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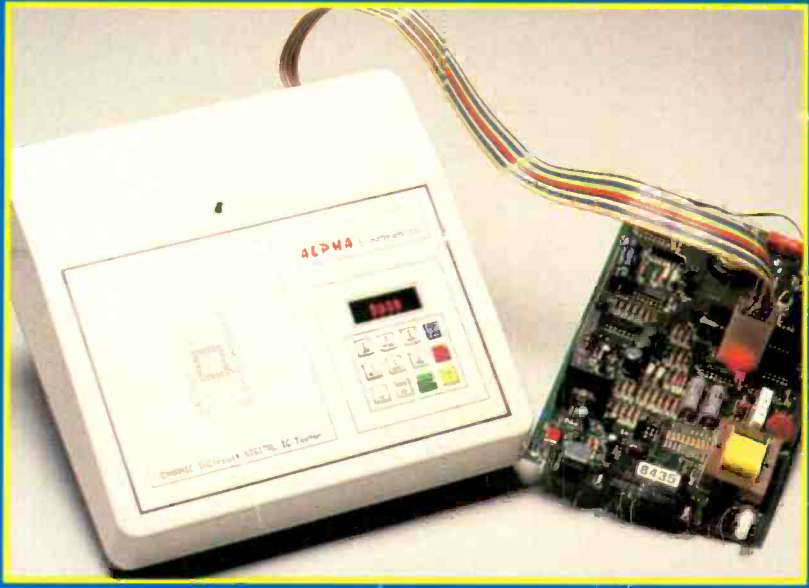

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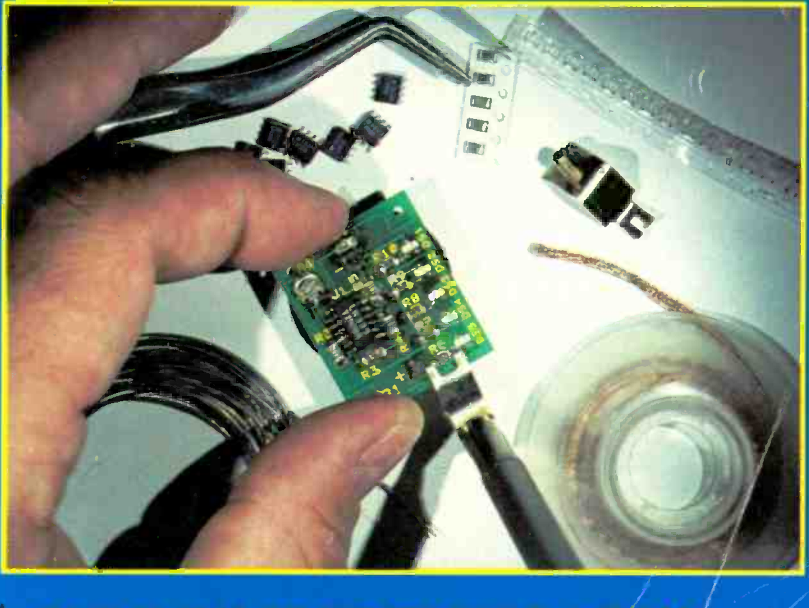

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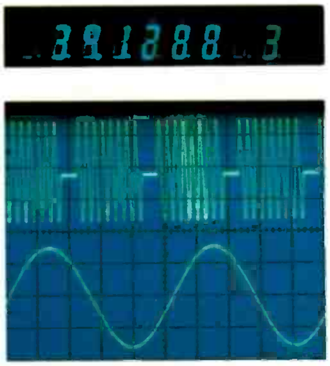
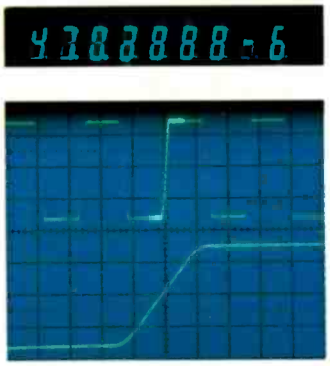
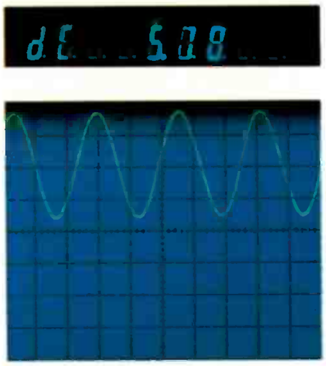


Gated frequency measurement. B sweep triggering during the intensified portion of the A sweep. Intensified portion frequency is measured with the counter/timer/DMM.



Delay time measurement. Delay time from the start of A sweep to the start of the B sweep is measured with *crystal accuracy.*



Channel 1 dc volts measurement. The average dc component of a waveform is measured directly through channel 1 with direct digital fluorescent readout.

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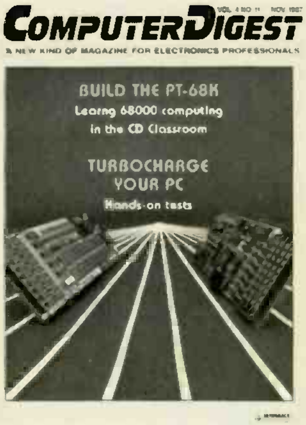
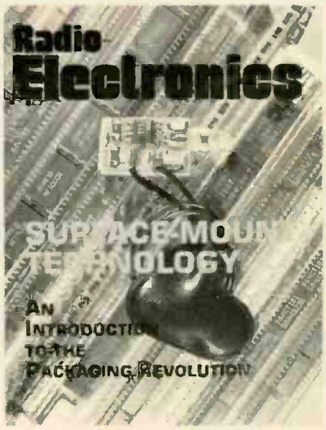


PAGE 91



PAGE 57

AND MORE

ON THE COVER

Troubleshooting a complex piece of electronics equipment is seldom easy. But when the circuit contains a number of IC's, all soldered securely to a PC board, it can become a nightmare. This month we'll present a digital IC tester that can assess the condition of an IC, in circuit or out. What's more, it can be built at a very reasonable cost. The story begins on page 43.

Also this month, our special section on Surface Mount Technology focuses on one of the most important advances in component packaging. Written by noted author Forrest Mims, III, the special section begins on page 57.

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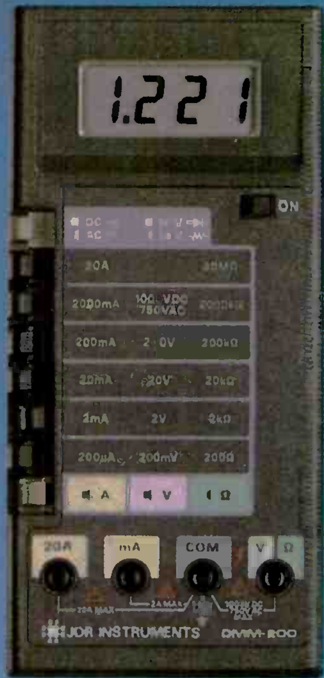
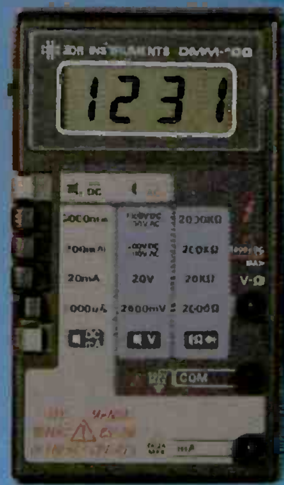
TEST EQUIPMENT THAT MEASURES UP TO YOUR SPECIFICATIONS





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- AC/DC current: 200uA — 20A, 6 ranges
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- 180 x 86 x 37mm, weighs 320 grams

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- AC/DC current: 20mA — 10A, 2 ranges
- Fully over-load protected
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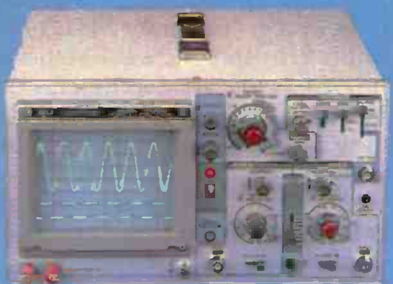
- DC current: 2mA — 2A, 4 ranges
- Fully over-load protected
- Input impedance: 10M ohm
- 130 x 75 x 28mm, weighs 195 grams



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- Input impedance: 11M ohm
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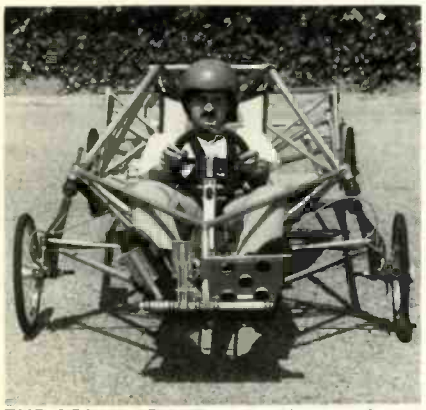
WHAT'S NEWS

Solar-powered cars to race across Australia

General Motors is entering a 1,950-mile trans-Australia motor race open only to solar-powered cars. The race, scheduled for November 1, may attract up to 25 entries. It will start from Darwin, on Australia's north coast, and finish at Adelaide, on the south coast, about six days later. The team with each car must be self-sufficient, carrying all its water, food, and supplies, and must camp overnight at the end of each day's driving.

The GM car, named the *GM Sunraycer*, runs entirely on storage batteries powered by the car's solar system and uses a new high-efficiency motor from GM's labs that uses low-friction bearings and *Magnaquench* magnets. A *Magnaquench* magnet is a super-strength, rare-earth, iron-based permanent magnet that may revolutionize the field of electronics because it makes possible electric motors having more power, higher energy efficiency, and smaller size and weight than motors made using conventional technology.



THE SOLAR-POWERED CAR's spaceframe and chassis gets its first test drive in California. Dr. Alec Brooks of AeroVironment, Inc., is checking its rigidity, handling and suspension. The lightweight spaceframe, made of aluminum tubing, will become a sleek, high-tech racer when covered by its integral body, canopy and solar panels.

THE *MAGNAQUENCH* MOTOR to be used in the solar-powered car is unusually small. Dr. Nady Boules, section manager at GMRL's Electrical and Electronics Engineering Dept., is holding the motor's rotor in his right hand, and the motor housing in his left.

A *Magnaquench* technology high-efficiency electric motor has been tested at 92% efficiency. Standard electric motors of comparable size run at only 75–85% efficiency. In practical terms, it means that an 8-pound *Magnaquench* motor can produce two horsepower continuously at 4000 rpm, which is about 30–40% more horsepower than comparable-size presently-available commercial motors.

In designing and racing the *Sunraycer*, GM expects to develop and demonstrate expertise in several advanced technologies with practical automotive applications. Those include lightweight structures and materials, low-speed aerodynamics and high-efficiency batteries, electric motors, and solar cells and panels.

Travelling robot to work in radiation-hardened IC lab

The new *R*adiation *H*ardened *I*ntegrated *C*ircuit (RHIC) facility nearing completion at Sandia National Laboratories, Albuquerque, NM, will be the first U.S. research lab to use a robot in the entire production process. The new robot will travel RHIC's 300-foot long clean room's center aisle, accessing 22 specialized processing bays (actually small clean rooms) that can be entered from that aisle.

Passing the bays, it will home in on selected work-in-progress stations and pick up the plastic cassettes (small boxes) housed there, moving them to other processing bays. The robot follows a reflective tape track laid on floors through the 12,500-foot clean-room area, and constantly receives routing instructions from the facility's computerized wafer-fabrication operating system.

"Other wafer-fabrication lines have used robots," says a Sandia spokesman, "but they have been confined to specific work stations. The case is the same as that for the highly acclaimed robots that work along modern automobile assembly lines."

Advantages of the new system include reduction of pollution possibilities due to greatly reduced human handling and to more gentle handling due to special force-sensing capabilities built into the robot. The latter makes make sure that the robot is using the right amount of energy in picking up and setting down the cassettes entrusted to it.

The RHIC is the latest major addition to Sandia's Center for Radiation-Hardened Microelectronics. The Center designs and builds microcircuits that continue to operate even after receiving high doses of radiation for use in nuclear-weapon, space, and satellite applications. **R-E**

VIDEO NEWS

DAVID LACHENBRUCH,
CONTRIBUTING EDITOR

• **SVHS and the Multi-Port.** A new compatibility headache may be in the works for cable, with the introduction of Super VHS recorders. Just when the cable industry thought it had solved its compatibility problems, along comes *S*uper *VHS* (SVHS) which is at least partly incompatible with the new Multi-Port standard (**Radio-Electronics**, April 1987). Multi-Port was developed over four years by an engineering committee representing receiver manufacturers and cable systems. It involves a 21-conductor connector to be built into future TV sets (a few already have it) that, in effect, will eliminate the need for external cable-tuning and -decoding boxes and make it possible to use a TV set's remote control system to tune all channels, including scrambled ones. The Multi-Port was also designed to accommodate all TV attachments, including VCR's, videodisc players, and home computers. It includes video and RGB inputs—but not Y and C (luminance and color) inputs. Although SVHS recorders have video outputs, a better picture results from using Y/C connectors, and new TV sets designed for use with SVHS recorders have special Y/C inputs. The committee that developed the Multi-Port is now meeting on the subject of SVHS, and one proposal is that the RGB input be made optional and replaceable by Y/C. Disgruntled committee members say that if the Japanese had taken a more active role in the committee's engineering work, the problem would never have occurred.

• **FCC looks at HDTV.** Responding to requests by 58 broadcaster groups, the FCC has opened a "comprehensive inquiry" into advanced television systems, particularly *H*igh-*D*efinition *TV* (HDTV). Among issues to be explored are the proposed specifications and characteristics of advanced television systems, timetables, public interest in better television systems, and the effect on existing TV systems. Because many of the proposals for HDTV require using more than the bandwidth of a single present channel, the FCC has frozen new proposed applications for TV channels in 30 of the largest markets. For example, some proposed compatible HDTV systems would transmit standard 525-line pictures on existing channels, using all or part of a separate channel for additional information to make up a picture with more horizontal lines and a wider aspect ratio.

Meanwhile, Home Box Office has started a campaign to encourage development of HDTV cable service. Because cable has no shortage of channels, HBO feels that cable has an edge over broadcasters in supplying HDTV, because it can assign wideband channels for HDTV while continuing to broadcast standard TV signals over other channels. HBO urged cable interests to avoid "the same kind of incompatibility problems we as an industry experienced with cable-ready TV's, connection of VCR's to the cable drop, and delivery of...stereo."

• **Flickerless 3-D disc.** The Japanese are relentless in their pursuit of 3-D television. JVC and Sharp both demonstrated 3-D videodiscs recently at the American Consumer Electronics Show. That system used electronically controlled LCD eyeglasses connected to the TV set by a wire. The system permitted each eye to see an alternate field of the picture, reducing the number of fields seen by each eye from the normal 60 to 30. The result was that the system suffered from a pronounced "flicker".

Now Sanyo and Japan's NHK (Japan Broadcasting Co.) have come up with a new version of the system that eliminates the flicker. Based on a laser videodisc, the system uses time compression to double the number of fields to 120 per second, letting each eye see 60 cycles, which is above the threshold of flicker. The system maintains full vertical resolution by using 4:1 interlace, letting each eye see a full 525 scanning lines. It also eliminates the wire connection for the eyeglasses by using an infrared wireless system. Of course, all that elaborate engineering is going to cost. The 3-D disc system, including a 30-inch color monitor, will cost almost $7,000, so the Japanese believe its first uses will be in commercial and industrial applications. **R-E**

LETTERS

LASER LISTENER LEGALITIES

The lead paragraph of your October cover story ("Build This Laser Listener") warns that "Breaking and entering to plant a listening device...can earn someone a long jail term." You then suggest that "A better and safer way to bug a room is to use a laser beam to eavesdrop on a window from across the street."

This suggestion is a serious disservice to your readers, for electronic eavesdropping of all kinds, including laser eavesdropping, is tightly regulated by both federal and state statutes. Severe penalties, including jail terms longer than those for breaking and entering, are specified for violators.

The federal statute prohibits the manufacture, assembly, possession, sale, and transport across state lines of devices whose primary purpose is the unauthorized interception of wire or oral communication (U.S. Code, Title 18, Chap. 119). Willful violators of this statute may be fined up to $10,000 and imprisoned up to 5 years. Under this statute, the assembly, possession and use of the **Radio-Electronics** laser listening device is clearly illegal, because the device is presented solely as a means "...to listen in to anything, anywhere, any time."

Your article warned of the possibility of "....eye damage if someone in the target area unknowingly stares into the beam...." Yet the cover photo shows a laser pointed very close to the faces of two people behind a window, and the opening paragraph states that laser eavesdropping is "better and safer" than conventional electronic bugging.

My personal experience with laser eavesdropping technology, which is neither high-tech nor new, is not unblemished. In "Siliconnections: Coming of Age in the Electronic Era" (McGraw-Hill, 1986), a memoir about some of my experiences as an electronics writer, I wrote about a 1976 assignment I received from a newspaper to use an infrared laser and receiver to intercept the conversations of Howard Hughes at his hotel in the Bahamas. Fortunately Hughes left for Mexico shortly before I was to leave for the Bahamas. The paper had convinced me Hughes's conversations might reveal possibly illegal conduct. They failed to warn me that laser eavesdropping is in itself illegal.

In 1985 I prepared a report on laser eavesdropping for the Senate Select Committee on Intelligence in which I warned of the vulnerability of government installations to that technology. Since then I have written several articles and papers that discuss the technical, legal, and safety aspects of laser eavesdropping as well as possible countermeasures. None of those articles included construction details. I have also demonstrated laser eavesdropping and discussed some of those same issues in several television interviews and a documentary film.

In short, I believe it is important for private citizens, businesses, and government to be informed about electronic eavesdropping technology. But I believe it was a serious misjudgment for **Radio-Electronics** to have published detailed construction plans for an illegal eavesdropping device and to have encouraged its readers to build and use it.

FORREST M. MIMS, III

"DREAMS OF RIO"

I think the readers of **Radio-Electronics** will be interested in ZBS Productions' latest audio adventure program, "Dreams of Rio." The 13-week series recreates the magic of old-time radio drama, using state-of-the-art digital recording techniques to capture the sounds of Brazil. The plot takes hero Jack Flanders and his anthropologist girlfriend, Frieda, from the night clubs of Rio, through the Brazilian jungles to find the "Lost City." Producer/writer Tom Lopez and composer Tim Clark spent a month on location, recording ambient sounds using Sennheiser 416 and Tram microphones along with Sony's PCM-F1 digital tape recorder. The high-quality recordings bring the characters to life, and make the listeners feel as if *they're* in Brazil.

The half-hour shows will be aired weekly over *N*ational *P*ublic *R*adio beginning in September. (Please check local listings, or contact your local NPR station, for exact dates and times.) Some of the major stations that will be airing the shows are: WJCT (Jacksonville, FL), WLRN(Miami, FL), WCBU (Louisville, KY), WVOM (Ann Arbor, MI), WCMU (Mt. Pleasant, MI), WNYC (New York, NY), WOUB (Athens, OH), KCRW (Santa Monica, CA), KOUW (Seattle, WA), KUER(Salt Lake City, UT), KQED(San Francisco, CA), KBOO (Portland, OR), KCRF (Denver, CO), KUNM (Albuquerque, NM), KMUW (Wichita, KA), KPBS(San Diego, CA), and KUAC (Fairbanks, AK).

I'm sure the series will appeal to fans of old-time radio, as well as anyone interested in the latest in audio technology.
KATHY GRONAU
ZBS Foundation
Fort Edward, NY 12828

SCA ERRORS

I noticed a few errors and discrepancies in the SCA receiver's parts layout ("Build This SCA Receiver, Part 2", September 1987): Diode D5 is shown backwards. No polarity is shown for C59; the upper end is the positive one. Capacitor C29 is shown twice; the one near FL3 is really C24. Also, the correct C29 is shown backwards. The base and collector leads for Q7 are misidentified; swap them and then move the connection from S2 to the unused hole that's approximately ¼-inch northeast of Q7. Switch S2 shows a wiring error: Remove the connection between pin 1 of the left-hand gang and the line to C59 and add a connection between pin 1 of the center gang and the line to J5.

Going back to Part 1 of the article, there is a missing dot in the schematic at the junction of C25, C26, R33, and pin 3 of IC1.
G.L. McDONALD
Auburn, WA

ON TESTING ERRORS

In his letter, "Testing Semiconductors" ("Letters", August 1987) Richard P. Morley is correct in assuming that the voltmeter will have an affect on the indicated leakage current of the diode under test. If we connect a standard 10-megohm voltmeter across that circuit, it will draw 10 μA at 100 volts, which is the maximum leakage current specified for a 1N4000-series diode. In that situation, it would be much better to place the current meter on the other side of the voltmeter.

Unfortunately, low-current ammeters tend to have very high internal resistance. Consequently, the voltage indicated by the voltmeter in the new configuration is not a true value; that is because the actual voltage across the meter/diode combination adds up to more than the voltage across the diode under test—meaning that the diode is receiving less voltage than indicated.

Should the leakage current be on the order of 1-mA (not uncommon), for example, then the voltage drop across a 2000-ohm milliameter will be two volts. Two volts may not seem like much, but at 10 volts it is a 20% error. Depending on the voltage and the current values involved, current-meter resistance can (and does) affect the measurement in your alternate configuration to the same extent that a parallel voltmeter may affect measurements in other situations.

The issue of voltmeter loading was discussed at length in Part 1 of the "Testing Semiconductor" series (**Radio-Electronics**, February 1987, page 60), and remedies were recommended. I realize that not all technicians take the time to evaluate the situation properly, and the problem of inaccurate test procedure cannot be overemphasized. My thanks to Mr. Morley for bringing it to our readers' attention one more time.

TJ BYERS

MAKING PC BOARDS

I am writing to share with your other readers a technique that I discovered for using a Xerox copier to make printed-circuit boards. I suspect that there are many hobbyists who would like to etch PC boards but, like me, have no access to a darkroom or the photoresist chemicals, but do have use of a Xerox machine. The technique that I worked out for transferring the layout image onto a copper-clad board is very simple; it is also fast, and it yields near-professional results.

The artwork is prepared as described in your series "Etch Your Own PC Board" (**Radio-Electronics**, December 1982 through February 1983) and then copied onto a Xerox transparency—the type used to make overhead projector slides; the contrast should be set for as dark as possible in order to get the heaviest possible coating of the toner. It is useful to make more than one transparency in case the first transfer does not come out.

The PC blank is prepared simply by buffing the copper with fine steel wool to remove oxidation and contaminants. The image on the transparency is transferred by heat. When a Xerox copy is made, a black powder called "toner" is deposited on the page and then heated to 300°F to fuse it in place. On paper, the fused toner is absorbed into the porous surface, but on plastic film it just builds up on top. That image can be remobilized by again heating it to about 300°F. I do that using a household clothes iron.

The iron is secured by clamps in a inverted position, so that its hot sole can be used as a work area. The iron is then brought to temperature for a moderately high setting ("wool"). Then the copper blank is heated from the back, with the transparency secured to the foil with its toner-side against the copper. The transparency is attached along only one edge with tape, so that it can easily be peeled off when done, without damaging the delicate image. While the copper comes up to heat, roll the film against the copper to transfer the image. (I used a 1" wallpaper roller.) As the toner melts, the film adheres to the copper, and after a minute or two, the entire image should be stuck down. Then, while the copper is still hot, carefully peel the transparency off and let the board cool. A mirror image of the layout should be affixed, in complete detail, to the copper.

If the results at that point are not completely satisfactory, there are two options. If there are only a few minor imperfections, they can be touched up with a very fine felt-tip pen. Otherwise, the image can be cleaned off and the copper re-buffed for another attempt with a fresh transparency. It is so quick and easy to transfer an image that it is worth while to make a couple of practice runs in order to get a feel for the process. Once a satisfactory mask is transferred, the board may be etched.

I was amazed at how good the results were: My very first attempt produced a slightly flawed but workable board. After modifying my methods, all subsequent runs have been totally successful.

I have never used the phototransfer method, so I cannot compare it first-hand to my xerox technique. I suspect that the photographic method is capable of producing slightly sharper detail and higher-density resist. (Minor pitting occurs on some of the traces, but so far that has not interfered with any circuit.)

There are several definite advantages to the Xerox process: Foremost is that almost everyone has access to a Xerox copier, either at work or through commercial copying services. The resist mask is totally visible on the copper blank, so that touch-ups can be made right on the copier, if needed. The process automatically transfers a mirror image. For work with single-sided boards, that is a definite plus. (It is not as useful for double-sided boards, and adjustment must be made for those.) And, finally, it is a great saving in time and expense. An existing layout can be transferred and etched onto a board, ready for drilling, in well under an hour for the cost of only a few Xerox copies.

So far, I have made only single-sided boards; I intend to try double-sided boards in the near future. I expect to etch each side separately, protecting one side with adhesive-backed film while working on the other.

C. BRUCE SNOW
Lafayette, LA

FOLLOW-UP

As a follow-up to "Build This Digital Tachometer for you Car" and "Build This Digital Speedometer for your Car", which were published in the June and July 1987 issues of **Radio-Electronics**, I would like to note a few minor corrections that may help any readers who are building those projects.

First, in the digital-tachometer article, D2 and D4 on the parts-placement diagram should be interchanged, and so should D5 and D6. The 10-µF capacitor labeled C14 on the schematic is C4.

In the digital-speedometer article, the schematic reference to IC5 should be labeled 4001 instead of 4011. The pick-up coil input should read P1 not P2. Also on the schematic, C12, a 0.1-µF bypass capacitor, was omitted. Getting on to the parts-placement diagram, the set of pads between S1 and IC6 should be labeled C7.

Because of the exceptional response to the digital tachometer and digital speedometer, and a significant number of request for kits, Dakota Digital (R.R. 1, Box 83, Canisota, SD 57012) has expanded its product line as follows:

For the digital tachometer: Display board (#430103), $6.95; main board (#430104), $12.95; parts kit (#2002-KIT), $75.00; Assembled and tested (#3002-UNIT), $99.95.

For the digital speedometer: display board (#430105), $6.95; main board (#430106), $12.95; pick-up coil (#2701278), $11.95; magnet set (4) (#2701279), $4.95; parts kit (#2004-KIT), $75.00; assembled and tested unit (#3004-UNIT), $99.95.

Add 5% shipping and handling to all orders. South Dakota residents must add 5% sales tax.

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PATTERN GENERATOR NCM MODEL 871

A true NTSC audio/video pattern generator

CIRCLE 20 ON FREE INFORMATION CARD

CONTRARY TO WHAT CONSUMER MAGazines often claim, in real life you get what you pay for. Buy junk and you get junk, only you don't know it until you get a chance to experience "quality." That holds true when it comes to color-bar generators—test equipment that we now call "TV pattern generators." The conventional rainbow color-bar generator was just fine as long as the TV's and VCR's themselves were no great shakes at reproducing color. But now that we have digital TV's, HQ VCR's, and computer monitors, all capable of producing pictures rivaling photographic prints, the washed-out colors, blended color-bar edges, and the color smear of many rainbow generators makes it almost impossible to determine whether modern TV's, VCR's, and computers are delivering a high-performance picture. That's why we can justify reviewing the NCM Electronics model *871* Video Wonderbox: a TV pattern generator that costs $519.00.

Professional quality

The Video Wonderbox is a true NTSC color generator, which means that its output signal is the same one that's used by the TV networks and stations to test and align their recording and broadcasting equipment. Typical of professional gear, the Video Wonderbox features several specialized outputs. First, there's a conventional 75-ohm video output with a switchable peak-to-peak output level of 0.5-, 1.0-, and 1.5-volts. Then there's an NTSC composite (V and H) TTL-level sync output, a conventional 9-pin D-connector RGB TTL-level output for testing computer and "universal" TV monitors, and finally, an RF output having a nominal output level of 5 mV into 75 ohms, with an output attenuator with a range of 0–20 dB.

Notice that we didn't refer to a "conventional" RF output. That's because it's anything but conventional. Instead of having an RF output on Channels 3 and 4 (or 2 and 3), the Video Wonderbox's output frequency can be tuned via a front-panel vernier control to any channel in the switch-selected bands of Channels 2–5, 7–13, and 14–40. If you suspect that the reason a TV has deficient color on only one or a few channels might be poor front-end alignment or internally generated *spuri*, you can set the Video Wonderbox right to the troublesome channel. In that way, at the very least you can be certain that you're working with a trouble-free input signal.

Because it's often necessary to make intercarrier checks and adjustments, the RF output has a 4.5-MHz sound intercarrier that can be 100% modulated (25-kHz deviation) at 1000 Hz. The ratio of video and sound carriers is fixed at 10:1.

The video, RF, and RGB test signals are switch-selected. They are:

- 8 × 14 B&W video checkerboard
- 19V × 15H B&W crosshatch
- 10V × 8H B&W crosshatch with centered dots
- Line and field squarewave. (Top half of frame B&W; bottom half W&B.)
- White field
- Black field (at blanking level).
- Red field
- 8 Vertical color bars (plus maximum screen brightness for 9 bars).
- 7 Horizontal color bars (no black or maximum brightness).
- Circle (which can be superimposed over any pattern)

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- Greyscale staircase
- Color burst disabled

The various crosshatch and checkerboard patterns are primarily used for indicating linearity and color-convergence at the sides and corners of the CRT. (When the corner squares start to resemble diamonds you know its the monitor that's stretching the picture, not your eyes.) The pure white and black screens are great for optimizing the adjustment of the CRT's min/max brightness range (blacks really look black—not gray), while the all-red screen is used to test for color purity.

If the picture has smear at brightness-level transitions, pulls, reflections, or other evidence of low-frequency misbehavior, the line and field squarewave will guide you right to the trouble-spot.

As far as the color bars are concerned, they are razor sharp at the color-bar transitions. Anything less than razor-sharp separation generally means that there's a problem with the monitor's frequency response. However, expect considerable separation smearing from a color TV because it simply doesn't have the overall frequency response necessary for sharp transitions.

The circle provides an excellent astigmatism test. Proper astigmatism adjustment can be extremely critical for the correct display of computer graphics. Although an astigmatism adjustment usually is provided only on the finest oscilloscopes, it can be partially simulated by a TV's H and V linearity controls. Since there is no easy way to use the circle part of a TV test pattern for a computer monitor alignment, and since few TV-station test patterns are transmitted during normal working hours, the circle overlay is one of the best tools for making critical astigmatism adjustments to high-performance TV and computer monitors. Essentially, the circle overlayed on the 19V × 15H crosshatch makes a good substitute for a TV test pattern.

The instruction manual claims that various color patterns can be attained by simultaneously depressing two pattern switches,

continued on page 30

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DIGITAL CIRCUITS COURSE. The *Microlab 1*, is intended to introduce students with little or no background to the world of digital electronics. The course includes a training board, two manuals, and all components required to conduct the course's experiments.

At the heart of the training board is a solderless breadboard that allows experimental circuits to be quickly assembled and taken apart. Surrounding the breadboard are support circuits for the experiments, including a bar-graph meter, a seven-segment LED display with driver, switches, a relay, a speaker, and more.

Of the two manuals, one contains 40 experiments that lead the user through the fundamentals of digital circuitry. The other contains support information such as manufacturer's data sheets for IC's used in the course; information about the training board, including schematics and parts lists; an index, and answers to the questions posed in each experiment.

The *Microlab* is priced at $220.00, plus $15.00 for shipping and handling (U.S. funds).—**Mastertech Laboratories, Inc.,** 302 Royal Trust Building, 612 View Street, Victoria, British Columbia, Canada V8W 1J5.

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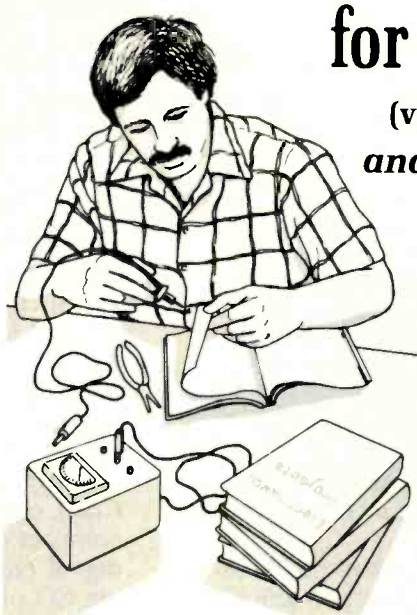

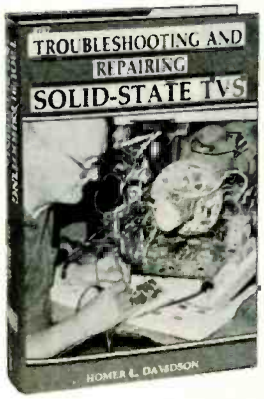

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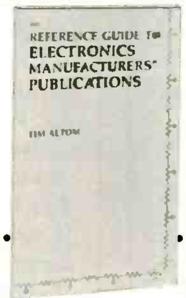

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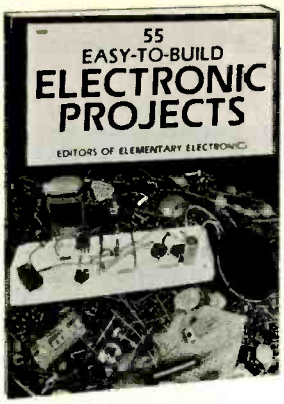

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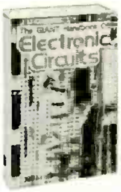

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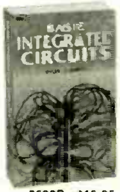

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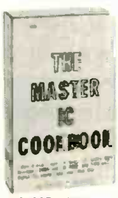

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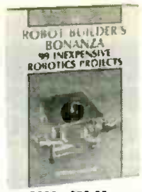

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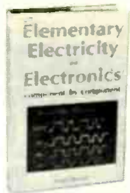

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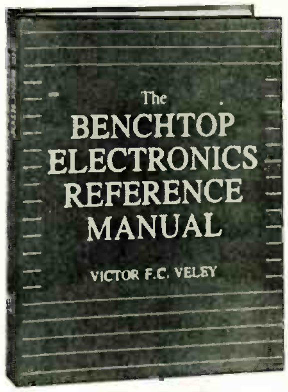

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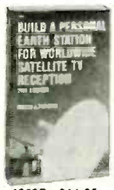

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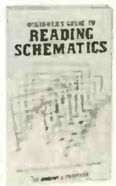

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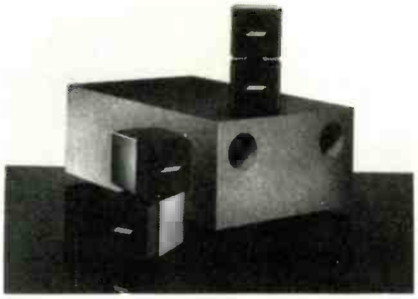
All books are hardcover unless otherwise indicated.

Smaller than a quart container of milk and the weight of a standard telephone, each two-cube speaker array can literally fit in the palm of a hand. Two of those arrays and an *Acoustimass* module (about the size of a typewriter) comprise the system.



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In addition to the flexibility offered by the small and adjustable cube-speaker arrays, the model *AM-5* is available with several mounting brackets and accessories that allow it to be placed or suspended anywhere. The wide-range driver in each cube speaker is also magnetically shielded for use with a video monitor or TV set.

The model *AM-5* is priced at $699.00.—**Bose Corporation,** The Mountain, Framingham, MA 01701.

TABLE-TOP RADIOS. The model *100* (shown) and the model *200B*, are compact clock radios with the controls and the sound of a high-fidelity system.

The model *100* is monaural, and features frequency-synthesis tuning with three memory presets, high-density pressboard cabinet, separate bass and treble controls, dual independent alarms (buzzer at one time, music at another), ramp-up (increasing-loudness) alarm, continuously variable "sleep" timer, and dimmer control. Time, station, and status are indicated on a liquid-crystal front-panel display. It has a suggested retail price of $159.00.

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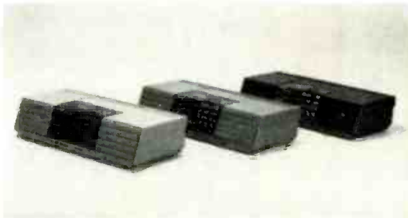
The model *200B* is stereo, and comes in two pieces. One contains the radio and left-channel speaker; the other contains the right-channel speaker. It has all of the features of the model *100* except dual alarms. Besides stereo reception and reproduction, the model *200B* offers an auxiliary input suitable for a tape deck or CD player. It has a suggested retail price of $275.00.—**KLH Division of Kyocera Electronics, Inc.,** 100 Randolph Road, CN 6700, Somerset, NJ 08873-1284.

CD MUSIC SYSTEM. The model *CR-CD10*, combines an AM/FM-stereo compact disc player and a built-in digital clock timer. The top-loading CD player features Automatic Programmable Music Selector and Automatic Program Search System functions. Twin 3⅛" speakers deliver full-bodied sound. The LCD clock section features a convenient wake-up timer and a sleep function.



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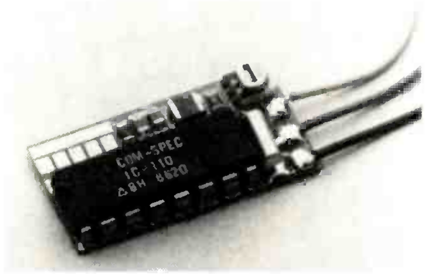
The model *CR-CD10* has a suggested list price of $319.95.—**Sharp Electronics Corporation.** Sharp Plaza, Mahwah, NJ 07430.

CTCSS ENCODER. The model *SS-32SMP*, is designed for use in handheld radios and other size-restricted applications. It measures .53 × 1.00 × .16-inch, and offers full tone versatility and a high audio level.

Any 32 tone frequencies between .01–255 Hz may be selected for storage into a 32-bit EEPROM memory. The tone frequencies can be standard or non-standard, and may be changed at a later date if desired. The required tone frequency is selected by soldering binary-coded jumpers on the tone board. The model *SS-32SMP* may also be ordered to work as a six-tone encoder (no switching di-

odes are necessary) at no extra charge. Multiple-tone switching over six tones can be done with switching-diode networks or a binary switch. Tone frequencies above 255 Hz can be ordered for a slight additional charge.



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The model *SS32SMP* features a low-impedance, low-distortion, adjustable sinewave output that can provide sufficient deviation for most handheld radios. It operates on 6–15 volts DC so that voltage-dropping resistors should never be required. It is priced at $27.95.—**Communications Specialists, Inc.**, 426 West Taft Avenue, Orange, CA 92665-4296.

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LINEAR AMPLIFIER. The model *SB-1000*, provides a full 1000-watt PEP SSB output, or an 850-watt CW output. It provides full HF coverage from 160 to 15 meters, including 80% of rated output on the three WARC bands. The amplifier uses a single 3-500Z tube in a high-efficiency circuit, and has a hypersil steel E-I core transformer for high-performance operation. It also features a quiet computer-style fan, a full-wave power supply with computer grade capacitors, adjustable ALC, and vernier-tuned plate and load controls.

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The model *SB-1000* is priced at $739.95—**Heathkit**, P.O. Box 1288, Benton Harbor, MI 49022.

RELAY SERVICE KIT. The model *JTK-64*, contains a comprehensive tool selection for relay maintenance. Furnished in a compact 12½ × 10 × 2¼-inch padded zipper case, the tool selection includes

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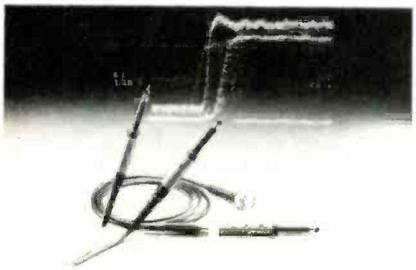
over 40 items, including brushes, burnishers, files, gauges, lamp extractor, mirror and magnifier, ignition wrench, pliers, circuit tester, soldering iron, wire stripper, and more.

The model *JTK-64* is recommended for professional service and repair of magnetic relays and solenoids in telephone/communication systems, process controls, and other plant equipment. It is priced at $289.—**Jensen Tools,** 7815 S. 46th Street, Phoenix, AZ 85044.

MODULAR OSCILLOSCOPE PROBES. The *SP300 Series,* range in bandwidth from 10 MHz to 100 MHz and adapt to all oscilloscopes. They feature replaceable tips, probe cables, probe heads, and ground leads. Designed to be used in a wide number of applications, each probe is equipped with its own accessory kit having two insulating tips, a quick-connect BNC adapter, a spring hook, and a trimmer.



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A highly-flexible silicone-insulated probe cable is offered in one, two, and three-meter lengths. A read-out actuator option for use with all ×10 probe cables is also available.

Prices for the *SP300 Series* start at $27.00.—**OK Industries, Inc.,** 3455 Conner Street, Bronx, NY 10475.

COAXIAL SWITCH. The model *DSK,* measures only 3.1" × 1.9" × 1" overall. It functions as an SPDT A-B switch, and is supplied with three BNC connectors. The large actuator provides a positive switching action. That design incorporates an unusually high isolation between unused lines.

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The switch is easily mounted on the side of a desk, or on a wall, by use of two-sided adhesive tape (included). It is equally useful in offices or labs where there is a need for switching coaxial lines that terminate with BNC connectors. The model *DSK* is priced at $22.00.—**L-Com Data Products,** 1755 Osgood Street, North Andover, MA 01845.

REMOTE POWER SWITCH. The model *R119,* is a single-outlet device that can be used for remote control of multiple-outlet strips, surge suppressors, computers, or peripherals. It features a Velcro mounting pad, so that it can be placed conveniently under a desk or work table to control an entire workstation.

The model *R119* converts a sur-

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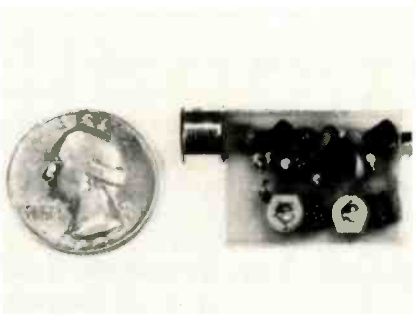

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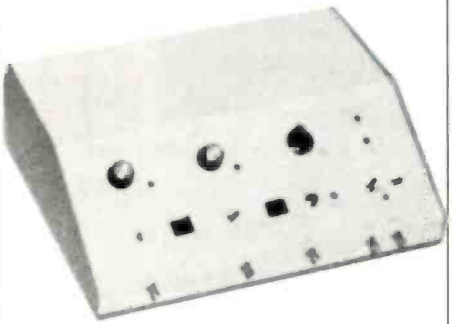

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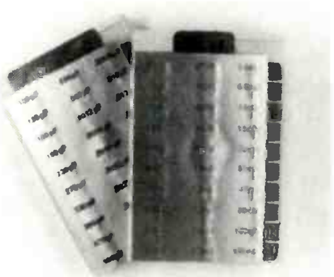

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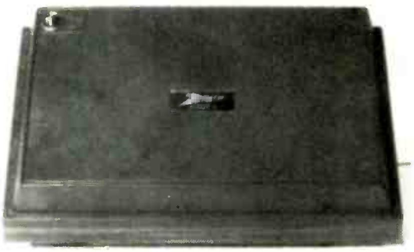

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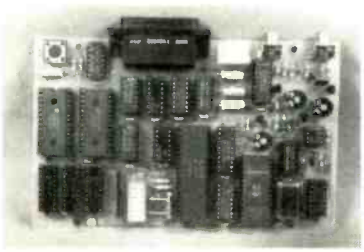

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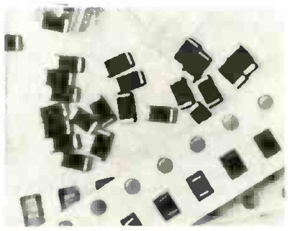

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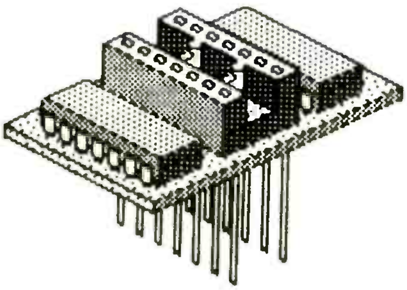

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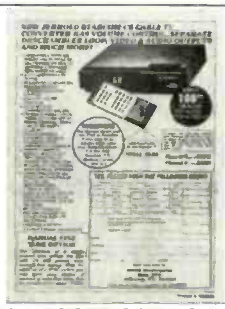

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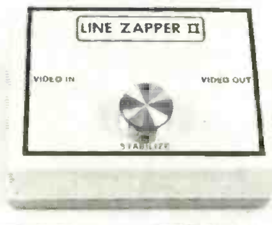

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ge-suppressor or outlet strip to instant remote control by simply plugging it in. The switch itself is lighted so that on/off status can be seen easily. The switch is rated for 1,800 watts, 15 amps maximum. The device is UL listed and features a one-year warranty; the price is $19.95.—**Perma Power Electronics, Inc.**, 5601 Howard Street, Chicago, IL 60648. **R-E**

EQUIPMENT REPORTS

continued from page 20

such as the switches for a B&W crosshatch and the vertical color bars. While it's true that pressing two switches creates unusual color patterns, except for the two that create the all-red field, they are useless. It's just something that occurs, and making mention of that fact probably saves the company many complaints that "something is wrong with my unit."

The Video Wonderbox is line-powered and toolbox size: only 8 × 2 × 5⅝-inches. The carrying handle is detented and also serves as an adjustable tilt-mount. No accessories other than the instruction manual are provided. Optional accessories for the unit include a 75-ohm BNC-to-BNC cable, a 75-ohm BNC-to-IEC cable, and a DB-9-to-DB-9 (IBM-compatible RGB/RS-232) cable.

For additional information write to *NCM Electronics*, 1500 Wyat Drive, Santa Clara, CA 95054. **R-E**

NEW IDEAS

Simple multi-tone generator

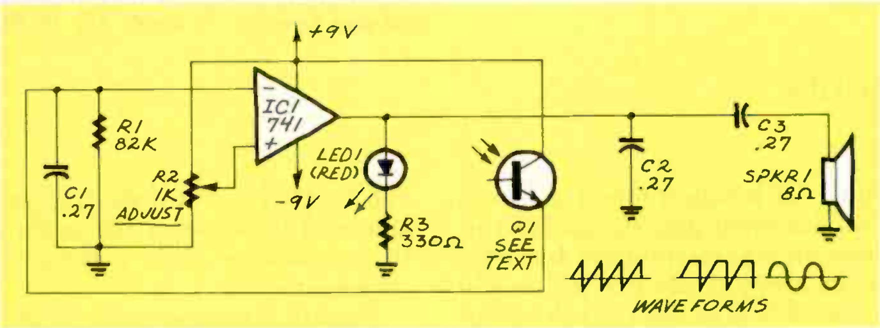

FIG. 1

SOMETIMES YOU NEED A WAVEFORM having a particular shape, frequency, or amplitude that's not provided by your signal generator; or maybe you just don't own a signal generator. If you don't mind spending a bit of time experimenting with parts values, the multi-tone generator circuit described here might give you just the waveform that's needed.

The circuit shown in Fig. 1 can actually be built from parts you probably have lying around on the workbench. A bi-polar power supply is required; two 9-volt batteries wired in series, with their junction used as the "ground" will do.

How it works

Op-amp IC1 is used as a sensitive voltage comparator, whose trip level—the value at which the output changes state—is determined by potentiometer R2. The resistance of R1 in series with the resistance of phototransistor Q1 provides the feedback divider for IC1's inverting input. Since Q1's "dark" resistance—the resistance when there is no light—is very high. Very little voltage appears across R1; therefore, IC1's output will normally be high.

When power is first turned on, IC1 goes high, causing the LED to glow. However, the instant it glows it shines on Q1, causing a decrease in Q1's collector-emitter resistance, which causes a large voltage drop across R1. The comparator immediately switches to a low output, thereby turning the LED off, which restores Q1's dark resistance. The increase in Q1's resistance causes the cycle to repeat, thereby producing an oscillating output voltage.

Logically, the circuit should "lock up" because the LED and phototransistor would be competing with each other for control of the circuit, and IC1 would get stuck at some equilibrium state. Capacitor C2 prevents that from happening by keeping the LED lit slightly longer that the normal turn-off time. (C1 also helps avoid lock up, but its use isn't critical and it can often be eliminated.)

The output frequency can be changed by varying the values of C1–C3, but keep in mind that making their values too small will defeat their primary purpose, which is avoiding circuit lock-up.

The frequency, amplitude, and the shape of the waveform are determined by R2. Three of the typical waveforms that can be obtained by adjusting R2 are also shown in Fig. 1.

LED1 can be any red light-emitting diode. Q1 can be any phototransistor—try whatever you have lying around or can get cheaply. The only critical part of the assembly is the positioning of LED1 and Q1. They must be facing and close, and shielded from ambient light—perhaps by placing them inside a small cardboard or opaque plastic tube. Alternately, you could try substituting an opto-isolator for LED1 and Q1. However, bear in mind that the spacing between LED1 and Q1 provides some control over the output waveform; an opto-isolator would eliminate that degree of control.—Mohd Amjad Khan. **R-E**

SERVICE LOG

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Surface-mount components

THE BIGGEST CHANGE IN ELECTRONICS since the widespread use of the integrated circuit is now beginning. It will affect virtually all industrial and consumer electronic products and cause some grief for the technicians who must service and maintain those products. In fact, just as in the transistor transition days of the late sixties, some technicians will flatly refuse to work on the new systems. Yet, unlike the development of IC's and the introduction and proliferation of the microprocessor, the coming revolution does not inherently involve the introduction of radically new devices. This revolutionary change is the simple packaging of components in new cases. It is called *S*urface-*M*ount *T*echnology, or SMT.

Today, the vast majority of components are attached to printed-circuit boards by passing their leads through holes in the PC boards and soldering them to conductive pads on the other side. This is known as insertion-mount technology and is used to attach virtually all conventional IC's, transistors, resistors, capacitors, and inductors to boards. Surface-mount technology involves the connection of components to the surface of the printed-circuit board by simply laying a component's leads on conductive pads under the component and soldering them. Surface-mount devices are soldered on the side of the board to which they are mounted. Several major consumer and industrial product manufacturers are currently gearing up for surface-mount technology. Industry estimates indicate that within five years 80% of all devices will be surface-mount types.

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Advantages

Manufacturers are moving to SMT for several reasons. With the development of more complex IC's, the number of pins needed on the package has increased. Because a *D*ual *I*n-line *P*ackage, or DIP, is not economical if more than 48 pins are required, new packages had to be developed. Those include the *P*lastic *L*eaded *C*hip *C*arrier (PLCC) and *L*eadless *C*eramic *C*hip *C*arrier (LCCC), and were designed to accommodate more pins and to take advantage of SMT. SMT packages for both IC's and passive components are 60% to 80% smaller than insertion-mounted packages. That allows the design of smaller printed circuit boards. It also shortens interconnecting leads and allows the development of faster boards. Because SMT packages are soldered on the side of the PCB to which they are mounted, components can be mounted on both sides of the board. This also lessens the number of layers needed for a typical board.

Disadvantages

Unfortunately for the technician, this miniaturization is not without disadvantages. Many surface-mounted components are glued to the board before soldering. Removing a glued device without damaging the solder runs can be tricky. J-lead devices are soldered underneath the outline of the package itself, making removal difficult.

