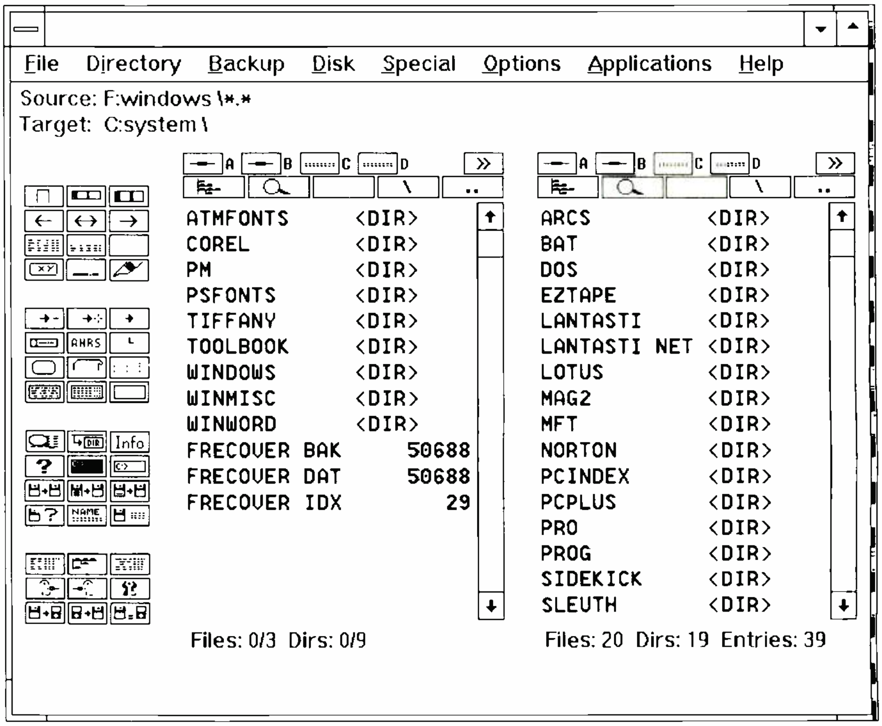

FIG. 1—BeckerTools 2.0 is the best file manager I've found. It's crammed with useful utilities and customization options. It works better than Windows' own File manager, and it does so in a manner familiar to users of MS-DOS file managers.

Public domain and shareware utilities: Pickings here are pretty slim at present (another parallel to 1981). However, I have located a few gems that I now load automatically via the LOAD= line in WIN.INI. They'll be posted on the RE-BBS (516-293-2283, 1200/2400, 8N1).

- WinExit: Exit quickly from Windows simply by double-clicking on an icon.
- Digital: Formatted display of time, date, available memory, disk space.
- WinClock: Time/date display, includes alarms, count-down timers.
- IconLib: 200 icons for various programs, stored in a single EXE file.
- Click: Adds keyboard click.
- ZM: ZIP File Manager. Functions as a shell for PKZIP, PKUNZIP, and several other compression schemes. Buggy and doesn't use the Windows interface effectively, but saves shelling to DOS.

If you'd like to keep track of shareware/PD offerings but don't relish the thought of scanning BBS's and on-line services, check out the Public Software Library. The company maintains a well-organized collection of software for DOS, Windows, and OS/2 (and the Macintosh), which it distributes for $5/disk.

Every program in the library has been reviewed; descriptions are available in printed and electronic format. PSL publishes a monthly newsletter, the PSL News, describing new and updated programs. Subscriptions are $24/year. For more information, contact PSL at P.O. Box 35705, Houston, TX 77235-5705, (800) 2424-PSL, (713) 524-6394. **R-E**

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In retaliation, Intel will release several "crippled," lower-cost versions of the 486, one without the math coprocessor, one without the cache. In addition to fighting the cloners, this gives Intel a chance to sell 486's that don't pass final inspection. **R-E**

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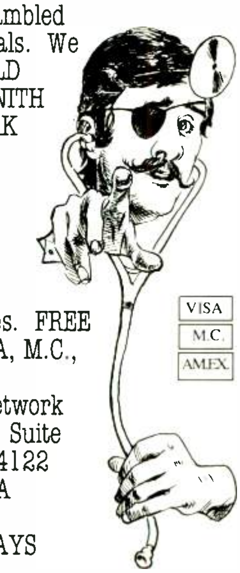

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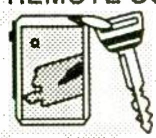

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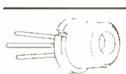

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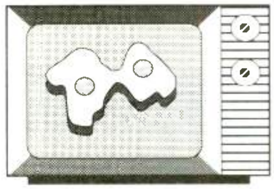