Manufacturers generally recommend special tools for the testing, removal, and replacement of SMT devices. Even with these tools, the job of servicing of SMT devices is tedious. Lead spacing is generally 50 mils, half that used on standard DIP's. Attaching test leads to 50-mil leads that lay beneath a package can be a problem unless a special test clip is used. Alignment of the replacement part and the solder pads—which is essential for SMT devices—is tricky.

Finally, SMT resistors and capacitors are so small that their values or part numbers cannot be printed on them. Good documentation becomes imperative for successful service of equipment that is SMT-based. Look for manufacturers to begin special training on SMT servicing early next year.—*Elmer Poe CET, PhD*

"How was I supposed to know you have to plug it in?!"

AUDIO UPDATE

Stereo Spatial Imaging

LARRY KLEIN,
AUDIO EDITOR

IN PAST MONTHS WE'VE DEVOTED SEVeral columns to those special products and techniques used to enhance spatial perspective and imaging in stereo listening. Dedicated audiophiles, who would never dream of adding "artificial" enhancement devices to their systems, eagerly seek out those components—including special cables—that they believe "naturally" add desirable sonic properties. In that, they resemble the food faddists who insist that vitamin C extracted from rose hips has far greater virtue than vitamin C derived from chemically-produced ascorbic acid. Let's look at some of the electrical, mechanical, acoustic, and psycho-acoustic factors that serve to produce an enhanced stereo sound stage.

The influencing factors

The most dramatic influence on the perceived depth of the stereo image is usually the type and amount of reverberation in the recording itself. The sound field embodied in a well-miked, simply-mixed recording consists of three sonic components picked up by the microphones: the direct sound, the early reflections, and the reverberation. The direct sound, which is the first heard, is used by the ear to localize the source of the sound. Next, the early room reflections contribute a sense of the size of the acoustic space. When the late-arriving reflections become numerous, they become homogenized and blend into reverberation, which adds a sense of warmth and continuity to the sound.

FIG. 1

The factors in a home system that can influence the perceived spatial properties of a stereo signal are: accidental or deliberate phase shift between channels, channel separation, out-of-phase crosstalk between the channels, frequency-response irregularities, and the ratio of directly perceived versus delayed or reflected sound within a room. That last factor is basically determined by the designed-in dispersion of the speakers and their placement in the listening room. And, of course, we can't neglect the speakers' interactions with the acoustic environment they find themselves in. Some of those factors are worth some additional discussion.

Crosstalk

Out-of-phase crosstalk between channels, whether introduced deliberately or otherwise, will deemphasize the center-recorded sounds, thus increasing the depth and width of the stereo stage. Because crosstalk in a phono cartridge usually varies to some degree across the audio-frequency range, so can imaging. There was one highly esteemed British phono cartridge whose coils had a matrixed output. If the coils were not properly aligned via a small setscrew adjustment, there would be a high level of out-of-phase crosstalk that provided (for some ears) a wonderfully open, wide-stage quality. Those cartridges that were properly adjusted didn't manifest that effect and were therefore considered defective by many U.S. audiophiles.

Some critical listeners have complained that music recorded on compact discs frequently lacks depth when compared with LP's that were made from the same masters. It could well be that phase anomalies in phono cartridges—which are not present in CD laser pickups—are responsible for the differences heard. Such enhancing crosstalk can also occur accidentally in a component through capacitive coupling on the circuit board, or purposely through design.

Frequency-response differences, particularly small ones, heard during critical A/B listening tests are frequently interpreted as differences in depth, openness, or "air," rather than as tonal-balance differences. For example, a small bump in frequency response at about 300 Hz (which is where the reverberant energy in a recording is concentrated) may contribute to subjectively-enhanced depth. And many moving-coil cartridges—and some electronic components—have had a rising high-end response that is frequently inter-

continued on page 38

AUDIO UPDATE

continued from page 33

preted as "airiness" and increased depth.

Hiss

Also related is the fact the a *small* amount of *stereo noise* (random hiss) added to otherwise-clean program material can add to the subjective appearance of airiness of the stereo image.

I wasn't aware of the hiss-equals-highs phenomena until it was brought to my attention by Bob Carver, many of whose designs have shown an in-depth awareness of psycho-acoustics. When, during a demonstration of a prototype of his "autocorrelator" noise-reduction system many years ago, I complained about a slight loss of highs, he didn't seem to be surprised or upset. He simply used an external white-noise generator to add a touch of hiss to the cleaned up signal—and the "lost" high-frequencies subjectively reappeared!

He then mentioned that there was early resistance to the Dolby professional noise-reduction system because the reduction of tape hiss resulted in a subjective dulling of the program material. It recently occurred to me that some of today's complaints about the "closed-in" quality of CD's might also arise from their inherent lack of background noise.

Speaker spatiality

As long as I can remember, there have been disagreements, even among equally learned and experienced speaker engineers, about the optimum radiation patterns for a home speaker. In other words, what is the best (most realistic sounding) way for a speaker to deliver its sounds into a room? In my view, the question is so difficult—and provokes so many different answers—because of the essential *artificiality* of the stereo-reproduction process.

When I discussed the matter in earlier columns, I pointed out that nowhere in nature do you find the illusion of a localized *single* sound source generated by the level and phase cues in the sound coming from *two* widely spaced sound sources (speakers). It is really no wonder then that speaker engineers disagree in their design approaches.

In past columns I've described in detail how phase and level cues are used by the ear/brain mechanism to localize the source of a sound in real life. Stereo reproduction attempts to use those same psycho-acoustic cues to construct a sonic illusion, but the essential artificiality of the process gets in the way. Speaker designers have been manipulating speaker dispersion in a rather hit-or-miss fashion for years in an attempt to achieve greater realism. You will find speakers with drivers facing every which way, including away from the listener, all in an effort to generate the phase, level, and arrival-time cues that the ear/brain uses to construct an acoustic image. The fact that each speaker ultimately must operate in an acoustic environment that is unknown to the speaker designer tremendously complicates the matter.

Audiophiles tend to disagree as to the "best" speakers in respect to their imaging properties. Assuming that none of the speakers argued about are specifically designed for special properties, I think that the disagreements simply reflect an (usually) *accidental* fortuitous match of dispersion characteristics of a particular pair of speakers, their location, and the reflective characteristics of the listening room. Those same speakers in a different room or location might not sound as good.

In the past two or three years two companies (Acoustic Research and dbx) have addressed the speaker-radiation/room-environment problem from a scientifically analyzed psycho-acoustic/acoustic perspective. The result is a substantial enhancement of the spatial realism of several of their systems, one of which, the dbx *SF-10*, is shown in Fig. 1. I think the audio industry is finally getting around to appreciate that creating a realistic stereo illusion in a home environment takes something more than two channels of stereo feeding a pair of conventional forward-facing speakers. **R-E**

ANTIQUE RADIOS

RICHARD D. FITCH

Restoring a classic, part 2

LAST TIME WE LOOKED IN DETAIL AT THE schematic for one of the most popular radios of its time, the GE *A-53*. See Radio-Electronics, June 1987. As I mentioned, I've had one of those units in my collection for quite a while, but have never attempted to restore it, until now. To show how a typical restoration task might go, we'll restore that radio together now. But first, let's finish up with the circuit.

Back to the circuit

For space reasons, we were not able to finish up our look at the schematic in the June issue. I'll rectify that problem now. Incidently, you will likely want to have that figure ("Antique Radios," June 1987, Fig. 1) handy as we proceed, and you will certainly want it when we turn to the restoration itself.

Plate and grid voltages are supplied by a 5Z4 rectifier tube. The output of the tube is fed to L16, the field coil. The field coil serves two purposes: First of all, it is the loudspeaker's electromagnet (permanent magnets were not used in early speakers). Secondly, it works as a choke, filtering the output of the power rectifier. That was a typical design for the period.

Power transformers for the GE Model A-53 (and many other) receivers require some added caution. There were three possible transformers that could have been installed in this chassis, depending on the requirements of the area where the set was sold. Transformer information is usually available on a sticker at the rear of the chassis. In the case of my set, information indicated that it was a universal transformer. The transformer is shown schematically in Fig. 1. By properly tapping the unit, output voltages from 115 to 240 volts were available. Again information indicated that my transformer was set up for 115 volts.

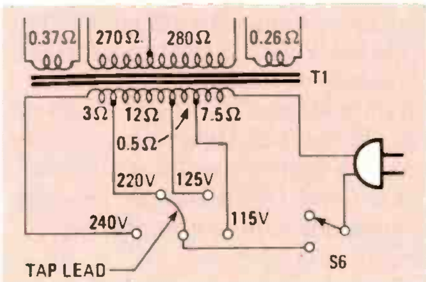


FIG. 1

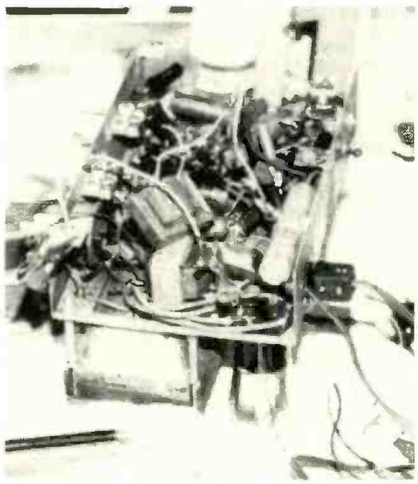


FIG. 2

Troubleshooting

Of course you realize that we have been afforded a rare luxury with this set. Often I don't even have the complete tube layout, let alone a schematic and the original factory specifications. That's one reason the set was chosen—it made an ideal "first-time" project.

Now that we are familiar with the chassis, we can proceed with returning the radio to operating condition. But first we must make sure that restoration is possible and worthwhile. Following the safety rules I outlined last time, the set was plugged in and turned on. All of the glass envelope tubes lit except the rectifier (5Z4). A slight movement of the tube in the socket brought that tube to life. The set was one of the first to use metal-envelope octal tubes. To tell whether or not those tubes were lit required touching each one *carefully*. The touch test told me that they were lit. Despite that, only a slight hum could be heard emanating from the electrodynamic loudspeaker.

I next made a few attempts to inject a signal via the antenna terminals and then the grid caps, but with no luck. Changing the position of the toggle switch that was added at the rear apron produced the same result. The missing band switch was discounted as the cause of the problem because even if the unit had been reduced to a simple phono amp, it should still pass a signal.

My past experience with similar radios told me that a likely place to look for the cause of the trouble is somewhere between the plate of the output tube, here a 6F6, and the speaker coil. I unplugged the unit to make a few continuity tests. The speaker was also unplugged from the chassis. My tests showed that the voice coil and the secondary winding of the output transformer, which on this set is located under the chassis, were both fine.

At this point, we've done about all we can do without pulling the chassis. That's because several components, including the the first and second IF transformers, as well as the circuit alterations, are located under the chassis. A good sign was that the chassis bolts and the (remaining) front-panel knobs were firmly in place. That indicates to me that this set was operable after the alterations were made, even if just as some kind of amplifier. Human nature, being what it is, no one would bother to tighten the bolts on something that was not working.

Examining the underside of the chassis, after removal, showed that it was clean and neatly done. I didn't even need my handy can of insecticide. In short, there was no obvious reason why the set shouldn't pass a signal. Plugging in the speaker and the line cord, I took a few voltage readings at the output tube. That voltage didn't correspond to what was indicated in the specifications (having those numbers was truly a luxury), so I unplugged the set once again; it was time for some more probing.

Still working in the same area first suspected, one more continuity test located the problem: It was an open in the primary winding of the output transformer.

No, I don't have a new transformer for that set in my stock. Also, all of the suppliers were closed at that late hour. However, I was obsessed with getting the set to play that night so I went searching through my junkbox (I never throw any old parts away). Luckily, I found one that was almost a perfect match.

I laid the substitute in the chassis of the GE, and clipped the wires into the circuit with alligator clips as shown in Fig. 2. (Not forgetting, of course, to disconnect the original transformer.) Crude as it looks, that is a very valid way to substitute parts for testing, and one that has been used by nearly all service technicians almost from the beginning of radio.

After making the proper connections and disconnections, I again plugged in the line cord and waited. In a few minutes my efforts and frustrations were rewarded. The set began to play the music of the big bands, just as it did in the 1930's. (I tune all my antique radios to the local "big bands" station.)

Finishing touches

Restoring the cabinet was no big problem. A few veneer patches and some stain to match the patches to the rest of the cabinet were all that were required. There were no inlays or decals to be concerned with, so the cabinet just got a light sanding. The sanding has to be done with extreme care, however. The finish layer of veneer is often no thicker that the paper that this page is printed on. Once you sand through that finish, it's harder to cover up than a hole.

I decided not to bother replacing the missing bandswitch. In its place an almost-matching knob was bolted to the front of the cabinet to maintain at least a look of authenticity.

To finish restoring the chassis, the test output transformer will be bolted in place of the original, or a suitable new one will be used. The tubes will all be tested and all the tube sockets will be cleaned. The toggle switch and the jack will be removed from the rear of the chassis. That will leave two holes on the rear of the chassis, as well as a dummy bandswitch knob on the front of the cabinet. Just think, 50 years from now some future radio restorer will get his hands on the set and wonder what was in all of those holes, and what kind of modifications were made.

But he won't have to wonder for long. I intend to attach full information on the set to the inside of the cabinet. Included will be details on all alterations and circuit changes that were made by me, and others before me. Leaving information on circuit changes for future servicers is an important habit to get into, and one that has been observed almost from the start. Don't be surprised to find parched, hand-drawn diagrams rolled up inside your antique radio. All early well-trained hobbyists and servicemen followed that procedure.

Some closing notes

Tube-socket terminals are one of the prime causes of wiring shorts in antique radios. Wires are dressed along their sharp edges, and over the years that causes breaks in the insulation. If you find that situation, at least bend the wire away from the terminals. Or, even better, you could replace the wire, put a piece of spaghetti tubing over it, or coat it with some liquid high-voltage insulation.

Finally, in the course of our poking around the set we discovered that a wave-trap had been installed between the antenna (blue) and ground (white) leads. That was done in the 1930's and indicated that the owner was located near a powerful telegraph station. Without those traps, the code signals would have overpowered the receiver and would be heard over the entire band. It's fairly common to find such filters on receivers of the period.

Much of the procedure we followed can be applied to any depression-era radio. Of course, things just happen to work out better sometimes than others: I'd say I lucked out on this set. **R-E**

DESIGNER'S NOTEBOOK

An under-voltage monitor

ROBERT GROSSBLATT,
CIRCUITS EDITOR

JUDGING BY THE RESPONSE I'VE GOTTEN to October's circuit, there are a lot of you out there who are interested in ways to keep an electronic eye on the state of your batteries. We've already seen how to watch out for excessive voltages, so I guess it's only right to take a look at the other side of the coin—under-voltage indicators.

Just as it is with over-voltage monitors, there are lots of ways to go about designing a circuit to make sure that an input voltage is greater than a particular preset value. As a matter of fact, I've described a few of them in the past. The reason I've decided to talk about it again this month is not only to show you a neat little circuit, but also to demonstrate how a few small changes can let a circuit do two apparently opposite jobs.

The circuit shown in Fig. 1 is really made up of two separate sections. The first is the familiar 7805 regulator and the second is, well, everything else. If you have a copy of October's column handy, you'll find it interesting to compare the circuit there with the one shown here. The basic idea behind the over-voltage indicator was to let the Zener diode look at the voltage and start conducting if it exceeded the Zener voltage. As soon as that happened, the Zener would turn on a transistor, making its collector go low and lighting an LED.

The schematic in Fig. 1 uses the same design approach, but the Zener diode is used in exactly the opposite fashion. As long as the voltage stays above the Zener's threshold voltage, the collector of Q1 is kept low. If the unregulated voltage falls below 6.7, the Zener will turn off and Q1's collector will go high. That's 6 volts for the Zener plus the normal 0.7-volt drop across the transistor's emitter-base junction.

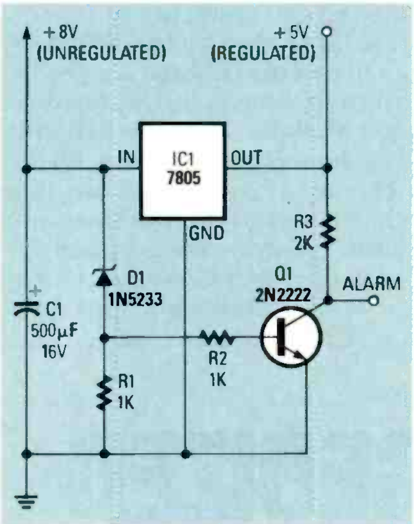


FIG. 1

I've shown the circuit working in conjunction with a 7805 since it's often very convenient to detect a power drop before it makes itself known in the actual circuit. It is useful to watch the unregulated voltage since there will be a finite time before it gets so low that the regulator turns off. A 7805 will continue to put out 5 volts as long as the input voltage stays above about 7.5 volts. The reason I've set this circuit to trip at 6.7 volts is to guard against any false triggering.

Heavy current demands in other parts of the circuit can cause a transient drop on the unregulated voltage. Those are handled by C1, a 500-µF unit that stores enough energy to supply the 7805 during the transient voltage drop. When the unregulated voltage really starts to fall to zero, C1 will discharge and the voltage at the input of the regulator will start sliding down to zero. Once it gets below 6.7 volts, the Zener will shut down and the alarm output will turn on. The bottom line here is that if the alarm goes off, you can be sure that your circuit is in real trouble. The alarm output can be used to kick in emergency power, do a quick memory write, turn on a siren, etc.

Although you can use the alarm output to trigger anything you want, it's a good idea to stay away from mechanical relays since it won't be too long before you have no power at all. The actual time you will have depends on the circuit you're protecting—how much current it draws, total circuit capacitance, and so on. There will likely be enough time to take electronic action, but most mechanical relays will just be too slow. By the time the relay has closed, you'll be out of juice, and out of luck.

Product of the month

It's time to award another of our highly coveted Silver Soldering Iron awards. This one goes to Telebyte Technology, Inc., of Greenlawn, NY, for their RS-232 Mini Analyzer Kit. See Fig. 2. It consists of a model *43* RS-232 line monitor, a model *51* Mini Patch Box, and a bag of colored jumper wires. Both units are housed in the same type of plastic hoods that are usually used to make null modems and gender changers. Since they each have a female DB-25 connector on one end and a male on the other, they can easily be inserted into most RS-232 lines.

The line monitor, called the *MicroPeeper*, has both red and green LED's on lines 2–6, 8, and 20. The LED's are high-efficiency types, so they're nice and bright. That is important because RS-232-level changes can be very brief and easily can be missed if the LED's are too dim. That is the problem with the less-expensive units that use tri-color LED's rather than separate red and green ones.

The *MicroPeeper* has an unassigned pair of LED's that are tied to a TEST pin. That is a neat feature, since it allows you to watch any other line you want. The seven lines already monitored are the most common ones, but some applications use the RS-232 standard in less than standard ways. Using the Mini Patch Box and the

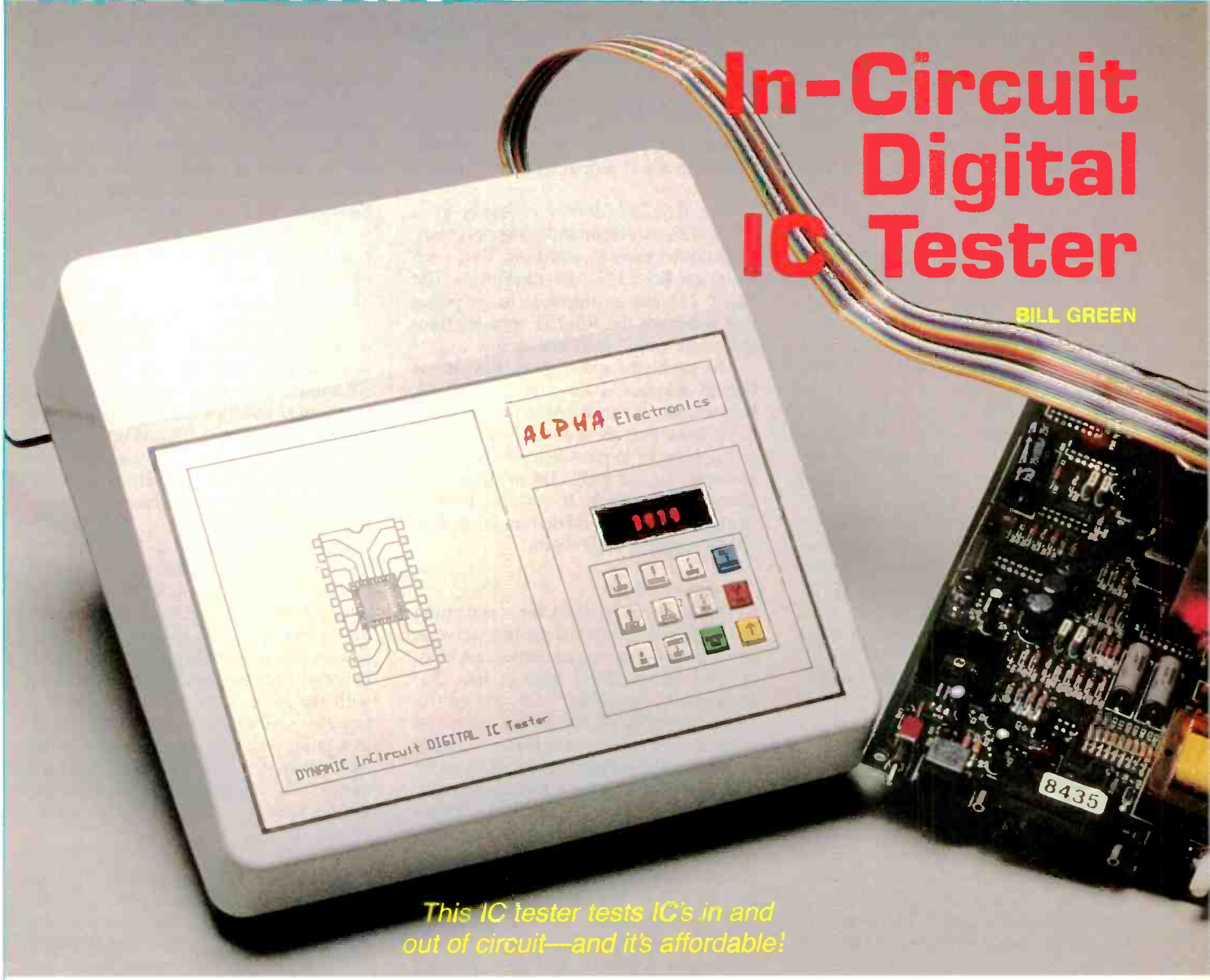
FIG. 2

MicroPeeper together gives you complete control of the routing and testing of the entire RS-232 line. That is valuable when you're trying to troubleshoot a printer line, modem, or finding out whether your computer's UART is working.

The *MicroPeeper* is priced at $49, and the Mini Patch Box lists for $25. If you buy them together as the Mini Analyzer Kit for $74 (model *301*) you'll get a plastic carrying case and the bag of wire jumpers as a bonus. If you shop around there's no doubt you'll be able to find a cheaper RS-232 analyzer kit, but not a better one. **R-E**

In-Circuit Digital IC Tester

BILL GREEN



This IC tester tests IC's in and out of circuit—and it's affordable!

SERVICING DIGITAL ELECTRONIC EQUIPMENT is seldom easy; difficulties arise from several sources. For example, microprocessors, RAM, and ROM IC's are usually socketed, but digital "glue" IC's (gates, flip-flops, etc.) are seldom socketed, because the sockets may cost as much as the IC's themselves.

Not using sockets reduces manufacturing costs, but causes nightmares for the serviceperson. Often, an inexpensive assembly can be discarded and replaced for less than it would cost to repair it. But when a board must be fixed, the headaches begin. For example, how do you locate a bad IC when most or all are soldered to the board?

One way is to remove IC's one by one, replacing each until the board starts functioning again. However, if two or more IC's are bad, the difficulty of locating them increases tremendously. Defect isolation using logic probes, logic analyzers, oscilloscopes, and other equipment can be performed, but doing so requires a high degree of technical knowledge, which may not always be available. Clearly, a better method is needed.

The in- and out-of-circuit IC tester presented here is such a method. It is a moderately priced device that can test most parts in most TTL families, as well as TTL-compatible MOS and CMOS devices. You use the device by selecting a test routine, clipping a test probe to the *D*evice *U*nder *T*est (DUT), and examining an LED display.

Other IC testers in its price range ($300 for a complete kit, other configurations available) require a known-good IC of the type to be tested for comparison; ours doesn't. In addition, our tester has enough memory to store 105 different IC test routines, and it has a serial interface to upload and download test routines. Those capabilities allow a field-service technician to load different test set-ups depending on the device he or she will be servicing.

Test routines may be entered by hand on the tester's keyboard or downloaded from any computer with an RS-232 serial port. In addition, routines entered via the tester's keypad may be uploaded and saved for future use. Simple BASIC programs allow you to upload and download test routines. Those programs will appear here, and will be available on the RE-BBS; the routines run (or can be adapted to run) on many computers, including IBM's and clones, Radio Shack *Models III* and *IV*, the *Color Computer*, Commodore and Apple computers, etc.

Basic features

The tester has a 12-key keyboard to allow manual entry and editing of test data and commands, and transfer of test data to and from a personal computer. A four-digit sixteen-segment alphanumeric display prompts the user to enter data and displays pin-by-pin test results (both expected and actual data).

External back-up batteries are unnecessary because data and programs are stored in a special non-volatile 32K-byte CMOS RAM IC.

IC's are tested dynamically: inputs are cycled high and low as many as forty times, according to the test routine. That capability allows thorough testing of difficult-to-test parts, including counters, flip-flops, and registers.

Using the tester

Testing an IC out-of-circuit is straightforward: Simply attach the test clip and run the appropriate test routine, which is selectable by part number. The tester then writes data to the device and reads back the results for comparison. (We'll show you how to generate the test data later.) An out-of-circuit IC is not connected to any other devices, so we needn't worry about input pins of the DUT that might be connected to outputs of the same or another device, or to ground or V_{CC}.

To test IC's in-circuit, the tester allows for inputs that may be connected to outputs, ground, or V_{CC} as follows: The tester's output drivers can be floated (i. e., placed in a high-impedance state); in addition, they have enough current drive (both sourcing and sinking) to pull an input high or low (briefly), even if it is connected to an output. Further, you can specify that the test routine ignore any desired pin or pins.

How it works

All circuitry is contained on two PC boards, which are interconnected by a short length of ribbon cable. One board contains the interface circuitry through which the DUT and the on-board microprocessor communicate. The other contains the microprocessor, the RAM, and the support circuitry, including a 5-volt regulated power supply, an RC reset network, and a 2-MHz crystal-controlled clock. Crystal control is required for precise timing of the serial communications channel. A Z80 microprocessor directs all tester operations.

A major design goal of the tester was the ability to store many test routines, so a large amount of nonvolatile storage is provided by a DS1230 32K byte non-volatile static RAM. The lower 4K of the RAM contains the control program.

The tester's schematic is shown in Fig. 1. It uses several custom CMOS gate arrays for various purposes. Part of IC5 (a 75498) provides the write-enable function. It decodes address lines A12–A14 and disables the processor's write enable signal whenever all three address lines are low, thus preventing corruption of the control program. The remainder of IC5 decodes the input and output strobes for the driver board and the display.

Another custom IC (IC6, a 75500) is the input/output port for the keyboard and the display. That IC latches the appropriate keyboard row signals and reads the column signals of the keyboard, and it latches the digit address lines for the display.

The third custom IC (IC4, a 75499), is used in the RS-232 I/O channel. The IC decodes the port strobes and latches the serial input and output data and "busy" signals.

The RS-232 driver/receiver is a MAX-233, which provides the necessary level conversions to and from TTL (+5 volts) and RS-232 (±10 volts) levels. The MAX 233 has an internal charge pump that generates the RS-232 voltages from the single-ended five-volt supply.

The keyboard and display provide the human interface. Twelve tactile-feedback keyswitches are arranged in two columns of six rows; they are scanned by the 75500 (IC6). In order to provide legible operator prompts, we use a DL1414 intelligent alphanumeric display. It contains built-in storage, decoders, and drivers for its four red 16-segment LED digits.

The driver board

The IC tester provides for a maximum of 24 test pins. Each test pin may serve as an input or output; as an output, each pin may be forced either high or low. So, functionally, speaking, each test pin is connected to three IC's in the tester: an input latch, a pull-down driver, and a pull-up driver. The outputs, of course, can be three-stated so that the input can be read.

As shown in Fig. 2, that DUT interface circuit is implemented with nine IC's (IC7–IC15) on the driver board, including three each of the NE590, the NE591, and the 74LS373. The 74LS373's are 8-bit data input latches; the NE590's and NE591's are 8-bit addressable latches with open-collector and open-emitter Darlington output transistors, respectively. The NE590's outputs pull to ground and the NE591's pull to V_{CC}. Each of the NE590/1 IC's has three address inputs and one data input. The data present at the latter is routed to the internal latch/output circuit decoded by the former when $\overline{CS}$ and $\overline{CE}$ are low.

We connect those drivers to the pins of the DUT through P3 by way of a test cable and a DIP header clip. There are 24 test connections, plus power and ground, for a total of 26 pins. You can wire up different test cables for IC's with different sizes and shapes.

An additional ground wire in the test cable is terminated with a miniature clip, which should be connected to ground on the circuit board being tested. The V_{CC} pin may be terminated in the same manner to supply power to an IC for out-of-circuit testing. The tester's power supply will not supply much current for external circuitry, so the system being tested must have its own power supply.

Buffer space

Now let's talk about how test data is stored in the tester's non-volatile RAM. First, each test routine takes 256 bytes of memory. In addition to the stored routines, a separate 256-byte buffer is used to store input data.

Next, corresponding to the 24 test pins are 24 "slots" in memory. Each slot consists of five groups; each group contains two bytes. That accounts for 240 bytes (24 × 5 × 2). An additional 16 bytes are reserved for the part number and the number of pins. That makes a total of 256 bytes (240 + 16).

The first byte in each group determines the function of the pin: input, output, indeterminate, or ignore. The second byte constitutes test data for that pin. Each group may have a different pin function (input, output, etc.). That is useful when you are testing an IC that uses the same pins for inputs and outputs at different times (a 74LS245 octal bus transciever, for example.)

One bit of test data is used per test cycle. Each cycle consists of sending a bit of data to each of eight drivers in each of three NE590's and NE591's, starting with the lowest pin. The drivers latch those signals. Then the level on each pin is read in and stored, one byte at a time, starting with the lower eight pins. The cycle is repeated seven more times, for each byte in a group; the procedure is repeated for each group, for a total of 40 (5 × 8) test cycles. We'll present several practical examples later.

Assembly

Start assembly by procuring or making the printed-circuit boards. We will present foil patterns in "PC Service next month." Etch the boards and carefully drill the 700 holes. Several hundred connections are made through the board (via plated-through holes), so you will have to make these connections with short pieces of bare wire soldered on both sides.

As shown in Fig. 3, the display may be mounted in one of two positions, depending on whether the boards are mounted in a case or are allowed to "float." If you are using a case, mount it on the foil side of the PC board in the area outlined with dashed lines in the diagram. Otherwise, mount the display on the component side of the board in the area that is outlined with solid lines.

Similarly, if you use a case, the pushbuttons must also mount on the foil side of the board. In that case, the key legends must be reversed left to right.

If you use a case, install the keyswitches first. Lay the board on a flat surface, foil side up. Orient each switch so that the flat sides on each is toward the Z80. The keyswitches are colored differently: the 0–8 switches are white; the ENTER switch, green; the SHIFT key ('),

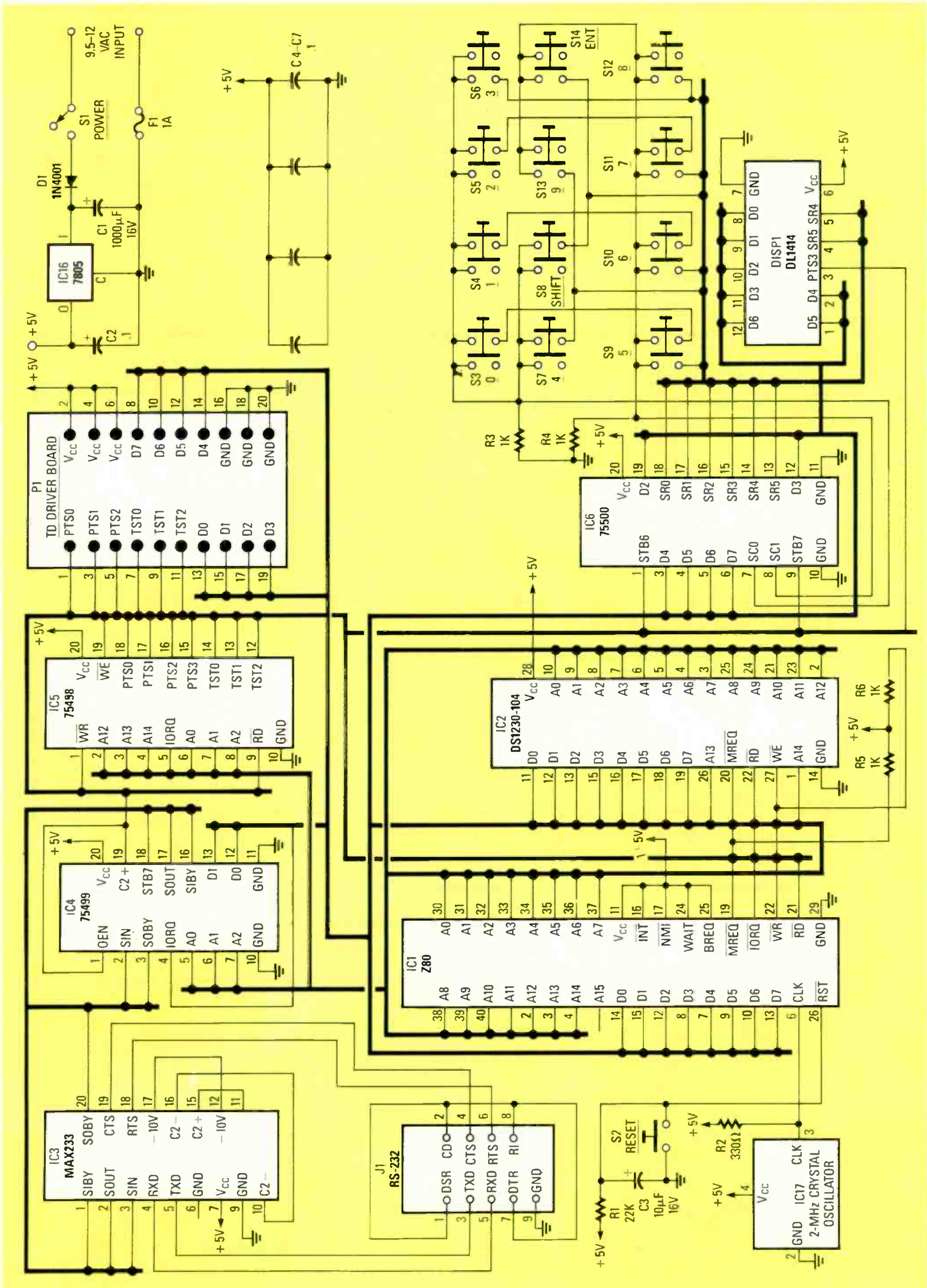


FIG. 1—THE IC TESTER'S MAIN BOARD is built around a Z80 microprocessor running at 2 MHz.

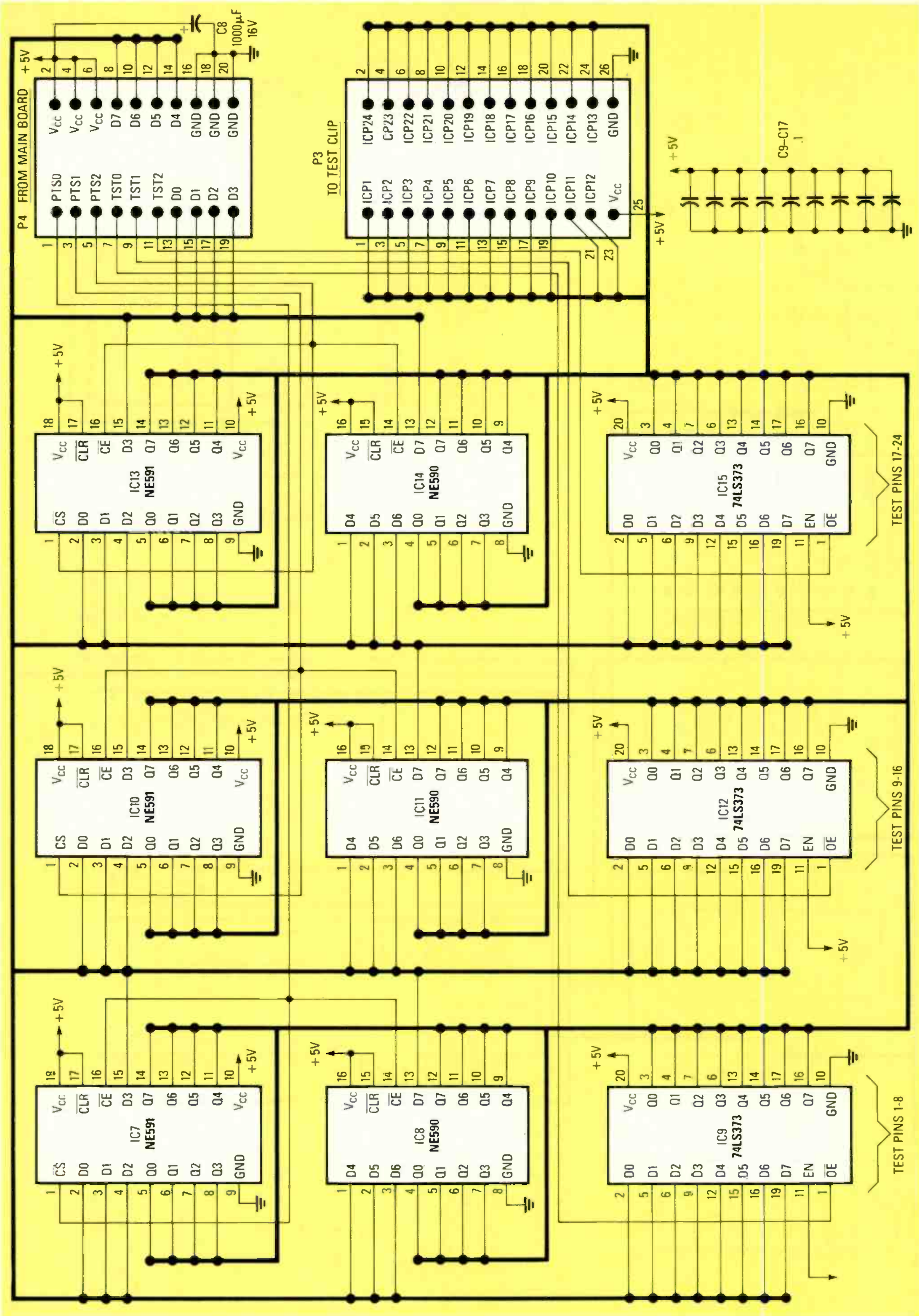


FIG. 2—THE IC TESTER'S DRIVER BOARD provides separate inputs, sourcing outputs, and sinking outputs for each of 24 test pins.

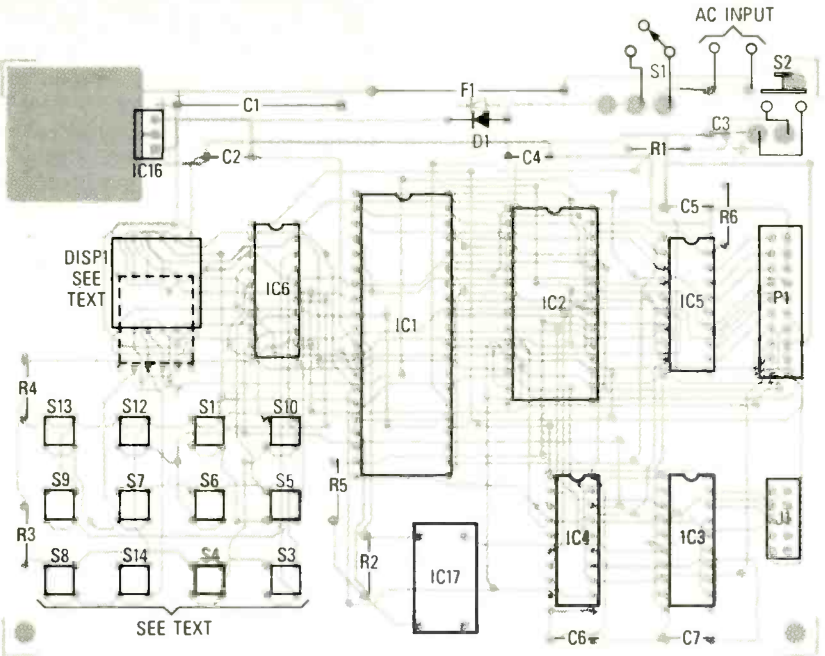


FIG. 3—STUFF THE MAIN BOARD as shown here. Mount the display and switches S3–S14 on the foil side if you will install the tester in a case. Note that the display is oriented differently depending on whether or not the tester is installed in a case.

yellow; the 5 key, red, and the 9 key, blue. Select the proper color and install and solder one pin of each switch from the solder side of the board. Then turn the board over and solder the remaining three pins of each switch from the component side. Mounting the keyswitches that way lifts them off the board enough to protrude through the panel of the case. Now install the 12-pin display socket made from a 24-pin IC socket that has been cut in half.

When not using a case, the keyswitches are installed on the component side of the board and are not spaced away from the board. To mount the power and reset switches on the board, you'll have to enlarge the holes indicated in the parts-placement diagram.

The remainder of the instructions apply to both case and case-less installation. Install the IC the sockets on the component side of both boards next, followed by the remaining components, starting with the low-profile devices.

Be sure to orient the electrolytic capacitors, the diode, the clock module and the voltage regulator (IC16) correctly. It is installed so that its metal tab will contact the foil area of the PC board. To provide extra heatsink capacity, you want to slip a clip-on heatsink on the regulator.

Next mount the male header strips on both boards. (See Fig. 4.) Connect the power and reset switches to the board with 10-inch insulated wires (or directly to the board if you're not using a case). Connect the leads of a 9–12-volt AC, 1-amp wall-mount power transformer to the board. **Do not install any IC's yet.** Connect the driver board to the main board with an 8-inch, twenty-conductor ribbon cable terminated on each end with a twenty-pin female header.

CAUTION! At this point it is possible to erase the control program in the CMOS RAM. For example, if there is a solder short on the board in the right place, the write-protect function of the 75498 will be defeated. Or the write enable pin on the RAM may be shorted to ground, allowing just about anything to be written to the IC. To prevent that from happening, use an ohmmeter or continuity tester to ensure that there are no connections between the following pins and ground, V_{CC}, or any nearby traces on the board: IC5, pins 1, 2, 3, 4, and 19; IC2, pins 20, 27, and all of the address lines, and IC1 pins 20, 21, and 22. Fix any shorts before proceeding.

Measure the output of the regulator; it should be +5 volts, ±0.25 volt. Assuming it's correct, insert the clock module, and check pin 3 for a 2-Mhz squarewave. Now remove power from the board and allow a minute for the filter capacitors to discharge. Being careful to observe proper procedures to avoid static damage to the MOS (Z80) and CMOS (RAM, MAX233, 75498, 75499 and 75500) IC's, install all IC's in their sockets properly oriented. A square foil pad on the board indicates pin 1 of all IC's. Pin one of the display is marked with a small triangle.

When you're certain that all parts are installed correctly, in the correct place, with no pins bent under any of the IC's, and so on, apply power again. The word *COMMAND?* should scroll across the display repeatedly. If it does, you are ready for final assembly. Turn power off and unplug the transformer.

PARTS LIST

All resistors are ¼-watt, 5% unless otherwise noted.
R1—22,000 ohms
R2—330 ohms
R3–R6—1000 ohms

Capacitors
C1, C8—1000 µF, 16 volts, electrolytic
C2, C4–C7, C9–C17—0.1 µF, 10 volts, ceramic disc
C3—10 µF, 16 volts, electrolytic

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

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

Miscellaneous: One 10-pin, two 20-pin and one 26-pin double-row female IDC header connectors. Two 24-pin single-row female IDC header connectors. Flat ribbon cable. 16-pin, 20-pin and 24-pin DIP test clips, others as desired.

Note: The following are available from: ALPHA Electronics Corporation, P.O. Box 1005, Merritt Island, Florida 32952-1005, (305) 453-3534: Kit of parts for $299.00 + $6.00 P&H. Includes all parts, punched and screened panel, case, and labeled keys. Test cable and clips not included. Completely assembled tester for $399.00 + $6.00 P&H. Includes test cable with 16-, 20-, and 24-pin IC test clips. Partial kit, including all IC's, display, and PC boards for $199.00 + $5.00 P&H. Three custom IC's (75498, 75499 and 75500) for $60.00 + $4.00 P&H. Florida customers please add 5% State sales tax. Canadian customers please add $3.00 additional postage to all orders. All foreign orders add appropriate postage for Air shipping and insurance.

Final assembly

Using the keyboard layout (shown in Fig. 5) as a guide, label the keyswitches. If you plan to use the board without a case, the arrangement of the keys must be reversed from left to right. If you are installing the tester in a case, you will need

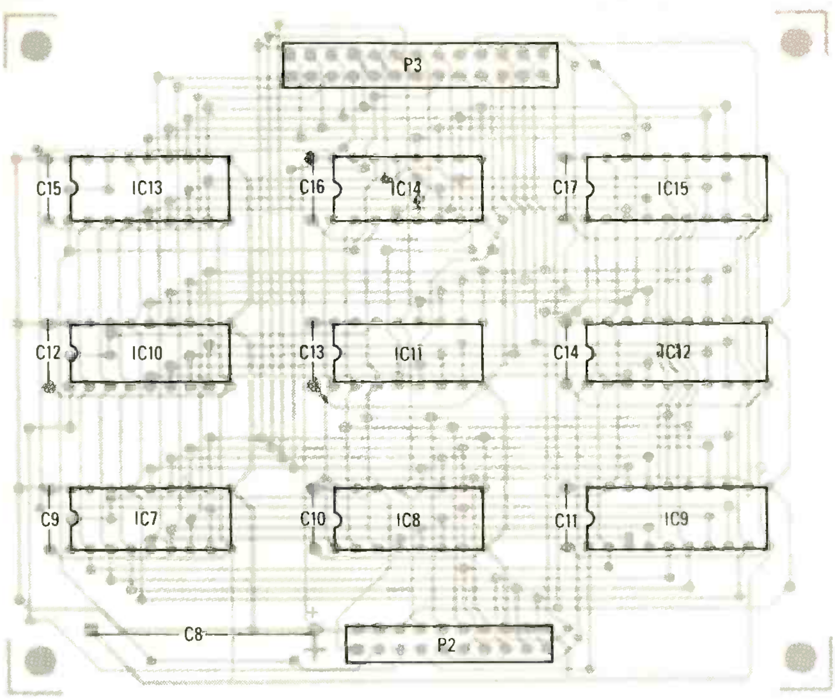


FIG. 4—STUFF THE DRIVER BOARD as shown here. Mount all parts on the component side of the board.

to prepare a front panel for the display and switches; Fig. 6 shows a suitable layout. To protect the display and enhance contrast, install a thin (0.040") plastic bezel inside the panel opening. Then mount the two PC boards to the case.

Using a maximum of three feet of 26-conductor flat ribbon cable, make a test cable. Terminate one end with a 26 pin female header connector. On the other end of the cable separate the 25th and 26th wires. Terminate the 25th wire (+5 volts) with a red test clip, and the 26th wire (ground) with a black test clip. Terminate the remaining 24 wires with two 12-pin single-row female header connectors.

Depending on your needs, you'll want to obtain several IC test clips with different numbers of pins: 16-, 20-, and 24-pin clips will allow you test 14- and 16-, 18- and 20-, and 24-pin IC's easily. When attaching the test clip to the cable, orient the clip so that pin 1 of the cable connects to pin 1 of the test clip.

If you are going to use the serial port to send and receive files, connect a 10-pin female header connector to one end of a 10-conductor ribbon cable, and a DB9 chassis-mount connector to the other. Mount the DB9 connector on the rear of the case. Also mount the power and reset switches on the back of the case. Wire an interface cable to connect the IC tester's port to that of your computer. RS-232 ports come in many configurations, so you will have to determine which pins are needed for your computer. The tester sends and receives serial data at 1200 baud, no parity, 8 data bits, and 2 stop bits. Pin 4 (CTS) is the transmit busy signal, and pin 6 (RTS) is the receive busy signal. The tester requires no other signals to work, but your computer's serial port might. On PC-compatibles, try connecting DSR, CD, DTR and RI together.

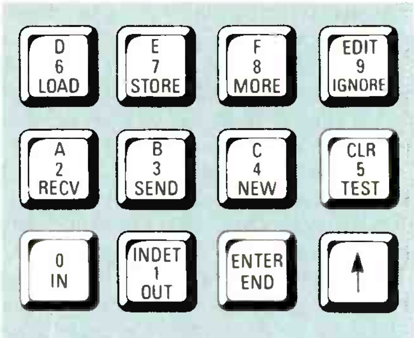


FIG. 5—LABEL THE KEYS as shown here for installation in a case. Otherwise, reverse labels from left to right.

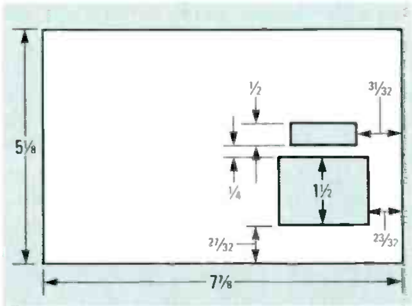


FIG. 6—BASIC DIMENSIONS for the front panel.

Finally, put the case together, plug in the test clip cable and the power transformer, and turn the power switch on.

Basic test procedure

The following commands are available when *COMMAND* is scrolling in the display: Load, Store, Send, Recv, New, Test, and Clr. The Shift key (') is always used to perform the function associated with the upper legend on each key. For example, '6 is a "D," used to enter hexadecimal numbers. The Shift key is a toggle. The first depression causes the shift symbol (') to appear in the display; it will disappear when the Shift key is pressed again, or when any other key is pressed. Shift must be pressed each time you want to use a shifted key function.

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

Here's how to enter a new test routine. With *COMMAND?* scrolling, press New. The input buffer is cleared of any previous test data. (That also occurs at power up and when the reset button is pressed.) *ENTER PART NO.?* will scroll now. You may enter between one and eight numbers or letters, followed by Enter. *ENTER NO. OF PINS?* appears now. You may enter any even number between 4 and 24 inclusive. Press Enter. *TYPE? PN01* appears. Enter the function of pin 1 by pressing In, Out, Indet, or Ignore, and then the test byte in two hex digits. (We'll show you how to create the test byte later.) For example, I55, OAA, X (no data necessary), or D98.

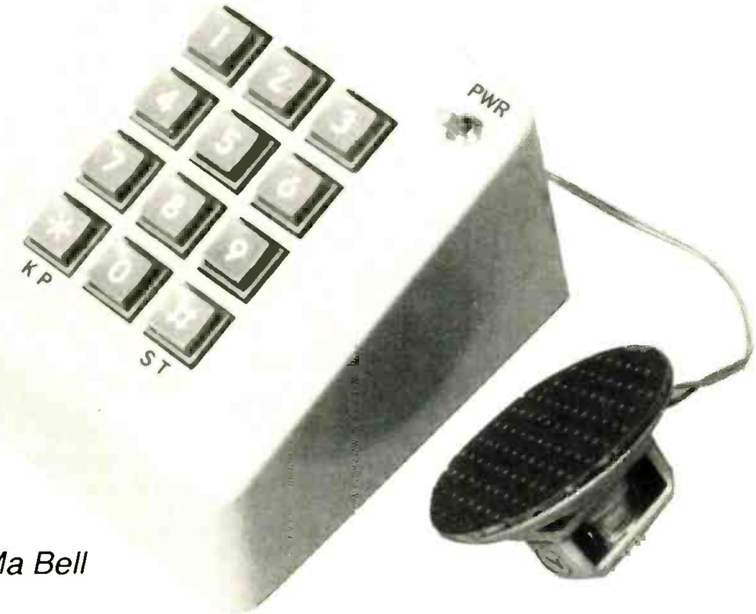
After entering data for all pins (or all pins you want to enter data for) press End. The display will ask *MORE OR END?*. Unless you wish to enter data for another test group (remember, there are five possible), press End again to indicate you are finished entering data.

The Edit key allows you to back up one pin if you make an error after entering the three (or one if a pin is set for IGNORE) of the test data characters. Each time you press Edit, you back up one pin. The Clear key works any time the tester is expecting a keyboard entry, and pressing that key is functionally the same as pressing the reset button.

Press the Test key after all data has been entered. The IC will then be tested. If it is good, the display will read *IC TESTS GOOD*. Otherwise, *ERROR PN?? GRP? EXP/RD ????* will scroll across the display for each pin in error, showing the pin number, the group, and the expected and read data. Each question mark in the preceding message will be replaced by a numeral. For example, *ERROR PN01 GRP 01 EXP/RD 0100* would indicate a problem with pin 1 in test group 1; a "1" was read where a "0" was expected.

Next time we'll show how to send data to and receive data from an external computer. In addition, we'll give several specific examples of how to generate test data for various kinds of IC's. **R-E**

THE BLUE BOX AND MA BELL

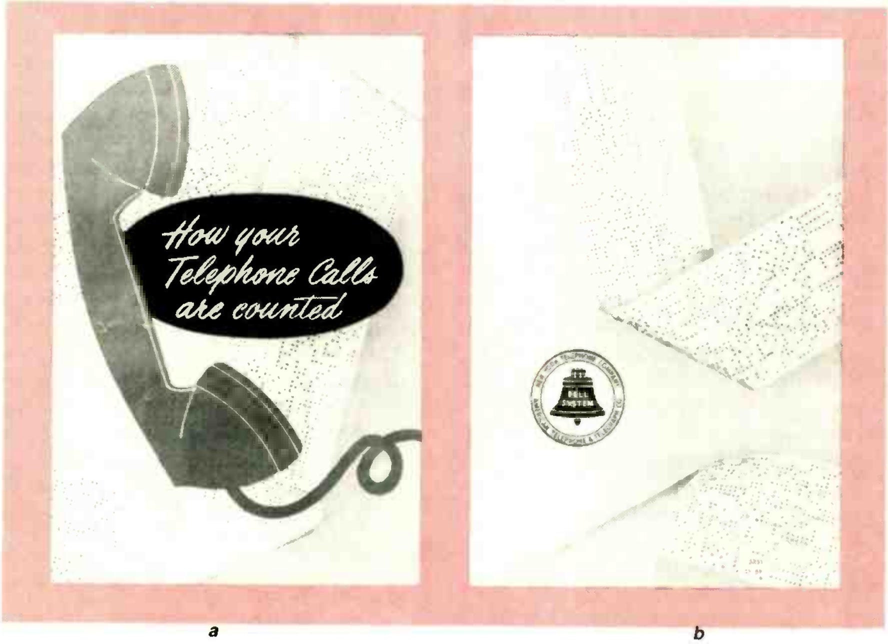


When blue and red meant the trashing of Ma Bell

HERB FRIEDMAN, COMMUNICATIONS EDITOR

BEFORE THE BREAKUP OF AT&T, MA BELL was everyone's favorite enemy. So it was not surprising that so many people worked so hard and so successfully at perfecting various means of making free and untraceable telephone calls. Whether it was a *Red Box* used by Joe and Jane College to call home, or a *Blue Box* used by organized crime to lay off untraceable bets, the technology that provided the finest telephone system in the world contained the seeds of its own destruction.

The fact of the matter is that the Blue Box was so effective at making untraceable calls that there is no estimate as to how many calls were made or who made them. No one knows for certain whether Ma Bell lost revenues of $100, $100-million, or $1-billion on the Blue Box. Blue Boxes were so effective at making free, untraceable calls that Ma Bell didn't want anyone to know about them, and for many years denied their existence. They even went as far as strong-arming a major consumer-science magazine into killing an article that had already been prepared on the Blue and Red boxes. Further, the police records of a major city contain a report concerning a break-in at the residence of the author of that article. The only item missing following the break-in was the folder containing copies of one of the earliest Blue-Box designs and a Bell-System booklet that described how subscriber billing was done by the AMA machine—a booklet that Ma Bell denied ever existed; Fig. 1 proves otherwise. Since the AMA (Automatic Message Accounting) machine was the means whereby Ma Bell eventually tracked down both the Blue and Red Boxes, we'll take time out to explain it. Besides, knowing how the AMA machine works will help you to better understand Blue and Red Box "phone phreaking."



a b

FIG. 1—THE BOOKLET THAT NEVER EXISTED. Although its existence was denied, the front (*a*) has a photograph of an AMA tape, while the back (*b*) has the Bell System logo.

Who made the call?

Back in the early days of the telephone, a customer's billing originated in a mechanical counting device, which was usually called a "register" or a "meter." Each subscriber's line was connected to a meter that was part of a wall of meters. The meter clicked off the message units, and once a month someone simply wrote down the meter's reading, which was later interpolated into message-unit billing for those subscriber's who were charged by the message unit. (Flat-rate subscriber's could make unlimited calls only within a designated geographic area. The meter clicked off message units for calls outside that area.) Because eventually there were too many meters to read individually, and because more subscribers started questioning their monthly bills, the local telephone companies turned to photography. A photograph of a large number of meters served as an incontestable record of their reading at a given date and time, and was much easier to convert to customer billing by the accounting department.

As you might imagine, even with photographs billing was cumbersome and did not reflect the latest technical developments. A meter didn't provide any indication of what the subscriber was doing with the telephone, nor did it indicate how the average subscriber made calls or the efficiency of the information service (how fast the operators could handle requests). So the meters were replaced by the AMA machine. One machine handled up to 20,000 subscribers. It produced a punched tape for a 24-hour period that showed, among other things, the time a phone was picked up (went off-hook), the number dialed, the time the called party answered, and the time the originating phone was hung up (placed on-hook).

One other point, which will answer some questions that you're certain to think of as we discuss the Red and Blue boxes: Ma Bell did not want persons outside their system to know about the AMA machine. The reason? Almost everyone had complaints—usually unjustified—about their billing. Had the public been aware of the AMA machine they would have asked for a monthly list of their telephone calls. It wasn't that Ma Bell feared errors in billing; rather, they were fearful of being buried under an avalanche of paperwork and customer complaints. Also, the public believed their telephone calls were personal and untraceable, and Ma Bell didn't want to admit that they knew about the who, when, and where of every call. And so Ma Bell always insisted that billing was based on a meter that simply "clicked" for each message unit; that there was no record, other than for long-distance calls, as to who called whom. Long distance was handled by, and the billing information was done by an operator, so there was a written record Ma Bell could not deny.

The secrecy surrounding the AMA machine was so pervasive that local, state, and even federal police were told that local calls made by criminals were untraceable, and that people who made obscene telephone calls could not be tracked down unless the person receiving the call could keep the caller on the line for some 30 to 50 minutes so the connections could be physically traced by technicians. Imagine asking a woman or child to put up with almost an hour's worth of the most horrendous obscenities in the hope someone could trace the line. Yet in areas where the AMA machine had replaced the meters, it would have been a simple, though perhaps time-consuming task, to track down the numbers called by any telephone during a 24-hour period. But Ma Bell wanted the AMA machine kept as secret as possible, and so many a criminal was not caught, and many a woman was harried by the obscene calls of a potential rapist, because existence of the AMA machine was denied.

As a sidelight as to the secrecy surrounding the AMA machine, someone at Ma Bell or the local operating company decided to put the squeeze on the author of the article on Blue Boxes, and reported to the Treasury Department that he was, in fact, manufacturing them for organized crime—the going rate in the mid 1960's was supposedly $20,000 a box. (Perhaps Ma Bell figured the author would get the obvious message: Forget about the Blue Box and the AMA machine or you'll spend lots of time, and much money on lawyer's fees to get out of the hassles it will cause.) The author was suddenly visited at his place of employment by a Treasury agent.

Fortunately, it took just a few minutes to convince the agent that the author was *really* just that, and not a technical wizard working for the mob. But one conversation led to another, and the Treasury agent was astounded to learn about the AMA machine. (Wow! Can an author whose story is squelched spill his guts.) According to the Treasury agent, his department had been told that it was impossible to get a record of local calls made by gangsters: The Treasury department had never been informed of the existence of automatic message accounting. Needless to say, the agent left with his own copy of the Bell System publication about the AMA machine, and the author had an appointment with the local Treasury-Bureau director to fill him in on the AMA machine. That information eventually ended up with Senator Dodd, who was conducting a congressional investigation into, among other things, telephone company surveillance of subscriber lines—which was a common practice for which there was detailed instructions, Ma Bell's own switching equipment ("crossbar") manual.

TABLE 1—CCITT NUMERICAL CODE

Digit	Frequencies (hz)	
1	700 + 900	
2	700 + 1100	
3	900 + 1100	
4	700 + 1300	
5	900 + 1300	
6	1100 + 1300	
7	700 + 1500	
8	900 + 1500	
9	1100 + 1500	
0	1300 + 1500	
Code 11	700 + 1700	FOR INWARD
Code 12	900 + 1700	OPERATORS
KP	1100 + 1700	PRIME (START OF PULSING)
KP2	1300 + 1700	TRANSIT TRAFFIC
ST	1500 + 1700	START (END OF PULSING)

The Blue Box

The Blue Box permitted free telephone calls because it used Ma Bell's own internal frequency-sensitive circuits. When direct long-distance dialing was introduced, the crossbar equipment knew a long-distance call was being dialed by the three-digit area code. The crossbar then converted the dial pulses to the CCITT tone groups, shown in Table 1, that are used for international and trunkline signaling. (Note that those do not correspond to *Touch-Tone* frequencies.) As you can see in that table, the tone groups represent more than just numbers; among other things there are tone groups identified as KP (*prime*) and ST (*start*)—keep them in mind.

When a subscriber dialed an area code and a telephone number on a rotary-dial telephone, the crossbar automatically connected the subscriber's telephone to a long-distance trunk, converted the dial pulses to CCITT tones, set up electronic cross-country signaling equipment, and recorded the originating number and the called number on the AMA machine. The CCITT tones sent out on the long-distance trunk lines activated special equipment that set up or selected the routing, and caused electro-mechanical equipment in the target city to dial the called telephone.

Operator-assisted long-distance calls worked the same way. The operator simply logged into a long-distance trunk and pushed the appropriate buttons, which generated the same tones as direct-dial equipment. The button sequence was KP (which activated the long-distance equipment), then the complete area code and telephone number. At the target city, the connection was made to the called number but ringing did not occur until the operator there pressed the ST button.

The sequence of events of early Blue Boxes went like this: The caller dialed information in a distant city, which caused his AMA machine to record a free call to information. When the information operator answered, he pressed the KP key on the Blue Box, which disconnected the operator and gave him access to a long-distance trunk. He then dialed the desired number and ended with an ST, which caused the target phone to ring. For as long as the conversation took place, the AMA machine indicated a free call to an information operator. The technique required a long-distance information operator because the local operator, not being on a long distance trunk, was accessed through local wire switching, not the CCITT tones.

Call anywhere

Now imagine the possibilities. Assume the Blue Box user was in Philadelphia. He would call Chicago information, disconnect from the operator with a KP tone, and then dial anywhere that was on direct-dial service: Los Angeles, Dallas, or anywhere in the world if the Blue Boxer could get the international codes.

The legend is often told of one Blue Boxer who, in the 1960's, lived in New York and had a girl friend at a college near Boston. Now back in the 1960's, making a telephone call to a college town on the weekend was even more difficult than it is today to make a call from New York to Florida on a reduced-rate holiday using one of the cut-rate long-distance carriers. So our Blue Boxer got on an international operator's circuit to Rome, Blue Boxed through to a Hamburg operator, and asked Hamburg to patch through to Boston. The Hamburg operator thought the call originated in Rome and inquired as to the "operator's" good English, to which the Blue Boxer replied that he was an expatriate hired to handle calls by American tourists back to their homeland. Every weekend, while the Northeast was strangled by reduced-rate long-distance calls, our Blue Boxer had no trouble sending his voice almost 7,000 miles for free.

Vacuum tubes

Assembly plans for Blue Boxes were sold through classified advertisements in the electronic-hobbyist magazines. One of the earliest designs was a two-tube portable model that used a 1.5-volt "A" battery for the filaments and a 125-volt "B" battery for the high-voltage (B+) power supply. The portable Blue Box's functional circuit is shown in Fig. 2. It consisted of two phase-shift oscillators sharing a common speaker that mixed the tones from both oscillators. Switches S1 and S2 each represent 12 switching circuits used to generate the tones. (*No, we will not supply a working circuit, so please don't write in and ask—Editor.*) The user placed the speaker over the telephone handset's transmitter and simply pressed the buttons that corresponded to the desired CCITT tones. It was just that simple.

Actually, it was even easier than it reads because Blue Boxers discovered they did not need the operator. If they dialed an active telephone located in certain nearby, but different, area codes, they could Blue Box just as if they had Blue Boxed through an information operator's circuit. The subscriber whose line was Blue Boxed simply found his phone was dead when it was picked up. But if the Blue Box conversation was short, the "dead" phone suddenly came to life the next time it was picked up. Using a list of "distant" numbers, a Blue Boxer would never hassle anyone enough time to make them complain to the telephone company.

The difference between Blue Boxing off of a subscriber rather than an information operator was that the Blue Boxer's AMA tape indicated a real long-distance telephone call—perhaps costing 15 or 25 cents—instead of a freebie. Of course, that is the reason why when Ma Bell finally decided to go public with "assisted" newspaper articles about the Blue Box users they had apprehended, it was usually about some college kid or "phone phreak." One never read of a mobster being caught. Greed and stupidity were the reasons why the kid's were caught.

It was the transistor that led to Ma Bell going public with the Blue Box. By using transistors and RC phase-shift networks for the oscillators, a portable Blue Box could be made inexpensively, and small enough to be to be used unobtrusively from a public telephone. The college crowd in many technical schools went crazy with the portable Blue Box; they could call the folks back home, their friends, or get on a free network (the Alberta and Carolina connections—which could be a topic for a whole separate article) and never pay a dime to Ma Bell.

simply monitored the booth. Ma Bell might not have known who originated the call, but she did know who got the call, and getting that party to spill their guts was no problem.

The mob and a few Blue Box hobbyists (maybe even thousands) knew of the AMA machine, and so they used a real telephone number for the KP skip. Their AMA tapes looked perfectly legitimate. Even if Ma Bell had told the authorities they could provide a list of direct-dialed calls made by local mobsters, the AMA tapes would never show who was called through a Blue Box. For example, if a bookmaker in New York wanted to lay off some action in Chicago, he could make a legitimate call to a phone in New Jersey and then Blue Box to Chicago. His AMA tape would show a call to New Jersey. Nowhere would there be a record of the call to Chicago. Of course, automatic tone monitoring, computerized billing, and ESS (*E*lectronic *S*witching *S*ystems) now makes that all virtually impossible.

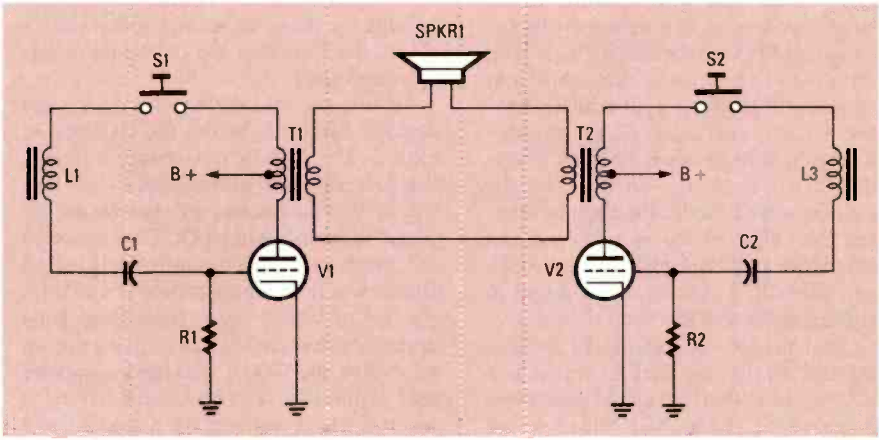


FIG. 2—A POPULAR BLUE BOX DESIGN used two phase-shift oscillators, vacuum tubes, and a simple speaker connection that mixed both oscillators into a single two-tone output.

Unlike the mobsters who were willing to pay a small long-distance charge when Blue Boxing, the kids wanted it, wanted it all free, and so they used the information operator routing, and would often talk "free-of-charge" for hours on end.

Ma Bell finally realized that Blue Boxing was costing them *Big Bucks*, and decided a few articles on the criminal penalties might scare the Blue Boxers enough to cease and desist. But who did Ma Bell catch? The college kids and the greedies. When Ma Bell decided to catch the Blue Boxers she simply examined the AMA tapes for calls to an information operator that were excessively long. No one talked to an operator for 5, 10, 30 minutes, or several hours. Once a long call to an operator appeared several times on an AMA tape, Ma Bell simply monitored the line and the Blue Boxer was caught. (Now do you understand why we opened with an explanation of the AMA machine?) If the Blue Boxer worked from a telephone booth, Ma Bell but that's the way it was.

You might wonder how Ma Bell discovered the tricks of the Blue Boxers. Simple, they hired the perpetrators as consultants. While the initial newspaper articles detailed the potential jail penalties for apprehended Blue Boxers, except for Ma Bell employees who assisted a Blue Boxer, it is almost impossible to find an article on the resolution of the cases because most hobbyist Blue Boxers got suspended sentences and/or probation if they assisted Ma Bell in developing anti-Blue Box techniques. It is asserted, although it can't be easily proven, that cooperating ex-Blue Boxers were paid as consultants. (If you can't beat them, hire them to work for you.)

Should you get any ideas about Blue Boxing, keep in mind that modern switching equipment has the capacity to recognize unauthorized tones. It's the reason why a local office can leave their subscriber *Touch-Tone* circuits active, almost inviting you to use the *Touch-Tone* service. A few days after you use an unauthorized *Touch-Tone* service, the business office will call and inquire whether you'd like to pay for the service or have it disconnected. The very same central-office equipment that knows you're using *Touch-Tone* frequencies knows if your line is originating CCITT signals.

The Red Box

The Red Box was primarily used by the college crowd to avoid charges when frequent calls were made between two particular locations, say the college and a student's home. Unlike the somewhat complex circuitry of a Blue Box, a Red Box was nothing more than a modified telephone; in some instances nothing more than a capacitor, a momentary switch, and a battery.

As you recall from our discussion of the Blue Box, a telephone circuit is really established before the target phone ever rings, and the circuit is capable of carrying an AC signal in either direction. When the caller hears the ringing in his or her handset, nothing is happening at the receiving end because the ringing signal he hears is really a tone generator at his local telephone office. The target (called) telephone actually gets its 20 pulses-per-second ringing voltage when the person who dialed hears nothing—in the "dead" spaces between hearing the ringing tone. When the called phone is answered and taken off hook, the telephone completes a local-office DC loop that is the signal to stop the ringing voltage. About three seconds later the DC loop results in a signal being sent all the way back to the caller's AMA machine that the called telephone was answered. Keep that three-second AMA delay in mind. (By now you should have a pretty good idea of what's coming!)

Figure 3 shows the simplified functional schematic of a telephone. Switch S1 is the hook switch. When S1 is open (on-hook) only the ringer circuit consisting of C1 and BELL1 is connected across the line. Capacitor C1 really has no purpose in the ringing circuit; it only serves to keep DC from flowing through BELL1. When the local telephone office feeds a 20-pps ringing signal into the line it flows through C1 and a ringer coil in BELL1. A vibrating device attached to BELL1 strikes a small bell—the ringing device. When the phone is answered by lifting the handset from its cradle, switch S1 closes (goes off-hook) and connects the handset across the telephone line. Since the handset's receiver and transmitter (microphone) are connected in series, a DC path is established from one side of the line to the other—what is called completing a DC loop with the central office. The DC current flowing in the loop causes the central office to instantly stop the ringing signal. When the handset is replaced in its cradle, S1 is opened, the DC loop is broken, the circuit is cleared, and a signal is sent to the *originating* telephone's AMA machine that the called party has disconnected.

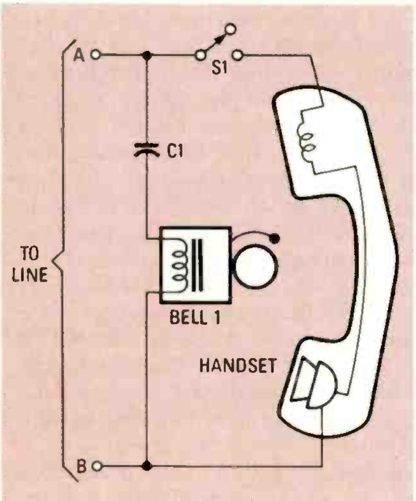


FIG. 3—A SIMPLIFIED TELEPHONE circuit. The handset is connected across the line when hook switch S1 is closed. The handset closes the DC loop with the telephone company's switching equipment.

Now as we said earlier, the circuit can actually carry AC before the DC loop is closed. The Red Box is simply a device that provides a telephone with a local battery so that the phone can generate an AC signal without having a DC connection to the telephone line. The earliest of the Red Boxes was the surplus military field telephone, of which there were thousands upon thousands in the marketplace during the 1950's and 1960's. The field telephone was a portable telephone unit having a manual ringer worked by a crank—just like the telephone Grandpa used on the farm—and two D-cells. A selector switch set up the unit so that it functioned as a standard telephone that could be connected to a combat switchboard, with the DC power supplied by the switchboard. But if a combat unit wasn't connected to a switchboard, and the Lieutenant yelled "Take a wire," the signalman threw a switch on his field telephone that switched in the local batteries. To prevent the possibility of having both ends of the circuit feeding battery current into the line in opposite polarity—thereby resulting in silence—the output from the field telephone when running from its internal batteries was only the AC representing the voice input, not modulated DC.

Figure 4 is the functional simplified schematic for a field telephone **(do not attempt to build that circuit)**. Momentary switch S4 is not part of the field telephone, it is added when the phone is converted to a Red Box; so for now, consider that S4 does not exist. Once again, S1 is the hook switch. When S2 is set to N (NORMAL) and S1 is closed, DC flows from line A through T1's secondary (S),

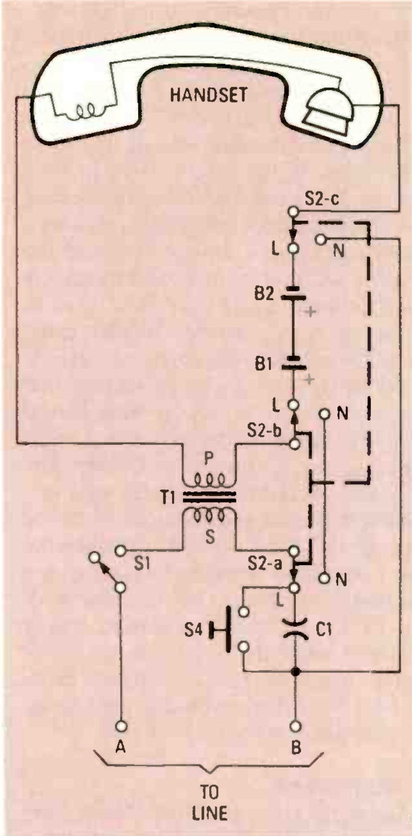


FIG. 4—A SIMPLIFIED RED BOX. Switch S2 lifts the handset from the telephone line and connects two D-cells as a local power supply. The circuit is DC-isolated from the telephone line even when hook switch S1 is closed.

through S2-a to S2-b, through T1's primary (P), through the handset, through S2-c, to line B. There is a complete DC path across the line, and if the unit is connected across a conventional subscriber telephone line it will close the DC loop from the local office.

To use the field telephone as a Red Box, switch S2 is set to L (LOCAL). Switches S2-b and S2-c connect batteries B1 and B2 in series with the handset and the transformer's primary, which constitute an active, working telephone circuit. Switch S2-a connects T2's secondary to one side of the telephone line through a non-polarized capacitor (C1), so that when hook-switch S1 is closed, T1's secondary cannot close the DC loop.

Press once to talk

The Red Box was used at the receiving end; let's assume it's the old homestead. The call was originated by Junior (or Sis) at their college 1000 miles from home. Joe gave the family one ring and then hung up, which told them that he's calling. Pop set up the Red Box by setting S2 to LOCAL. Then Junior redialed the old homestead. Pop lifted the handset when the phone rang, which closed S1. Then Pop closed momentary-switch S4 for about a half-second, which caused the local telephone

continued on page 129

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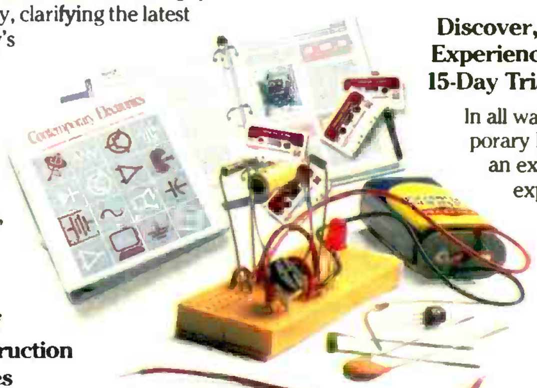

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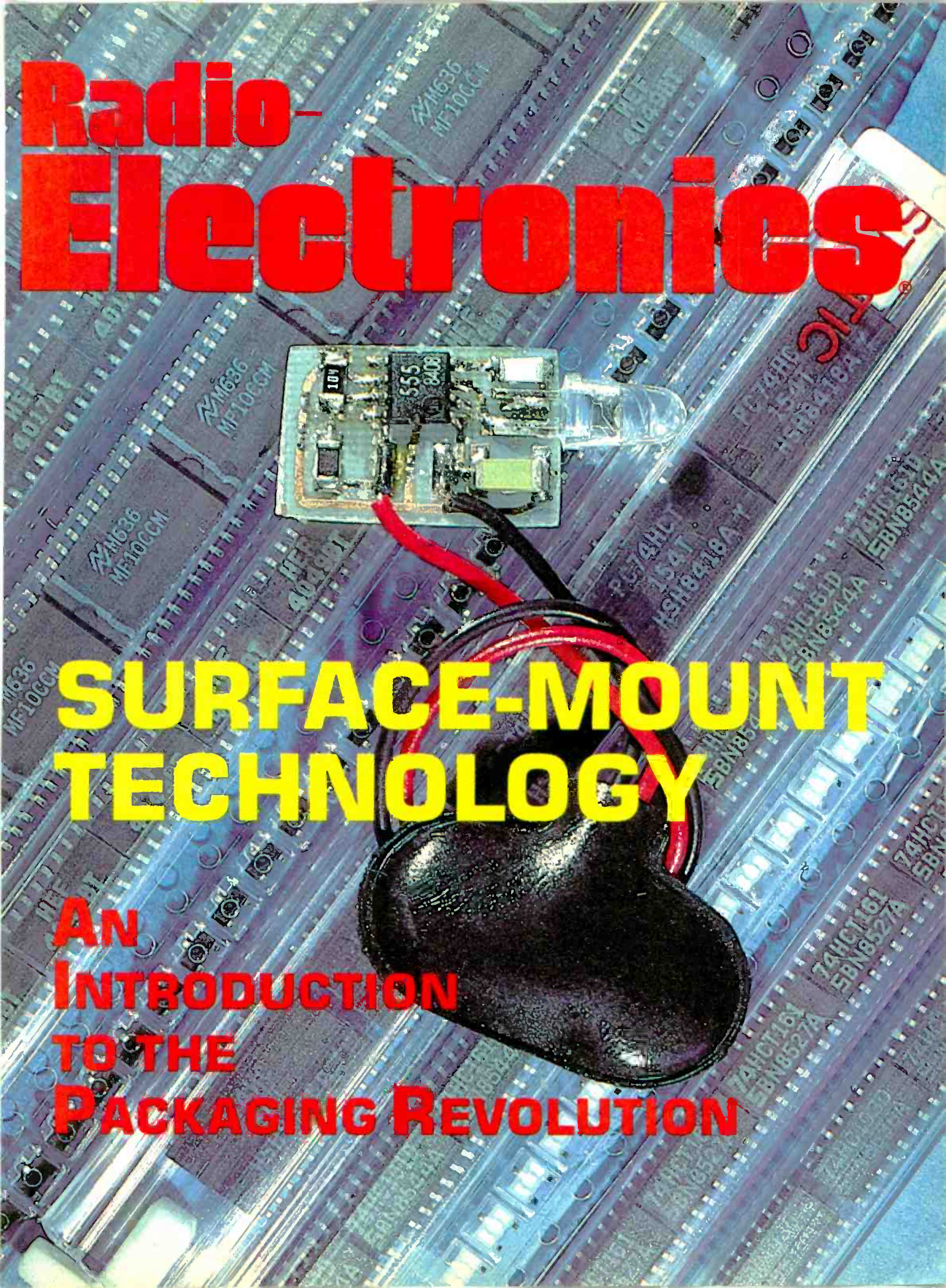

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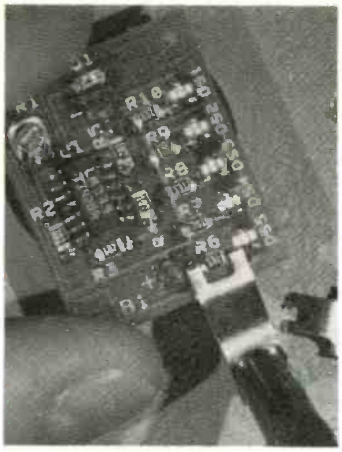
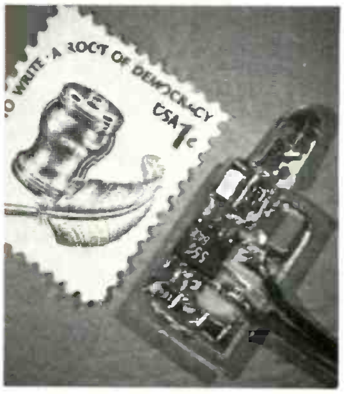
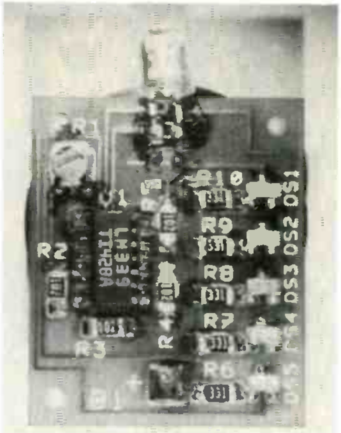
SURFACE-MOUNT TECHNOLOGY

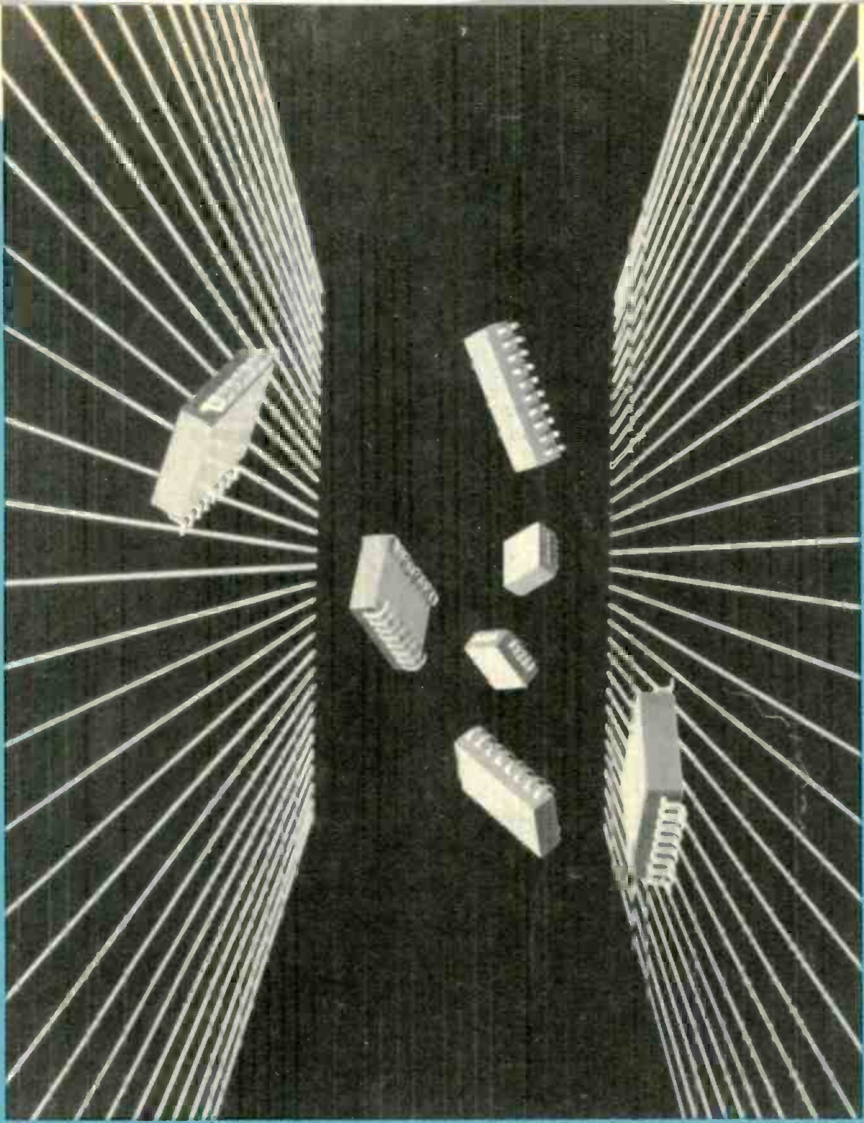
AN INTRODUCTION TO THE PACKAGING REVOLUTION

SURFACE MOUNT TECHNOLOGY









Surface-Mount Technology

Surface-mount technology is literally changing the shape of electronics manufacturing and packaging.

Introduction to SMT

FORREST M. MIMS, III

THE COMPACT SIZE OF MICROCASSETTE RECORDERS, CAMcorders, and credit-card size calculators and radios is not a result of radically new solid-state developments. Rather, those amazingly tiny personal electronic devices are made possible by a clever electronic component packaging and assembly means known as *surface mount technology.*

In *S*urface *M*ount *T*echnology, or SMT, both components and conductive traces are installed on the same side of a substrate or surface. Many kinds of substrates can be used, including ceramic, paper, plastic, and both rigid and flexible printed-circuit boards.

Though components used for conventional through-hole circuit board assembly can be modified for SMT, the vast majority of SMT components, like those shown in Fig. 1, are considerably smaller than their conventional through-hole counterparts. That means that a circuit assembled with SMT components is much more compact than an identical circuit assembled with conventional components.

Surprising as it may seem, SMT is not a new technology. Its roots can be traced to the development of miniature circuit assemblies in the United States during World War II. Similar techniques were applied to the assembly of circuit boards for hearing aids. Many of the components and techniques used in the well established field of hybrid microcircuits are used in SMT.

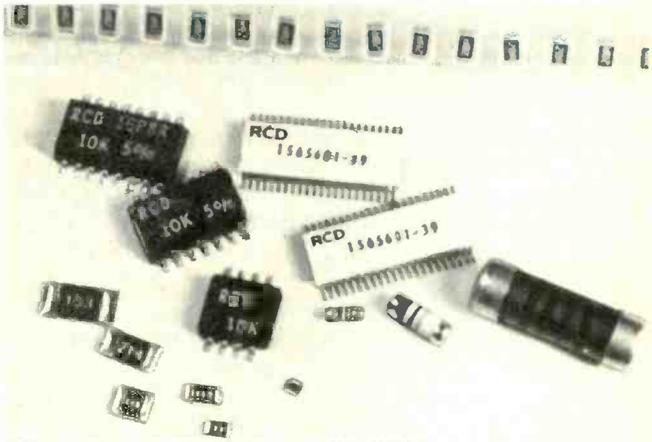


FIG. 1—SURFACE-MOUNTABLE COMPONENTS are supplied in a wide range of miniature package types.

Though SMT has a history at least 30 years long, only in the past decade has it made major inroads in consumer electronics. In coming years SMT will impact virtually everyone whose career or avocation is electronics. Those who choose not to become familiar with SMT do so at their own peril, for SMT will inevitably replace most conventional circuit assembly methods during the 1990's.

Of course, none of that is news to the electronics technicians who service the personal electronic products mentioned above as well as electronically-controlled 35-mm cameras, pocket and laptop computers, and a host of other products. They have learned, sometimes the hard way, that troubleshooting and repairing SMT circuitry requires different techniques and tools than those used with conventional through-hole circuits.

Engineers, product managers, and entrepreneurs have found that surface-mount technology offers a vitally important means for competing with off-shore electronics manufacturers. Moreover, the economics of SMT are such that circuits can often be produced on-shore using automated production equipment for less money than having them built off-shore.

Finally, SMT provides electronics experimenters and inventors with unprecedented miniaturization capabilities. The proverbial "garage inventor" can now produce functional prototype circuits every bit as tiny as the personal-electronic products popularized by the Japanese; and he can produce an SMT circuit in the same time required to produce a conventional circuit.

Advantages of SMT

The advantages of SMT that we've outlined so far are only some of the reasons the electronics industry is moving so rapidly to SMT. Here is a brief discussion of each of the advantages of SMT:

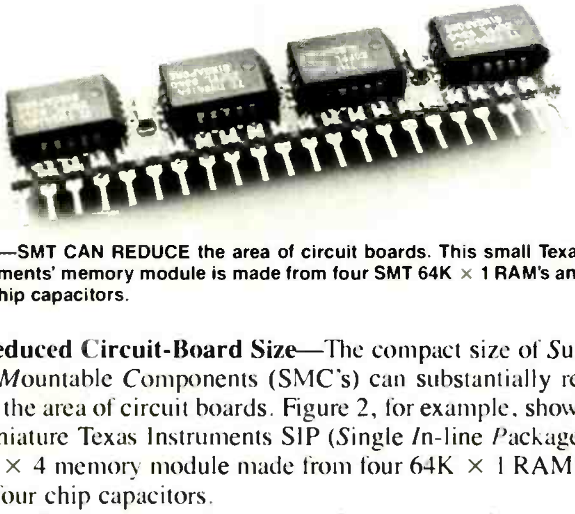


FIG. 2—SMT CAN REDUCE the area of circuit boards. This small Texas Instruments' memory module is made from four SMT 64K × 1 RAM's and four chip capacitors.

• **Reduced Circuit-Board Size**—The compact size of *S*urface-*M*ountable *C*omponents (SMC's) can substantially reduce the area of circuit boards. Figure 2, for example, shows a miniature Texas Instruments SIP (*S*ingle *I*n-line *P*ackage) 64K × 4 memory module made from four 64K × 1 RAM's and four chip capacitors.

Texas Instruments and other manufacturers have found that an SMT memory board requires from 30 to 60 percent of the area required by an equivalent board assembled with conventional through-hole DIP (*D*ual *I*n-line *P*ackage) integrated circuits. A surface-mountable SOT-23 transistor occupies only a tenth of the board space of a conventional TO-92 transistor package. A 44-pin surface-mountable PCC (*P*lastic *C*hip *C*arrier) integrated-circuit package occupies only 27.5 percent of the board space required by a standard 40-pin DIP.

A few years ago, TI engineers made an SMT memory board that had been previously assembled with standard

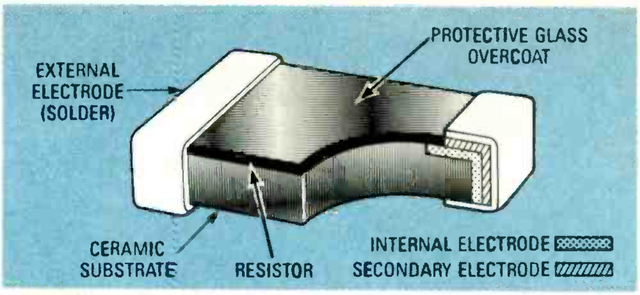


FIG. 3—INSIDE A LEADLESS CHIP RESISTOR. The construction is identical to a that of a thick-film resistor deposited directly onto a ceramic substrate.

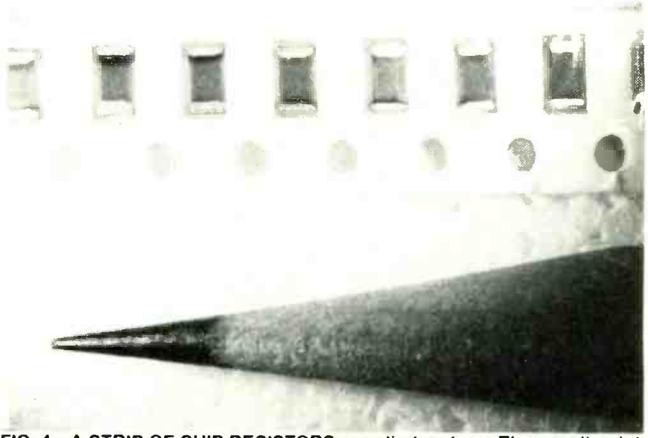


FIG. 4—A STRIP OF CHIP RESISTORS supplied on tape. The pencil point in the photograph is shown for scale.

DIP's. The area of the original board was 152.5 square inches while the area of the SMT version was 62.4 square inches, or only 41 percent of the area of the original board. Ray Prasad, the SMT Program Manager at Intel Corporation, has observed that a 4- × 4-inch board containing half a megabyte of 256K DRAM memory DIP's can contain a full megabyte of surface-mountable DRAM's. If both sides of the board are used, the board can hold 2 megabytes.

SMC's are considerably lighter than their through-hole counterparts. For example, the 8-pin DIP version of National Semiconductor's popular LM308M operational amplifier weighs 600 milligrams. The SO (*S*mall *O*utline) version of the same IC weighs only 60 milligrams. The low weight of SMC's and the smaller circuit boards they require combine to give typical SMT boards a 5-to-1 weight advantage over conventional boards. Furthermore, the very low profile of SMC's keeps SMT boards very thin and gives them as much as an 8-to-1 volume advantage over conventional boards.

SMT boards are not necessarily used only in highly miniaturized products. Consider, for example, the coming generation of small footprint desktop computers. Those machines will be made possible by 3.5-inch disk drives and SMT. As for add-on peripheral cards, two or more SMT cards will fit in the same space required by a conventional board.

• **Double-Sided Circuit Boards**—Conventional circuits are often installed on boards that have printed or etched wiring on both sides. Plated-through holes provide interconnections between the two sides of the board.

SMT can also make use of double-sided boards but with a new twist. Components can be installed on *both* sides of an SMT board, thereby greatly increasing the savings in space over boards assembled with conventional components. Since many SMC's have a much lower profile than conventional components, an SMT board having components on *both*

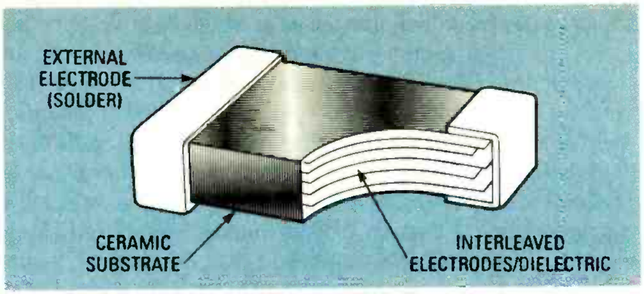


FIG. 5—INSIDE A CERAMIC CHIP CAPACITOR. The device is a sandwich of interleaved metal film and dielectric layers.

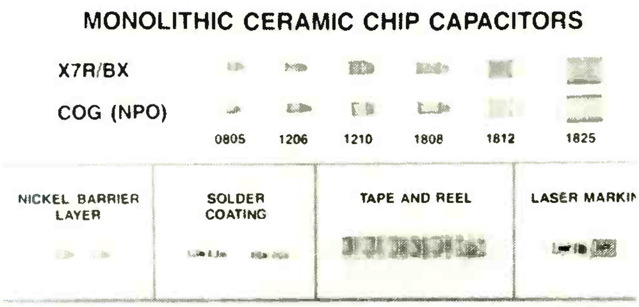


FIG. 6—CHIP CAPACITORS, like these from American Precision Industries, come in a variety of sizes and values.

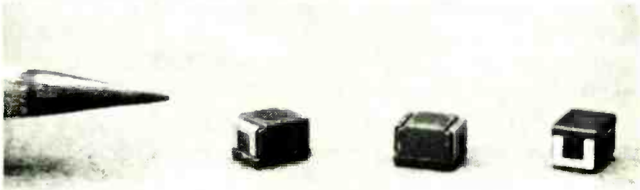


FIG. 7—SMT INDUCTORS are available in values that range from a few tens of nanohenries to one millihenry.

sides can be thinner than a board assembled with conventional components.

● **Subminiature Circuits**—SMT is a spinoff of hybrid microcircuit technology, and some SMT circuits are nearly as tiny as their hybrid cousins. Moreover, subminiature SMT circuits are considerably cheaper than hybrid circuits and prototypes can be assembled in as little as a day using inexpensive assembly tools. Now engineers, technicians, and experimenters can assemble tiny circuits on a low budget and without special facilities.

● **Automated Assembly**—Conventional through-hole components can be installed on circuit boards by means of automated assembly machines. SMT, however, is much more compatible with automated assembly equipment. Unless the board includes plated-through holes, the time-consuming chore of drilling holes in the circuit board is eliminated. SMC's have no wire leads to cut, bend, and insert. For those and other reasons, SMT boards can be automatically assembled much more quickly than conventional boards using through-hole components.

Although automated pick-and-place SMT assembly equipment is expensive, it's also very fast. At the low end are machines that pick and place up to several thousand SMC's per hour. Faster machines can pick and place from 15,000 to 20,000 SMC's per hour. Sophisticated multihead pick-and-place machines can operate at rates exceeding 500,000 SMC's per hour. Automated assembly, the chief driving force behind the rapid acceptance of SMT, will be covered in more detail in the next article.

● **Lower Cost**—The cost of individual SMC's has fallen rapidly in recent years, but SMC's generally cost more than their through-hole counterparts. Nevertheless, SMT can reduce overall board cost for a variety of reasons. According to National Semiconductor, for instance, a savings of up to 40 percent results from the elimination of drilled holes required for conventional-component leads and pins and the reduction of plated-through holes and conductive trace layers in multilayer boards.

● **Other Advantages**—Some advantages of SMT are less obvious than those listed above. For instance, the compact size of SMT boards can significantly improve a waveform's rise and fall times, and reduce crosstalk in high-performance logic systems. Those advantages are a result of shorter current paths and reduced pin-to-pin capacitance and mutual inductance. Finally, there is the undeniable advantage that SMT is the wave of the future. Those firms that adopt SMT today will be better prepared to compete tomorrow.

Disadvantages of SMT

Since SMT will eventually become the dominant circuit-assembly technology, it's important to fully understand its limitations and drawbacks. They include:

● **The SMT Learning Curve**—*Before* the advantages of SMT can be realized, the new SMT user, whether a large corporation or a home experimenter, *must* fully understand the many pitfalls that can trap the unwary. Some companies have learned about the pitfalls of SMT the hard way. They committed to manufacturing a new product using SMT *before* fully understanding the potential problems. Whether through overconfidence or ignorance, the end result in several such cases has been a very costly disaster. It's important to keep the principle of the SMT learning curve foremost in mind as you review the rest of the drawbacks.

● **SMC Standardization**—As recently as 1983, only around 300 specific SMC's were available in the United States. According to Bourns, Inc., by the end of 1986 some 15,000 specific SMC's were available. While that increase has helped spur the rapid growth of SMT, it has been accompanied by standardization problems. Supposedly identical components, especially semiconductors, made by different manufacturers may have slightly different dimensions. In view of the close tolerances required for SMT circuit-board design, dimensional compatibility is an essential requirement. Even when identically configured components are available from two or more manufacturers, each company may package its SMC's for different automated assembly formats. The SMT industry recognizes the standardization problem and is working toward solutions. Meanwhile, engineers and parts buyers for companies entering SMT for the first time are often surprised by the lack of standardization that currently exists.

● **SMC Availability**—While some 15,000 components may be available as SMC's, not all of them may be available when needed. The author's experience has been that ordering SMC's from major electronics distributors can be trying. It's particularly frustrating to order an assortment of subminiature SO integrated circuits and receive a package of monster DIP's having the same part numbers. It is extremely important that before committing to an SMT product, manufacturers find one or more reliable sources for the components. And care must be taken to be sure that the supplied components will be identically packaged and both functionally and dimensionally equivalent.

● **High Start-Up Expense**—The start-up cost of SMT for

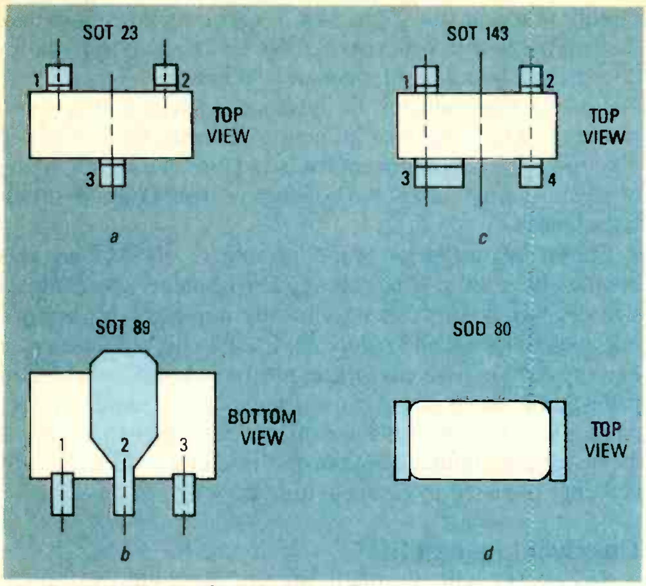


FIG. 8—FOUR MAJOR SO package outlines.