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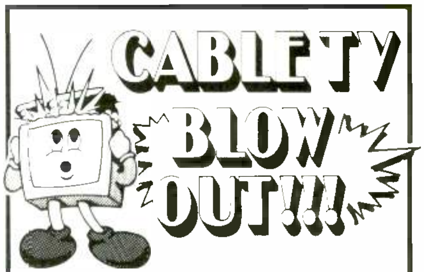

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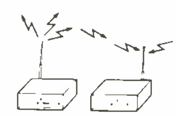

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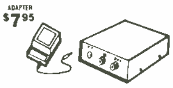

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LOGIC ANALYZER

continued from page 38

a controller chip. Coupled with a standard low-power SRAM, the SmartSocket provides all of the benefits of standard non-volatile memory. The logic analyzer currently uses a 32K × 8-RAM.

The TTL levels of the V25 are converted to RS-232 levels by IC41, a Maxim MAX232 RS-232 transceiver. The part requires only a +5-volt supply and has integral charge-pumps to create the necessary −10-volt and +10 volt RS-232 levels.

The negative contrast-voltage for the LCD panel is generated by IC42, also a MAX232 chip. The V25 address and control lines are decoded by IC44 and IC20 to produce device selects for the memory, LCD, and control registers. A programmable logic device (PLD) from Lattice Semiconductor, IC44, (a GAL16V8) produces the control signals required by the LCD panel. It also generates the RAM and ROM chip selects. The chip selects for the registers which control the logic analyzer section are produced by IC20.

The LCD is a 240 × 64 pixel graphics display with built in RAM, controller, and microprocessor interface. That display allows the logic analyzer to run a true windowed graphics interface under the control of the V25.

The TL7705 is a reset and power-supply monitor circuit. It produces a glitch-free reset signal on power up. It will also reset if the drops below 4.75 volts.

Each IC on the circuit board is de-coupled using a 0.1 μF capacitor. That is shown in the large capacitor array in Fig. 6. The power supply uses a standard three-terminal voltage regulator, IC43. Because the logic analyzer draws approximately 600 mA, a TO-3 type case and heat sink are used.

The analyzer is powered from a plug-in wall transformer which supplies an unregulated 9 volts DC. Note that the logic analyzer can also run off batteries. Six D-cell alkaline batteries will run the analyzer for over eight hours.

Next month when we continue, we'll show you how to build the logic analyzer, and how to use it to troubleshoot circuits. R-E

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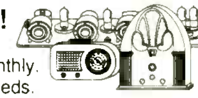

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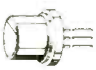

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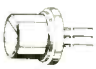

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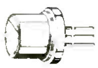

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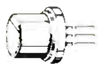

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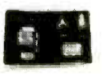

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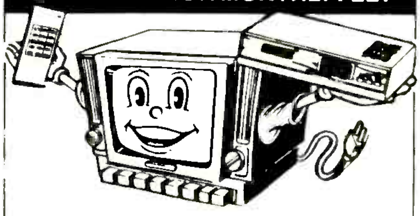

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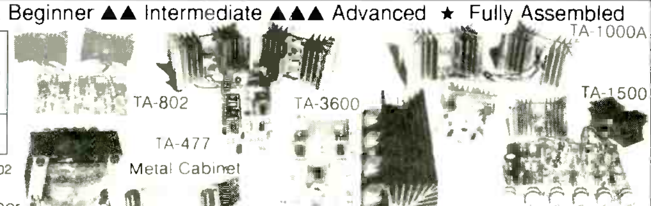

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LG-1925	5"	19"	11½	TA-477, TA-800, MK2, TA-1500, TA-1000A, TA-3600	35 80
LG-1983	2½"	19"	8"	TA-377A, TA-2800, TA-2200, TA-120MK 2	29.25

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MODEL	DESCRIPTION	MATCHING	PRICE
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002	36V x 2 3A	TR-503, TA-323A, TA-400, TA-300, TA-377A	22 00
003	40V x 2 6A	TA-477	28 00
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006	18V x 2 5A	TR-355A	15.50
007	53V x 2 8A	TA-3600	43.00

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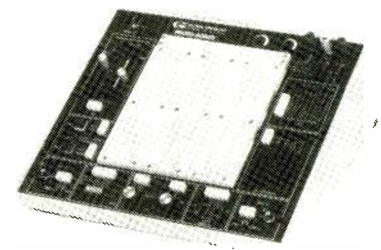

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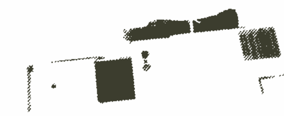

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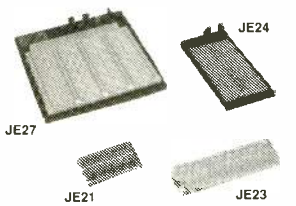