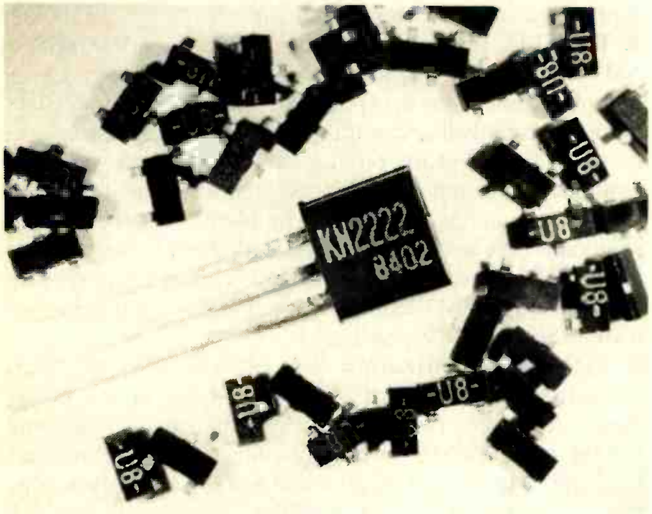


FIG. 9—A TO-92 TRANSISTOR dwarfs its SOT-23 counterparts.

both manufacturers and individual experimenters can be high. For manufacturers, automated production equipment is by far the most expensive investment. Experimenters face the problem of acquiring new assembly tools and a stock of surface-mountable resistors, capacitors, LED's, diodes, transistors, and integrated circuits. While the cost of an individual SMT project may be only slightly higher than the same project assembled with through-hole components, acquiring a sufficient stock of SMT components can easily cost a few hundred dollars or more. That situation will change when retail and mail-order electronics dealers begin offering kits of SMC's.

• **Soldering**—The components of virtually all manufactured through-hole circuit boards are wave soldered. A variety of soldering options, each with various advantages and disadvantages, is available to the SMT user. They include single- and double-wave soldering, and reflow soldering. Wave soldering requires that the SMC's be attached to the circuit board with a droplet of non-conductive adhesive. Reflow soldering involves the use of solder paste or cream. The paste is screened over the SMC footprints or pads, or applied directly to the pads with either an automated or a hand operated syringe. The terminals of the SMC's, which adhere to the sticky paste, are soldered to the pads when the board is heated in a convection oven, in a vapor-phase chamber, or by infrared lamps. Some SMC's are connected in place with conductive adhesives. SMT soldering methods, including their advantages and drawbacks, will be discussed in detail elsewhere in this section. Suffice it to say that a careful understanding of whichever soldering method is selected is crucial to the production of functioning, reliable SMT circuits. In the final analysis, nothing replaces practical, hands-on experience.

• **Troubleshooting and Repair**—The best way to fully appreciate the differences between conventional and SMT circuitry is to take a peek inside a handheld video camcorder. The optics, focusing motor, gears, and image sensor of the typical camcorder are virtually surrounded by thin circuit boards that are peppered with hundreds of tiny SMC's. The sight of those boards will provide convincing proof that servicing SMT circuits requires a completely different set of tools and skills than those that are required to service conventional through-hole circuits.

Since most SMC's are very closely spaced and do not have leads, conventional test instrument probes may not be suitable. Fortunately several companies now make a variety of probes and clips specifically intended for connection to SMC's. Desoldering and resoldering SMC's requires specially shaped soldering iron tips that permit all the terminals of an SMC to be simultaneously heated. Hot air desoldering and soldering tools can also be used for that purpose if care is taken to avoid inadvertent desoldering of nearby SMC's. In short, servicing SMT circuits requires new skills and much more attention to detail than the servicing of conventional through-hole circuits. The observation about the vital role of practical, hands-on experience given in the discussion of soldering surface-mountable components applies equally well to servicing SMT circuits.

• **Other Drawbacks**—Some of the pitfalls awaiting new SMT designers are less obvious than those discussed so far. Thermal overload is a good example. Since surface-mountable semiconductors are so small, they dissipate less heat than their conventional counterparts. That, and the fact many such devices can be densely packed together on a compact circuit board, can lead to unanticipated thermal-overload problems in your designs.

Another drawback is that SMT boards require tighter dimensional tolerances than conventional through-hole boards. In addition, board designers and draftsmen must become acquainted with the configuration of the many different kinds of SMC's. Computer-aided drafting software may have to be updated or even replaced if it doesn't include an SMT capability.

Surface-mountable components

Many, but not all, through-hole components have a surface-mountable counterpart. Physical limitations often prevent a conventional component from being manufactured as an SMC. For example, high-capacity capacitors and power transformers are simply too large. And the pinouts and chip dimensions of some IC's don't readily lend themselves to standard surface-mount packages. Nevertheless, most circuits can be assembled using SMT, even if some conventional through-hole components are required.

It's important for SMT circuit designers, draftsmen, and service technicians to be aware of the general physical configurations and operating parameters of the various families of

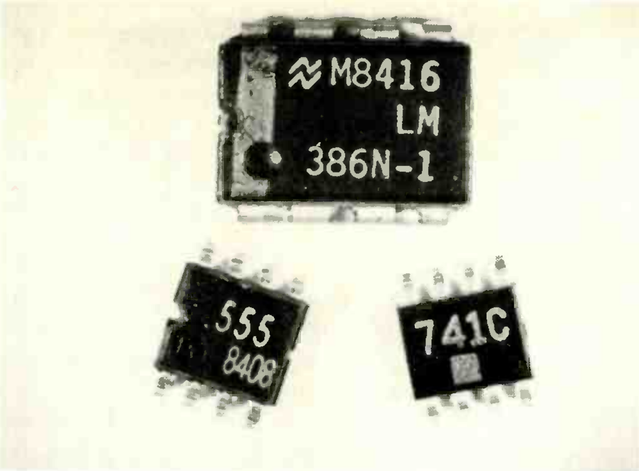


FIG. 10—TWO SO INTEGRATED CIRCUITS and a conventional 8-pin mini-DIP.

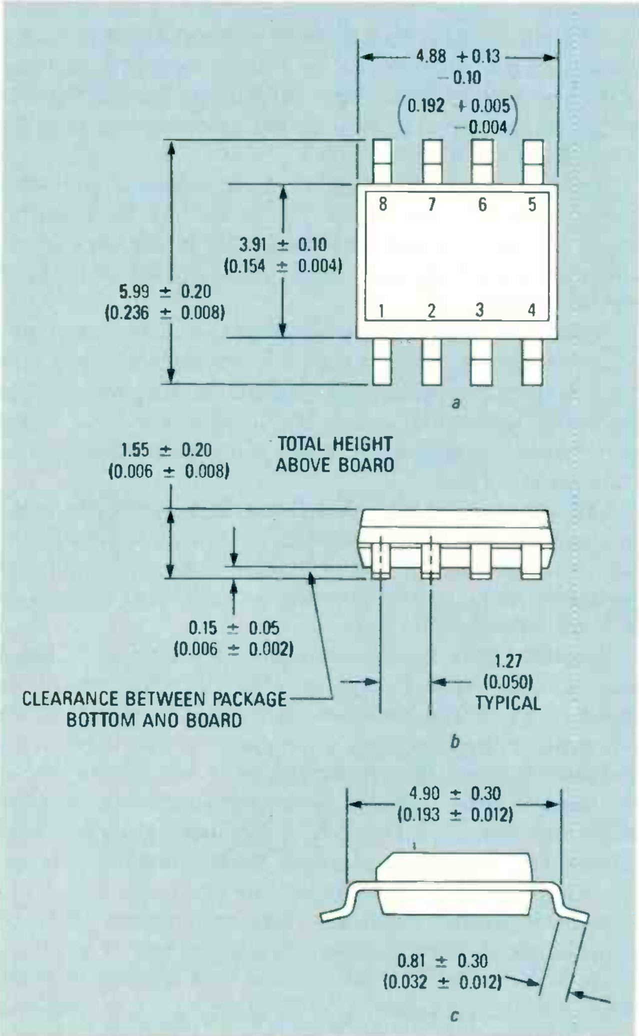


FIG. 11—TOP VIEW (*a*), side view (*b*), and front view (*c*) of a Texas Instruments 8-pin SO integrated circuit.

SMC's. What follows is a quick tour of the most important families of SMC's. All SMC's in those families are available individually or in quantity. SMC's intended for automated assembly are supplied in reels of paper or embossed plastic tape, or in magazines. Some automatic assembly equipment is equipped with vibratory feeders that can be loaded with non-packaged leadless chip components, such as resistors and capacitors.

Chip resistors

Chip resistors are the most widely produced of all SMC's. Originally developed for use in hybrid microcircuits, chip-resistor technology was well established when SMT was adopted for consumer and industrial products.

Figure 3 shows the cross section of a typical leadless chip resistor. The construction of the device is identical to that of a thick-film resistor deposited directly on the ceramic substrate of a hybrid microcircuit. The nickel barrier between the inner electrode and the solder coating prevents the electrode from leaching during soldering. Without the nickel barrier, leaching may impair the connection between the chip resistor and the external circuit.

Figure 4 shows the very small size of chip resistors. The taped resistors in the photo are classified as 1206, a type designation indicating a physical size of 1.6 × 3.2 millimeters. Other types are the 0805 (1.4 × 2.0 mm) and 1210 (2.6 × 3.2 mm). The resistance range of most chip resistors is 10 ohms to 2.2 megohms. Some companies offer values up to 10 megohms and even higher.

Trimmers and potentiometers

Both single- and multi-turn trimming potentiometers are available in surface-mountable configurations. They are made from ceramic or high-temperature plastics to protect them from the heat of immersion soldering. The smallest single-turn trimmers measure less than 4 × 4 millimeters. Multi-turn trimmers, which closely resemble their through-hole counterparts, measure 6.35 × 6.35 mm (0.25 inch) or 8.9 × 8.9 mm (0.35 inch).

Although surface-mountable trimmers are adjustable, it's important to realize that most of those devices are not designed for repeated adjustments. A typical trimmer, for example, might be rated for no more than 10 adjustment cycles. Another consideration is the adjustment mechanism itself. Most trimmers are designed to be adjusted by means of a miniature screwdriver or special tool. The required slot or slots may not be compatible with all kinds of automated pick-and-place equipment. Also, trimmers that require a special adjustment tool can pose a major problem when only a screwdriver is available.

Chip capacitors

Like chip resistors, leadless chip capacitors were developed originally for use in hybrid microcircuits. There are three principle categories of surface-mountable chip capacitors: multilayer ceramic, electrolytic, and tantalum. Four out of five chip capacitors are ceramic multilayer devices. As shown in Fig. 5, a ceramic chip capacitor is a sandwich of interleaved layers of metal film and ceramic dielectric. At opposite ends of the chip, every other metal layer is interconnected by an external metal electrode. Often a nickel layer is added to prevent leaching of the internal metal layers.

Ceramic chip capacitors, like the ones in Fig. 6, are rugged, very stable, and highly reliable. Capacitance values ranging from 1 pF to 1 μF are available. Package styles identical to those of chip resistors described above (0805 and 1206) are available, as are larger packages. Unlike chip resistors, the size of a chip capacitor is directly related to its value.

For high capacity, electrolytic and tantalum chip capacitors are available. Tantalums are available in values from 0.1 to 100 μF. Aluminum electrolytics, which are larger than tantalums, are available in values from around 1.5 to 47 μF.

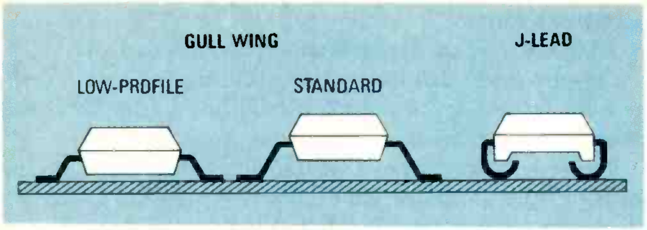


FIG. 12—GULL-WING VS. J-LEAD SMC packages. J-lead packages can be mounted using sockets

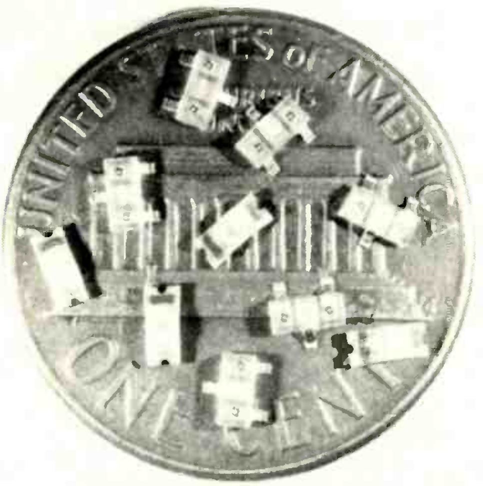


FIG. 13—SOT-23 DUAL-CHIP red LED's and single-chip green LED's are dwarfed by a penny.

FIG. 14—COMPONENTS SUCH AS CRYSTAL FILTERS, relays, switches, and crystals are available as SMC's. An SMC crystal is shown here.

Those capacitance ranges continue to be expanded as new products are added.

Inductors

Many kinds of surface-mountable leadless and formed-lead inductors, and even toroidal transformers, are available. Inductance values range from a few tens of nanohenries to one millihenry. Figure 7 shows several surface-mountable inductors.

Discrete semiconductors

Many diodes, transistors, and other discrete semiconductors are available in miniature surface-mountable packages. Figure 8 shows the outlines of the four major package styles SOT-23 (Fig. 8-*a*), SOT-89 (Fig. 8-*b*), SOT-143 (Fig. 8-*c*), and SOD-80 (Fig. 8-*d*). The SOD (*S*mall *O*utline *D*iode) package is a leadless cylinder used for diodes. The SOT (*S*mall *O*utline *T*ransistor) packages are used for transistors, diodes (1 or 2 chips), and various optoelectronic components. Figure 9 compares the SOT-23 transistor with its conventional through-hole counterpart.

Referring back to Fig. 8, note the configuration of the leads of the SOT packages. The SOT-23 and SOT-143 packages are equipped with formed leads in a gull-wing configuration. The SOT-89 leads are not formed since they emerge from the lower side of the package.

The package configuration determines the power dissipation of any semiconductor. SOT-23 and SOT-143 devices can dissipate from 200 to 400 milliwatts. SOT-89 devices can dissipate from 500 to 1000 mW.

Integrated circuits

Surface-mountable integrated circuits have been available since Texas Instruments developed the gold-plated flat pack IC in the early 1960's. Today more than a dozen families of surface-mountable IC packages are in use.

The most popular surface-mountable IC package, the *S*mall-*O*utline (SO) configuration developed by Philips, resembles a miniature DIP. An SO device occupies around a fourth the board space of an equivalent DIP. Of even more importance is the very low profile provided by the SO package. Figure 10 shows two 8-pin SO devices together with a conventional 8-pin mini-DIP for a size comparison, and Fig. 11 is an outline view of an 8-pin SO device. Note that the pins of SO devices are placed on 50-mil centers rather than the 100-mil spacing found on DIP's.

While the leads of most SO devices have a gull-wing configuration, a newer design popularized by Texas Instruments has flat pins that bend under the IC package in a J configuration. The chips mounted on the SIP shown in Fig. 2 are J-lead devices.

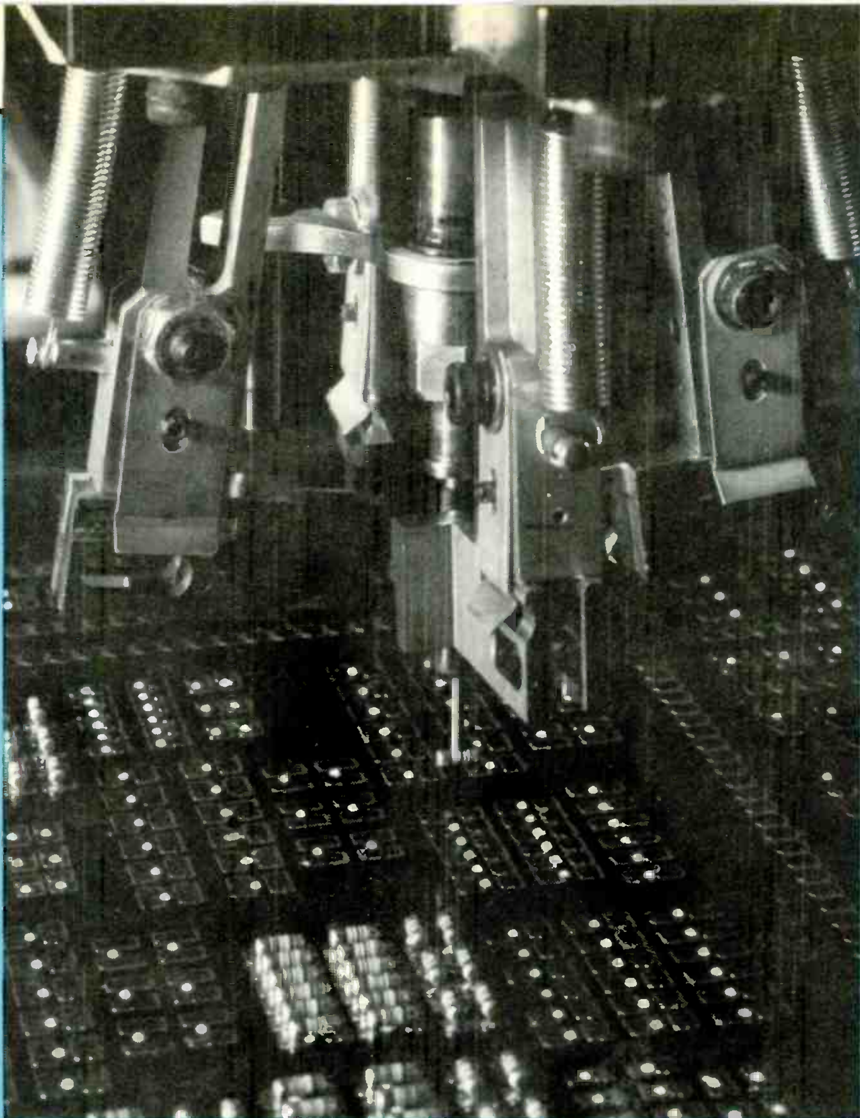
Figure 12 compares the gull wing and J-lead formats. Gull-wing devices are easier to solder and replace. They also provide sufficient flexibility to prevent the SO package from fracturing should the board be slightly bent. The J-lead devices use less space and, unlike gull wing devices, can be installed in sockets.

Chips that require more than 28 pins are generally installed in square *P*lastic *L*eaded *C*hip *C*arriers (PLCC's). The PLCC uses J-shaped leads and has up to 84 or more leads around its perimeter. Many new microprocessors and other large-scale IC's are offered in PLCC's.

Recently, there has been considerable interest in using tape- or wire-bonded chips in SMT circuits, particularly those in which the pin count is high. The wire-bonding process involves cementing a chip directly to a circuit board and making connections to the chip by means of gold wire in the same manner in which connections are made between chips and pins in packaged IC's. The bonded chip is then protected by a small blob of epoxy. The tape bonding process, also known as TAB (*T*ape *A*utomated *B*onding), is easier to implement because individual chips are supplied on a tape with completed electrical connections. The tape is actually a string of connected lead frames similar or identical to those used to make packaged IC's. Epoxy protects the delicate chips and connection leads from damage. TAB chips can be used in automated assembly.

Other Surface Mountable Components

In addition to the component families discussed above, there are many other surface-mountable devices. For example, many optoelectronic components are available, including phototransistors, optoisolators and many kinds of one- and two-chip infrared and visible LED's (see Fig. 13). Also available are ceramic filters, relays, switches and crystals (see Fig. 14). **R-E**



Surface-Mount Technology

Now that you know what SMT is all about, here's how to use and repair surface-mount components.

Industrial SMT Assembly

SURFACE MOUNT TECHNOLOGY IS FAST BECOMING AS IMPORtant to modern electronics as microprocessors, programmable logic arrays, and megabit RAM IC's. Microminiature surface-mountable components and the advantages and drawbacks of SMT were previously discussed. Now we'll tackle the assembly and repair of SMT circuits.

SMT assembly methods

Surface-mountable components, like conventional through-hole components, can be placed on a board and soldered in place either by hand or by machine. Both soldering methods fill important roles in SMT. Hand assembly is used by home experimenters and electronics companies, the latter for the production of prototype SMT circuits. Automated assembly is used to manufacture SMT circuit boards.

Automated SMT assembly

Automated placement equipment can select and position on a circuit board from 1,000 to 500,000 components per hour. There are three major categories of automatic SMC placement equipment: Mass placement, in-line pick-and-place, and x–y pick and place.

Mass placement equipment permits many or all the SMC's in a

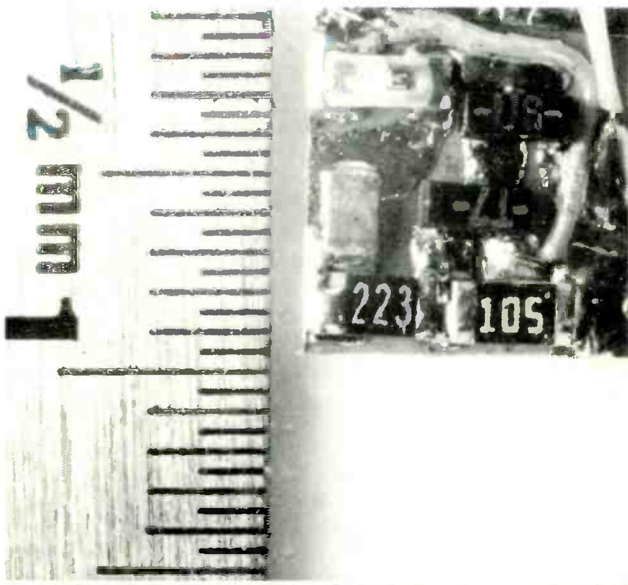


FIG. 1—MICROMINIATURE INFRARED LED transmitter assembled by the author.

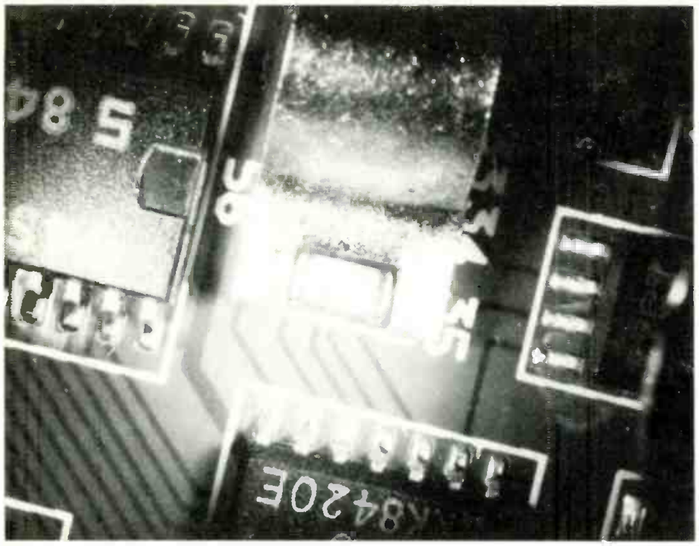


FIG. 2—A U-SHAPED SOLDERING IRON tip can be used for soldering and desoldering chip resistors and capacitors.

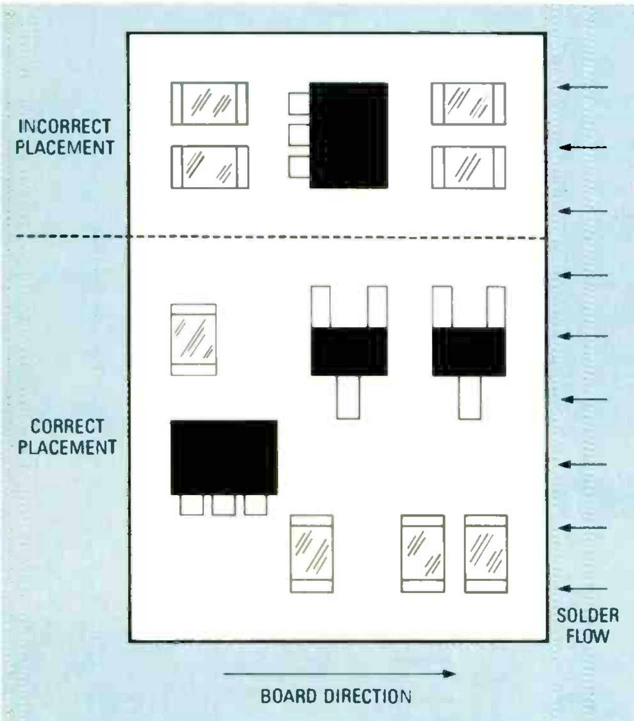


FIG. 3—THE CORRECT ORIENTATION of SMC's for effective wave soldering.

circuit to be simultaneously placed over adhesive dots or solder paste that was previously deposited on a circuit board. Since mass placement equipment provides exceptionally fast board loading, it is well suited for the manufacture of consumer-electronics devices. Its major drawback is that the equipment must be specially configured for specific board designs. Consequently, even minor board design changes can be expensive and time consuming.

In a typical mass-placement system, magazines loaded with SMC's are mounted in the same orientation as the SMC's to be placed on the board. A vacuum head then picks up a complete set of SMC's, transfers them to a board and returns for another set.

Bench, or *in-line pick-and-place equipment*, uses a vacuum pickup head to pick an individual SMC from a dispensing tape, magazine, or bin dispenser. The head then places the SMC at the proper position on the circuit board. A single machine may have a series of pick-and-place heads. Boards prescreened with solder paste or adhesive are placed on a belt that moves under the row of pick-and-place heads. After each head places a single SMC on the board, the board advances to the next head.

In-line equipment, which has long been used to produce hybrid microcircuits, is able to handle many different shapes and sizes of SMC's. And in-line machines can be set up to assemble different circuits much more rapidly than mass placement equipment is capable of.

X–Y pick-and-place equipment is the most popular method for the automated assembly of SMT boards. Two basic approaches are used. In one, a moving pick-and-place vacuum head fetches components one at a time and places them on a fixed-position board. In the other, the vacuum head is fixed and the board is attached to a moving x–y table that places the appropriate SMC footprint or pad directly under the head. SMC's are fed to the head by a feeder mechanism.

Understanding the operation of mass placement and pick-and-place SMT assembly equipment is not the only requirement for the effective use of such machines. Automated assembly of an SMT circuit also includes provisions for automated flux application and soldering; procedures that can greatly complicate matters. Soldering of SMC's will be discussed in more detail shortly. For now, it's important to understand that automated soldering requires careful attention to board design and proper component placement.

If the board is to be inverted and wave soldered, then the components must be glued to the board, a process that requires the careful hand or machine application of small dots of adhesive at each component position. Adhesive can be hand-applied with a wire or a probe that picks up a small blob of material when it is dipped into the adhesive, or by a syringe that automatically dispenses a preset amount of adhesive. Adhesive can also be screened onto a board in a single application. In fully automated systems, the adhesive can be applied by a syringe that is mechanically moved to each SMC location, but *automatic pin transfer* is an even faster way to apply the adhesive. An array of pins that exactly matches the SMC locations is dipped in adhesive and then lightly touched to the board. When the pin array is moved away, dots of adhesive are left behind at each SMC location.

All these methods require careful attention to detail. If too little adhesive is applied, the SMC may fall off when the board is

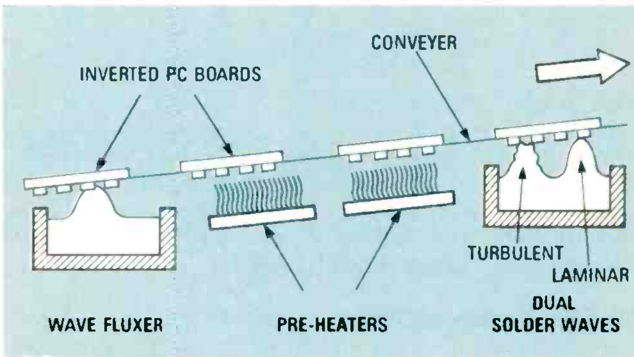


FIG. 4—THE DUAL-WAVE SMT soldering system.

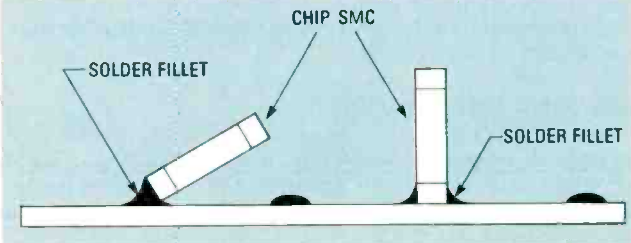


FIG. 5—SOLDERING DEFECTS known as the *drawbridge* and *tombstone* effect.

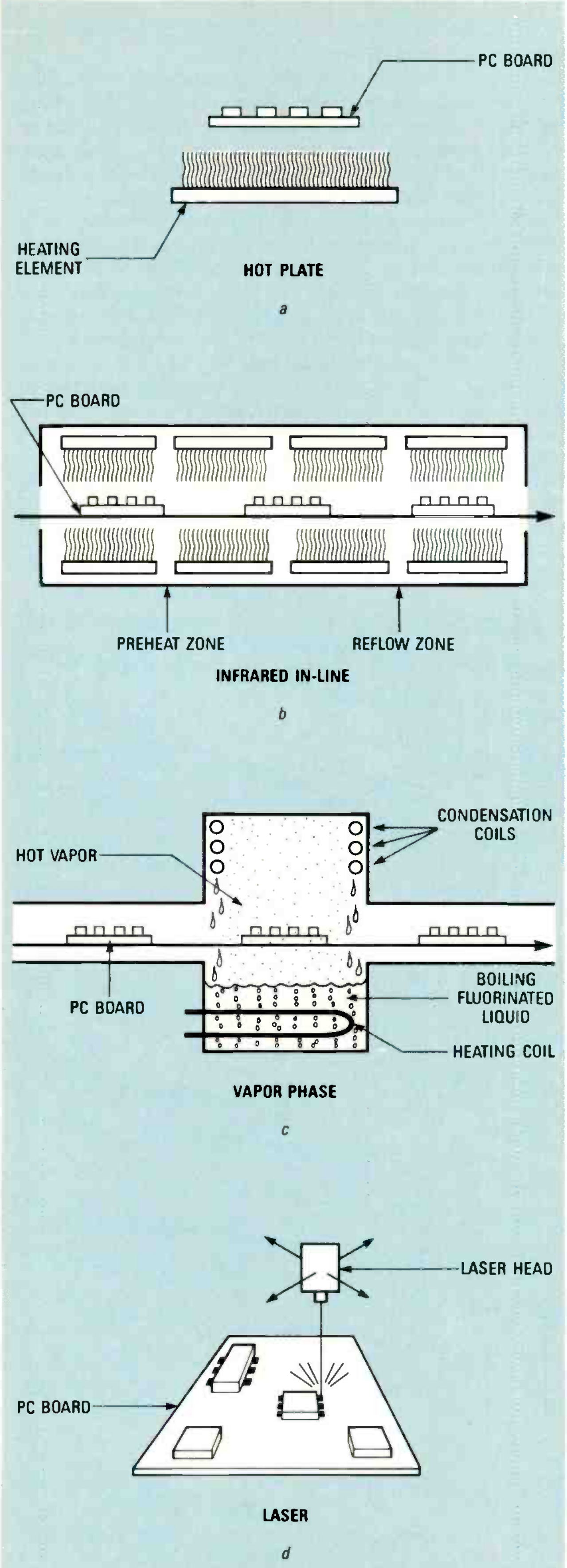


FIG. 6—REFLOW SOLDERING METHODS: Hot plate reflow soldering is shown in *a*, infrared reflow soldering is shown in *b*, vapor-phase reflow soldering is shown in *c*, and laser reflow soldering is shown in *d*. The laser method causes the least component heating.
(*d*) causes the least component heating.

soldered. If too much adhesive is applied, one or more of the solder pads may be covered, thereby preventing solder from establishing a conductive bond between the terminals of one or more SMC's and their respective pads.

The delay between the application of the adhesive and the SMC's placement must be carefully controlled—the adhesive must be fresh and any solvents it contains must not attack the board or the SMC's. And, the adhesive must be properly cured before the board is soldered.

Although automated installation of SMC's receives the most attention, hand assembly of SMT circuits is also important since it permits prototypes to be assembled, tested, and evaluated prior to committing a board to machine production. Another important aspect of hand assembly of SMT circuits is that individuals, whether home experimenters or engineers in a large corporation, can quickly and easily build microminiature circuits that rival hybrid microcircuits in size and complexity.

This is a remarkable capability. For example, the circuit shown in Fig. 1 is a miniature pulse generator circuit that drives an on-board LED with high-current pulses. Although the circuit is about the size of a shirt button (0.3 x 0.3 inch) and is so thin it slips easily between two adjacent pins of a conventional DIP, it was assembled from scratch in about an hour using a 15-watt soldering iron.

Conductive bonding

Though soldering is the chief method for bonding surface-mountable component and socket terminals to circuit board pads, conductive adhesives are also used. Both methods are important, and the prospective SMT circuit designer or service technician should be familiar with each method.

Conventional through-hole circuit boards are soldered either by hand or by passing the bottom side of a component-stuffed board over a wave of molten solder. The same methods and various kinds of *reflow soldering* can be used to solder SMC's onto a board. Reflow soldering is a three-step process in which solder paste or cream is applied to SMC pads on a circuit board, SMC's are placed on the board, and the SMC's are heated simultaneously or one by one. No matter which soldering method is used, the heat sensitivity of the SMC's must be considered because SMC's having a ceramic substrate—such as chip capacitors and chip resistors—can be permanently damaged by the sudden application of the heat necessary for the solder to melt. The problems can be avoided during automated soldering by preheating the SMC's and carefully controlling the time during which the SMC is subjected to the temperature of soldering. Thermal damage during hand soldering can be avoided by keeping the heated tip of a soldering iron from touching the center of the SMC. Instead, only the conductive terminals should be heated.

Soldering

Manufacturers of SMC's specify the soldering guidelines for their components; be sure to keep them in mind when considering SMT soldering methods. The most important guidelines include:

1. Hand Soldering—Although most surface-mount publications and articles relegate hand soldering to the replacement of defective SMC's, as noted earlier, hand soldering can play an important role in the assembly of prototype circuits. To meet that need, some SMC manufacturers provide detailed guidelines for the hand soldering of their components.

Conventional soldering irons, soldering tweezers, and hot air soldering tools are used to hand solder SMC's. Soldering tweezers grip an SMC between two heated tips until soldering is complete. Many different soldering iron tips are available for conventional irons, most of which permit all the terminals of an SMC to be heated simultaneously. For example, a U-shaped slotted spade tip, such as the one shown in Fig. 2, that wraps

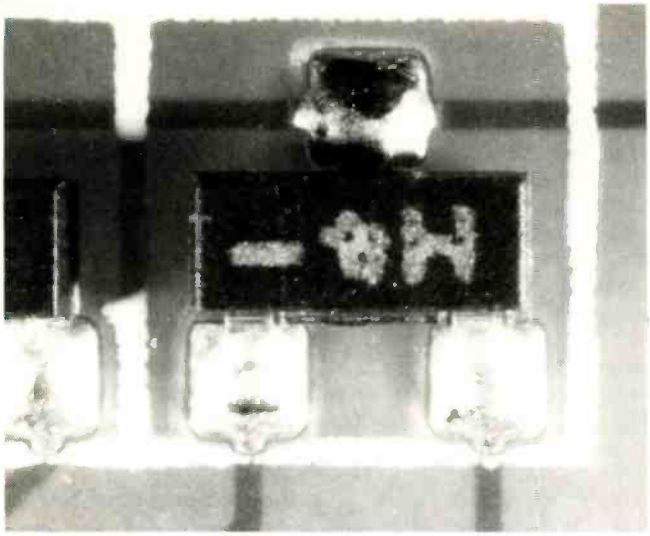


FIG. 8—PERFECT SOLDERING of a leadless diode and a chip capacitor.

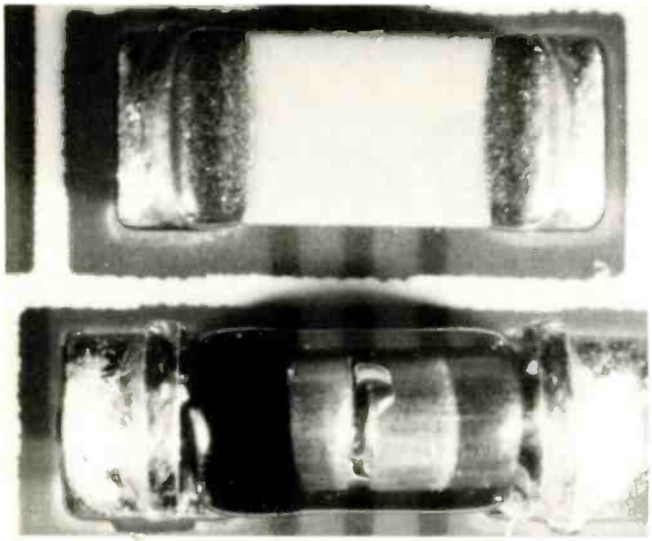


FIG. 7—PERFECT SOLDERING OF AN SOT-23 TRANSISTOR. Note how the solder has flowed completely over the terminals and pads.

itself around the SMC is used to reflow solder and desolder leadless chip resistors and capacitors. Hot-air tools, which are commonly used for desoldering both SMC's and through-lead components, can also be used for hand reflow soldering.

Despite the wide variety of soldering tools designed especially for SMT, an ordinary low-wattage soldering iron having a conical tip and 0.03-inch or smaller rosin core wire solder can be used to solder SMC's. Soldering is fast and reliable if the pads are tinned and if the SMC is held in place with masking tape. Hand soldering is discussed in more detail elsewhere in this special section.

2. Wave Soldering—Wave soldering is a well-established means for simultaneously soldering all the leads of through-hole components that protrude through the bottom side of a circuit board. Briefly, boards are machine or hand stuffed with components and placed on a moving carrier. The boards are carried, in turn, over a radiant heater, then a wave, foam or spray of rosin, and finally, a wave of molten solder. The soldered boards are usually cleaned to remove flux residue. Although the residues of rosin-based and other fluxes will cause no electrical problems if left on a board, the residues of some fluxes will cause corrosion if not removed.

When SMT began to become popular several years ago, it was only natural for companies to want to adapt their existing wave-soldering assembly lines for soldering SMT boards. Although wave soldering is widely used to solder SMT boards, doing so requires solving several important problems.

The most crucial problem is SMC thermal shock, since *all* the SMC's on a wave soldered SMT board are briefly but totally immersed in molten solder. Pre-heating by means of ovens or heat lamps eliminates most danger to ceramic chip devices, while the use of high-temperature plastics protects the package integrity of both discrete and integrated semiconductors.

Another drawback to wave soldering is incomplete wetting of the SMC terminals due to the shadow effect caused by adjacent, closely-spaced SMC's. That can cause cold and even missed solder joints. One way to reduce the problem is to plan the circuit board so chip components are aligned with their end terminals perpendicular to the flow of the solder wave, as shown in Fig. 3. Another way is to pass the board over *two* waves of solder, as shown in Fig. 4. The first wave is made purposely turbulent so that solder can reach even shadowed regions. A second, laminar wave completes the process by removing excess solder and leaving behind a clean solder fillet at every connection point.

3. Reflow Soldering—The most important conductive bonding method for SMC's is reflow soldering. The simplest form of reflow soldering occurs when the junction of a tinned terminal and a thickly-tinned pad is heated by a soldering iron or other

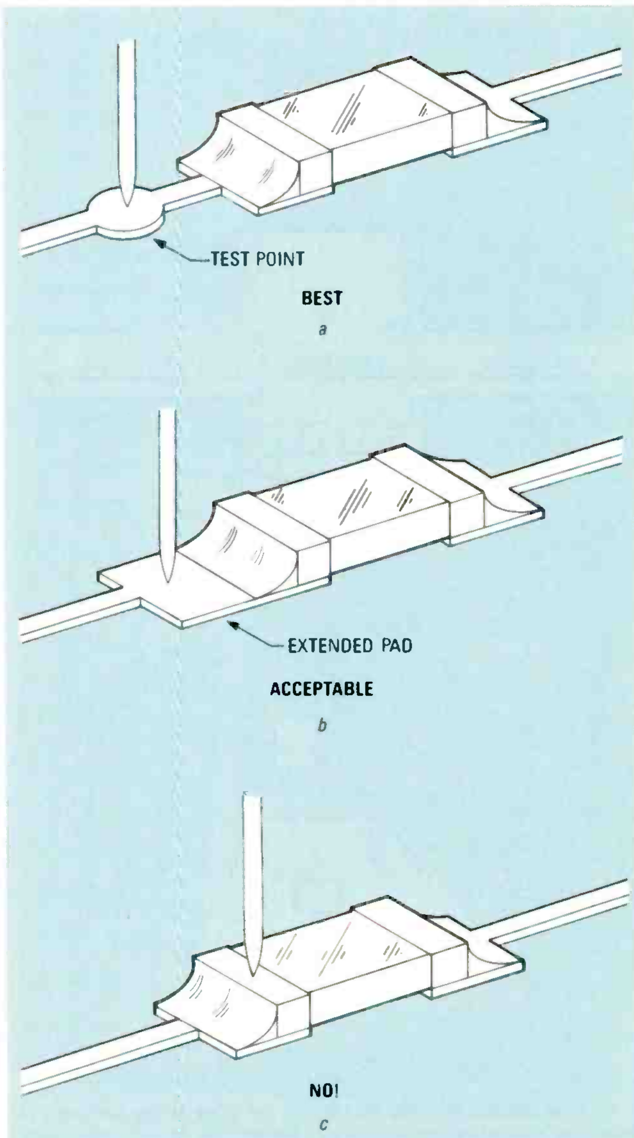


FIG. 9—HOW TO USE A TEST PROBE ON AN SMC. The test probe can touch any part of the board's traces or pads, but not the chip itself.

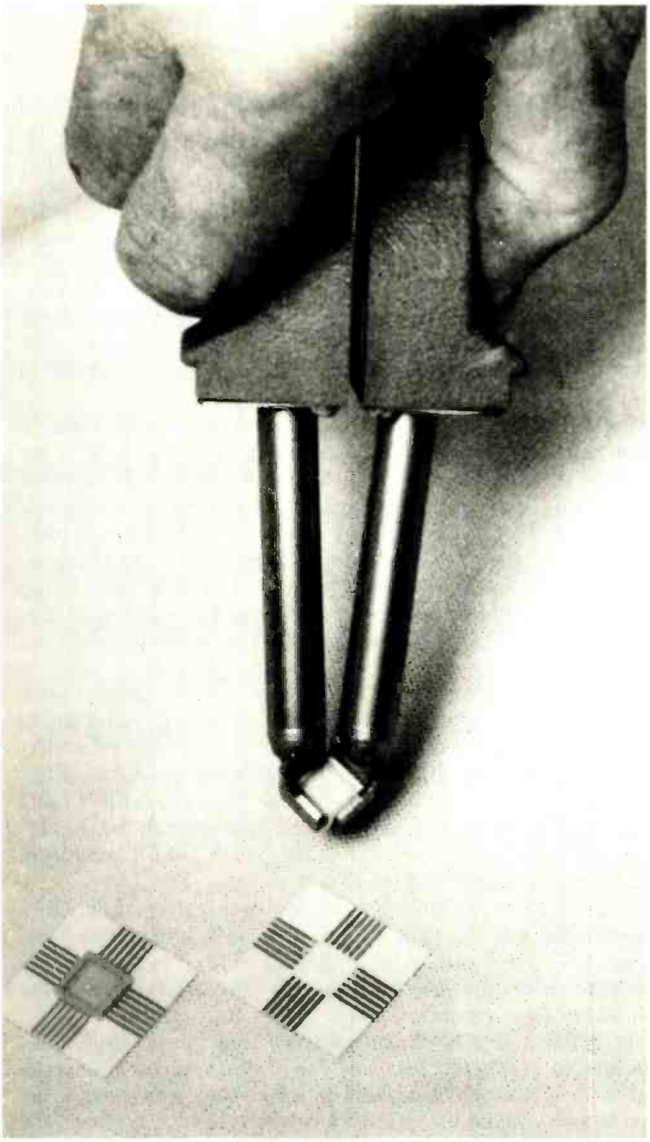


FIG. 10—A PAK-X-TRAC™ DESOLDERING SCISSORS can be used to simultaneously heat the terminals on all four sides of a quad PLCC.

means until the two tinned layers melt and merge together. Reflow soldering can also be accomplished by placing a small, thin square of solder called a *preform* between a terminal and a pad. Preforms are also used to solder semiconductor chips (e.g. laser diodes, LED's, transistors, etc.) to a metal header or substrate.

Solder pastes or creams, which consist of microscopic particles of solder suspended in a flux, are used for SMT reflow soldering. Small dots or squares of solder cream are placed over each SMC pad, the SMC's are placed on the board, and the entire board is heated until the solder melts. No adhesive is required since the SMC's are held in place by the sticky paste or cream.

The cream can be applied to the SMC pads with a handheld wire, a squeeze applicator, a manual syringe, a pneumatic syringe that dispenses a preset quantity of cream, or by stenciling or screening. And solder cream can be applied by means of a pin array using the same principle sometimes used to simultaneously deposit adhesive at each SMC location on a board.

An advantage to using solder cream is that the placement of the SMC's is less critical. When the solder melts, its surface tension tends to pull slightly misplaced SMC's back into position precisely over the solder pads. Even boards having SMC's on both sides can be reflow soldered without adhesive. First, the SMC's on the top side of the board are reflow soldered. The board is then inverted. SMC's are placed on the second side, and heat is applied. Even though the solder on the lower side of the board may melt, the SMC's will be held securely in place by the surface tension of the molten solder.

Although solder pastes and creams are widely used for reflow soldering of SMC's, they are not without disadvantages. For example, non-uniform heating during soldering or non-uniform deposition of the paste or cream can cause one end of a 2-terminal SMC to lift off the board entirely, as shown in Fig. 5. Sometimes an SMC will actually stand completely on end. That phenomenon, which is commonly called *tombstoning* or *drawbridging*, is caused by the surface tension of the molten solder at one terminal exceeding that at the other joint.

Although a handheld soldering iron can be used to reflow solder one connection at a time, a better way—and a must for production quantity soldering—is to heat the entire board so that all the solder cream melts at the same time, thereby soldering the entire board in one step.

Figure 6 shows some of the various methods for generating the heat necessary to reflow-solder entire boards in one operation, or one SMC at a time.

Hot-plate reflow soldering (Fig. 6-*a*) is sometimes used to solder hybrid microcircuit components atop a ceramic substrate. The ceramic substrate is placed on a hot plate until the solder melts. A modified version of that process, *convection-oven reflow soldering*, can be used to reflow solder production quantities of SMT boards. Boards are placed on a conveyer belt and moved over a series of hot plates arranged on an oven. One or more hot plates preheat the boards and drive off solvents present in the solder cream, while a single hot plate at a higher temperature melts the solder. The boards are then cooled by a forced-air blower.

Convection-oven reflow soldering has many variations, all of which incorporate an oven through which boards loaded with SMC's ride on a moving belt. Ovens may have one or more preheating sections or chambers.

Infrared reflow soldering (Fig. 6-*b*) is claimed by its advocates to provide a higher degree of temperature control than any reflow solder method. That's because the boards to be soldered are heated by a bank of infrared lamps whose power output can be carefully controlled. Moreover, the same lamps that gently preheat a board can also take the board to solder temperatures. The negative side of infrared reflow soldering is that dark-colored SMC's, such as semiconductors and many chip components, absorb heat much more readily than their highly reflective terminals. Also, high profile components may block the radiation intended for other components, thereby resulting in shadow regions containing cold or otherwise imperfect solder joints.

Vapor-phase reflow soldering (Fig. 6-*c*) is a clever procedure, developed by Western Electric, in which a board loaded with SMC's is placed within the hot vapor given off by a boiling fluorinated liquid. The vapor condenses on every exposed surface of the board and its SMC's, thereby heating the entire board more uniformly than any other reflow soldering method. After the solder melts, the board is removed from the vapor. Meanwhile, the condensed vapor is collected, cleaned, and recycled or, in simple systems, falls back into the reservoir of boiling fluorinated liquid.

Vapor-phase soldering provides highly uniform heating of SMC's. Also, the temperature of the condensed vapor remains constant so there is no danger of overheating a component designed to accept vapor-phase temperatures (typically 215-250 degrees Celsius).

On the down side, the near instantaneous heating produced by the vapor-phase process can cause some SMC's to fail. For example, ceramic chip capacitors should be heated at a maximum rate of from 2 to 6 degrees per second; otherwise, the ceramic might develop microcracks that can lead to degradation and eventual failure. Without preheating, a vapor-phase system

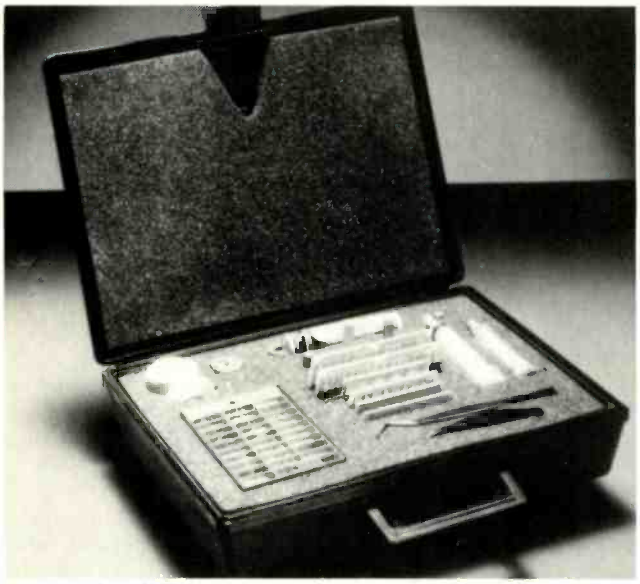


FIG. 11—The SMT 2000 TRAINING KIT includes SMC's, conductive adhesive, solder, solder paste, tweezers and practice boards.

can take a chip capacitor from room temperature to 215 degrees in less than a second. There is also some question about the integrity of vapor-phase solder joints.

Laser reflow soldering (Fig. 6-*d*) is among the most gentle soldering method. A pulsed laser beam heats each SMC terminal in sequence. Laser heating results in considerably less heat stress than other solder-reflow methods. However, it is slow and the laser controller requires extensive programming.

Conductive Adhesive Bonding

Electrically-conductive adhesives have long been used to bond the terminals of components to the conductive traces of hybrid microcircuits. They are relatively easy to use and they eliminate the thermal shock of soldering. Several families of conductive adhesives are available, all of which consist of a conductive powder suspended in a 1- or 2-part base. The most common conductive powders, in order of increasing resistance, include gold, silver, copper, nickel, carbon, and graphite. Adhesive bases include urethane, acrylic, polyester, and 1- and 2-part epoxies.

Conductive adhesives can be applied by hand using a squeezable dispenser, an automatically metered syringe, or a piece of wire. They can also be applied by screening, or by an x-y pick-and-place machine using the same kind of equipment that dispenses dots of non-conductive adhesive on circuit boards.

Thermoplastic conductive adhesives can be reworked using heat from an ordinary soldering iron or a hot air gun; the SMC can be removed after the adhesive softens. A new SMC can then be bonded to the same location by reheating the adhesive.

A significant drawback of conductive adhesives is their relatively high cost, especially for gold- and silver-filled material. Since the conductive particles tend to settle out during shipment and storage, conductive adhesives must be carefully stirred or shaken before use. Most conductive adhesives, like solder pastes and creams, have a limited shelf life of typically 6 to 12 months. Finally, some conductive adhesives may tend to give off hazardous vapors.

Inspection, testing, and repair

Because of the very small size of the components, a just-completed SMT board requires a more careful inspection than a conventional, through-hole board. In particular, look for solder balls, solder bridges, improperly-soldered joints, missed solder connections, and for SMC's that have moved out of position or "tombstoned" during soldering. Figure 7 is a close-up of a properly-soldered SOT-23 transistor. Note the smooth, uniform appearance of the solder fillets at each terminal. Figure 8 is a close-up of a soldered diode and chip capacitor.

Some components are especially difficult to inspect. For example, quad PLCC's (IC's having J-profile pins along each of four sides) can trap solder balls and conceal cold solder joints.

Completed SMT boards can be tested by hand or with automated test equipment. A single- or double-sided "bed of nails" test fixture can be used to isolate defective SMC's and cold solder joints. While that permits quick identification of problems, building the test fixture is time consuming.

Whether testing is done by hand or automatically, test probes should be touched to SMC solder pads or their conductive traces and not the terminals of the SMC. Properly designed SMT boards incorporate test point locations, such as those shown in Fig. 9.

Replacing defective SMC's requires more patience and care than replacing through-hole components because SMC's are considerably smaller and have a much higher placement density. A soldering iron fitted with the same kind of tip used to hand-solder an SMC to a circuit board can be used to simultaneously heat the terminals of the same device in preparation for removal. Figure 10, for example, shows how a Pak-X-Trac desoldering scissors is used to simultaneously heat the terminals on all four sides of a quad PLCC. Hot air and vacuum desoldering tools can also be used.

When desoldering, extra care must be taken to prevent overheating of the board and adjacent SMC's. Also, it's important to use non-vacuum hot-air desoldering tools with care since they might blow away the chip being removed and spray molten solder across the circuit board. When the solder melts, the SMC should be twisted before it is lifted from the board to break the solder's surface tension; otherwise, the solder pad might lift away from the board.

The procedure is unnecessary if the solder is *slurped* away by a vacuum desoldering tool. Removal of SMC's that have been cemented to the board is more difficult since it is necessary to twist the device in order to break the adhesive bond after the solder has been vacuumed away.

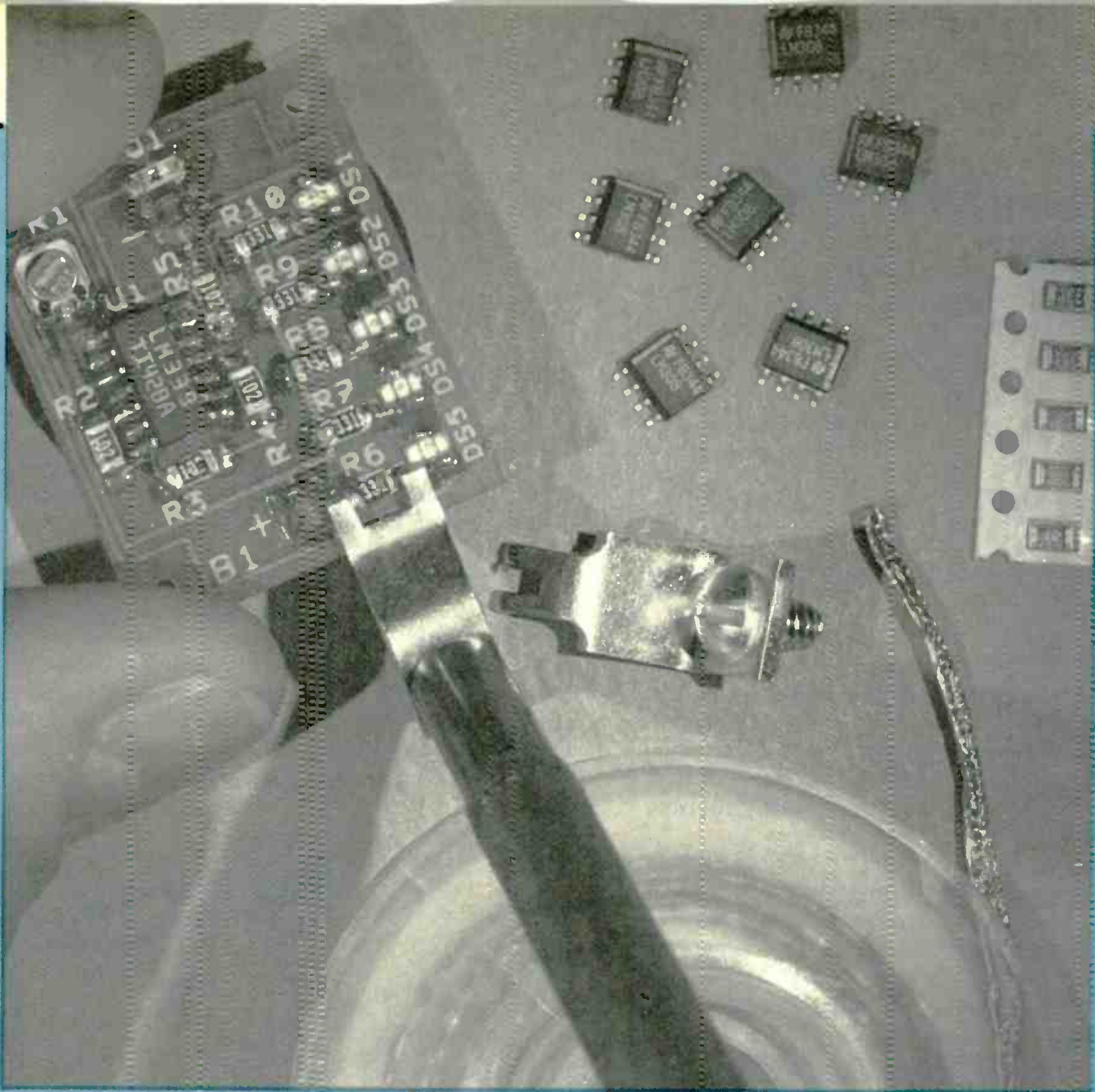
Installing a new SMC isn't difficult. Indeed, it's sometimes possible to simply place the SMC in position and heat its terminals with an iron or a hot air tool until the solder remaining on the pad reflows around the terminals. For best results, however, the old solder should be removed with desoldering wick or a desoldering tool. The pads should then be retinned and fluxed, or coated with solder cream. Finally, the new SMC is placed over the pads and its terminals reflow-soldered to the board.

Going further

Only the highlights of surface mount technology can be covered in this special section. However, you can learn more and you can gain valuable firsthand experience by assembling the various SMT projects in this issue.

For an even broader hands-on introduction to SMT, consider the Vector Electronic Company's (12460 Gladstone Avenue, Sylmar, CA 91342) *SM2000 Training Kit*, shown in Fig. 11. The kit includes solder, solder paste, conductive adhesive, pre-etched boards, tweezers, desoldering wick, some SOT-23 diodes and transistors, and hundreds of assorted chip capacitors and resistors. The kit sells for $279.95. Items included in the kit can be purchased separately.

Manufacturers of surface mount components, equipment, and supplies publish brochures, technical reports and specification sheets that provide excellent background information about SMT. Electronics trade magazines often carry both news and technical articles about various aspects of SMT. For those who need up-to-the-minute news about surfce-mount technology, contact the Surface Mount Technology Association (Box 1811, Los Gatos, CA 95031). **R-E**



Hand-Soldering SMC's

Once you master the techniques, soldering SMC's is easy, and fast.

FORREST M. MIMS, III

THE EASIEST WAY TO HAND-SOLDER SMC'S TO A CIRCUIT board is to use soldering tools and materials, such as soldering tweezers and hot-air soldering/desoldering systems, which are designed specifically for that task. Unfortunately, specialized SMC soldering tools can be expensive and difficult to locate. However, it is safe to assume that such items will become more economical and widely available in coming years. In the meantime, SMC's can be installed using only the common tools shown in Fig. 1. Those tools include an ordinary soldering pencil and a soldering iron equipped with a slotted tips designed for SMC's.

There are two chief differences between hand-soldering conventional through-hole components and SMC's. First, SMC's are installed and soldered on the foil side of a circuit board. Second, the absence of wire leads and pins inserted through holes means that the SMC's must be secured in place during soldering.

In industry, small droplets of adhesive are used to secure SMC's in place for wave soldering. While wave soldering may be impractical for hobbyist applications, the same technique for securing SMC's in place is used when hand-soldering circuits. For reflow soldering, SMC's are held in place by sticky dabs of solder paste or cream that are placed over each footprint before the SMC's are placed on the board. Reflow soldering can also be used by hobbyists.

Let's now examine some hand- and reflow-soldering techniques.

Conventional soldering

It's surprisingly easy to solder or "tack" SMC's in place using only a handheld iron and small-diameter wire solder. Solder 25 mils (0.025 inch) in diameter works best, but 30-mil solder, which is more readily available, can also be used. The only special requirement is that the SMC must be held in place until at least one terminal or pin is soldered.

It's possible to use various kinds of adhesives to cement an SMC in place for hand soldering. That, however, can unnecessarily complicate what is essentially a very simple procedure. The adhesive must not be allowed to flow over the SMC's footprints, must be non-corrosive, and must be allowed to set before the SMC's can be soldered. For those reasons, we have experimented with two simpler and faster methods.

One method is to secure one side or corner of an SMC in

FIG. 1—SMC's CAN BE HAND SOLDERED using only the common tools and materials shown here.

place with masking tape as shown in Fig. 2. An exposed terminal or corner pin can then be soldered. The tape is then removed and the remaining terminals or pins can be soldered.

Another method is to place a tiny bead of reusable adhesive between the terminals on the bottom side of the SMC. Suitable reusable adhesives include *Plasti-Tak*, *Fun-Tak*, and *Stikki-Wax*. Those and similar adhesives are widely available at department stores.

Use a toothpick, a sharply pointed probe, or pointed tweezers to apply the adhesive. Then grasp the SMC with pointed tweezers, place it on its footprints, and press it in place. It is important that the SMC be pressed flat against the board. Too much adhesive will keep the SMC suspended slightly above the board and may even cause adhesive to creep between a terminal and its footprint.

After an SMC is attached to the board with tape, cement, or reusable adhesive, carefully touch the tip of a soldering pencil to the junction of a terminal and its footprint. After a second or so, lightly touch the end of a length of solder to the junction and immediately remove both the iron and the solder. A shiny solder fillet should neatly bond the terminal to the footprint.

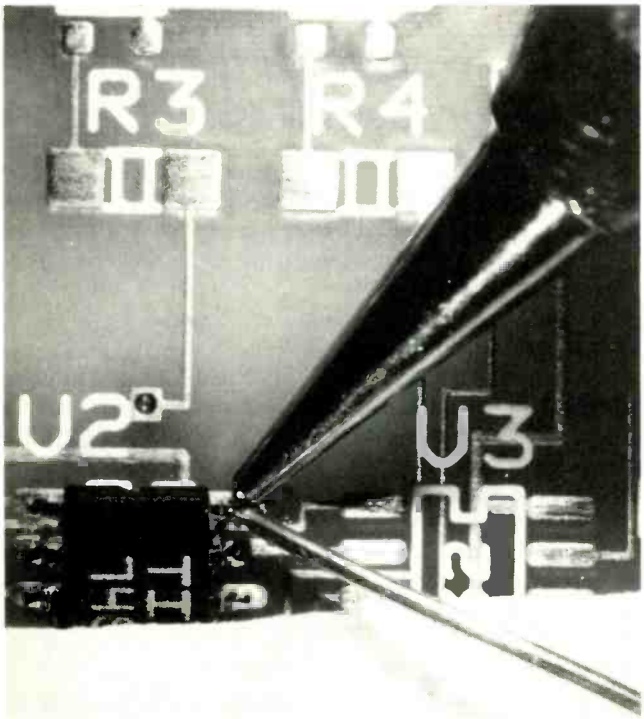


FIG. 2—ONE SIMPLE METHOD of securing an SMC in place is to tape down one side with masking tape.

Until you gain some hands-on SMC soldering experience, *always* inspect the completed junction with a magnifying lens before moving to the next terminal or SMC. If you use too much solder or form a solder bridge, use desoldering braid to carefully remove the excess solder. Place an unused section of desoldering braid over a footprint and press it in place with a soldering iron tip. Within a second or so, capillary action will wick the excess solder on the footprint into the braid. Remove the iron and braid and go on to the next footprint as needed. Be sure to use a fresh section of braid at each footprint. Clip off used sections of braid as necessary. If necessary, reapply a small amount of solder.

Reflow soldering

The most straightforward approach to mounting SMC's is reflow soldering. The SMC is held in place with tweezers while a soldering iron presses one end terminal or corner pin against a pretinned footprint. The tinned layer then melts and reflows around the terminal or pin and the footprint. Since no additional solder is used, the tinned layer must include enough solder to provide a good joint.

FIG. 3—SOLDER PASTE OR CREAM is available in a syringe. That makes dispensing the paste or cream convenient, once you get the hang of how it's done!

Reflow soldering works best with SMC soldering tools that simultaneously heat all the pins or terminals of the chip being soldered. When a standard soldering iron is used, only one pin or terminal at a time can be heated. That can lead to problems when working with chip SMC's. If the tinned layer is too thick, only the terminal being reflow soldered will be pushed through the molten solder against the footprint; the remaining terminal will remain atop the tinned layer over its footprint. Also, the SMC will be badly tilted when the second terminal is soldered. On the other hand, if the tinned layer is too thin, there will be insufficient solder to form the bond. Therefore, consider other soldering techniques when working with chip components.

Reflow soldering with solder paste or cream is particularly interesting since all the SMC's are soldered in place in a single operation without a soldering iron. Instead, the entire board is heated in a convection oven or on a hot plate. Unfortunately, solder pastes and creams are not always readily available, have a limited shelf life, and have instructions that must be strictly followed. Nevertheless, the method is so efficient that it warrants discussion here.

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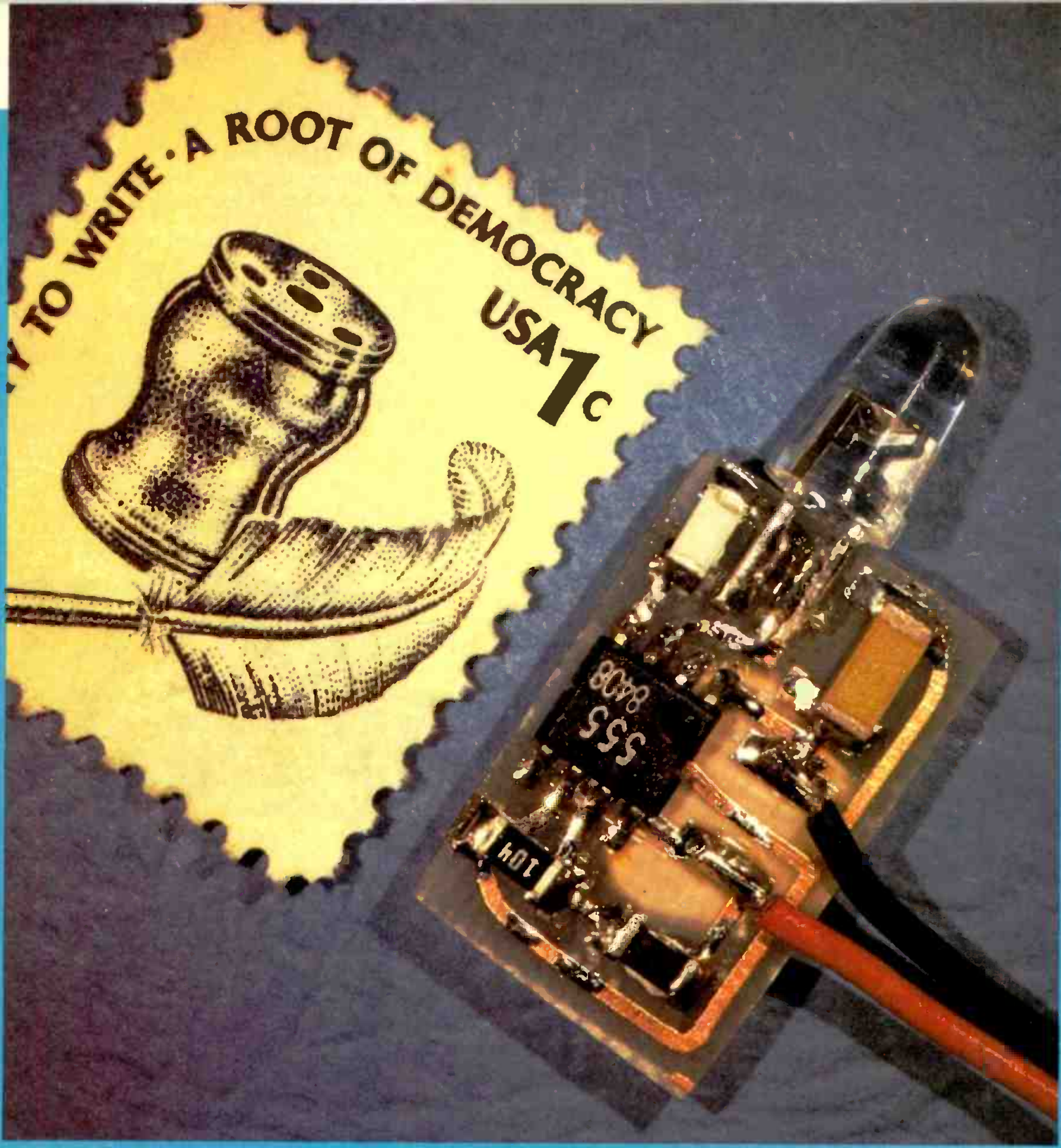

SMT PROJECT: *LED FLASHER*

Use surface-mountable components to build this subminiature LED flasher.

FORREST M. MIMS, III

A GOOD WAY TO APPRECIATE THE MINIATURIZATION POTENTial of *S*urface-*M*ountable *C*omponents (SMC's) is to assemble the subminiature LED flasher described in this article. Besides teaching you the basics of how to assemble a simple circuit using SMC's, the flasher has many practical uses. It can, for example, function as a warning flasher, indicator, a tracking beacon for night-launched model rockets or in a number of other applications.

A flasher made with conventional through-hole components can be assembled on a circuit board of about the same size. But while the conventional circuit is more than 0.4-inch thick, the surface-mount version is less than 0.1-inch thin. That means that the surface-mountable circuit can be easily slipped inside a slim slot or a space that might never be used or be usable otherwise.

How it works

Figure 1 is the circuit for the flasher. In operation, the 555 is connected as an astable multivibrator whose frequency of oscillation is given by 1.44/(R1 + 2R2)C1. With the values shown in Fig. 1, LED1 will flash once each second. The rate can be speeded up by reducing the value of R1 or C1. Resistor R3 is a current limiter.

For best results, the LED should be an AlGaAs superbright unit. At night the flashes from such an LED can be clearly seen from more than several hundred feet away. Keep in mind that the light level from the LED is directly proportional to the supply voltage. Although Fig. 1 specifies a 9-volt supply, the circuit can be powered by from 3 to 12 volts. Figure 2 shows the relative power output of the LED over that range of supply voltages.

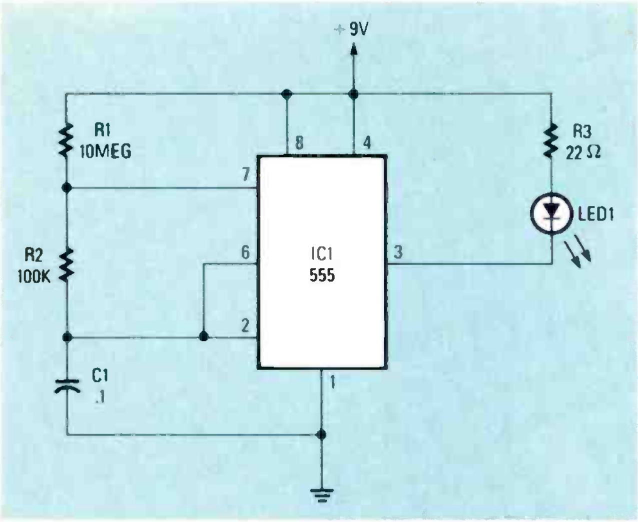

FIG. 1—**WHEN THIS LED FLASHER** is assembled using SMC's, the assembly is about 0.1-inch thick.

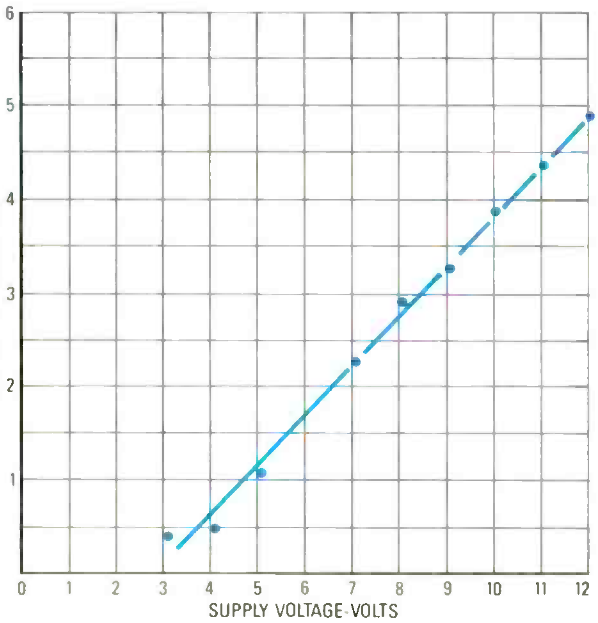

FIG. 2—**RELATIVE OUTPUT** of a super-bright LED is a function of its supply voltage.

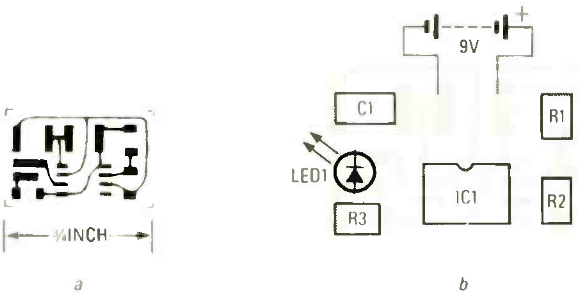

FIG. 3—**USE THE PC PATTERN** shown in *a* to etch the board. The parts layout is shown in *b*.

Preparing the board

The circuit should be assembled on a thin PC board. A pre-etched board and all necessary components are available from the source given in the Parts List. You can also make your own board using the pattern shown in Fig. 3-*a*. However or wherever you obtain your board, the component layout is shown in Fig. 3-*b*.

PARTS LIST

R1—10 megohms, chip resistor, 1206 size SMC
R2—100,000 ohms, chip resistor, 1206 size SMC
R3–22 ohms, chip resistor, 1206 size SMC
C1—0.1 μF, ceramic chip capacitor, 1206 size SMC
IC1—555 timer, SO-8 package
LED1—super-bright red LED, see text
Miscellaneous:PC board, 9-volt battery clip, 30-mil solder, reusable adhesive, etc.
An etched circuit board, super-bright LED, and all SMC's are available for $10.00, including postage and handling, from Gilbert Electronics, P.O. Box 95, Leesville, TX 78122. Texas residents please add appropriate sales tax.

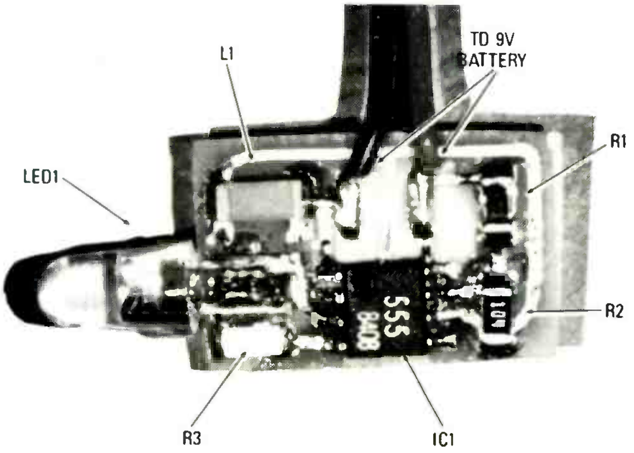

FIG. 4—**THE COMPLETED CIRCUIT BOARD.** The light from the super-bright LED can be seen for several hundred feet.

The circuit can be assembled in less time than an equivalent conventional circuit since no holes need be drilled in the circuit board. Although an experienced technician can install the components with a 30-watt soldering iron having a wedge tip, for best results use a 15-watt pencil iron having a pointed or conical tip.

Begin assembly by tinning the component footprints on the board. First, use an abrasive cleanser or steel wool to polish the copper traces. Wash and dry the board. Then use masking tape to attach a corner of the board to a flat, movable surface placed on your workbench.

Tinning the board takes just a few minutes. Just touch the soldering iron tip to a footprint for a second or so and then touch the end of a length of 30-mil rosin-core solder to the footprint. When the solder flows over the footprint, immediately remove the iron and solder and proceed to the next footprint. Be sure to rotate the board for best access to each footprint.

After the footprints on the board are tinned, remove any excess solder from the footprints with desoldering braid. That procedure will also remove any solder bridges.

After the board is tinned and the excess solder is removed, remove any solder balls or splashes from the traces and the substrate. Then use a defluxing agent to remove the flux residue from the board.

Installing the SMC's

Begin assembly of the LED flasher by first attaching the 555 to the board. Use the methods described in the article on SMC soldering, which can be found elsewhere in this sec-

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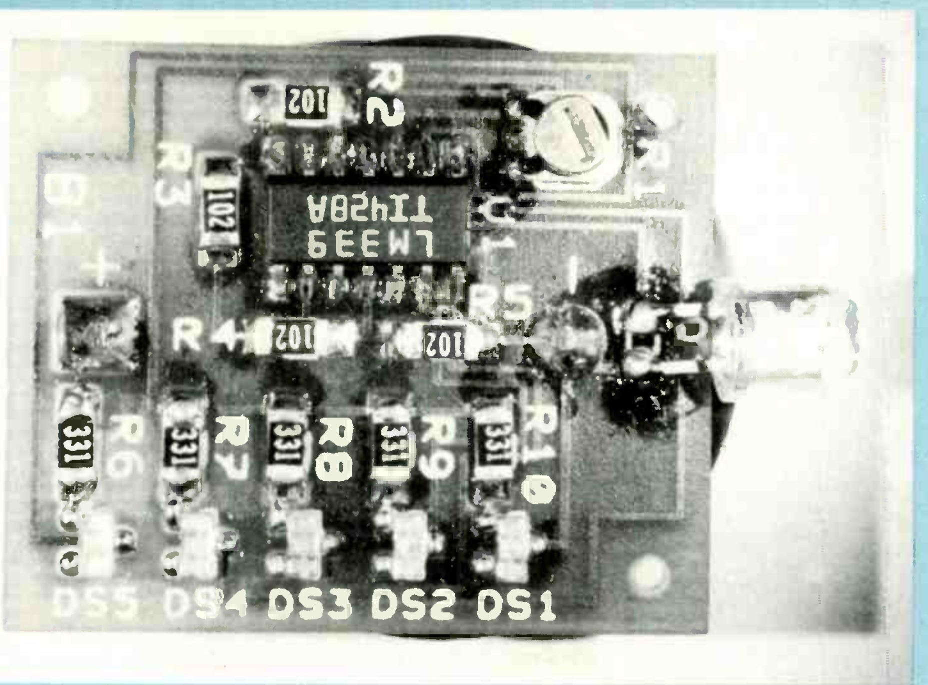


SMT PROJECT: *LIGHT METER*

Here's a simple "dark meter" that you can build using SMC's.

FORREST M. MIMS, III

IN THIS ARTICLE WE WILL SHOW YOU A SIMPLE LIGHT METER with a built-in four-element LED bargraph readout that combines the advantages of analog and digital displays. Since the number of illuminated elements in the bargraph increases as the light reaching a phototransistor decreases, the circuit can be considered a "dark meter." A bonus feature of the circuit is that it can also be used as a four-step timer or as a simple resistance indicator.

The circuit shown in Fig. 1 can be assembled on a tiny circuit board having an area of only about 1.25 square inches, a size made possible by the use of surface-mountable components. Consequently, the circuit is much more compact than an equivalent circuit assembled from conventional through-hole components.

Though the circuit is configured as an inverse light meter or "dark meter," it can be revised so that the number of glowing elements increases with the light level. It can also be used as a timer or resistance indicator by omitting phototransistor Q1. Even if none of the applications for the circuit are of interest, you might want to assemble it anyway since it provides an excellent hands-on introduction to surface-mount technology.

How it works

There is nothing new about the design of the circuit in Fig. 1, which is often called a parallel or "flash" analog-to-digital converter. To understand how the circuit works, it's necessary to review the operation of the basic inverting comparator shown in Fig. 2. In that circuit, a reference voltage is applied to the non-inverting input of an operational amplifier operated without a feedback resistor. That provides a two-state (off-on) output voltage instead of the linear output that characterizes an op-amp operated with a feedback resistor.

A voltage input is applied to the inverting input of the op-amp. When that input exceeds the reference voltage, the output of the op-amp is low; as far as the LED is concerned, the output is ground. Therefore, the LED switches on. Series resistor R1 limits current to the LED, thereby protecting both the LED and the output-driver stage of the op-amp. When the input voltage is below the reference voltage, the output from the op-amp swings to near the supply voltage (output high). The output LED, which no longer receives sufficient forward bias, then switches off.

The circuit is called a "comparator" since it compares the voltages at its two inputs and switches *on* when one exceeds the other. The circuit shown in Fig. 2 can be changed from an inverting comparator to a non-inverting comparator simply by switching the connections to the inputs. Then the output will swing from low to high when the input voltage exceeds the reference voltage.

Referring back to Fig. 1, IC1 is a quad comparator in a 14-pin SO package. Resistors R1 through R5 form a 4-stage voltage divider with taps connected to the non-inverting inputs of each comparator. The reference voltage delivered to each comparator is determined by the setting of trimmer R1.

Each comparator in Fig. 1 functions exactly like the model comparator in Fig. 2. Therefore, the outputs from the comparators will swing, in sequence, from high to low as the input voltage rises above the reference voltage applied to each comparator. The output LED's will then switch *on* in sequence as the voltage rises.

When the circuit is configured as a light meter, the inverting inputs of the comparators are connected in common to the

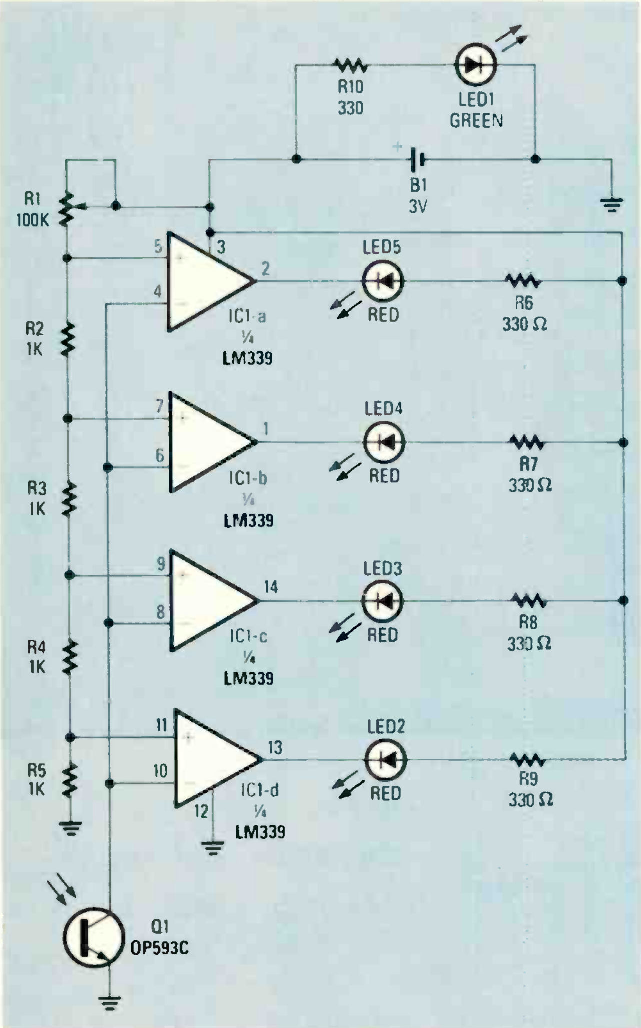


FIG. 1—USING SURFACE-MOUNT COMPONENTS this bargraph "dark meter" can be assembled on a circuit board with an area of just 1.25 inches.

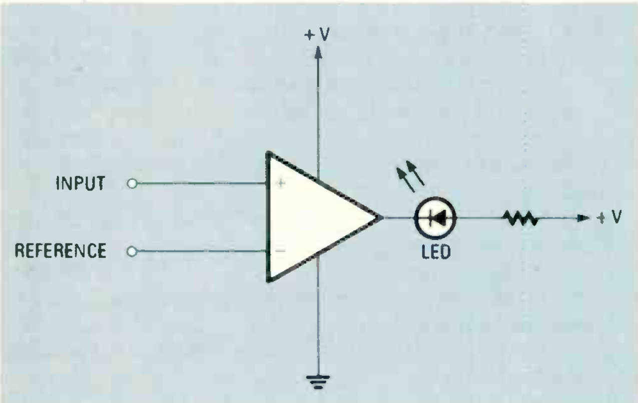


FIG. 2—IN AN INVERTING COMPARATOR, the output is low when the input voltage exceeds the reference voltage; the output is high when the input is lower than the reference voltage.

collector of phototransistor Q1. When Q1 is illuminated, its collector-emitter junction conducts, thereby placing all the inverting inputs within a few millivolts of ground. For most settings of R1, each of the four reference voltages exceeds that value. Therefore, when Q1 is illuminated, the output from each comparator is high and its respective indicator LED is off. As the light level at Q1 is gradually decreased, the voltage at the inverting inputs rises until it exceeds the first comparator's reference voltage (pin 10). The output from that comparator (pin 13) then

PARTS LIST

All resistors are 1206 size SMC's unless noted

R1—100,000 ohms, trimmer potentiometer, Micro-Ohm RV43B-CV or equivalent
R2–R5—1000 ohms
R6–R10—330 ohms

Semiconductors

IC1—LM339 quad comparator, SO-14 package
LED1—Green LED, SOT-23 package, ROHM SLM-13M or equivalent
LED2–LED5—Red LED, SOT-23 package, ROHM SLM-13V or equivalent
Q1—OP593C NPN phototransistor (TRW), or equivalent

Other components

B1—CR2320 or similar 3-volt lithium coin cell

Miscellaneous: Lithium coin cell holder (Keystone P/N 107), PC board, Reusable adhesive or masking tape, 25 or 30 mil solder

A complete kit including a drilled, etched, and plated PC board, Q1, all SMC's, battery, battery holder and solder is available from the Heath Company, Benton Harbor, MI 49022 for $19.95 plus postage and handling; for credit-card orders, call 800-253-0570. Michigan residents must add appropriate sales tax. Specify catalog number SMD-1.

swings from high to low and LED1 switches on. Additional LED's switch on in sequence as the light level continues to fall.

Incidentally, note that the common inverting inputs appear to be floating when Q1 is fully switched off (dark). Actually, a few tenths of a volt appear between those inputs when Q1 is dark. The inputs can be connected to the positive supply through a pull-up resistor, but leaving them "floating" makes the applications discussed at the end of this article possible.

Preparing the circuit board

Figure 3-a shows a suggested layout for the circuit board; the board itself is shown in Fig. 3-b. Also, an etched, silk-screened,

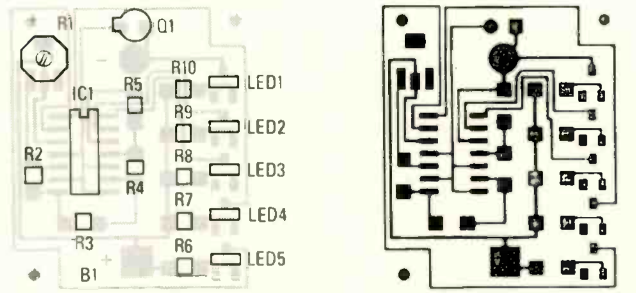


FIG. 3—USE THIS LAYOUT *a* when building the circuit. The PC board is shown in *b*.

and pre-tinned board is available as part of a kit that includes all necessary components: see the Parts List for more information. Note that the board in the kit also includes a solder-mask coating that both simplifies soldering and greatly reduces solder-bridge problems. The board also includes drilled mounting holes for a Keystone 107, or equivalent, lithium coin-cell holder.

If you build your own board, follow the tinning procedure given in the LED-flasher project described elsewhere in this special section. Also review the SMC soldering procedures given elsewhere in this special section before soldering SMC's to the circuit board.

Begin construction by installing the LM339. Be sure to solder a corner pin first. If the device stays aligned over the remaining pads, then continue soldering.

Next, install the chip resistors one at a time. If you use the tape method to hold the chip resistors in place, you can solder one terminal of each resistor; then you solder the remaining terminals. You can use the same approach when installing the LED's. No matter which method you use, until you become an experi-

continued on page 88

SMT PROJECT: *I-R REMOTE ON A KEYCHAIN*

Use surface-mount technology to build an infrared transmitter small enough to fit on your keychain.

FORREST M. MIMS, III

ONE OF THE MAJOR CAPABILITIES OF SURFACE-MOUNT TECHNOLOGY is that experimenters and prototypers can assemble ultraminiature, fully functioning circuits only a few millimeters thin. For example, you can make an optoelectronic remote-control transmitter that is so small that it can be slipped inside a plastic identification-tag holder, yet it's powerful enough to activate a receiver located more than 10 feet away.

The transmitter, shown in Fig. 1, projects a pulse-modulated red or near-infrared beam. Although a 555 timer is often used as an LED driver in this kind of application, the simple two-transistor driver shown is a better choice because it can drive an LED with greater current. Moreover, it can be powered by a supply of less than one volt.

How it works

Referring to Fig. 1, assume that Q1 and Q2 are initially off when power switch S1 is closed. Capacitor C1 then begins charging through resistors R1 and R2, and LED1. Eventually the charge on C1 becomes high enough to switch Q1 on, which then switches Q2 on.

When Q2 is on, LED1 is connected directly across battery B1 through Q2's emitter-collector junction. Meanwhile, C1 discharges to ground through Q1's base-emitter junction. Eventually the charge on C1 falls below that necessary to keep Q1 on. Transistor Q1 then switches off and, in turn, switches Q2 off. The LED is then switched off. The charge/discharge cycle is then repeated at a frequency that is determined by C1's value. The circuit drives the LED with 725 pulses per second using the values given in the Parts List.

Preparing the circuit board

An ultra-thin circuit board is required if the project is to fit inside the thin label space of a plastic ID-tag holder. A

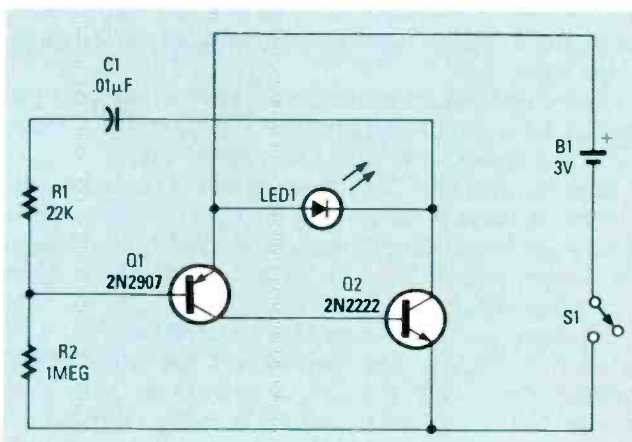


Fig. 1—THE KEY-CHAIN TRANSMITTER uses two transistors to generate a red or near-infrared beam that pulsates at approximately 725 Hz.

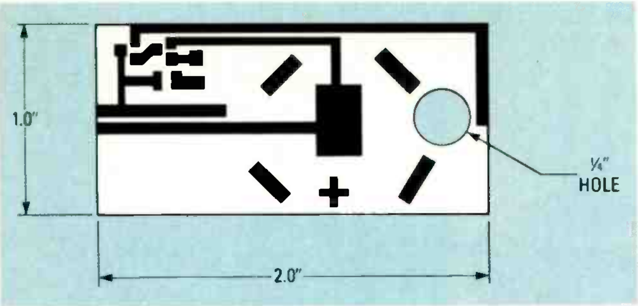


FIG. 2—USE THIS TEMPLATE as a general guide when making the printed-circuit board.

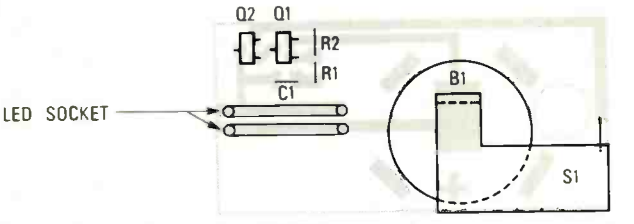


Fig. 3—THE COMPONENT LAYOUT is somewhat unusual because the LED's socket is made from thin tubing, while the battery is secured by four bumps of solder.

double-sided copper-clad board only 7-mils thick that is ideal for the project is available from the Edmund Scientific Co. (101 E. Gloucester Pike, Barrington, NJ 08007). A 12 × 18 inch sheet of the board, catalog number E35,652, sells for only $2.50.

Although the transmitter is assembled on only one side of the board, keep in mind that SMC's can be mounted on both sides of a double-sided circuit board. The foil pattern for the board is shown in Fig. 2; use it as a general guide and apply the resist by hand using a small brush, which is a somewhat faster way to make a small board compared to using the photo-resist technique.

Hand-made board

Use a pair of scissors to cut the board to size, then polish the foil with fine steel wool. Use a ¼-inch hole punch to create the hole for the keychain, then place the various components including B1, a 2016 lithium coin cell, on the board in the approximate locations shown in Fig. 3. Mark their terminal or pin locations on the board with a pencil. Then remove the parts and pencil in the required terminal footprints and interconnection traces. Be sure to include four marks around the perimeter of the lithium cell. Later, solder bumps will be placed on the marks to keep the coin cell in its proper place.

Finally, use a sharp-pointed resist pen to trace over the penciled traces and footprints. Use a straightedge for best results and be careful to avoid smearing the ink.

After the resist dries, cover the back side of the board with a protective layer of tape. Then immerse the board in an etchant solution. Etching time can be speeded up by agitating the solution. After the board is etched, thoroughly rinse the board under running water.

Unless you plan to attach the SMC's to their footprints with conductive adhesive, the footprints of the etched board should be plated with a thin layer of solder or tin. A dip-and-dunk tin-plating solution is available from The DATAK Corporation (Guttenberg, NJ 07093). Alternatively, you can melt a thin layer of standard rosin-core solder over each footprint. For best results, the solder layer should be thin and flat.

PARTS LIST–TRANSMITTER

R1—22,000 ohms, SMT size 1206
R2—1 Megohm, SMT size 1206
C1—0.1 μF, SMT size 1206
Q1—2N2907, PNP transistor, SOT-23 package
Q2—2N2222, NPN transistor, SOT-23 package
LED1—Light-emitting diode, near-infrared or super-bright red
B1—3-volt lithium coin cell, type 2016
Miscellaneous: circuit-board material, plastic keychain ID-tag holder, solder, masking tape, wire, etc.

Therefore, after all the footprints are coated, use desoldering braid to remove excess solder and solder bridges.

Installing the SMC's

The SMC's can be attached to the board with either conductive adhesive or solder. Both methods are described in detail elsewhere in this special section. If you use solder, the method of temporarily securing the SMC's in place with tape works best. Attach the SMC being soldered to the board with a bit of masking tape across one of its ends and solder the exposed terminal or pins with a small amount of solder. If necessary, make sure the SMC is flat against the board by pressing it down with a pencil eraser while the solder is still molten. Then remove the tape and solder the remaining terminal or pins.

After the SMC's are soldered in place, prepare a socket for the LED by cutting two 0.5- to 0.65-inch lengths of 62.5 mil (1/16 inch) O.D. brass tubing purchased from a hobby shop. Prepare the tubes for soldering by burnishing them with steel wool or fine sandpaper. Insert the wire from a bent paper clip in one end of one tube and melt a line of solder along its entire length. Repeat the procedure for the second tube. Then use the paper clip to hold one of the tubes in place over its footprint and remelt the solder on both the tube and the footprint until the tube is bonded in place. If necessary, apply some additional solder to the side of the tube away from the second tube's location. Repeat the procedure for the second tube. Be sure to keep solder from entering the open ends of

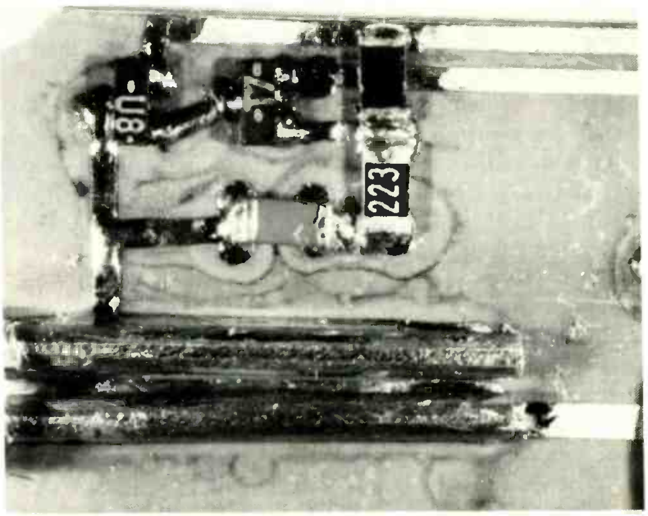


Fig. 4—THIS CLOSE-UP SHOWS how really small the components are. The transistor, labeled U8, is actually smaller than the resistor and capacitor chips. The two "giant" horizontal tubes near the bottom are the LED socket.

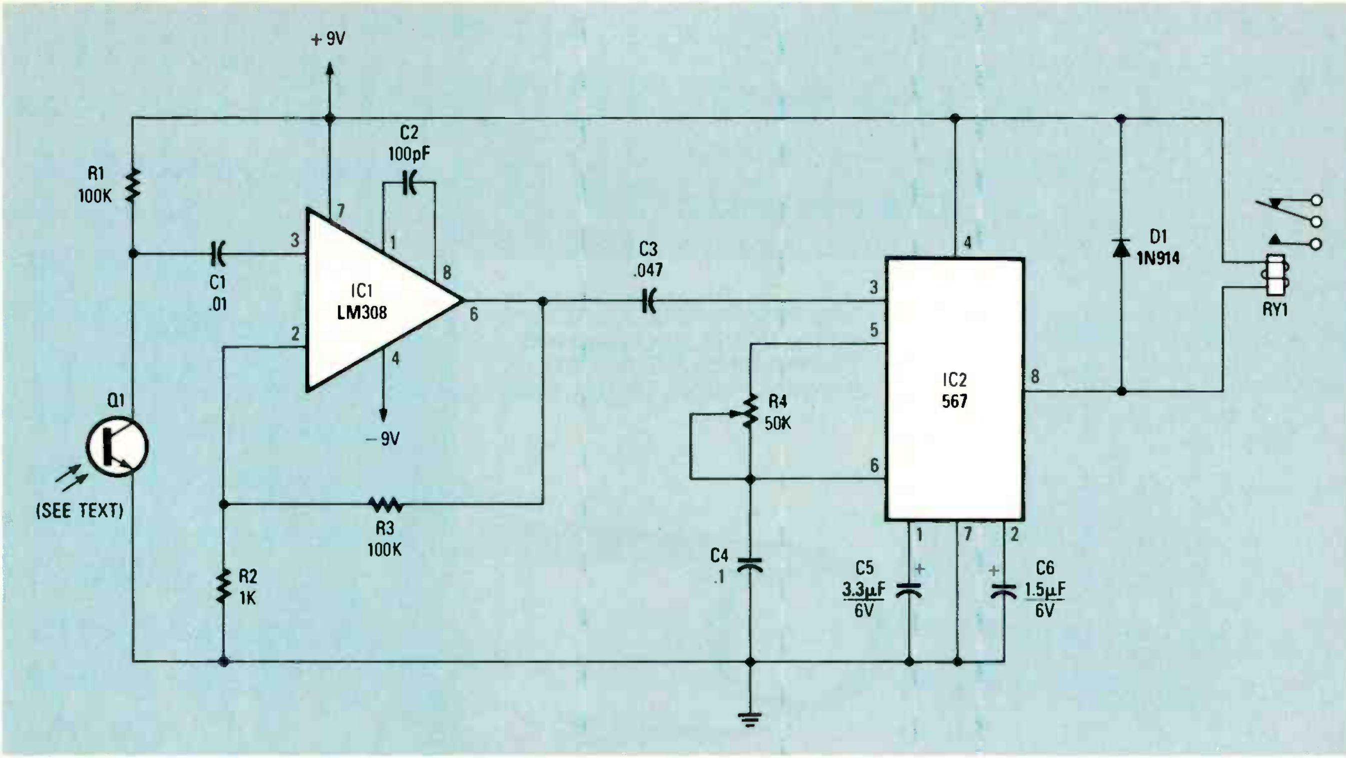


Fig. 5—IF YOU NEED A RED-LIGHT RECEIVER, try building this circuit. Most of what's needed is probably lying somewhere around your shop. Relay RY1 can be any low-current relay rated from 5 to 9-volts DC; such relay's are called "sensitive relays."

the tube, especially the end closest to the edge of the circuit board. Fig. 4 shows the tubes, and the Q1/Q2 circuit soldered to the board.

Switch S1 is a *squeeze switch* made from an L-shaped piece of circuit board, as shown in Fig. 3. The exact shape of the switch is unimportant so long as it fits the allowed space. Solder a short length of wire-wrap wire to the lower side of the base of the L. With the exception of a narrow strip of exposed copper along the end of the lower side of the L (the dashed line in Fig. 3), cover both sides of the L with a clear tape. Solder the exposed end of the wrapping wire to the adjacent positive circuit-board foil. Then attach the copper L to the board with a hinge made from a strip of clear tape.

Testing the circuit

Test the circuit before installing it in an ID-tag holder. First, insert the leads of a red AlGaAs super-bright LED into the LED socket (be sure to observe polarity). Then place B1 on the board (positive side down) and press the squeeze switch. The LED should glow. When the LED is pointed toward a phototransistor or solar cell connected to the input of an audio amplifier, a 725-Hz tone should be heard from the amplifier's speaker.

If the circuit is working properly, remove the LED and slip the circuit inside the ID-tag holder. You might want to first place a self-adhesive label on the back side of the board. You can leave the label blank or record the circuit's operating parameters on it. At least two kinds of plastic keychain ID-tag holders are available from office supply companies. The one used for this project, which has a retail cost of approximately 70 cents, has a 2-mm high slot at one end, opposite the hole for the keychain.

After the circuit is inside the holder, insert the LED into its holder through the 2-mm slot. The slot also simplifies removal of the circuit board: Simply push the board out with a small screwdriver or a flat implement passed through the slot. Adjusting the squeeze switch can be tricky. If the LED stays on when the board is slipped inside the tag holder, bend the exposed copper end of the L slightly upward. If excessive pressure is required to close the switch, expose additional copper by removing a narrow strip of the tape with a knife.