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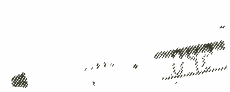

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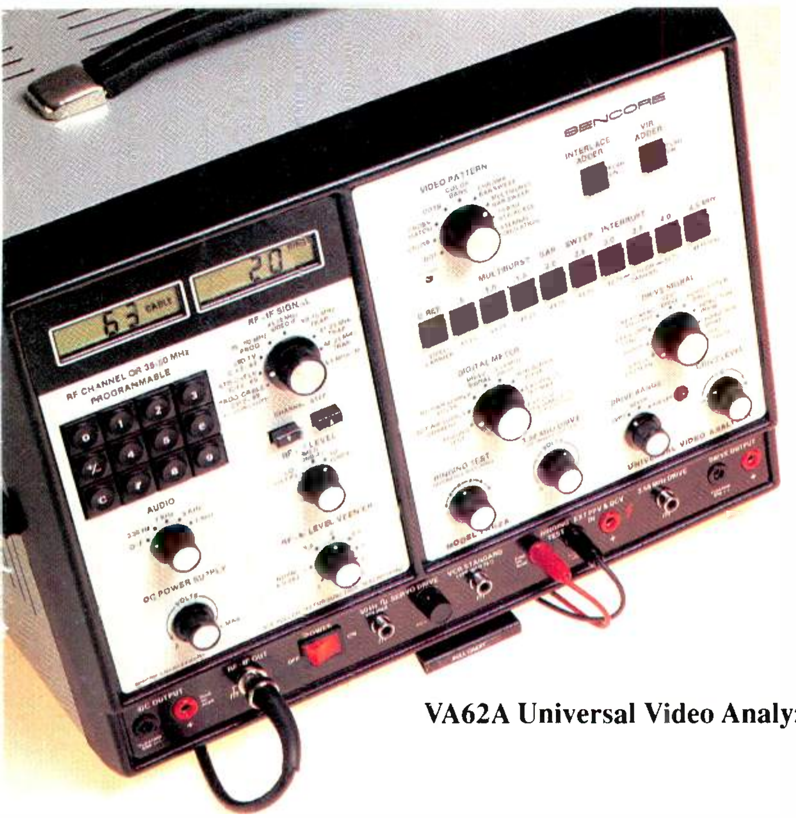

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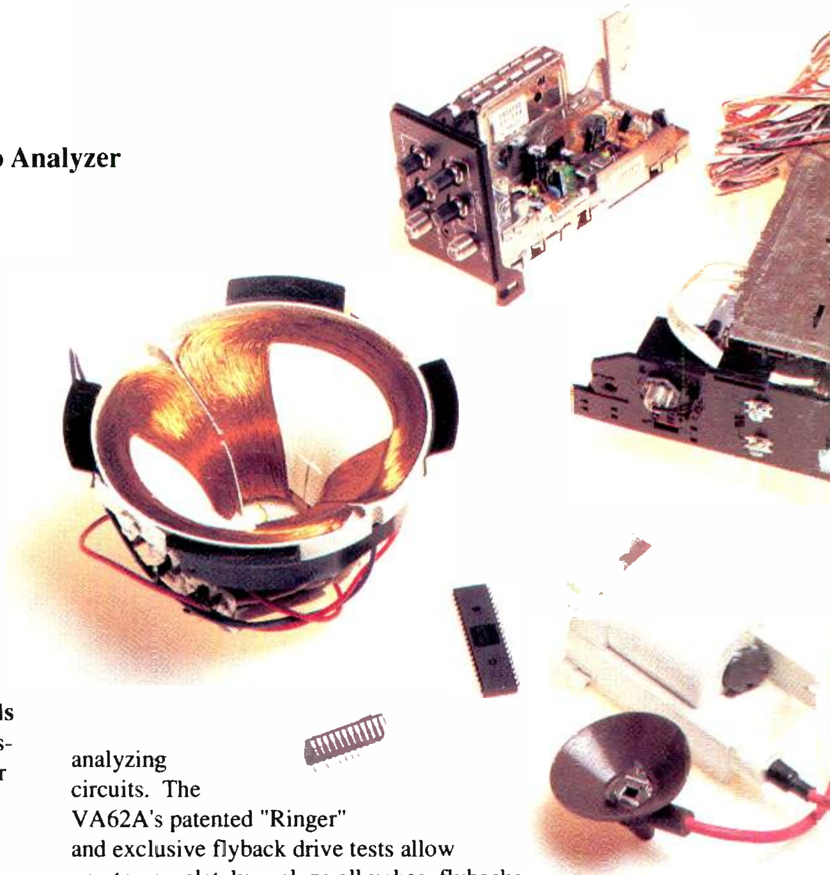

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