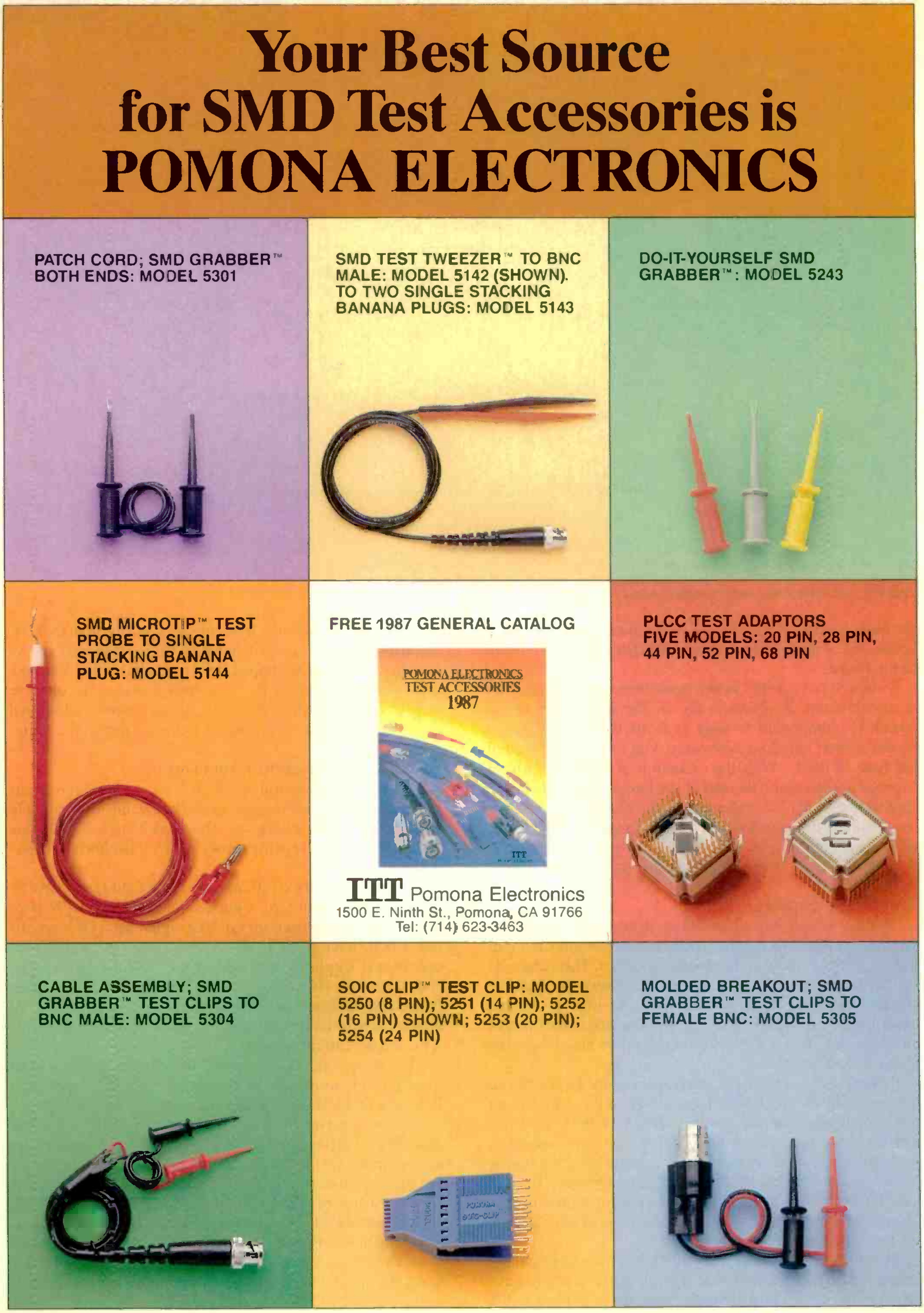
Suitable remote-control receivers

The keychain transmitter can be used to trigger various kinds of optoelectronic receivers. The circuit for a suitable receiver is shown in Fig. 5. The circuit uses a 567 tone decoder to help prevent triggering by any unauthorized transmitters.

In operation, pulsed infrared or visible light is received by Q1 and transformed into a pulsed voltage. Any NPN phototransistor can be used for Q1. The signal from Q1 is amplified 1,000 times by IC1, an LM308 high-input impedance operational amplifier, and is passed to IC2, a 567 tone decoder. Resistor R4 and capacitor C4 determine IC3's center frequency. Resistor R4 is a potentiometer rather that a fixed resistor to permit the receiver to be tuned. IC3's output drives RY1, a low- current relay.

The receiver can be assembled on a printed-circuit board using either conventional or surface-mountable components. Both IC1 and IC2 are available in small outline packages.

Test the receiver by pointing the transmitter at Q1 while carefully adjusting the receiver's R4. With R4's wiper set near its midpoint, the relay should pull in when Q1 is receiving the transmitter's signal. For best results, bright ambient light must not be allowed to strike Q1; otherwise, Q1 may become saturated and fail to respond fully, or at all, to incoming pulses from the transmitter. If ambient light proves to be a problem, place one or two pieces of developed color film in front of Q1 to serve as a near-infrared filter, and insert a near-infrared LED into the transmitter. **R-E**



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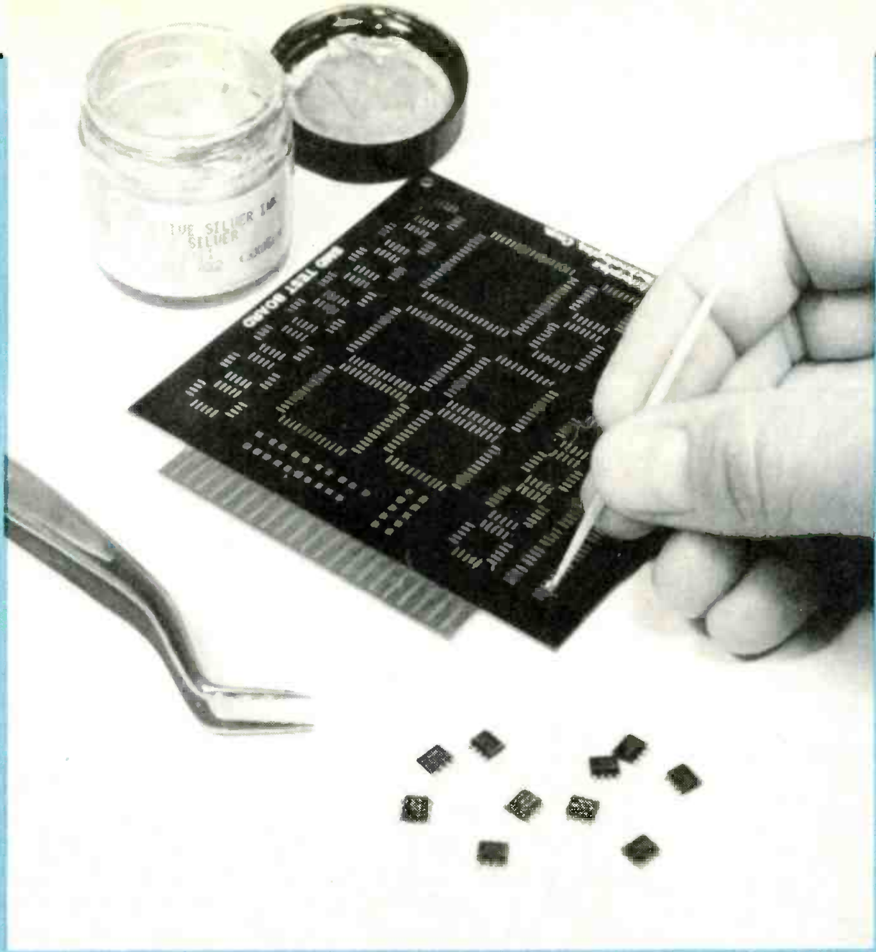


Surface-Mount Technology

Who needs copper foil and solder when you can use these conductive inks and adhesives?

Conductive Inks and Adhesives

FORREST M. MIMS, III

FOR MANY YEARS, THE HYBRID MICROELECTRONICS INDUSTRY has used electrically-conductive inks and adhesives to interconnect components, and to bond them both mechanically and electrically to a substrate. Those same inks and adhesives can also be used with all sorts of surface-mountable components.

While conductive inks and adhesives are usually used with standard circuit boards or ceramic substrates, they also make possible some very unusual and even novel circuit-assembly methods. For example, they permit surface-mountable components and even complete circuits to be installed on paper, plastic, glass, wood, painted surfaces, and many other substrates. Do-it-yourself examples of such circuits are presented elsewhere in this special section.

Figure 1 shows an assortment of conductive inks and adhesives. Whether or not you decide to experiment with conductive inks and adhesives now, chances are you will encounter those versatile counterparts of copper foil and solder sometime in the future. Therefore, let's take a close look at both conductive inks and adhesives.

Conductive inks

Electrically conductive liquids and pastes that can be applied to a substrate to form a network of interconnections are collectively known as *conductive inks*. Those materials are usually much more viscous than drawing ink, and often resemble paints. Indeed, conductive paints and coatings are available that will add RF shielding to enclosures.

Conductive inks are often used to repair broken traces and to form new traces on etched circuit boards. For decades, however, their chief application has been to form conductive traces on hybrid microelectronics substrates. Generally, a conductive-ink pattern is screen or stencil printed on a ceramic substrate that is then fired in an oven. The result is a very tough and permanent conductive network. Additional conductive layers can be added if previously-applied conductive layers are first coated with a dielectric paste.

Figure 2 shows a very simple hybrid microcircuit, a microswitch Hall-effect sensor assembled on a thin ceramic substrate. The Hall sensor is installed behind the oval protrusion. The three shaded rectangles are thick-film resistors that have been screened onto the substrate. Upon close examination, two of them show the thin slice marks that result from laser trimming, a method used for tuning a low-tolerance thick-film resistor to a precise value. The Hall sensor, the resistors, and the three terminals are interconnected by a solderable conductive ink that has been screened onto the substrate and then fired.

The conductive property of an ink is provided by powdered gold, silver, and other metals. Gold, while expensive, provides very low resistance and long-term stability. Silver is cheaper than gold but has several times its resistance. Further-

FIG. 1—CONDUCTIVE INKS AND ADHESIVES are available from a variety of manufacturers.

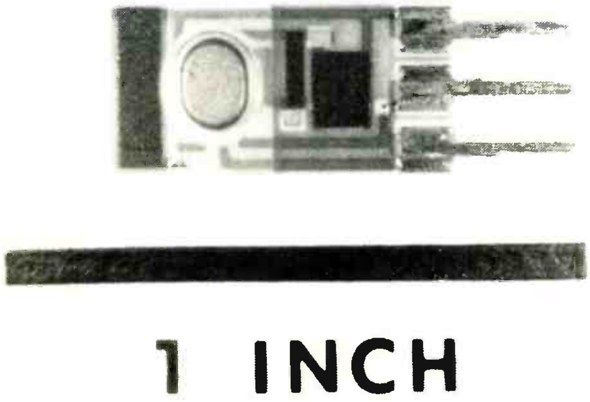


FIG. 2—THIS MINIATURE THICK-FILM hybrid microcircuit uses conductive ink for its interconnections.

more, silver may migrate from the fired ink over time. Alloys of platinum and gold or silver are used when it is necessary to solder to the fired ink. Copper and nickel are used as inexpensive substitutes for gold and silver. Both, however, have higher resistance and other less-desirable characteristics.

The resistance of conductive inks is often specified in terms of sheet resistivity. Sheet resisivity, which is given in terms of ohms-per-square centemeter, is the electrical resistance across opposite sides of a square pattern of conductive material. Resistance of conductive inks can also be given in terms of a line of material having specified dimensions. The resistances of several common inks used in the hybrid-microelectronics industry are shown in Table 1.

Ink properties

The ideal conductive ink would be an inexpensive material having zero sheet resistivity, a short curing time, and an

TABLE 1

Conductor Composition	Sheet Resistivity (ohms/square cm)	Line Resistance (1" × 0.02")
Gold	0.003	0.15 ohm
Silver	0.020	1.00 ohm
Palladium Silver	0.035	1.75 ohms
Platinum Gold	0.100	5.00 ohms

Source: "Designers Handbook on Thick Film Microcircuits," Paine Instruments, Inc.

unlimited shelf life. It would be non-corrosive, simple to apply, odorless, non-flammable, and non-toxic. It would be available in bulk for screen printing, and in a handheld pen for the instant preparation of SMC-prototype circuit boards and for the repair of conventional boards.

Though many different kinds of conductive inks are available, none possess all of the properties of the ideal material we've outlined. Inks blended with powdered gold or silver provide the lowest resistance, but they are expensive. Copper- and nickel-filled inks are inexpensive, but their higher resistance can affect the operation of a circuit if not properly compensated for.

Another drawback to conductive inks is that shelf life is relatively short, usually ranging from six months to a year. Still another disadvantage is that some materials require special handling since they may be hazardous to health. And while some conductive inks will dry fairly rapidly in open air, others require that you select either heat or a considerably longer drying time.

Applying inks

In an industrial setting, conductive inks are usually applied by screening or stenciling. Those methods require considerable preparation time and often are impractical when only a few boards are needed.

Fortunately there are several ways to apply conductive inks by hand to make relatively simple circuit boards. It's even possible to make multiple-layer boards by interspersing conductive layers with a layer of insulating material.

Before going on, a few caveats are in order. The best conductive inks can be very expensive. Also, the physical properties of various inks, both when liquid and after hardening, can be very different. The metal particles in a conductive ink generally do not remain in suspension. Instead, they sink to the bottom of their container under a layer of syrupy carrier fluid. Therefore, for lowest resistance it is essential that the particles be thoroughly mixed with the carrier before the ink is applied. Shaking alone may not be adequate; stirring may be required. Finally, the carriers of most conductive inks are volatile and may be flammable, hazardous to health, or both. Therefore, it is essential to use conductive inks in a well ventilated area and to follow the safety instructions provided with a specific product.

The ideal way to apply conductive ink by hand would be with a drawing pen. However, the author has been unable to find a pen intended for that application. It is possible to load conventional drawing pens with conductive ink. But, the viscous nature of most conductive inks means that they must first be thinned with a suitable solvent or carrier. The drawback to that procedure, aside from it being rather messy, is that thinning increases the resistance of the ink. Furthermore,

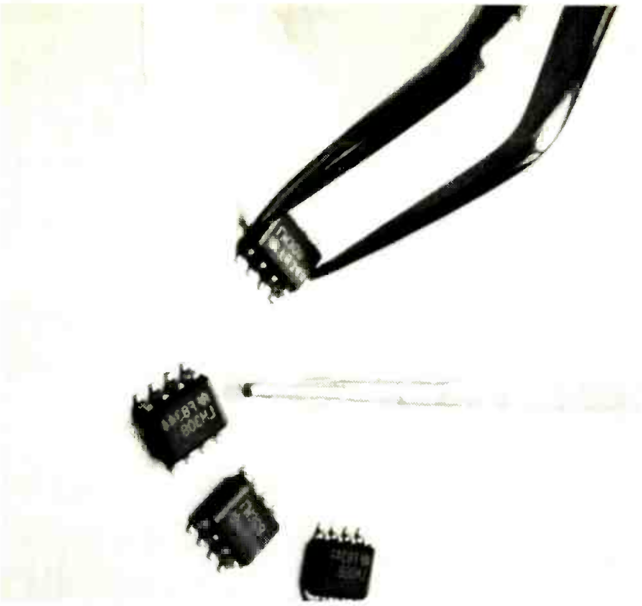


FIG. 3—USING THE TRANSFER METHOD to apply conductive adhesive to the pins of an SO device.

FIG. 4—THESE TWO CONDUCTIVE INKS are low priced, readily available, and suitable for hand application.

considerable experimentation may be needed to arrive at the best combination of pen-orifice size, ink, and thinner.

A simpler method is to apply the ink dot-matrix style; that is, a droplet at a time, by means of a small wire dipped into the material. Generally, dipping the wire into the ink will pick up enough fluid for several dots. The dots should be placed close together so they form a continuous line. That is best done by a quickly tapping the end of the wire against the substrate while moving it in the desired direction. With practice, you can form closely-spaced component footprints and both curved and straight lines. While that low-tech method is both slow and tedious, it works quite well with simple circuits. In fact, a complete interconnection pattern for a circuit consisting of an IC and half a dozen outboard components can be produced in 10 minutes or so.

Another method is to use a hand-held automatic dispensing syringe to form lines consisting of precisely metered dots of material. The necessary equipment, however, is expensive. A conventional syringe with a hand-depressed plunger can be used but only after some experience has been gained to avoid dispensing too much material.

It's best to experiment before selecting a method for hand applying a conductive ink. Then, before beginning work, plan each step carefully. For best results, use a pencil to draw the outline of the circuit on the substrate. If you use a transparent substrate such as Mylar, you can draw the circuit outline on a sheet of white paper that is then placed under the substrate, allowing you to trace several circuits from a single pattern.

Using inks as adhesives

The composition of some conductive inks and adhesives is very similar. And there are some inks that can provide a relatively strong bond to an SMC terminal or pin. Therefore, it follows that some conductive inks can double as conductive adhesives.

The surface-mount circuit builder can exploit the adhesive property of some conductive inks to speed up the assembly of simple prototypes. For example, the author has assembled a number of miniature circuits using only a lacquer-based conductive ink. First, the footprints for a component are formed with the material. The SMC is then placed on the footprint. Additional component footprints are made and their SMC's are positioned in place. Interconnections between the footprints are made as the circuit is assembled. Any remaining interconnections are formed after all the SMC's are in place. Though the lacquer-based ink hasn't the strength of a conductive adhesive, circuits assembled in that fashion have survived being dropped on the floor from a distance of as much as a few feet.

Conductive adhesives

Heretofore, the principle application of adhesives in surface-mounting technology has been to use non-conductive materials to bond SMC's to a circuit board in preparation for wave soldering. Although considerable literature and many application notes on the use of non-conductive adhesives for that purpose have been published, comparatively few publications about surface-mount technology even discuss conductive adhesives. That is surprising, particularly since conductive adhesives provide a fast and reliable method of attaching SMC's to a circuit board without using solder. Moreover, conductive adhesives are well suited for use with heat-sensitive components, and they can be used to make quick circuit repairs and modifications when soldering equipment is either unavailable or impractical.

The ideal conductive adhesive would be an inexpensive, single-part material having zero electrical resistance, a short curing time, and an infinite shelf life. It would be non-corrosive, simple to apply, provide a strong bond, and be easily reworked. Finally, it would be odorless, non-flammable, and non-toxic.

While the perfect conductive adhesive has yet to be formulated, a surprising number of products possess many of those properties. Adhesives blended with powdered gold or silver provide the lowest resistance, but they are expensive. Copper- and nickel-filled adhesives provide reasonably low resistance for less cost.

Some conductive adhesives have novel properties. For instance, some can actually be soldered-to using conventional tin-lead solder. And some conductive adhesives are thermoplastics that can be reworked merely by reheating the existing adhesive. In other words, a connection can be heated until the adhesive softens enough for the SMC to be removed. A replacement SMC can then be bonded in place with fresh adhesive or, with some materials, by heating the joint once again.

Unfortunately, the typical shelf-life of conductive adhesives ranges from two months to a year, with six months being fairly typical. Another drawback is that some materials require special handling since they may be hazardous to health. While those drawbacks are certainly undesirable, they are not unique to conductive adhesives. Indeed, most adhesives, conductive or otherwise, have limited shelf lives and some require special handling.

Conductive-adhesive types

Regardless of their conductive filler, conductive adhesives can be divided into several major classes. The two most important are:

- Thermosetting adhesives.—Those adhesives have proven their reliability during many years of use in the electronics industry. Thermosetting adhesives provide a very strong, inflexible bond. They are cured by means of a chemical reaction that is initiated by a chemical catalyst, heat, or ultraviolet radiation. The resulting bond is permanent, and cannot be reworked unless the adhesive is first shattered or dissolved with a solvent. Examples of thermosetting adhesives include 1- and 2-part epoxies, acrylics, and also, the polyesters.
- Thermoplastic adhesives.—Those adhesives do not undergo a chemical change when a bond is formed. Therefore, they can be reworked simply by applying heat until the material softens enough to remove the bonded component. A second application of heat permits a replacement component to be attached. Though thermoplastic adhesives provide a weaker bond than thermosetting adhesives, the fact they can be reworked makes them well-suited for many applications in which they will be subjected to only mild mechanical stresses. Examples of thermoplastic adhesives include nylon, polyimide siloxane, and various proprietary materials. Very flexible thermoplastic adhesives can be formulated by mixing synthetic or natural polymers (e.g. neoprene or rubber) in a solvent or other suitable carrier.

Applying conductive adhesives

In an industrial setting, dots of conductive adhesive are applied to each SMC footprint by screening, an array of pins, or an automatic syringe dispenser. The SMC's are then placed over the footprints and the adhesive or ink is allowed to cure or dry.

There are several ways to apply conductive adhesives by hand. A hand-held automatic dispensing syringe will place a precisely metered quantity of material over each footprint. The necessary equipment, however, is expensive. Fortunately, there are some very simple alternatives.

The simplest method is to dip a toothpick or wire into the adhesive to pick up a small droplet of material. The droplet is then touched to the desired footprint. If the material is slow drying, the conductive material can be applied to all the footprints before the SMC's are installed. If the material is fast drying, only the material required for an individual SMC should be applied.

It's possible to apply conductive adhesive to the footprints using a syringe or similar applicator. However, that application method requires some experience to avoid applying too much material. A toothpick or wire applicator gives the same-sized droplet each time.

An alternate way to hand-apply conductive adhesive is the transfer method. In that method, the adhesive is applied to the terminals or pins of an SMC instead of to its footprints on the circuit board. An advantage of the transfer method is speed, since all the terminals or pins on one side of an SMC can be coated with material in a single operation. To use that method, first place a few drops of material on a flat surface such as a glass microscope slide or paper card taped securely to a work surface. Then grasp the SMC with tweezers and simply dip each terminal or pin into the material as shown in Fig. 3. With practice, all the pins on one side of a small outline IC can be dipped at once. The SMC is then placed over its footprints on the circuit board.

No matter which application method you use, always remember that conductive adhesives, like many other adhesives, may be flammable or hazardous to health. Therefore, always work in a well-ventilated area and be sure to follow the safety precautions provided with the product.

Conductive-ink and -adhesive manufacturers

An acrylic-based, silver-filled ink that is easy to mix and to apply by hand is made by the Hysol Division of the Dexter Corporation. The product number is *140-18-Q*. That material adheres well to paper, cardboard, wood, phenolic, polystyrene, vinyl and butyrate.

Another silver-filled ink that is easy to mix and to apply is Amicon's *C-225-3*. That ink adheres well to paper, polyester film, phenolic, and ceramic.

Dynaloy, Inc. sells an evaluation kit containing four 50-gram bottles of either epoxy-base or polyester-base silver-filled conductive ink. Each 200-gram kit costs $100. Those inks are more viscous than the preceding ones and must be stirred to mix the silver particles and the carrier.

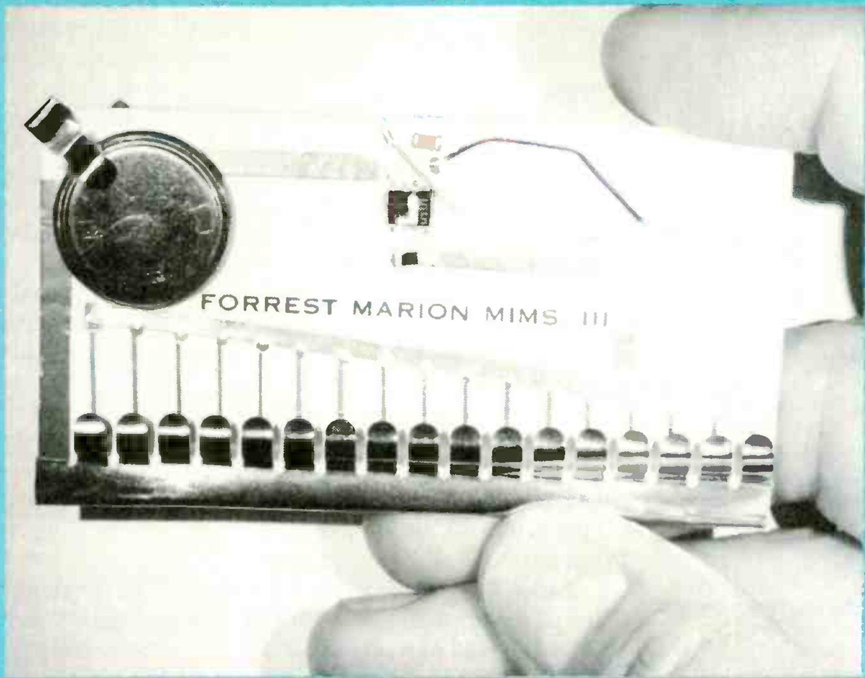
Most inks can be cured by placing a freshly prepared substrate under a desk lamp. For best results, however, be sure to refer to the instructions supplied with the product.

If you can't find the industrial-grade inks described above, don't despair. GC Electronics sells conductive inks for repairing etched circuit boards that are also suitable for bonding SMC's to a circuit board. Their highly conductive *Silver Print* (Cat. No. 22-201) is $21.62 for half a troy ounce (price subject to change with the price of silver). GC's *Nickel Print* (Cat. No. 22-207), has a higher resistance than *Silver Print*, but the two-ounce bottle shown in Fig. 4 costs only $3.83. Both of those products can be ordered from GC Electronics or purchased at many electronics dealers.

If those GC products aren't readily available, you can obtain satisfactory results with a silver-filled conductive lacquer available from some automotive parts stores that sell NAPA parts. The product, which is dyed to resemble copper, is Loctite Quick Grid Window-Defogger Repair Kit. The kit, which sells for around $7.25, includes a small bottle containing 0.05 fluid ounces of silver-filled lacquer. It is also shown in Fig. 4.

Dynaloy, Inc. sells various one-part conductive-epoxy pastes that are well-suited for conductive bonds. An evaluation kit containing 50 grams each of one pure-silver and two silver-alloy adhesives costs $100. Conductive adhesives are also available from Amicon. **R-E**

Surface-Mount Technology



SMT PROJECT: *A BUSINESS-CARD TONE GENERATOR*

Who needs a PC board?

FORREST M. MIMS, III

SURFACE MOUNT TECHNOLOGY OFFERS CIRCUIT BUILDERS entirely new methods of assembling solid-state circuits. For example, the circuit shown in Fig. 1 can be installed without solder on an ordinary paper business card. The prototype version of the circuit was built in around 90 minutes.

The primary value of this particular circuit-on-paper is that it vividly illustrates some of the unique capabilities provided by surface-mount technology. Among the more interesting techniques it will show you is how to form resistors simply by drawing them in place with a graphite pencil.

How it works

Referring to Fig. 1, the circuit for the tone generator consists of a 555 timer connected as an astable oscillator. The circuit's frequency of oscillation is controlled by resistors R1–R17 and C1. The output from the 555 drives a piezoelectric-buzzer element. Note that Fig. 1 specifies a power supply voltage of 6. Keep in mind that selected 555's and low power 555's can be powered by 3 volts.

Circuit assembly

Figure 2 shows both the conductor traces and the component layout for the assembled circuit. For the circuit to fit on a business card, two specialized components are required. The piezoelectric-buzzer element is a miniature 0.7-inch diameter unit made by Murata Erie North America, Inc. (2200 Lake Park Drive, Smyrna, GA 30080). The keyboard is a section of clip-on cylindrical-radius contacts made by Tech-Etch, Inc. (45 Aldrin Road, Plymouth, MA 02360). One finger from a contact section is used for the battery clip. An 18-finger section, which we'll call the switch strip, is used for the keyboard.

The circuit also requires conductive ink and adhesive-

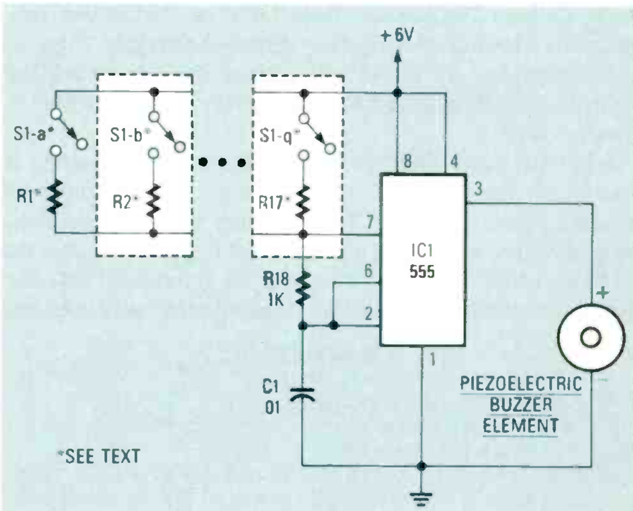


FIG. 1—A SIMPLE TONE-GENERATOR. Resistors R1–R17 consist of nothing more than lines drawn with a graphite pencil.

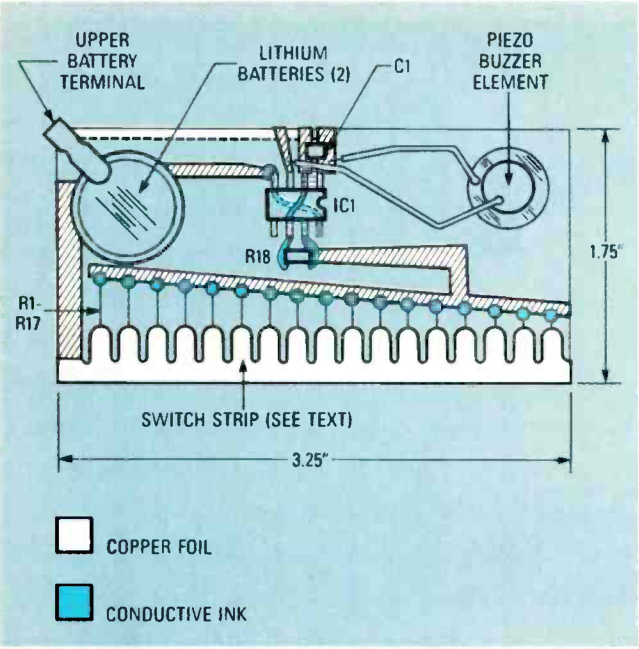


FIG. 2—WHO NEEDS A PC BOARD? As show here, the entire circuit can be mounted on a piece of paper or cardboard, like a business card.

backed copper foil. Many kinds of conductive inks can be used. Silver-filled inks, however, will work best. Adhesive-backed copper foil is available from The Datak Corporation (3117 Patterson Plank Road, North Bergen, NJ 07047).

Begin assembly of the circuit by using conductive ink and a suitable applicator (a wire or a sharp toothpick) to interconnect pins 4 and 8 on the back side of the 555. Set the 555 aside to allow the ink to dry.

Next, follow the layout in Fig. 2 and apply adhesive-backed copper strips to a business card. Note that a single strip is placed along the upper left side of the back of the card.

Cut an 18-finger section from a length of the cylindrical-radius contacts to form the switch strip. Clip off the left-most flexible finger from the switch strip and slip the strip over the lower side of the card. Use a pencil to make a small mark directly below each contact finger, and then remove the switch strip.

Use a multimeter to measure the resistance of lines drawn on paper with various kinds of pencils. While some pencils produce non-conductive lines, others produce lines having an easily measured resistance. Select a sharp pencil that produces lines having relatively low resistance to draw 17 parallel lines between the marks under the contact fingers and the copper strip that runs diagonally across the lower center of the business card.

When the silver-filled ink on the lower side of the 555 is dry, attach the device to the card with a small piece of reusable adhesive or wax. Then use very small pieces of the same adhesive material to attach C1 and R18 to the card at the locations shown in Fig. 2. Note that C1 is mounted between two thin copper strips while R18 is simply attached to the card

PARTS LIST

R1–R17—graphite pencil lines, see text
R18—1000 ohms, 1206 package
C1—.01 µF, 1206 package
IC1—555 timer, SO-8 package
Miscellaneous: Lithium coin cells (2 each, 2016 or 2020 type), piezoelectric buzzer (Murata-Erie MSJ-70383, or equivalent), switch strip (see text), battery terminal (see text), adhesive-backed copper foil, conductive ink, graphite pencil, business card, etc.

below the 555. After the three SMC's are in place, clip the connection leads of the piezoelectric-buzzer element to a maximum length of 1.5 inches and remove 0.1 inch of insulation from the end of each lead. Attach the element to the upper right corner of the card with transparent tape.

Next, connect the pins of the 555 to the respective copper-foil conductors with small droplets of silver-filled ink. Apply the ink with a sharp toothpick or piece of wire. Also apply droplets of ink between the terminals of C1 and the copper-foil strips on which C1 rests. Then form traces of conductive ink between the terminals of R18 and pins 6 and 7 of the 555.

Use care when applying conductive ink. Too much ink will result in a short circuit should some of the ink run under the components. Be sure to follow any precautions supplied with the ink you select.

Next, form a path of conductive ink across the top of the 555 to interconnect pins 2 and 6. Then apply small droplets of conductive ink at the junction of each graphite resistor (R1–R17) and the diagonal copper conductor. Also apply conductive ink at the junctions of the various copper foil traces.

Fasten the leads from the piezoelectric-buzzer element to the card with clear tape so that the exposed ends of its leads are positioned over the copper foil traces connected to pins 1 and 3 of the 555. Secure the leads to the foil with droplets of conductive ink.

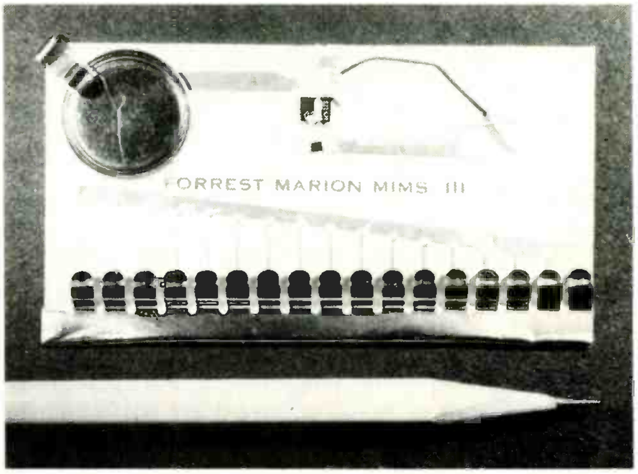


FIG. 3—THE AUTHOR'S PROTOTYPE. Pressing different contacts will cause different pitched tones to be produced.

After the conductive ink has dried, slip the switch strip over the bottom side of the card as shown in Fig. 2. Crimp the ends of the strip slightly to secure the switch strip in place. Crimping will also insure that the switch strip makes good electrical contact with the copper trace applied to the left border of the card.

Cut a single finger from a length of cylindrical-radius contacts to form the upper battery terminal. Place a layer of tape under all but the end of the flexible-finger portion of the terminal. The tape is necessary to prevent a possible short should the edge of one or both coin cells make contact with the terminal. Crimp the clip-on portion of that terminal to the upper-left corner of the card as shown in Fig. 2.

Figure 3 is a photograph of the completed circuit. Figure 4 is a highly magnified view of a droplet of conductive ink over the junction of one of the graphite resistors and the diagonal copper strip. Figure 5 is a highly magnified view of C1. Note that Fig. 5 also shows a droplet of conductive ink bonding one

continued on page 87

BUSINESS-CARD TONE GENERATOR

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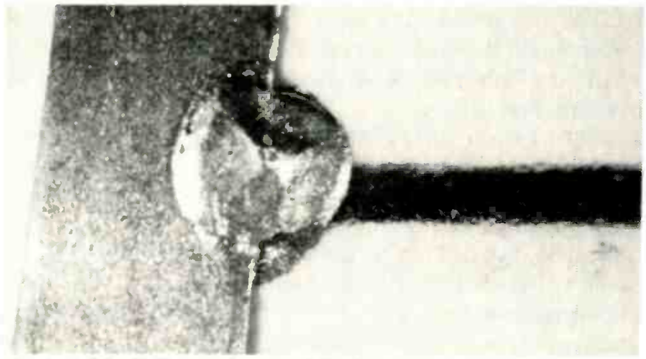

FIG. 4—A DROPLET OF CONDUCTIVE INK connects a graphite resistor to the copper strip.

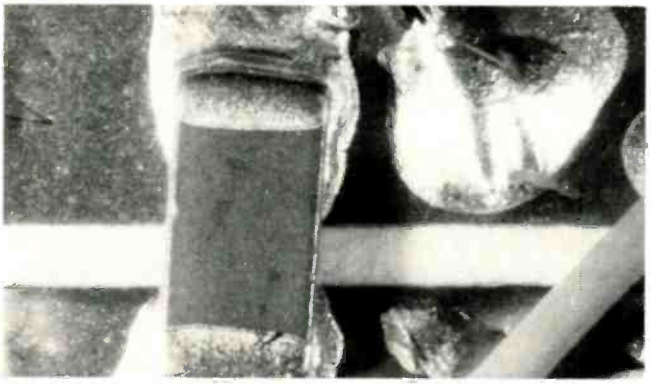

FIG. 5—A CLOSE-UP OF C1. To its right, a droplet of conductive ink bonds one lead from the buzzer to a foil strip.

of the wires from the piezoelectric-buzzer element to its respective copper strip.

Testing the circuit

Carefully inspect the circuit to make sure no errors have been made. Then insert a stack of two lithium coin cells under the upper battery terminal (positive sides down). A tone should be heard when one of the switch-strip fingers (keys) is pressed against its respective graphite line on the surface of the card.

Caution: Use care to avoid shorting the terminals of one or both coin cells. Lithium cells may explode when shorted.

When the circuit works properly, try pressing each of the keys in turn. That test will illustrate the difficulty of drawing graphite lines having uniform resistance per unit length. The prototype circuit yielded a rather irregular sequence of tones as each key was pressed in ascending order.

The circuit has no power switch. When the circuit is not being used, insert a slip of paper between the lithium coin cells and the upper battery terminal or remove the coin cells.

Going further

Whether or not you choose to build this circuit, I hope the construction details presented here have given you some new ideas about the unique possibilities offered by combining surface-mountable components and conductive inks. While you might not wish to build miniature circuits on paper business cards, you can build such circuits on glass, plastic, wood, painted metal and many other substrates. In short, a circuit can be built on virtually any available surface. For example, the author has used silver-filled ink and SMC's to build LED transmitter circuits directly on the battery holders that power the circuits. **R-E**

HAND-SOLDERING SMC's

continued from page 72

Solder paste or cream is offered in convenient syringe applicators by Alpha Metals and Multicore Solders. Figure 3 shows a syringe of solder paste that contains 1.5 ounces of 63%-tin/37%-lead solder paste. Note that when a paste or cream is supplied in that manner, it's generally necessary to mix the material before use by rolling the barrel of the syringe against a hard surface. After the needle is attached and the plunger is installed, a small quantity of material can be applied directly to each SMC footprint as shown in the opening of this article.

It's best to practice applying the paste on a piece of paper first. That will allow you to learn how to cope with unforeseen situations such as how to deal with paste that continues to emerge from the needle after you have coated a footprint. (Hint: Keep some paper towels handy.)

If the syringe method proves too tricky, you can apply the solder paste or cream directly to the terminals and pins of the SMC's themselves using what is called the transfer method. First, place some paste or cream on a clean, flat surface; a glass microscope slide works well. Next, use tweezers to pick up an SMC and then dip its terminals or pins into the paste. When all the terminals or pins are coated with a thin layer of the material, place the SMC on its footprints on the circuit board. The sticky flux will hold the SMC in place while you repeat that procedure for any remaining devices.

After all the components are in place, inspect the board to make sure each SMC terminal or pin is properly positioned. You must then cure the board by preheating it long enough to drive off the volatile solvents from the paste or cream. The curing procedure is very important because it precludes the formation of unwanted solder balls and reduces the thermal shock that that the board and its SMC's are subjected to during reflow soldering.

IMPORTANT: Various solder pastes and creams may require different curing times and temperatures. They may also require different reflow soldering times and temperatures. Therefore, it is essential to refer to the manufacturer's literature about a specific product to avoid unreliable solder connections.

With that *caveat* in mind, a typical curing procedure is to heat the board in a convection oven for from 10 to 30 minutes at 85° C. After the paste is cured, the board is removed and the oven temperature is increased to the melting temperature of the solder. The board is then placed back in the oven until the solder melts and then quickly removed. Alternatively, if the board can withstand the temperature, it can be reflow soldered by placing it on a hot plate. Another alternative is to use a desktop vapor-phase system such as Multicore Solders' *Vaporette*.

Once again, it is essential to carefully follow the instructions for a particular solder paste or cream. Also, it's very important to avoid overheating the SMC's. Most, but not all, SMC's can withstand the temperature of molten solder for 10 seconds. **R-E**

LED FLASHER

continued from pge 74

tion. Refer to the component placement diagram in Fig. 3 to make sure the 555 is oriented properly. Then solder each terminal in place.

Continue assembly by installing the resistors and C1 one at a time and soldering them in place as we've described. The value of the resistors is given by a code in which the last digit indicates the number of zeros. Thus the code 104 indicates a resistance of 10 followed by 4 zeros or 100,000 ohms.

Install the LED next. For the utmost in miniaturization, you can use a chip LED. For high-brightness applications, use a leaded device. Cut the leads 0.2 inch from the LED, place them over their respective footprints (be sure to observe polarity), and secure the LED in place with tape. Then solder the leads in place. Repeat that procedure for the leads from a 9-volt battery clip. Figure 4 shows the completed board.

Testing the Circuit

Carefully inspect the completed circuit to make sure that all the components are properly positioned. Pay particular attention to the orientation of the 555 and the polarity of the LED and battery clip leads. And be sure to remove any solder bridges and balls.

The LED should begin to flash as soon as a 9-volt battery is connected to the circuit. Operation of the circuit will be identical to that of a flasher made with through-hole components. The thinness of the SMC flasher, however, means that it can be installed in previously unusable locations. And the relative ease and speed with which it can be assembled should convince even the most skeptical builder that surface-mount technology is an idea whose time has come. **R-E**

LIGHT METER

continued from page 76

enced hand-solderer of SMC's, it is essential to carefully inspect each and every junction with a magnifying lens.

Next, solder trimmer R1 to the board. Since cementing R1 to the board might interfere with its rotor if you are not careful, it's best to use a bit of masking tape to secure R1 in place for soldering.

If you want to use the circuit as a light meter, solder Q1 in place next. However, if you want to use the circuit for one of the specialized applications that we'll describe later on in this article, you should omit Q1 and, instead, solder a pair of stranded, insulated hookup wires to its two mounting holes.

Note that Q1 is a conventional through-hole component. The prototype used a tiny surface-mount phototransistor (Stettner Electronics CR10TE1). However, that meant that the phototransistor was aligned in the same direction as the readout. The result was that someone viewing the readout could cast a shadow over Q1, affecting accuracy.

To overcome that, the surface-mountable version of Q1 was replaced with a leaded phototransistor that can be installed facing away from the person viewing the readout.

The leads of the phototransistor are installed in two holes drilled in the circuit board adjacent to the negative battery holder terminal. The emitter of Q1, which is indicated by a small protruding tab (see Fig. 4-*a*), must be installed in the hole connected to the negative battery-holder terminal. Therefore, bend Q1's leads as shown in Fig. 4-*b* and insert both leads through the bottom side of the circuit board so that Q1 points away from the circuit board as shown in Fig. 4-*c*. When the

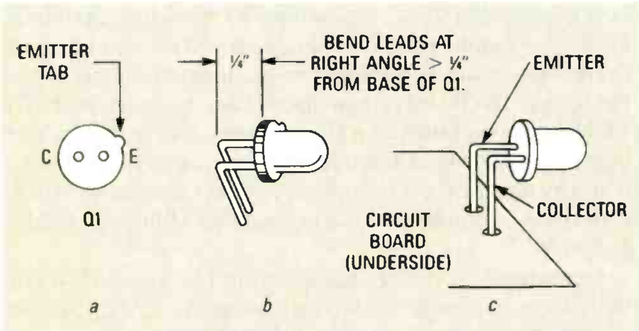

FIG. 4—THE PHOTOTRANSISTOR'S EMITTER is indicated by the tab (*a*). When installing the device, bend the leads (*b*) and mount it so that it is pointing away from the circuit board (c).

circuit is complete, Q1's leads will emerge from the board under the battery-holder. Therefore, be sure to keep those leads close to the board. Solder Q1's leads to their footprints and clip off the excess lead lengths.

Complete assembly of the board by installing the lithium coin-cell holder on the underside of the board. Be sure to orient the holder so that its positive terminal (the uppermost battery contact) is inserted in the hole marked +. Solder the terminals in place and clip off the protruding pins. Use caution; the clipped terminals may fly away from your clippers with considerable force.

Testing the circuit

If you have installed Q1, the circuit will function as a light meter when lithium cell B1 is installed in its holder. LED1 will glow to indicate the power is on. Use a jeweler's screwdriver to adjust trimmer R1 for the desired sensitivity. For best results, perform the adjustment with the circuit in subdued light. Generally, LED2–LED5 will switch off when Q1 is brightly illuminated. Those LED's will then glow in sequence as the light reaching Q1 is progressively reduced.

You can switch the circuit off by removing B1. Or, you can slip a small piece of paper or thin plastic under, or a short length of heat-shrinkable tubing over, the uppermost battery-holder electrode.

Going further

As noted previously, when Q1 is omitted the circuit can be used for other applications. For example, when a discharged capacitor is connected in the circuit in place of Q1, LED2–LED5 will glow in sequence as the capacitor is charged by the small voltage appearing at the common non-inverting inputs. One application for that configuration is as a timer whose period is determined both by the size of the capacitor and the setting of resistor R1.

The timing intervals can be increased by increasing the value of the capacitor. A new timing cycle can be started at any time by momentarily shorting the capacitor.

Another interesting application is to use the circuit to indicate resistance. When the input leads are open, all the LED's will glow. If a variable resistance is connected to the circuit in place of Q1, LED2–LED5 will glow in sequence as the resistance is lowered. We're sure that you have often wished for a visual continuity checker.

Finally, keep in mind that the circuit as presented here functions as a parallel array of inverting comparators. It can be revised to function as a parallel array of non-inverting comparators simply by reversing the connections to the inputs of the four comparators. **R-E**

SMT Resource Directory

THE QUANTITY AND VARIETY OF SURFACE mount components, supplies, literature, and services has grown rapidly during the past few years. Here's a listing of sources and vendors for some of what is now available. Many of these companies are represented by local electronics distributors. For additional information contact the Surface Mount Technology Association (Box 1811, Los Gatos, CA 95031).

SURFACE MOUNTABLE COMPONENTS

Amperex Electronic Corporation
George Washington Highway
Smithfield, RI 02917

Bourns, Inc.
1200 Columbia Avenue
Riverside, CA 92507

Exar Corporation
750 Palomar Avenue
Sunnyvale, CA 94086

Mepco/Centralab, Inc.
2001 West Blue Heron Blvd.
Riviera Beach, FL 33404

Motorola Semiconductor Products, Inc.
P.O. Box 20912
Phoenix, AZ 85036

muRata Erie North America, Inc.
2200 Lake Park Drive
Smyrna, GA 30080

National Semiconductor Corporation
P.O. Box 58090
Santa Clara, CA 95052

NIC Components Corporation
6000 New Horizons Blvd.
No. Amityville, NY 11701

Signetics Corporation
P.O. Box 3409
Sunnyvale, CA 94088

SMD Technology Service Center
5855 North Glen Park Road
Milwaukee, WI 53209

Sprague Electric Company
P.O. Box 9102
Mansfield, MA 02048

Stettner Electronics Inc.
3344 Schierhorn Court
Franklin Park, IL 60131

Texas Instruments
P.O. Box 809066
Dallas, TX 75380

CONDUCTIVE INKS AND ADHESIVES

Amicon, A Grace Company
25 Hartwell Avenue
Lexington, MA 02173

Dynaloy, Inc.
7 Great Meadow Lane
Hanover, NJ 07936

GC Electronics
400 South Wyman Street
Rockford, IL 61101

Hysol Division, The Dexter Corporation
P.O. Box 1282
Industry, CA 91749

Loctite, Electronics Division
705 North Mountain Road
Newington, CT 06111

SOLDER PASTES AND CREAMS

Alpha Metals, Inc.
600 Route 440
Jersey City, NJ 07304

Multicore Solders, Inc.
Cantiague Rock Road
Westbury, NY 11590

SURFACE MOUNT SOLDERING EQUIPMENT

Edsyn Inc.
15958 Arminta Street
Van Nuys, CA 91406

Hexacon Electric Company
P.O. Box 36
Roselle Park, NJ 07204

PACE, Inc.
9893 Brewers Court
Laurel, MD 20707

TOOLS

Edmund Scientific Co.
101 E. Gloucester Pike
Barrington, NJ 08007

Jensen Tools, Inc.
7815 S. 46th Street
Phoenix, AZ 85044

Pomona Electronics
1500 E. Ninth St.
Pomona, CA 91766

CUSTOM CIRCUIT BOARD DESIGN

Analytic Design, Inc.
3200 Scott Blvd.
Santa Clara, CA 95054

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TURBOCHARGE YOUR PC

Hands-on tests

A GERNSBACK PUBLICATION

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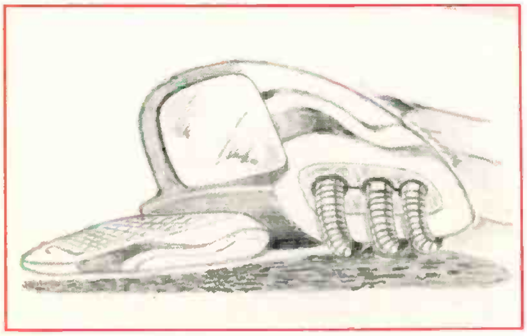
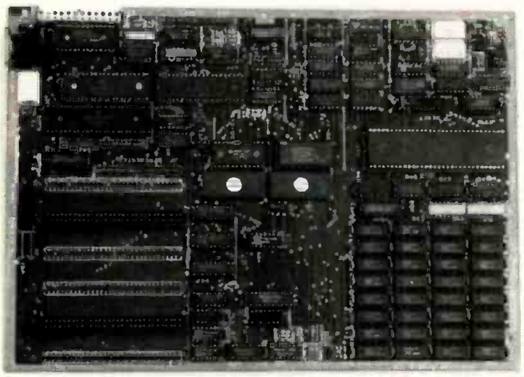
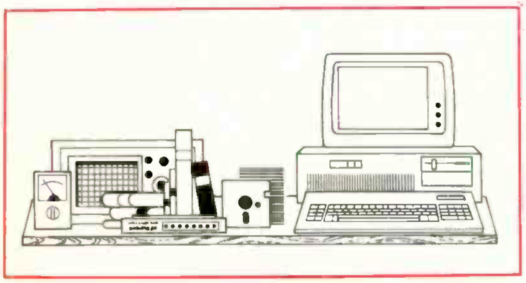
Vol. 4 No. 11







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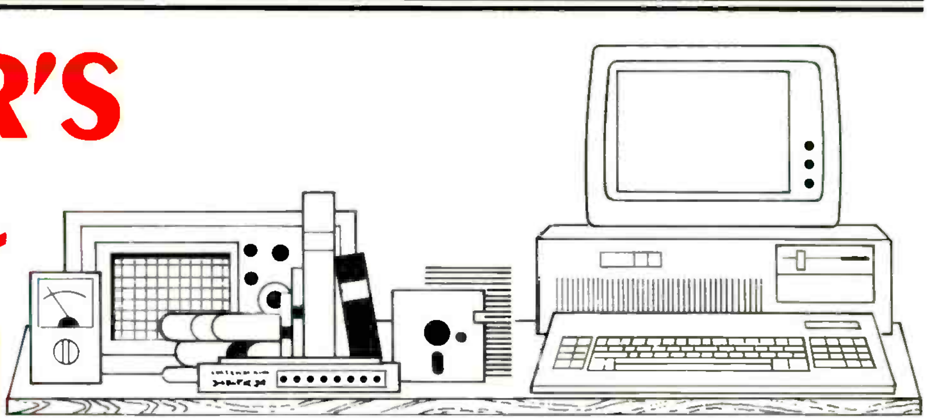
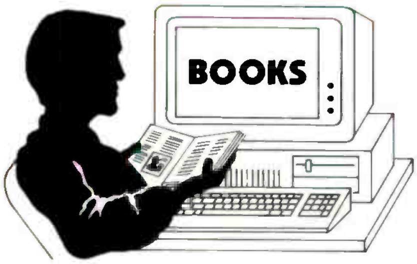




Portable Correction

Our article on portable MS-DOS machines (in the September issue) contained several errors regarding the DataVue 25. First, the machine is not AC-only; an external battery pack is available that will run the machine for about two hours. Second, the DataVue 25's backlighting is not electroluminescent, but fluorescent. Last, the machine's hard disk has a capacity of 20 megabytes, not 10 megabytes, as reported. In addition, contrary to what was stated in the article, it is possible to boot from the hard disk. We apologize for the errors and thank Peter Baron, a DataVue press agent, for pointing them out.

Back-To-School Booklist

Whatever your interest—80xxx, 680xx, or 65xxx systems, you'll find one of the books listed here useful. First we'll discuss several assembly-language primers for various systems, followed by several tomes specific to the IBM PC.

For hackers only

Leo Scanlon's *The 68000: Principles and Programming* (c. 1981, Blacksburg Continuing Education Series, Howard W. Sams & Co., Inc., 4300 West 62nd Street, Indianapolis, IN 46268) provides a good, brief introduction to the 68000. One highlight is chapter 6, which includes hardware information that's hard to come by elsewhere.

More comprehensive is *68000 Assembly Language Programming* by Lance A. Leventhal, Doug Hawkins, Gerry Kane, and William D. Cramer (c. 1986, Osborne McGraw-Hill, 2600 Tenth Street, Berkeley, CA 94710). The book contains in-depth treatment of the 68000, additional information on the 68010 and 68020, and much advanced information on topics like interrupts, debugging, and program design. An appendix lists all microprocessor instructions in an easily referenced format showing the assembly-language syntax, each instruction's bit-field format, flags affected, textual description, and version-specific variations (68020, for example).

6502, 65802, and 65816 fans will want to check out *65816/65802 Assembly Language Programming* by Michael Fischer (c. 1986, also published by Osborne McGraw-Hill, address above). A brief introduction summarizes microprocessor evolution since the early 1970's; the book then goes on to discuss the 65xxx family architecture, and then focuses on the advanced members of the family. There are many example programs, and appendices include hardware data sheets for most major members of the 65xxx family.

For Intel fans, *80386/80286 Assembly Language Programming* by William H. Murray III, and Chris H. Pappas (c. 1986, Osborne McGraw Hill, address above) will be indispensable reading. The book begins with several chapters of introductory material; chapter three gets into the 286/386 architecture, and is full of comparisons with the 8088/86. It then goes on to examine the 80287/80387 math co-processors, various assemblers, and other topics. Instruction sets of each processor and co-processor are listed, and an appendix provides information on how to maintain a library of often-used routines.

IBM PC

One of the most useful books I've seen on the internal workings of the IBM PC is *Compute's Mapping the IBM PC*, by Russ Davies (c. 1986, Computer! Publications, Inc., Greensboro, NC). The irony is that *Compute!* magazine is a traditional 6502 stronghold—but don't let that bother you; the book is chock full of charts, tables, and example programs showing you how to get at your machine's capabilities from both BASIC and assembly language. It's not for beginners, but you needn't be an advanced systems designer either. Highly recommended.

Beginners will, however, find *Understanding MS-DOS* by Kate O'Day (c. 1987 by The Waite Group, Howard W. Sams & Co., Inc., 4300 West 62nd Street, Indianapolis, IN 46268) useful. The book uses color, typeface, and illustration well to bring out important points. Topics include basic DOS commands, subdirectories, hard-disk management, batch processing, etc.; each chapter includes a quiz to help re-inforce your knowledge.

Users at all levels will find *IBM PC & PC XT User's Reference Manual* by Gilbert Held (c. 1987, Hayden Books, Howard W. Sams & Co., Inc., 4300 West 62nd Street, Indianapolis, IN 46268) valuable. Topics include system set-up, DOS operations, elementary and advanced BASIC, graphics, batch files, etc. When I forget the syntax of a command, I often find myself reaching for this book before the appropriate Microsoft or IBM manual.

Apple and IBM clone boards

NuScope Associates (P.O. Box 790, Lewiston, NY 14092) publishes several manuals with information on building Apple II and IBM PC and AT motherboards, peripheral cards, etc. We examiend the IBM book. It's divided into two parts, the first of which contains basic construction information, resistor color-code tables, etc. The second part is divided into eight sections that focus on building several models of each of the following types of boards: motherboard, disk controller, memory, video, multifunction, serial/parallel, miscellaneous, and prototype. Information on each board includes parts layout, parts list, and a few notes. It's definitely not for beginners.

PC-601 Bus Extender, Chenesko Products

Circuit development for the IBM PC bus is hindered by a myriad of merely physical problems, including getting at bus signals for examination with a scope or logic analyzer, wiring (and modifying) circuits on expansion cards, etc. The PC-601 (shown in Fig. 1) solves the problem by bringing the bus out to a solderless breadboard station with more than 3000 tie points. A half-length card with several buffers is inserted in your PC; a two-foot length of ribbon cable connects it to the breadboard box, which contains built-in ±5 and ±12 volt power, a scope multiplexer that allows a single-channel scope to display as many as four signals simultaneously, buffered address, data, and control lines, and provisions for daisy chaining additional PC-601's.

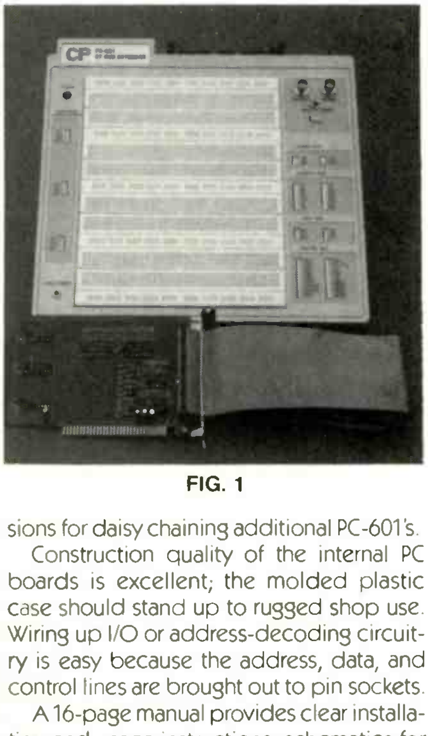


FIG. 1

Construction quality of the internal PC boards is excellent; the molded plastic case should stand up to rugged shop use. Wiring up I/O or address-decoding circuitry is easy because the address, data, and control lines are brought out to pin sockets.

A 16-page manual provides clear installation and usage instructions; schematics for the switching power supply, scope multiplexer, and buffer circuitry are also included.

The PC-601 lists for $369.95; contact Chenesko Products, Inc., 21 Maple Street, Centereach, NY 11720, (516) 736-7977 for more information.

CIRCLE 22 ON FREE INFORMATION CARD

Shareware Assembler/Debugger, Eric Isaacson

8088 assemblers are notoriously difficult to use because of the amount of "housekeeping" the programmer must do even to assemble a simple program. Beginners are turned off because learning how to use the assembler may be more difficult than learning the assembly language!

Eric Isaacson took that problem seriously and wrote a fast, easy-to-use assembler (A86) and an accompanying full-screen symbolic debugger (D86), shown in Fig. 2. The package has gone through several incarnations; early versions could not assemble Microsoft assembler source files, but versions of the assembler greater than 3.00 are now mostly Microsoft compatible. (We are still waiting for version 3.00 of the debugger.) Documentation has also improved considerably since the early versions. All programs and documentation fit in several ARC files on a single floppy disk. Many BBS's (including ours, (516) 293-2283, 300/1200,8,N,1) carry the ARC files; you can also order them directly from the author at 416 E. University St., Bloomington, IN 47401, (812) 339-1811. Evaluation copies are free; registration costs $40 for either A86 or D86, or $70 combined.

D86 can be used on any .COM file, but to do symbolic debugging, the file must have been assembled with A86. One nice feature of A86 is that it generates code for the 8088, 8086, 80286, 8087, 80287, and several NEC V-series microprocessors. 80386 code is not included in the present version.

In D86, you press F1 to execute a single instruction, or F2 to execute a subroutine. In addition, you can enter assembly-language code, referencing your program's symbols, if desired. An extensive set of memory display commands allow you to set up as many as six multi-format views into any desired area of memory. The micropressor's registers, flags, and the top of the stack are shown at all times.

Now that A86 is Microsoft compatible, and the documentation has been cleaned up, our main complaint with the package is that you can't load or save files from within D86 (as you can with DEBUG); you must specify the file name on the invoking command line. But we expect that file problems will be fixed when D86 is upgraded.

CIRCLE 23 ON FREE INFORMATION CARD

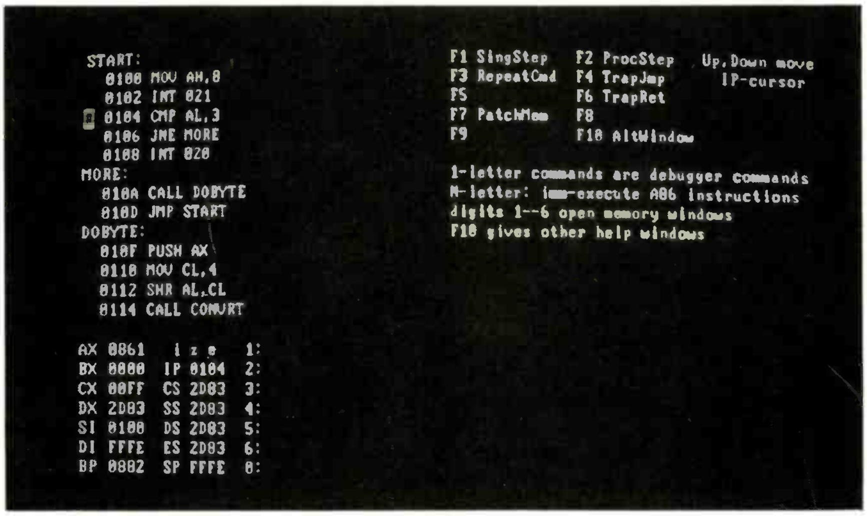


FIG. 2

MIX C Compiler, Editor, Debugger

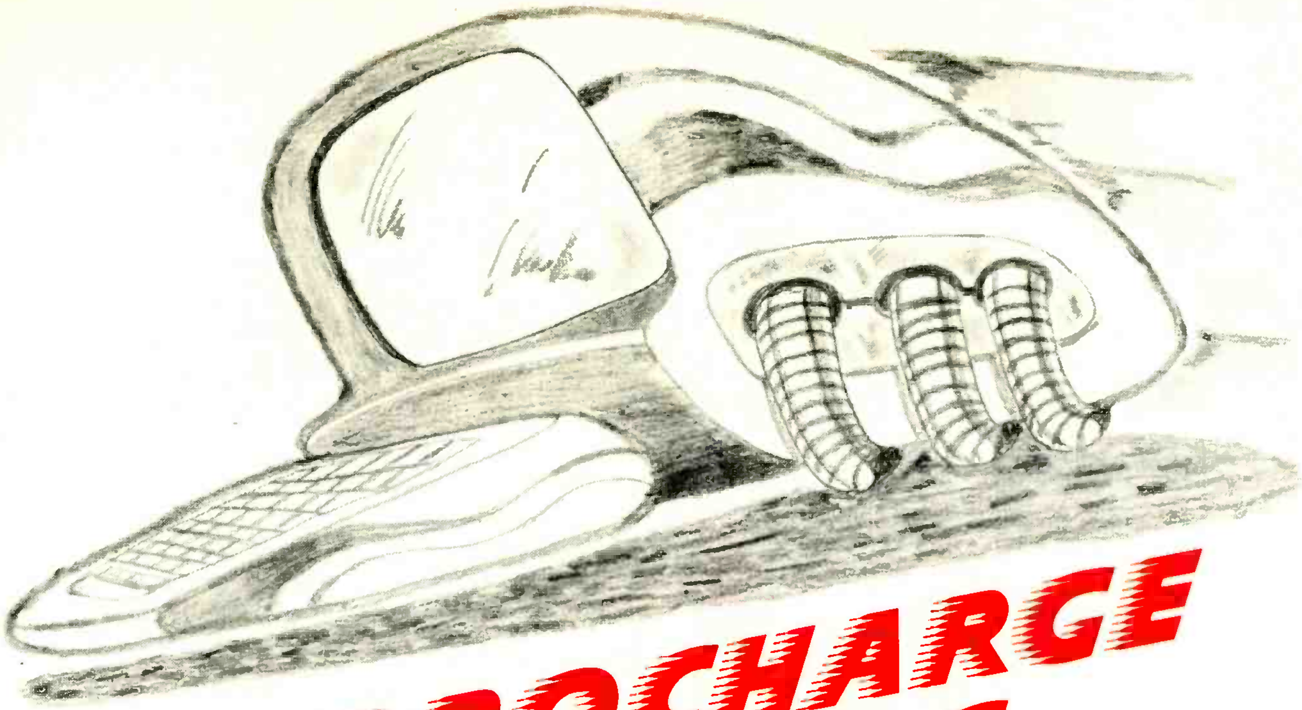
Compilers that operate in an integrated environment have been around for some time, but one that has been evolving for several years is marketed by Mix Software (1132 Commerce Drive, Richardson, TX (800) 523-9520). It combines a split-screen WordStar-like editor, a quality C compiler, and a windowed Trace utility, which allows source-level debugging. Each program is available separately; the three can be purchased together discounted. CP/M and MS-DOS versions are available.

The editor is highly configurable, allowing you to define keyboard controls and macros. In splitscreen mode, you can edit two files simultaneously, transferring text between them.

The compiler itself is highly compatible with the Kernighan and Ritchie standard; Mix includes special utilities to either compress or speed up programs created with the compiler. The manual contains a tutorial that should help intermediate programmers get up to speed quickly.

The real gem of the package is the Trace utility, which includes a faster (and larger) version of the compiler. Trace allows single-stepping, tracing, and fullspeed tracing. It also allows you to set up as many as four windows to display source code, program output, and variable values simultaneously. Mix C is hard to beat.

CIRCLE 24 ON FREE INFORMATION CARD



TURBOCHARGE YOUR PC

JEFF HOLTZMAN,
TECHNICAL EDITOR

Speed—you can never get enough. At last count there were about eight million PC's, XT's, and clones out there, and we'd be willing to bet that most of the people using those machines would jump at the chance to get them running faster. Programs for CAD, circuit design and analysis, desktop publishing—they all work better when the computer thinks as fast as you do.

But how do you increase the speed of a PC, XT, or clone? When you look into it, you quickly find that there is a bewildering variety of choices available, ranging in price from about $10 to about $1500—more than a full-blown PC or XT!

Does a $10 upgrade provide any significant advantage? At the other end of the price spectrum, is a high-speed 386-based motherboard worth as much as—or even more than—the original purchase price of a piece of equipment?

The answer depends on what your needs are and on your previous equipment investment. But before we try to provide the answer, let's talk about each of the upgrade solutions and examine some hard data. Later we'll show how the numbers don't tell the whole story. The hardware we tested is summarized in the sidebar on page 100 alphabetically by manufacturer.

Accelerator basics

Basically, there are three types of accelerators: clock-speed enhancers, replacement processors, and co-processors. The usual clock-speed enhancer is what we call an *octopus board,* a small PC board that does not require an expansion slot, but rather dangles over the motherboard and somehow injects a faster clock signal into it. Octopus boards have one or more "tentacles" that must connect to various points on the motherboard, both to pick up signals and to insert them.

A replacement processor is a full- or half-length card that requires an expansion slot. You must remove the host computer's 8088 microprocessor from its socket and connect the vacant socket to the accelerator card via a 40-conductor ribbon cable. In some cases the host computer's 8088 microprocessor is installed on the accelerator card to provide a compatibility mode; in other cases compatibility is achieved by running the accelerator's microprocessor at a slower speed. Replacement processors usually are built around 80286 IC's, but some are built around 8086's. Most early replacement processors ran at 8 MHz; many now run at 10 or even 12 MHz.

A co-processing accelerator adds what amounts to a second, fully independent, computer to your PC. Some co-processing accelerators can actually function at the same time as the host's microprocessor, allowing you to work on completely independent tasks simultaneously.

There exists a fourth and increasingly popular way of speeding up your PC: replacing your motherboard. Replacing it can provide most of the advantages of the previous methods, with few of their disadvantages. We'll examine at least one of each type of accelerator option in what follows.

Test strategy

To test compatibility, we attempted to run the following software on all hardware: WordStar 4.0, AutoCad 2.6, AutoSketch, VP Planner, Microsoft Windows 1.03, PageMaker 1.0a, and Direc-Link. All tests were performed under PC-DOS 3.30. Each piece of hardware ran each program without problems, although in some cases firmware (EPROM's, PLD's, etc.) upgrades were necessary.

We ran the **Computer Digest** interpreted-BASIC benchmarks on each piece of hardware, except Hauppauge Computer Works' 386 motherboard, so it is not included in the quantitative results. The benchmark consists of five tests, including sequential disk read and write, integer math, floating-point math, and screen write. Except for the replacement motherboards, all tests were run on a standard IBM PC XT. Except for boards with built-in display adapters, all boards were tested with a Hercules monochrome card; those with built-in adapters were tested in Hercules emulation mode. Those boards were also tested in EGA mode for comparison. Last, the disk-speed tests were all run on the same hard-disk drive.

TABLE 1—SPEED COMPARISON

Machine	Abbrev	Disk Write	Disk Read	Integer Math	Float Math	Screen Write	Speed Factor	Price
IBM PC XT	XT	42.3	28.7	32.0	33.3	31.0	100%	$0
IBM PC XT (V20)	V2	40.3	29.0	30.0	31.7	28.3	105%	$12
NickelX (7M,V20)	N7	26.7	18.0	17.3	19.0	17.3	170%	$70
NickelX (8M,V20)	N8	27.0	16.0	16.0	18.0	17.0	178%	$70
MCT Turbo	MC	29.7	18.0	18.3	20.3	20.0	157%	$130
Mach 10	M1	29.7	20.0	16.3	20.0	19.3	159%	$399
Breakthru 286	B2	14.3	9.0	5.3	7.7	10.0	361%	$595
Tiny Turbo	TT	19.0	13.7	11.0	12.0	20.0	221%	$595
TurboEGA	TE	21.3	13.7	11.7	11.0	14.0	233%	$749
286 Rainbow Plus	RB	25.3	16.0	25.7	28.0	20.7	145%	$945
PCTurbo 286e-8	PT	11.3	9.3	7.0	8.0	6.0	402%	$1,195
SOTA MB 5.0	SO	10.0	7.0	6.0	6.3	9.3	433%	$1,295

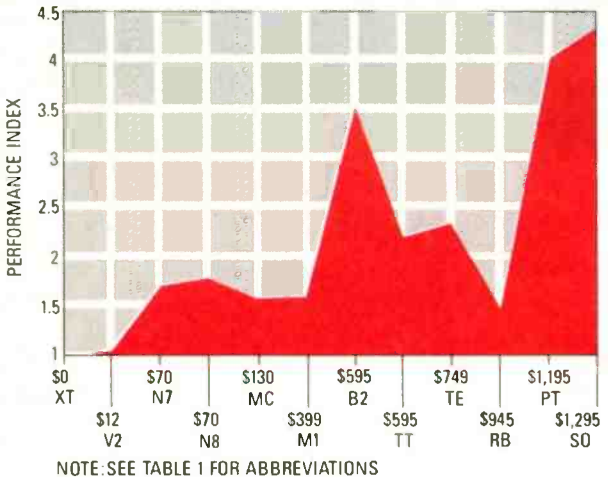


FIG. 1—Performance Comparison Chart

The numbers

The raw numbers obtained are shown in Table 1, which is sorted by price. The first entry is our base test machine, an XT with a Miniscribe hard disk (100-ms average seek time).

Figure 1 shows the speed-test data graphically. (Refer to Table 1 for the meanings of the abbreviations on the horizontal axis.) The shorter the overall height of each bar, the faster the overall speed. From that graph you can see that SOTA's MotherCard 5.0 is the fastest, followed closely by Orchid's PCturbo 286e, and then by PCSG's Breakthru 286.

Figure 2 plots speed factor (from Table 1) vs. cost. In general, as you would expect, greater speed costs more. However, there are several exceptions, the most significant of which is the PCSG board (labeled B2), which provides about 85% of the performance of the fastest boards, at about 50% of the cost.

What follows are our comments derived from installing each piece of hardware, running the quantifying benchmarks and the compatibility-test software, and overall impressions. The comments are presented in alphabetical order by manufacturer or distributor.

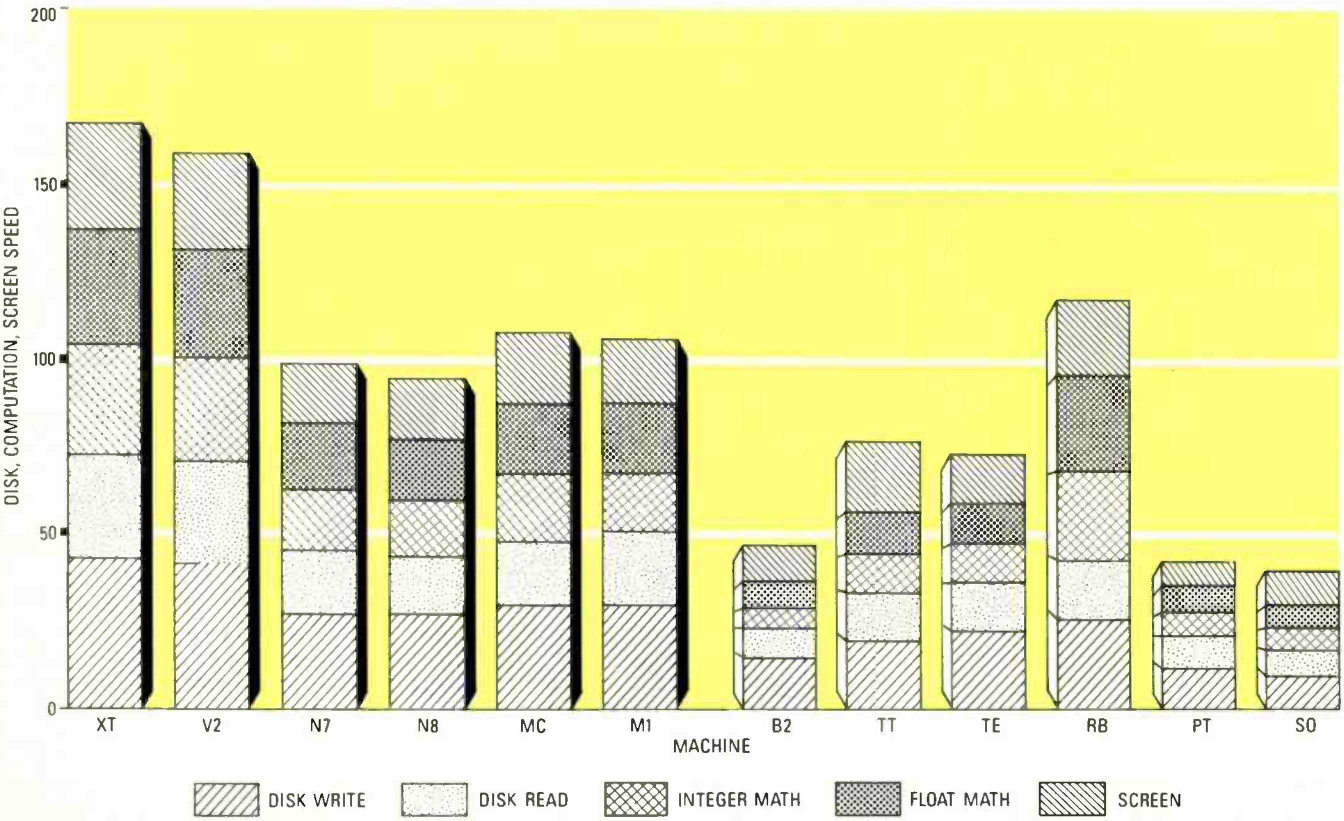


FIG. 2—Price/performance Comparison Chart

386 Motherboard

Hauppauge Computer Works got its start selling math co-processor speed-up kits; the 386 Motherboard (shown in Fig. 3) is designed as a replacement for a standard PC or XT motherboard. After dismantling your PC, you install the new motherboard, re-insert your old expansion cards, and you're off into the world of truly high-speed computing. Due to a shortage of boards, we were unable to perform an actual installation and run our benchmarks, but the company was kind enough to allow us to run our compatibility software on a test board in their engineering laboratory. We also installed and successfully ran several pieces of expansion hardware, including our favorite digitizing tablet, Pencept's Penpad 320, which uses a 68000 co-processor.

Subjectively, the 386 Motherboard ran all software frighteningly fast. AutoCad and PageMaker screen redraws happened nearly instantaneously. In fact, with a 387 math co-processor installed, AutoCAD was able to redraw a test screen in twelve seconds; the same redraw on an un-enhanced PC takes over four minutes!

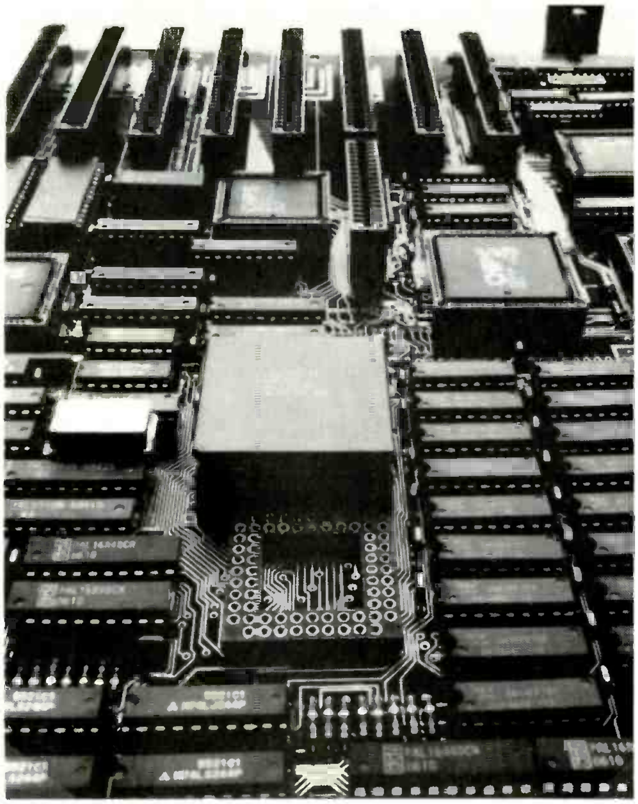


FIG. 3—Hauppauge's 386 Motherboard

Nickel Express and Turbo Motherboard

JDR Microdevices markets a number of IBM-type expansion and enhancement products, including the Nickel Express (shown in Fig. 4) and the MCT-Turbo, an 8-MHz XT motherboard (shown in Fig. 5). Like the 386 motherboard, the MCT-Turbo is a direct plug-compatible replacement for a standard XT motherboard; it may also be used as the brains of a build-it-yourself clone. It includes an 8088-2 microprocessor that you can run at either 4.77- or 8.0-MHz. Speed is selectable by means of a shorting jumper plug located near the keyboard connector at the rear of the board. The board's documentation claims that speed is also keyboard selectable, but the keystrokes mentioned had no effect on speed.

The MCT-Turbo accepts 36 4164 RAM IC's, for a total of 256K of memory, or by moving a jumper, two banks can be filled with 41256 IC's for a total of 640K. In addition, seven sockets are provided for EPROM's, one of which is occupied by the MCT BIOS EPROM.

The MCT-Turbo comes with a thin User's Manual that contains a brief theory of operation, complete schematics, switch settings, and troubleshooting hints. An additional loose-leaf page discusses installation.

After setting up the board, we installed our XT's hard disk and controller in it, and then ran our compatibility and benchmark tests. We also tested several pieces of expansion hardware; the only problem we experienced was with a CGA card that had trouble running at the faster speed, and caused our monitor screen to display snow in some, but not all, circumstances.

The Nickel Express is an octopus board. To install it you must remove the 8284 clock IC from your motherboard and then insert a short 16-conductor ribbon cable into the vacant socket. The other end of the cable plugs into a socket on the small (approximately 2" × 3") circuit board, which contains two clock IC's, a PLD, three crystals (corresponding to the board's three speeds: 6.66-, 7.37-, and 8.0-MHz), and several jumpers and discrete components. In addition, speed-selection and reset switches are provided. The board and switches are mounted on a sheet-metal housing that clips on the outside of the rear panel of your PC, thereby providing a reasonably stable mounting scheme. An additional wire may be attached to an IC on the motherboard to allow software speed selection. In that respect the Nickel Express is "cleaner" than most octopus boards.

To use the Nickel Express you have to find the maximum speed at which your motherboard will run. Unfortunately, trial and error is the only way to do so. To run the board at maximum speed, you must run a small program that becomes memory-resident and thereafter slows down the clock whenever the floppy disk is accessed.

The test results shown in Table 1, Fig. 1, and Fig. 2 are with the Nickel Express running at the two highest speeds with an 8-MHz NEC V20, which is included in the purchase price.

The board comes with a slim installation manual that provides detailed installation instructions and some theory of how the board works. It's not fancy, but it gets the required information across.

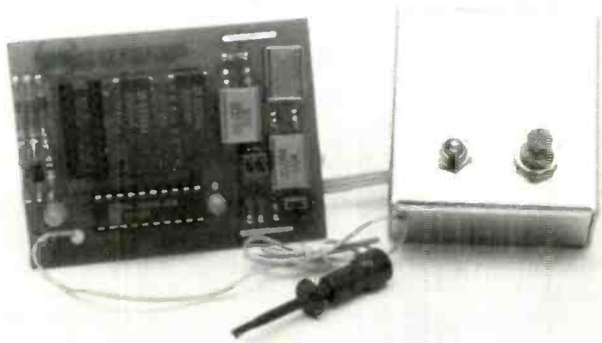


FIG. 4—JDR's Nickel Express

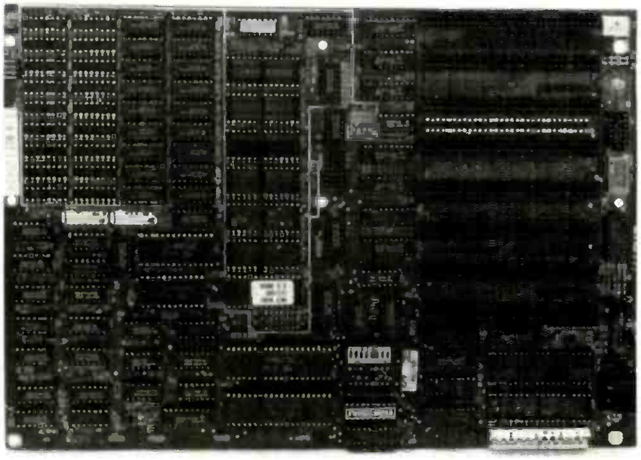


FIG. 5—JDR's MCT-Turbo

Mach 10

Microsoft sells the Mach 10 (shown in Fig. 6), a replacement processor, in two configurations: the board alone, or bundled with a mouse and Microsoft Windows. In either case, the accelerator

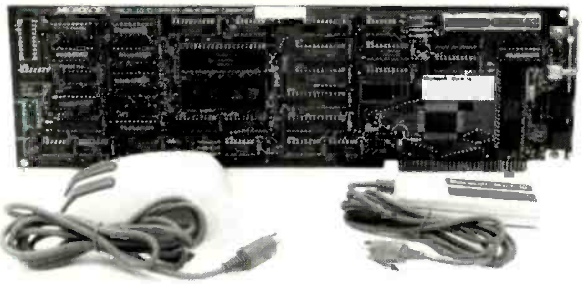


FIG. 6—Microsoft's Mach 10

board runs an 8086 at 9.54 MHz, twice normal speed.

To install the Mach 10, you set some jumpers, remove the CPU from your motherboard, connect a ribbon cable from the CPU socket to the Mach 10 board, and insert the board into an unused full-length expansion slot. The jumpers determine the mouse's interrupt, caching of BIOS and BASIC, (some programs may not run when the BIOS or BASIC is cached) and 8087 presence. The rear-panel mounting bracket has a socket for the mouse, a toggle switch for changing speed, and a socket for an optional speed-select switch that lights up when in turbo mode. The optional switch is nicer than most speed-select switches because it is mounted at the end of a cable, so you don't have to reach behind your PC to change speeds. It's also nicer than most switches (and more convenient than some software speed switches) because you can change speed at any time (after booting) without causing a reboot.

Installation is a snap; documentation is excellent. The only thing we don't like is the use of Microsoft's Inport mouse connector. The problem is that when you outgrow the Mach 10, the mouse may end up being useless, because few third-party vendors support it. Use of a standard serial mouse would have provided more options as your needs change.

Microsoft will be releasing another accelerator board (286-based) called the Mach 20; however, we were unable to obtain one in time for this article.

NEC V20

The least expensive accelerator option provides a modest increase in speed—about 5%. Installation is as simple as swapping IC's; there are no jumpers, DIP switches, or memory-resident software programs to contend with. Compatibility is high, but not perfect; we've seen a number of programs that won't run on a V20, including a version of GW-BASIC, a compiled Turbo Pascal CAE program, and several games and educational programs. Considering the price, however, it can't hurt to try a V20, especially if you're on an austere budget.

Tiny Turbo, TurboEGA, and PCturbo 286e

Orchid Technology has been in the accelerator-board business longer than anyone else, and the quality of their boards, some of which have been reviewed here before, reflects that longevity. We've had minor complaints with their documentation and technical support, but we have since found that in those regards, Orchid is at least as good as the competition, and in many cases better.

The least expensive board is the Tiny Turbo, shown in Fig. 7. It is a half-length replacement processor that contains an 80286 processor running at 7.16 MHz, and an 80287 math co-processor socket. To install the board, several jumpers must be set; the jumpers indicate co-processor speed, amount of system memory, and cache enable/disable. The host's 8088 is inserted on a small daughterboard to which the 40-conductor ribbon cable attaches. A toggle switch that protrudes through the board's mounting bracket selects fast (80286) or slow (8088) mode, and also functions as a reset switch. Changing speeds forces a complete system

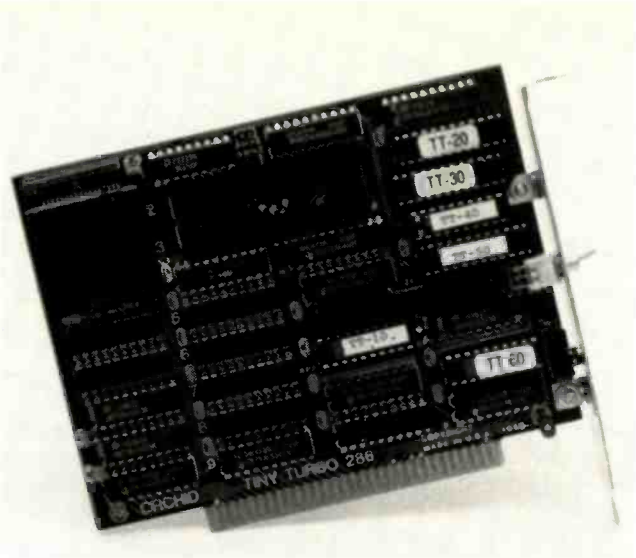


FIG. 7—Orchid's Tiny Turbo

FIG. 8—Orchid's TurboEGA

reboot. Documentation is contained in a clearly written 12-page booklet.

The next model up, the TurboEGA (shown in Fig. 8), combines the performance increase of the Tiny Turbo with a built-in multi-mode EGA adapter. The TurboEGA is a full-length card with an 80286, an 80287 socket, a reset/speed-select switch, and the EGA adapter, which also has modes that emulate CGA and Hercules monochrome text and graphics. The figures presented in Table 1, Fig. 1, and Fig. 2 are with the board running in Hercules emulation mode; in EGA text mode, screen output speed is about 15% faster, due to Orchid's optimized EGA BIOS.

Installation amounts to setting jumpers and DIP switches for monitor type (color, monochrome, or EGA) and number (the TurboEGA can co-exist with either a CGA or a monochrome adapter), co-processor speed, memory size, and cache enable/disable. The host 8088 is inserted into a socket on the TurboEGA's board, which is then connected to the vacant motherboard socket via a 40-conductor ribbon cable.

The mounting bracket has a speed-select/reset switch, a nine-pin D connector (for the monitor), access to the monitor-select DIP switch, and RCA jacks for the EGA's auxiliary outputs.

Documentation consists of a small spiral-bound manual; the manual is well written and well produced. A diskette is included that contains programs to turn monochrome and CGA emulation on and off, a program to display the BIOS ROM's date (the TurboEGA will not work on IBM PC's with ROM's dated before 10/27/82; the ROM can be upgraded), and a screen saver.

Unlike some multi-mode display adapters, Hercules and CGA emulation work fine on the TurboEGA.

Orchid's PCturbo 286e (shown in Fig. 9) is available in 8- and 10-MHz versions; we tested the 8-MHz version, which is faster than most 10- and 12-MHz accelerator cards. The 286e is a co-processor card that plugs into the expansion bus and has no electrical connections with the host 8088. The 286e really consists of a complete computer on a card, with its own, separate 16-bit 1-megabyte address space. An additional megabyte of RAM can be added via an optional daughterboard; that RAM can be configured as ex-

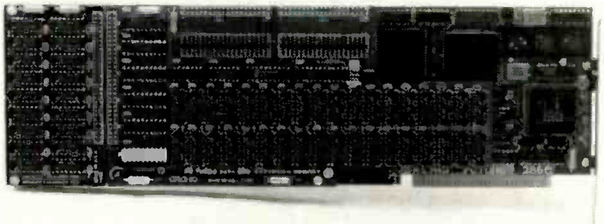


FIG. 9—Orchid's PCturbo 286e-8

panded or extended memory. The board also has a socket for an 80287 co-processor.

Until recently, the 286e was simply the fastest accelerator card you could buy. A good deal of the card's speed is due to the fact that it copies the host's BIOS and BASIC ROM's into its own 16-bit address space.

In turbo mode, programs are executed on the 286e's 80286 microprocessor; in standard mode, programs are executed on the host's 8088 microprocessor. In addition, it is possible to configure the system so that the 8088 and the 80286 execute programs simultaneously. In fact, you can add as many as four 286e cards to a single PC and operate each one independent of the others.

Installation consists of setting I/O port-select jumpers, interrupt line, 80287 interrupt and speed, and on-board memory. Then you must run a special installation program that configures the software that switches between turbo and normal modes. At that point a new AUTOEXEC.BAT file is created, and two new boot batch files. One contains the contents of your old AUTOEXEC.BAT; the other, any additional commands to be executed solely by the 286e. Any commands in the (new) AUTOEXEC.BAT file are then executed by both the 8088 and the 80286; commands in the other boot files are executed only by the appropriate processor. That allows you, for example, to set date and time only once, say in the 8088's file. A separate TURBO.SYS file is also created; it performs the same function as CONFIG.SYS does for the host.

Several useful utility programs are included: a RAM disk, a disk cache, and a print spooler. Typically you'll spend most of your time (and run your programs) in turbo mode, and use the 8088's address space for the RAM disk, cache, and spooler. All three programs are extremely useful and reliable, and greatly contribute to overall speed and convenience.

The 286e's manual is in Orchid's standard spiral-bound form. It contains a fair amount of information about how the 286e works in conjunction with the host PC, various kinds of memory (EMS, protected, DOS), installation instructions, memory maps, jumper settings, and information on using the utility software.

For all its power, the 286e is not without problems. For example, it is incompatible with third-party EGA cards, although a special EGA adapter is available from Orchid that is compatible. In graphics mode on a Hercules card, random "garbage" is often left on the screen; the garbage disappears, however, merely by moving the pointing device (mouse or digitizing tablet) in the affected area. And the way the manual intersperses technical with installation and operational information is confusing.

On the plus side, we used the board for a long period of time as the basis of a high-performance AutoCAD system. The 286e co-existed peacefully with a multi-function/EMS board made by Apparat (the Limbo II, reviewed in the March 1987 issue). In a different configuration, it also functioned with a 68000 co-processor board that controls Pencept's Penpad 320 digitizing tablet. Not counting the video controller, that made a total of three microprocessors running simultaneously inside a standard IBM PC XT! All in all, there's a great deal to like about the PCturbo 286e.

Breakthru 286

The Personal Computer Support Group has been around a long time supplying enhancement products for Radio Shack's portable computers, particularly the Model 100 and the Tandy 102. A few years ago, the company got into the PC business with an excellent disk cache program called Lightning; their first hardware entry is the Breakthru 286, which comes in 8- and 12-MHz versions; we reviewed the latter, which is shown in Fig. 10. Every board comes with a copy of Lightning; the program is also available separately for $89.95.

Like Orchid's Tiny Turbo, the Breakthru 286 is a half-size replacement processor. Unlike the Tiny Turbo, however, you remove and store your PC's 8088 (and 8087, if present); the 8088 does not mount on the Breakthru's board. In addition, a special plug must be inserted in the 8087 socket on your PC's motherboard. The Breakthru has a socket for an 80287. Installation continues by setting a switch on your motherboard and configuring several jumpers on the Breakthru. In addition, you may add a device driver to your CONFIG.SYS file; the driver allows you to change speed from the keyboard, and to set the hot-key combination that accomplishes speed switching. Alternatively, you can use Lightning to accomplish speed switching and to set the hot key. You can switch speed at any time without causing a reboot; a special Lightning command will force clock speed to be reduced whenever a floppy disk drive is accessed.

Separate manuals are provided for Lightning and the Breakthru. The Breakthru's manual is somewhat confusing, due to inconsistent use of the term *cache*. For example, to place the Breakthru in turbo mode, at the DOS prompt you type *A>L CACHE ON*. But to set up a 64K disk cache for drive C, the command is *A>L 64 C*. After overcoming the terminology, however, everything works well. In addition, lightning automatically senses the presence of EMS memory, and can use as much as 1.5 megabytes of it.

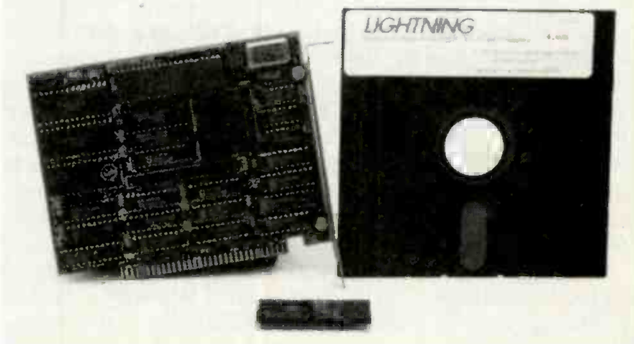


FIG. 10—PCSG's Breakthru 286

Compatibility Software

- PageMaker, Aldus Corp., 411 First Avenue South, Seattle, WA 98104, (206) 622-5500.
  CIRCLE 38 ON FREE INFORMATION CARD
- AutoCad 2.6 and AutoSketch, Autodesk, Inc., 2320 Marinship Way, Sausalito, CA 94965, (800) 445-5415.
  CIRCLE 39 ON FREE INFORMATION CARD
- WordStar 4.0, MicroPro International, P.O. Box 7079, San Rafael, CA 94901-0079, (800) 227-5609, (800) 343-3000 ext. 655.
  CIRCLE 40 ON FREE INFORMATION CARD
- Windows, Microsoft Corp., Redmond, WA 98073, (800) 426-9400, (206) 882-8088 (WA).
  CIRCLE 41 ON FREE INFORMATION CARD
- Direc-Link, Micro-Z Company, 4 Santa Bella Road, Rolling Hills Estates, CA 90274, (213) 377-1640.
  CIRCLE 42 ON FREE INFORMATION CARD
- VP Planner, Paperback Software, 2830 Ninth Street, Berkeley, CA 94710, (415) 644-2116.
  CIRCLE 43 ON FREE INFORMATION CARD

Hardware Manufacturers and Distributors

- 386 Motherboard, Hauppauge Computer Works, Inc., 358 Veterans Memorial Highway, Commack, NY 11725, (800) 443-6284, (516) 360-3827 (NY).
CIRCLE 27 ON FREE INFORMATION CARD

- MCT-Turbo and Nickel Express, JDR Microdevices, 110 Knowles Drive, Los Gatos, CA 95030, (800) 538-5000, (408) 866-6200 (CA).
CIRCLE 28 ON FREE INFORMATION CARD

- Mach 10, Microsoft Corp., Redmond, WA 98073, (800) 426-9400, (206) 882-8088 (WA).
CIRCLE 29 ON FREE INFORMATION CARD

- NEC V20, NEC Electronics, Inc., 401 Ellis Street, P.O. Box 7241, Mountain View, CA 94039, (800) 632-3531, (800) 632-3532 (CA).
CIRCLE 30 ON FREE INFORMATION CARD

- Tiny Turbo, TurboEGA, and PCturbo 286e, Orchid Technology, 45365 Northport Loop West, Fremont, CA 94538, (415) 683-0300.
CIRCLE 31 ON FREE INFORMATION CARD

- Breakthru 286, Personal Computer Support Group, 11035 Harry Hines Blvd., Suite 206, Dallas, TX 75229, (214) 351-0564.
CIRCLE 32 ON FREE INFORMATION CARD

- 286 Rainbow Plus, PC Technologies, Inc., 704 Airport Blvd., P.O. Box 2090, Ann Arbor, MI, 48106, (313) 996-9690.
CIRCLE 33 ON FREE INFORMATION CARD

- MotherCard 5.0, State of the Art Technology, Inc., 657 N. Pastoria Ave., Sunnyvale, CA 94086, (800) 237-1713, (408) 245-3366 (CA).
CIRCLE 34 ON FREE INFORMATION CARD

- MultiSync monitor (used for EGA compatibility testing), NEC Home Electronics, Computer Products Division, 1255 Michael Drive, Wood Dale, IL 60191, (800) NEC-SOFT.
CIRCLE 35 ON FREE INFORMATION CARD

- Pencept Penpad 320, Pencept, Inc., 39 Green Street, Waltham, MA 02154, (617) 893-6390.
CIRCLE 36 ON FREE INFORMATION CARD

- Limbo II, Apparat, Inc., 6801 South Dayton, Englewood, CO 80112, (303) 799-0818.
CIRCLE 37 ON FREE INFORMATION CARD

286 Rainbow Plus

PC Technologies markets a number of accelerator boards with various options. The Rainbow Plus (shown in Fig. 11) includes a 10-MHz 80286, a clock/calendar, a multi-mode EGA adapter, and an 80287 socket. In addition, an optional daughtercard provides a parallel interface and a Microsoft Inport mouse interface (like the Mach 10).

As with the Tiny Turbo, the host 8088 is removed and re-installed on a small daughterboard. A 40-conductor cable connects the assembly to the host PC. The rear connector provides speed- and monitor-select toggle switches, a 9-pin monitor connector, and access to the configuration DIP switch. The DIP switch selects monitor type, and allows you to set up for a dual-monitor system. It also enables the CGA and Hercules emulations (which are turned on and off via software). Others switches control cache state at power up and indicate host memory size. Toggling the speed-selection switch causes a reboot.

The board provides a moderate speed increase, and we detected no problems with the EGA adapter. However, in Hercules mode, the graphics screen (under AutoCAD 2.6) was simply unwatchable due to vertical rolling. With the optional parallel and mouse ports, the board could be useful in a situation where slot

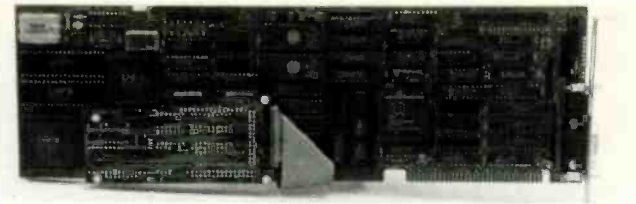


FIG. 11—PC Technologies'286 Rainbow Plus

usage was critical.

MotherCard 5.0

The flat-out winner in terms of overall speed, State Of The Art Technology's 12.5-MHz MotherCard 5.0 (shown in Fig. 12) basically packs an AT onto a single expansion card. Like the PCturbo 286e, it is a co-processor, but unlike that card, the MotherCard requires the 8088 to be mounted on it, and a ribbon cable to connect to the host. 8- and 10-MHz versions of the card are also available.

The board features a "re-configurable" BIOS, actually a battery-backed CMOS RAM that may be used to patch BIOS updates. The company claims that IBM's forthcoming OS/2 will run on the board, but was unable to verify that by press time. (The 5.0 in the name refers to one of the many names OS/2 was called before it was officially released.)

The basic MotherCard contains a battery-backed clock/calendar, an 80287 socket, and one megabyte of memory; on optional daughterboard will accept as much as four megabytes, built on special modules. However, if you use the daughtercard, you won't be able to install a full-length card in the adjacent slot. The rear mounting bracket has a reset switch; changing from 8088 to 80286 mode is done via software programs and causes a reboot. Reboot-

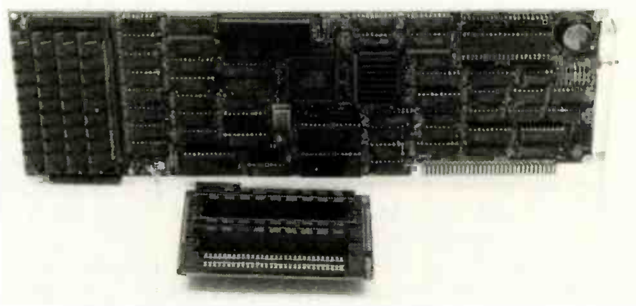


FIG. 12—SOTA's MotherCard 5.0

ing normally forces operation in 286 mode, but pressing F10 will initiate 8088 mode. Utility software is included.

The MotherCard is extremely fast—with a 12-MHz 80287, the board approaches 386 speed in CAD applications. In addition, unlike many boards, the MotherCard is compatible with EGA, LAN programs, and other "problematic" applications.

Recommendations

We examined a number of octopus boards; the Nickel Express is the only one that worked and the only one whose documentation was comprehensible. However, we don't like the idea of loose wires hanging off a PC board, so in the under-$150 price range, we'd really recommend upgrading to a turbo motherboard—unless you're working with an IBM PC (not a clone) and wish to retain use of the BIOS and BASIC ROM's.

In the $400-$800 price range, the choice becomes much tougher, especially because many products are often heavily discounted, so comparing list prices may not be appropriate. For example, we recently saw both the Tiny Turbo and the Mach 10 (bundled with mouse and Windows) being sold for about $350. The Tiny Turbo has the performance advantage, and it's a half-length card, but buying a mouse and a copy of Windows could easily cost you more

continued on page 106

BUILD THE PT-68K

This month we build test, reset, and clock circuits.

PETER STARK,
STARK SOFTWARE SYSTEMS CORPORATION

Last month we described the PT-68K computer's hardware and software in general terms, covered the data and address buses, and discussed how to get started. We are now ready to begin construction.

Although this month's installment presents the parts layout diagram for the entire printed circuit board, please don't blindly start stuffing parts in a big rush to get things finished. Instead, follow the sequence presented here. We are going to build the PT-68K in sections, providing detailed explanations of what each section does and why. In the process, we will also test each section by performing one or more simple experiments. There are two reasons for following that procedure: First, it gives us the chance to learn how the system really works. But, equally important, it will give us a chance to test each section and isolate small errors before they become big problems.

Some theory

Digital circuits represent the binary digits 0 and 1 by means of voltages; in most microcomputers, the two voltages are often called *low* (which is a voltage between zero and roughly 0.8 volts) and *high* (which is a voltage between about two and five volts). There are exceptions, of course—such as in an RS-232 circuit, which might connect a computer and a printer together, where larger positive (and negative) voltages are used. However, the specified ranges are the most common. In any case, the range between 0.8 volts and 2.0 volts is a "no-man's land;" if a digital signal is in that range it usually indicates a problem.

Many people think that a low voltage is a 0, and a high voltage is a 1, but that is not always true—in fact it could be the other way around. So talking about ones and zeroes can be ambiguous, but talking about lows and highs is always specific. Note that we don't really care about the exact value of a signal's voltage, so long as it falls into one of the specified ranges.

However, there's yet another way to talk about digital signals: We can say that a particular signal is *on* or *off*. Another way of expressing that is to say that a signal is *asserted* (on) or *negated* (off).

The problem is that some circuits use a high to assert a signal, and other circuits use a low to assert a signal. So that gives us two types of circuits: *active-high* and *active-low*. An active-high circuit is high when it is asserted and low when it is negated; an active-low circuit is low when it is asserted and high when it is negated. (Some books call that negative logic.) In a typical computer, both kinds of circuits may be used, and often are. In fact, an active-high circuit may be located a tenth of an inch from an active-low circuit.

In text and in schematics, active-low signals are marked with a bar over the signal name: $\overline{\text{HALT}}$, for example. By contrast, a signal without the bar, such as FC0 or A16, is active high.

Step 1: get ready

As shown in Fig. 2 last time, start by mounting the PC board and the power supply on a wooden board that measures about 12" × 24". Then hammer two brads through the appropriate board holes, as shown in that photo. Use the holes mentioned to avoid short circuiting the power supply.

Note, in Fig. 1, how the board is oriented: The power connector is right next to the power supply, and the six expansion connectors are in the left rear corner. We will use the words left, right, front, and back to describe the board when it is positioned like that; it will fit into a "baby" PC AT clone cabinet in the same orientation.

Note also that the side with all of the white lettering, called the *silk-screen layer*, is called the top, and the other side of the board is called the bottom. All soldering will be done on the bottom side; there are no solder joints whatsoever on the top or silk-screen side.

Step 2: learn to solder

If you already have experience soldering components to a delicate printed-circuit board, you may skip to step 3; otherwise get some advice from a professional on proper soldering technique.

Note that both sides of the board seem to be covered with a thin layer of green paint; that layer is called a *solder mask*. The entire surface area of each side of the board is masked except for the area surrounding each hole; the purpose of the solder mask is to keep the solder on a pad from spreading to adjacent pads or traces.

You can see the copper traces through the solder mask, and you can see that the traces on top of the board go mostly left-right, whereas the ones on the bottom go front-back. If a

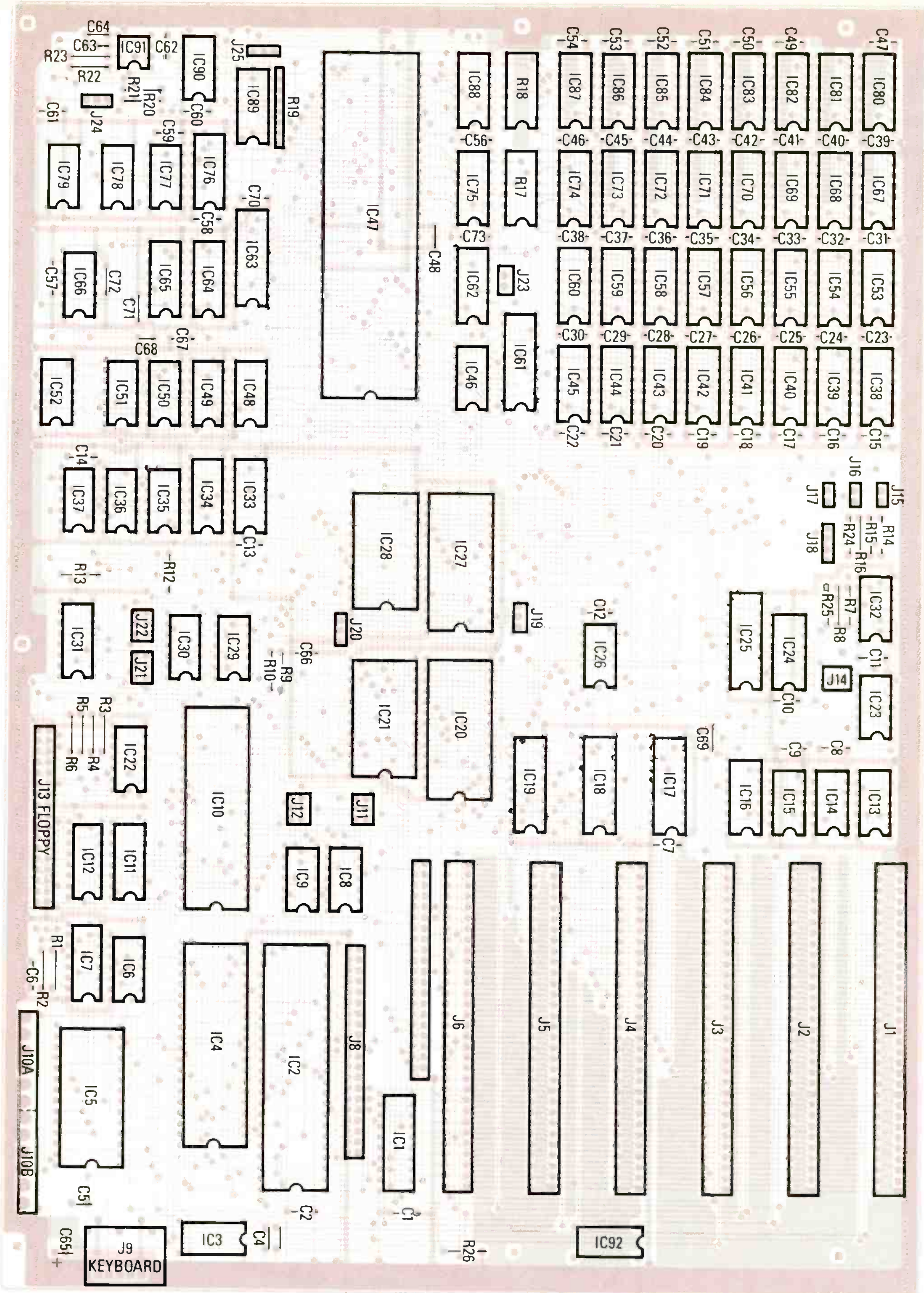


FIG. 1—PARTS PLACEMENT DIAGRAM shows where all board-mounted components are located. We'll use this diagram throughout the series of articles, so keep a copy handy.

connection has to go from one corner of the board to a diagonally opposite corner, it may travel in one direction on the top, then go through a hole to the bottom, and continue at a right angle there. In some cases, a particular connection may go back and forth, top to bottom, several times before it arrives at its destination.

The hole that connects a trace on the top to a trace on the bottom is called a *via* or a *feedthrough*, and it is plated with copper internally; hence it does not need to be soldered on both sides of the board. Solder only those joints into which you insert a lead. And don't wash the board prior to soldering.

Step 3: the power connectors

The power connector actually consists of two six-pin connectors, J10-a and J10-b, in the right rear corner of the board. They are shown in Fig. 2, where J10-a is on the left, and J10-b is on the right. **Read the following paragraphs before you do anything.**

The power connectors are a potential source of big problems. Note that the two board-mounted connectors are identical, and the two power-supply plugs are probably identical as well. In other words, it is extremely easy to make a mistake and plug the wrong power supply plug into the wrong connector on the board and burn up the works. We must make sure that never happens.

First, look at the two board-mounted power-supply connectors. One has six pins, the other, only five—the next-to-the-last pin is missing. To help remind you of which goes where, cut off the next-to-the-last board-mounted pin on J10-b, as shown in Fig. 2.

Next, compare the shells of those connectors with the connectors supplied in your kit. In the plastic, behind each of the metal pins, is a small rectangular opening with a tiny plastic "bridge" above it.

Now look at the two matching plugs from the power supply; six small plastic tabs protrude from the long side of each. When the plugs and sockets are brand new, the tabs on the plugs prevent them from being inserted into the sockets because the long tabs hit the bridges. The object is to cut just the right combination of tabs and bridges so that the six-wire plug only fits J10-a, and the five-wire plug only fits J10-b. If you look closely at Fig. 2, you will see how we accomplished it.

Now that you know what must be done, solder the two connectors to the board, and then match up the bridges and the tabs so that the power supply plugs in only one way. Make sure that the connectors are oriented correctly.

While working on this section of the board, also install C65 (10 µF, tantalum). Make sure it is oriented correctly, because tantalum capacitors have a nasty habit of exploding if connected backward! Then install C3, C4, and C5, three 47-pF disc ceramic capacitors. They look much like the many 0.1 µF capacitors; mounting them now avoids possible confusion later. Also mount C6 (0.1 µF) now.

Besides C63 (1 µF) all the remaining capacitors are 0.1 µF disc ceramics. Digital circuits are notoriously "noisy," and computer designers have learned the hard way that it is necessary to install small bypass capacitors between the +5-volt line and ground at many points on a PC board to keep that noise off the power lines. A general rule of thumb is that one such capacitor should be installed for every two or three digital IC's.

NOTE: Some IBM-type power supplies can be damaged if operated without a load, so never do so.

Step 4: LED indicators

Most "baby" AT cabinets have two or three status-indicator LED's on the front panel. Eventually we'll connect those LED's to J15, J16, and J17 on the board to indicate power on, hard-disk activity, and microprocessor halt status, according to the circuits shown in Fig. 3 (which also shows speaker wiring.) In each case, a resistor in series with the LED (or speaker) limits current flowing through the device, which is controlled by one section of IC32, a 7406 open-collector hex inverter.

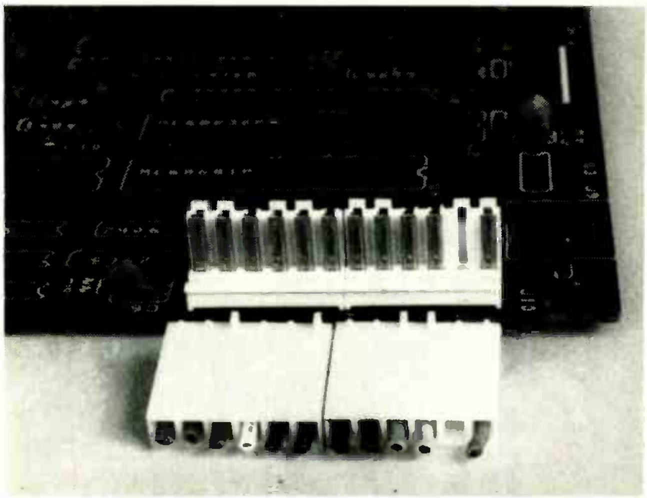


FIG. 2—POWER CONNECTOR J10A (left) and J10B (right). Also shown are the matching plugs from the power supply. Notice how the tabs on the plugs match the bridges that have been removed from the board-mounted connectors.

Note that IC32-b, IC32-c, IC32-d, and IC32-f are all part of one integrated circuit, IC32. It has six inverters; the other two are used elsewhere. For now ignore the fact that IC32-f has a small circle, called a *bubble*, on its input, instead of its output; that notation will be explained next time.

Before connecting them in their final form, we want to use the LED's for experimenting and debugging, so we'll solder the LED's directly to the PC board for the time being. Referring to Fig. 1, install R14 and R15 (330 ohms), R16 (220 ohms), R24 (2200 ohms), C11 (0.1 µF), and the 14-pin socket for IC32. While you're at it, also install R25 (33 ohms), and J18, the 4-pin header strip for the speaker. Do not install IC32 in its socket yet, and don't bother connecting the speaker to J18.

Then install the three LED's at J15, J16, and J17. The cathode lead of each LED, usually marked by a flat edge on one side, should go toward the resistors. If at all possible, check each LED first, because sometimes LED's are made with the flat on the wrong side, but rather than destroy those LED's, manufacturers sell them at low prices on the surplus market.

Install each LED so that it stands up straight, about ½ inch above the board. Later, when we're ready to mount the board in the cabinet, we'll cut each LED lead just below the LED itself and use the stubs as connectors for the panel-mounted LED's.

Now connect the power supply cables to J10-a and J10-b and power up the board. The power indicated LED (at J15) should light, though it may immediately go off again. If so, don't be alarmed—most PC-type power supplies shut themselves off if there is insufficient load, and a single LED is a very small load indeed. If that's the case, turn off the supply and temporarily connect a 150- or 330-ohm resistor between pins 7 and 14 of the IC32 socket. **Don't force the leads all the way into the socket; rather, hold them gently aginst the appropriate pins.** Then try again.

If the LED does not light at all, even for an instant, then most likely either the LED is in backward, R14 is the wrong value, or the power supply is defective or not properly connected to J10-a and J10-b. Correct the problem before continuing.

Important note

During construction, often we will solder some connections, turn on the power, try the new configuration, turn off the power, make more connections, and so on. **It is absolutely essential that you turn off the power before doing any more wiring, soldering, or inserting IC's into sockets.** Better yet, turn off the supply and also unplug it. If you forget to turn off the power,

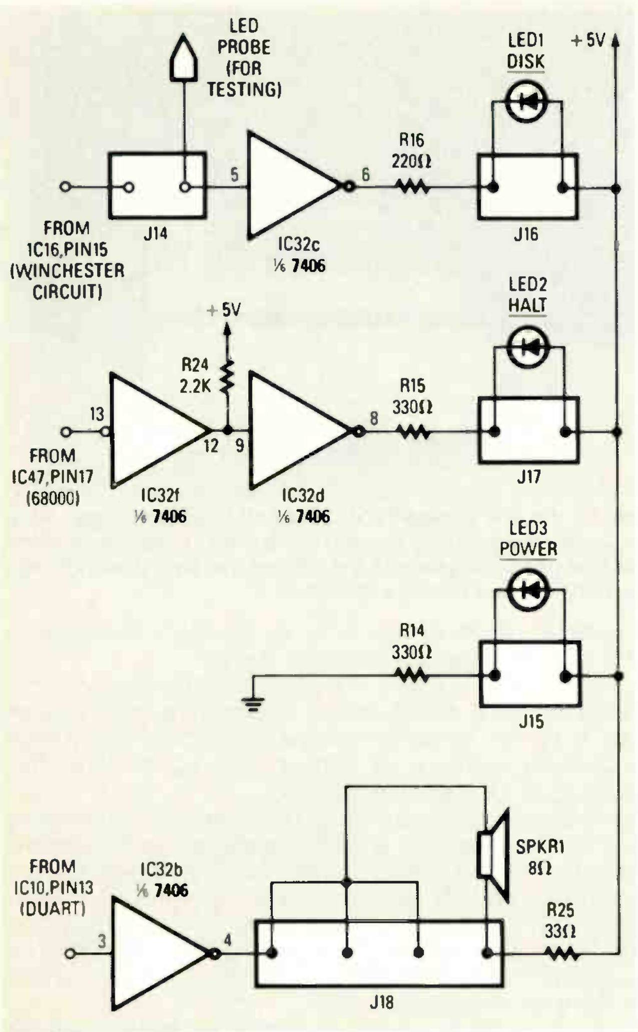


FIG. 3—LED AND SPEAKER CIRCUIT. Each device is driven by an open-collector inverter.

you may well burn out some or all of the components on the board, and perhaps burn a few of the PC-board traces as well.

So now *turn off the power* and connect a thin wire, 12–15" long, to terminal 1 (on the left) of J14. Try to use a thin solid wire, about 30 gauge. If you use stranded wire, twist the strands of the loose end and tin it. Next, insert a 7406 IC into IC32's socket. Note that all IC's on the entire board are oriented the same way: pin 1 (marked by a dimple or a notch, both on the IC and also on the silk screen layer on the board) goes toward the back. *Then* turn the power back on.

The wire connected to J14-1 (shorthand for terminal 1 of J14) is now a test probe, which we will call the LED probe. If you ground its loose end (to pin 7 of IC32, for example), the LED at J16 should go off; if you connect it to a high voltage (pin 14 of IC32, for instance), it should go on. In addition, when the probe is not connected, the LED will also be on. Furthermore, when connected to a source of pulses, the LED will light, but its brightness will depend on the type of pulses. For example, a pulse stream that is high most of the time will be brighter than one that's mostly low. But connecting the probe to *any* pulse stream will produce a slightly dimmer light; that's an easy way to recognize a pulse signal.

Now we've got a simple logic probe for checking out other parts of the computer. If you have a meter, an oscilloscope, or a "real" logic probe, feel free to use it instead. However, it may be more convenient to use the built-in probe.

Step 5: the reset circuit

The 68000 microprocessor must be initialized—placed in a known state—when the system is first turned on. The process is called *resetting*, and is done by temporarily grounding two 68000 pins: RESET and HALT. Remember that they are active-low signals, so grounding them asserts them. The pins must be grounded simultaneously for a minimum of 100 milliseconds.

The 68000 must be reset automatically every time power is turned on. It's also useful to be able to reset the microprocessor manually, by pressing a switch, when the computer does something it is not supposed to do. Both functions are accomplished with the circuit shown in Fig. 4.

The important device in that circuit is IC91, a 555 timer, which is connected to a timing circuit consisting of R23 and C63. When the computer is running, C63 is charged through R23 to about +5 volts, and the output (on pin 3) is low; IC22-c, IC22-d, and IC66-e invert the 555's signal to provide the desired active-low signals. The two 2200-ohm resistors (R20 and R21) are tied to +5 volts; they're called *pull-ups* because they pull the lines associated with them up to the supply voltage.

Getting back to the reset circuit, whenever the terminals of J23 are shorted, the trigger input of the timer goes low, which causes the timer to ground pin 7, which discharges C63. (When power is first applied C63 starts off discharged). The 555 timer sees that low voltage and outputs a high on pin 3. That signal is inverted by IC22-c and IC22-d, which then assert the RESET and HALT lines of the 68000, thereby resetting it. (The reset signal also goes elsewhere through IC66-e, but more on that later.)

When the short is removed (or the power-supply voltage has risen), C63 starts to charge through R23. The 555 monitors that rising voltage, and when it reaches about 66% of the supply voltage (3.3 volts in our case), shuts off the output on pin 3. That negates the RESET and HALT lines and lets the 68000 begin operation.

How long does it take for the voltage on C63 to reach 3.3 volts? Approximately one *time constant*, which is defined as the product of R23 and C63. Since R23 is 1 megohm (1×10^6) and C63 is 1 μF (1×10^{-6}), the product is ($1 \times 10^6 \times 10^{-6}$) = 1 second. Thus the RESET and HALT signals will go low for about 1 second at startup or whenever J23 is shorted. Later we'll connect a pushbutton switch to J23 to provide a manual reset function.

Now that we know how the circuit works, let's build it. Install the parts listed below, noting the polarization of tantalum capacitor C63. (Its positive terminal must go toward pin 6 of IC91.) Also, the two-pin header strip, J23, has a short end and a long end; the short end goes through the board and is soldered on the bottom. Now install these parts: R22 and R23 (1 megohm); R20 and R21 (2200 ohms); C57, C61, C62, and C64 (0.1 μF); C63 (1 μF); sockets for IC91 (8 pins), IC22 and IC66 (14 pins), and the two-pin header strip at J23.

Also install the two 0.1 μF capacitors to the left of IC66. Then install a 555 in the IC91 socket, a 7406 in IC22, and a 74LS04 in IC66, and turn on the power. The HALT LED should go on for about a second, and then go off.

Now use the LED probe to check the signals at the outputs of IC22-c, IC22-d, and IC66-e. Connect the probe to IC22-c and use a screwdriver or wire to short the two pins of J23; the test LED should go off and then, a second later, back on, indicating that the signal went low and then high. If all is well, check the outputs of the other two inverters. Otherwise track down the source of trouble before continuing.

Step 6: The clock circuit

The PT-68k's clock circuit is shown in Fig. 5. IC78 is a 16-MHz oscillator module that contains a crystal oscillator and all logic necessary to provide a TTL-level squarewave output. The oscillator's output goes to IC77-a, half of a 74ALS74 D flip-flop that divides the frequency of the clock signal by two. The 8-MHz output, called CLKB, is used in a number of places throughout the computer; a separate clock signal drives the 68000.

Jumper J24 selects the frequency at which the microprocessor

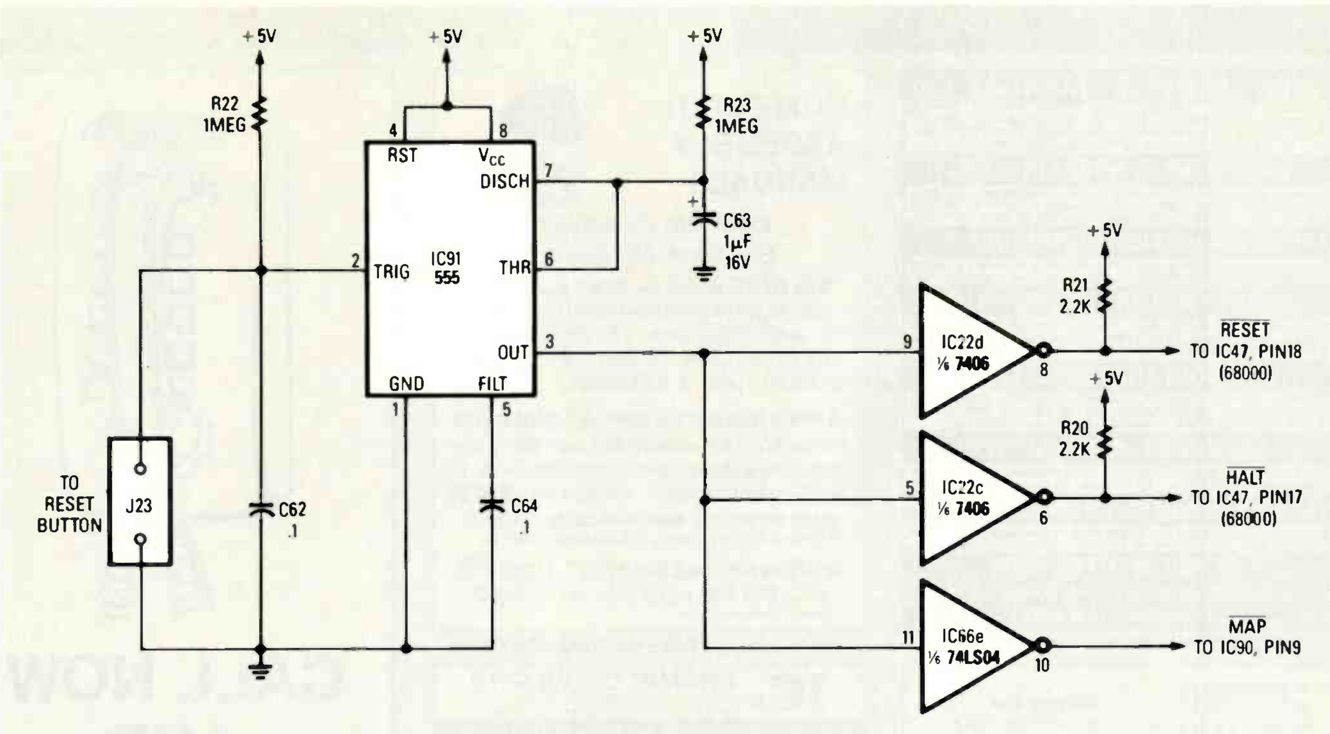


FIG. 4—RESET CIRCUIT. The 555 generates a high-going one-second pulse each time the terminals of J23 are shorted. The inverters (IC22-c, IC22-d, and IC66-e) drive the appropriate lines low.

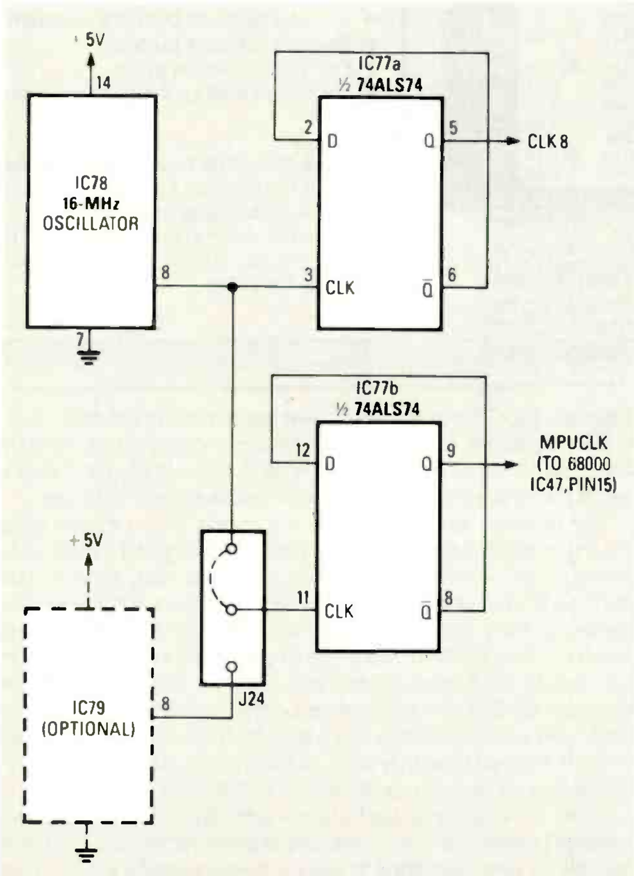


FIG. 5—CLOCK CIRCUIT. IC78 generates a 16-MHz signal that IC77-a divides by two to provide the main clock signal. IC77-b generates a separate clock signal for the microprocessor, thereby allowing it to run at another (faster) rate.

runs. That signal is known as MPUCLK. In the position shown, IC77-b divides the 16-MHz signal by two, to provide an 8-MHz clock. However, by adding optional oscillator module IC79, a different frequency may be chosen by moving the jumper to the other position. For example, to run the computer at 10 MHz, you would install a 20-MHz oscillator module at IC79 and place J24 in the alternate position. CLK8 would still be 8 MHz, but MPUCLK would now be 10 MHz.

Two modules are necessary because CLK8 is used elsewhere in the computer and must stay at 8 MHz even if the 68000 itself runs faster. However, do not try to increase clock frequency at this time; depending on the frequency chosen, some components may have to be altered. We'll discuss the details in a future installment.

Now mount the 16-MHz oscillator module (IC78) by soldering it directly to the board, without a socket. Note that three corners are rounded; the pointed corner identifies pin 1, which should be closest to IC65. Then install a socket for IC77, a 3-pin header at J24, and three 0.1 μF capacitors (C58, C59, and C60). Then insert a 74ALS74 (note: ALS, not LS) into the IC77 socket, and a shorting jumper from the center pin to pin 1 of J24.

Next, power up the computer. If you have an oscilloscope or a logic probe that can detect pulses, examine CLK8 and MPUCLK for the 8-MHz clock signals. (An inexpensive oscilloscope may have trouble displaying the clock signal, or may show it as a very distorted sine wave.)

To use the built-in LED probe, first note how bright the LED is when the probe wire is not connected to anything. Then connect it to CLK8. The LED is flashing on and off so fast you cannot see it, so it should be dim, indicating that the signal is high part of the time and low part of the time.

Next, connect the LED probe to MPUCLK and note its brightness. Then slip the shorting jumper from J24 and note whether the LED gets brighter or darker. Each time you remove the jumper, you stop IC77-b from counting. Sometimes it will stop in the set state, in which case the LED will be getting a full high voltage and become brighter; other times it will stop in the reset state, in which case the LED will go off. Try removing and installing the jumper several times; if you see the LED in both states, the clock circuit is most likely fully functional.

That's all we have time for now; next time we'll install the microprocessor itself and start learning about how it works.

TURBOCHARGE YOUR PC

continued from page 100

than $200, even at discounted prices. And the Mach 10's method of speed switching is more convenient. The overall price/performance leader is PCSG's Breakthru 286.

Above $800, Orchid's PCturbo 286e is hard to beat. The 8-MHz model we examined is faster than the 12-MHz Breakthru 286; the 10-MHz model should be a real screamer. However, the 286e won't run a third-party EGA, so SOTA's MotherCard is a strong contender, especially if it turns out that the board can run OS/2.

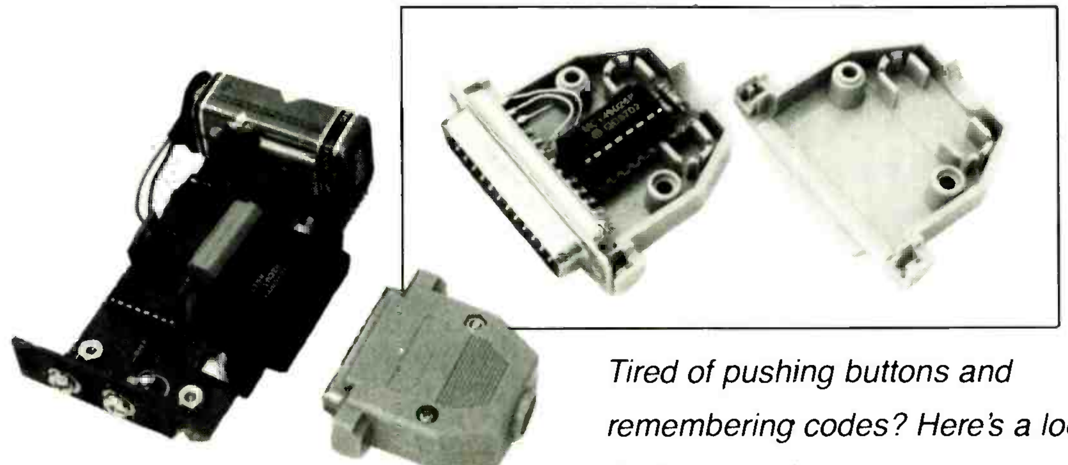
Conclusions

All of the accelerator boards we tested for this article enhance performance. At the same time, every single one exhibited some problem with compatibility or performance. For example, one board simply wouldn't run AutoCAD 2.6. Replacing a PLD allowed the program to run, but prevented use of EMS memory. A complete board re-design was necessary to solve the problem. Another board crashed under some combinations of resident and non-resident programs—but then so does a plain-vanilla XT. However, a plain-vanilla XT does not crash with the *same* combination.

We refrained from naming names in those examples because we can't blame the manufacturers involved; they simply can't be expected to test every combination of hardware and software.

The message for the buyer is not a new one: beware when buying, and be extremely careful when installing and initially using any type of accelerator. Back up your hard disk, rename your AUTOEXEC.BAT and CONFIG.SYS files, and then install your new hardware. Only after getting it to work should you add software drivers to your CONFIG.SYS file, and do so one by one, rebooting and testing after adding each one. Then do the same with any memory-resident programs loaded via AUTOEXEC.BAT. *Expect* that there will be problems and take a step-by-step approach to solving them. If a board works by itself, but not with a particular software driver, try changing the order in which things are loaded.

Later on, when you add a new software driver or memory-resident program, and your machine crashes, remember that the PC and the XT were designed to work in a very specific environment, and that you have drastically altered that environment in a way in which the original designers could not possibly have foreseen—so don't curse them. If you really need the speed, go out and buy a faster machine. R-E



Tired of pushing buttons and remembering codes? Here's a lock that's opened by an electronic key.

Electronic Combination Lock

PAUL RENTON

ELECTRONIC-LOCK CIRCUITS HAVE BEEN around, in various forms, for many years. Most have a keypad on which the user enters a combination of numbers. If the combination matches the one that's programmed into the lock, the lock opens. Unfortunately, it takes a relatively large amount of digital circuitry to decode and match keypad entries against the programmed combination.

On the other hand, the electronic-lock system shown in Figs. 1 and 2 uses only three integrated circuits: IC1, an MC145028 that is part of the lock itself (Fig. 1), IC2, an MC145026 that functions as an electronic key (Fig. 2), and IC3, a 5-volt regulator. That all-electronic approach allows the electronic lock to occupy only a couple of square inches of space, while the key is small enough to be carried in a pocket. Although anyone with access to the key can unlock the lock, which is not true for a keypad lock, the low cost and simplicity of the keyed electronic lock makes it somewhat more convenient to build.

The MC145026 is usually used to encode commands for radio-frequency, ultrasonic, and infrared remote-controllers. It has nine address pins. When instructed to send a command, the IC reads the pins, encodes them into a series of bits, and then sends the information out serially. The receiver, an MC145028, receives the serial transmission and checks the received address data against the programming of its own nine address pins. If the programming is an exact match then pin 11, the VT (*V*alid *T*ransmission) line, goes high.

Many combinations

When encoding data, IC2 can read one of three states on each of its address pins: 1) open with no connection; 2) low—connected to ground; 3) high—connected to the positive supply voltage. Since the IC reads each as a distinctly different state, the encoder operates on a "trinary" (three value) system. As there are nine address pins, the encoder can encode 3^9 (19,683) possible codes. But while the MC145028 decoder can read three states on address pins A1–8, it can only read a high or a low signal on its A9 pin, thereby allowing only 2×3^8 (13,122) possible addresses, a range that is still larger than that provided by a 4-digit keypad code. It gives reasonable assurance that if someone did build an electronic key, they would have a difficult time unlocking the

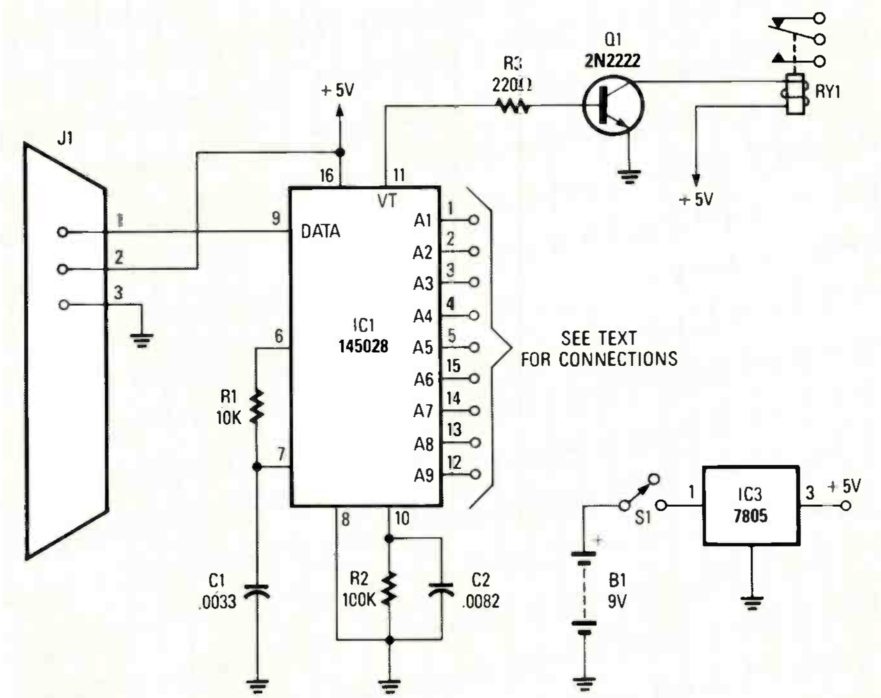


FIG. 1—THE ELECTRONIC LOCK is actually a decoder (IC2) that compares the wiring of its address pins with that of the key.

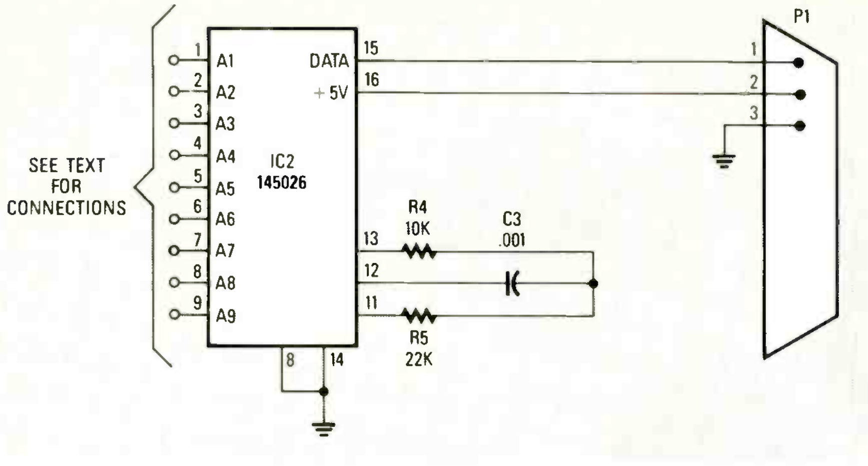


FIG. 2—THE ENCODING IC IN THE KEY, IC2, outputs a series of long and short pulses that represent the wiring of address pins A1–A9. The pins can be brought low, or high, or left open.

PARTS LIST

All resistors ¼ watt, 5%.
R1, R4—10,000 ohms
R2—100,000 ohms
R3—220 ohms
R5—22,000 ohms

Capacitors
C1—.0033 µF, ceramic disc
C2—.0082 µF, ceramic disc
C3—.001 µF, ceramic disc

Semiconductors
IC1—MC145028 decoder (Motorola)
IC2—MC14026 encoder (Motorola)
IC3—7805 5-volt regulator
Q1—2N2222 NPN transistor

Other components
B1—9-volt battery
J1—DB-25 socket
P1—DB-25 plug
RY1—5-volt DC relay
S1—SPST switch

Miscellaneous: Perforated wiring or construction board, terminal strip, battery clip, wire, solder, etc.

electronic lock without knowing the proper combination.

The encoded data sent from IC2 consists of a series of long, short, or a combination of long and short pulses that represent the state of the address pins. A low signal on an address pin is encoded as a sequence of two consecutive short pulses, a high signal is encoded as two consecutive long pulses. An open pin is encoded as a sequence of a long pulse followed by a short pulse. After the encoder sends out its sequence of encoding pulses it immediately re-transmits the sequence for added reliability. (The procedure is called *redundant transmission*. It is commonly used to insure the received integrity of transmitted data.)

Decoder IC1 uses the pulses it receives from the encoder to determine the state of the encoder's address pins. While receiving the data, it compares the state of the encoder's address pins against the state of its own address pins. If there is a perfect match on all pins the decoder brings its VT pin high to indicate that the proper address was received. By going high, the VT pin turns on transistor Q1, which powers relay RY1. The VT pin remains high, and the relay thereby remains powered until the decoder no longer receives a properly encoded sequence of pulses.

Construction

The timing of the pulses is not so critical that only high tolerance parts must be used; 5% resistors are acceptable for both the encoder and decoder, which contributes to the low cost of the electronic lock.

The decoder (Fig. 1) is powered by a 9-volt transistor-radio type battery and can be built on a small piece of perforated wiring or construction board. Nothing is critical and any layout can be used. To simplify connections to external equipment, such as a an electric door release, relay RY1's contacts should be brought out to a dual screw-type terminal strip. The decoder's combination should be wired after the encoder key is completed.

The encoder key (Fig. 2), does not have its own power source because it obtains power from the decoder when it is plugged in; hence, the key consists of only IC2, resistors R4 and R5, and capacitor C3.

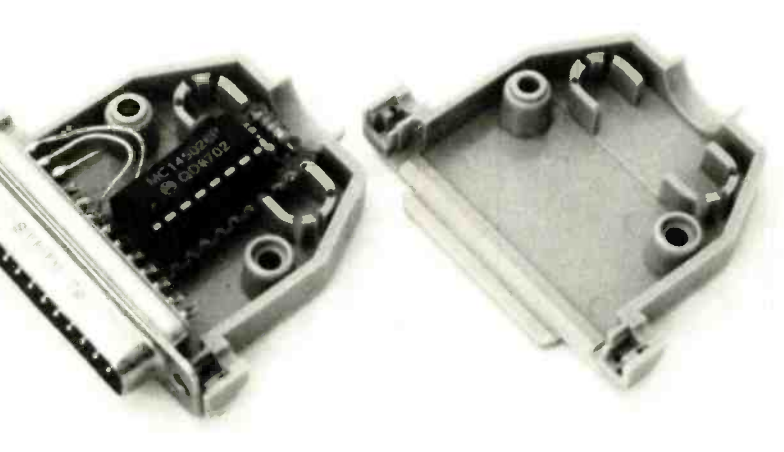


FIG. 3—THE ENCODING ASSEMBLY can be built small enough to fit within the hood of a DB-25 connector. Alternately, you can use any kind of connector large enough to house the circuit.

To set the combination, the encoder's address pins are connected to ground, the 5-volt power supply (pin 16), or left open. One way to program the address pins would be to use a set of switches to place each pin at to one of the three states. However, to keep the key pocket size, the pins are soldered directly to ground, to 5 volts, or simply left with no connection. Soldered pins allow the key to be made small enough to fit inside a conventional DB-25-type connector, although the soldered-pin programming cannot be easily changed to a new code.

If you only expect to set the combination once, then it would be appropriate to simply wire two or more address pins of the encoder and decoder to the positive supply and/or ground to generate the system's combination. If you anticipate having to change the combination, then you might want to consider putting switches on the address pins of the lock and key so that the addresses could be easily changed. But as stated earlier, doing so would mean the key would be larger. A compromise is to use switches on the decoder's address pins and take the time to rewire the key if you change the combination.

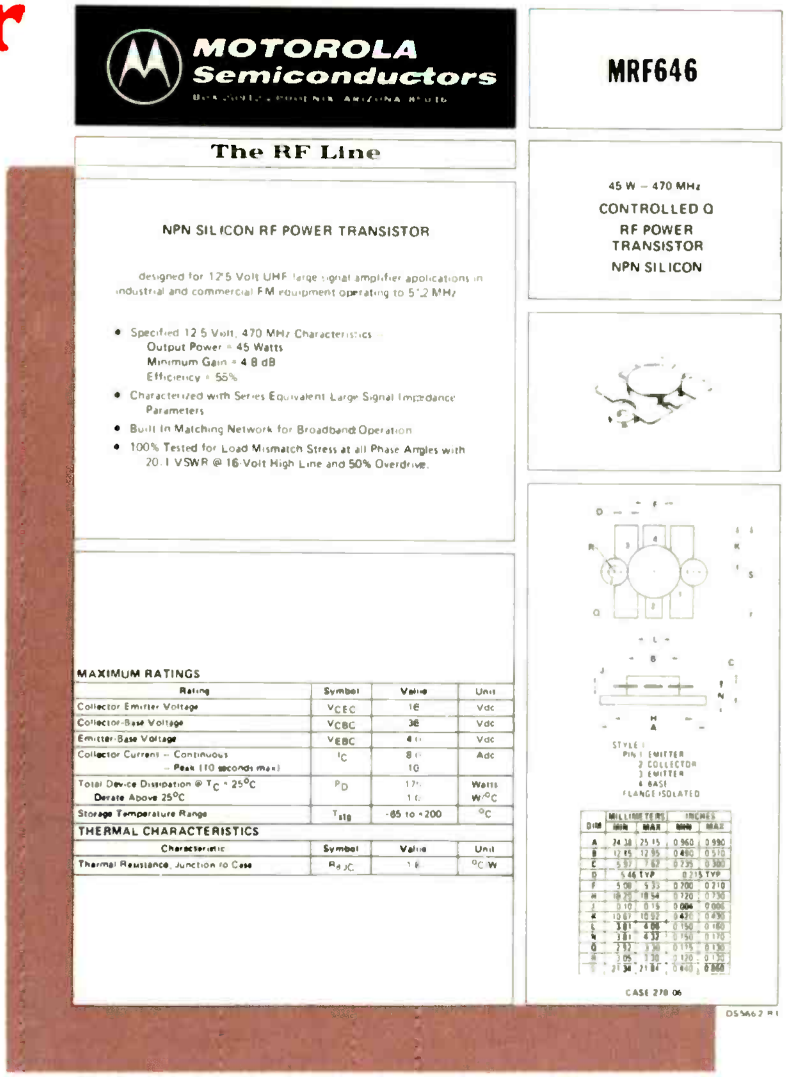
To make the electronic key, locate a connector that will hold IC2 along with the two resistors and the capacitor. Fortunately, the commonly-available DB-25-type connector shell has just enough space for those components, but feel free to use whatever case or connector meets your needs. Regardless of the kind of connector used as the key, it must have at least three terminals available for connection to the lock: one for power, one for data, and

continued on page 129

Understanding Data Sheets of RF Power Transistors

Data sheet parameters are what tell you whether an RF power transistor can do the job.

NORMAN E. DYE,
Motorola Semiconductor Products


MOTOROLA Semiconductors

MRF646

The RF Line

45 W — 470 MHz
CONTROLLED Q
RF POWER TRANSISTOR
NPN SILICON

NPN SILICON RF POWER TRANSISTOR

designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz

- Specified 12.5 Volt, 470 MHz Characteristics — Output Power = 45 Watts; Minimum Gain = 4.8 dB; Efficiency = 55%
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- Built In Matching Network for Broadband Operation
- 100% Tested for Load Mismatch Stress at all Phase Angles with 20:1 VSWR @ 16-Volt High Line and 50% Overdrive.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	16	Vdc
Collector-Base Voltage	V_{CBO}	36	Vdc
Emitter-Base Voltage	V_{EBO}	4.0	Vdc
Collector Current — Continuous — Peak (10 seconds max)	I_C	8.0 10	Adc
Total Device Dissipation @ $T_C = 25°C$ Derate Above 25°C	P_D	175 1.0	Watts W/°C
Storage Temperature Range	T_{stg}	-65 to +200	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.0	°C/W

STYLE 1: PIN 1. EMITTER 2. COLLECTOR 3. EMITTER 4. BASE FLANGE ISOLATED

CASE 278-06

DATA SHEETS OFTEN ARE THE SOLE source of information about the capabilities and characteristics of a product. That is particularly true of RF power transistors that are used throughout the world, so it's important that the user and the manufacturer of a product speak a common language; i.e., what the semiconductor manufacturer says about a transistor is understood fully by the circuit designer.

In this article we will review RF-power-transistor parameters from maximum ratings to functional characteristics. We'll cover critical specifications, and how values are determined and what they signify. Finally, we'll cover possible tradeoffs in device specifications and their importance to the circuit-design engineer.

But before we get into the subject, let's take time out for a brief explanation of the terms die, bond pads, and top metal, because, although those terms are used when describing RF-power-transistor parameters, they may be unfamiliar to many of you.

Although we consider an RF power transistor to be a "unit" device that visually resembles a transistor, it is, in fact, an integrated circuit that consists of several hundred to more than a thousand individual parallel-connected transistors on a single silicon chip. In this instance, the chip, with all its integral transistors, is called a *die*. The *bond pads* are the connections for the both the main emitter, base, and collector leads, and the individual transistors. The term *top metal* refers to the deposited metal wires that interconnect the individual bond pads. We'll cover dies and top metal in greater detail later.

DC specifications

Basically, RF transistors are characterized by two types of specifications: *DC* and *functional*. By definition, the DC specifications consist of breakdown voltages, leakage currents, h_{FE}, or beta (DC gain), and inter-element capacitances. The functional specifications cover AC parameters: gain, ruggedness, noise figure, and input and output impedance. Thermal characteristics do not fall cleanly into either category since thermal resistance and power dissipation can be either DC or AC, so we will treat thermal resistance as a special specification and give it its own heading of thermal characteristics. Figure 1 shows how DC and functional specifications are arranged on a typical data sheet.

Breakdown voltages are largely determined by material resistivity and junction depths. Each junction voltage—collector/base and emitter/base—is generally specified at a current level that is well within the safe-operating limits of a reverse-biased junction. The specifications are conventional and are generally standard throughout the semiconductor industry.

Leakage currents (defined as reverse-biased junction currents that occur prior to avalanche breakdown) are likely to be more varied in their specification and also more informative. Leakage currents are a result of material defects: mask imperfections and/or undesired impurities that enter during wafer processing. Some sources of leakage currents are potential reliability problems, most are not. Leakage currents that are material related, such as stacking faults and dislocations, or pipes, created by mask defects and/or processing inadequacies, result in leakage currents that are constant with time and, if initially acceptable for a particular application, will remain so. (Since they do not pose long-term reliability problems.) Some manufacturers do not list leakage

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS					
Collector-Emitter Breakdown Voltage (I_C = 20 mAdc, I_B = 0)	BV_{CEO}	16	—	—	Vdc
Collector-Emitter Breakdown Voltage (I_C = 20 mAdc, V_{BE} = 0)	BV_{CES}	36	—	—	Vdc
Emitter-Base Breakdown Voltage (I_E = 5.0 mAdc, I_C = 0)	BV_{EBO}	4.0	—	—	Vdc
Collector Cutoff Current (V_{CE} = 15 Vdc, V_{BE} = 0, T_C = 25°C)	I_{CES}	—	—	5.0	mAdc
ON CHARACTERISTICS					
DC Current Gain (I_C = 4.0 Adc, V_{CE} = 5.0 Vdc)	h_{FE}	40	70	100	
DYNAMIC CHARACTERISTICS					
Output Capacitance (V_{CB} = 12.5 Vdc, I_E = 0, f = 1.0 MHz)	C_{ob}	—	90	125	pF
FUNCTIONAL TESTS					
Common Emitter Amplifier Power Gain (V_{CC} = 12.5 Vdc, P_{out} = 45 W, I_C (Max) = 5.8 Adc, f = 470 MHz)	G_{pe}	4.8	5.4		dB
Input Power (V_{CC} = 12.5 Vdc, P_{out} = 45 W, f = 470 MHz)	P_{in}		13	15	Watts
Collector Efficiency (V_{CC} = 12.5 Vdc, P_{out} = 45 W, I_C (Max) = 5.8 Adc, f = 470 MHz)	η	55	60		%
Load Mismatch Stress (V_{CC} = 16 Vdc, P_{in} = Note 1, f = 470 MHz, VSWR = 20:1, All Phase Angles)	ψ*	No Degradation in Output Power			
Series Equivalent Input Impedance (V_{CC} = 12.5 Vdc, P_{out} = 45 W, f = 470 MHz)	Z_{in}		1.4 + j4.0	—	Ohms
Series Equivalent Output Impedance (V_{CC} = 12.5 Vdc, P_{out} = 45 W, f = 470 MHz)	Z_{OL}**		1.2 + j2.8	—	Ohms

Notes:

1. P_{in} = 150% of Drive Requirement for 45 W output @ 12.5 V

* ψ = Mismatch stress factor — the electrical criterion established to verify the device resistance to load mismatch failure. The mismatch stress test is accomplished in the standard test fixture (Figure 1) terminated in a 20:1 minimum load mismatch at all phase angles.

** Z_{OL} = Conjugate of the load impedance into which the device output operates at a given output power, η_T, and frequency.

FIG. 1—THIS IS JUST A SMALL SAMPLE of the kind of data you'll find in a data sheet.

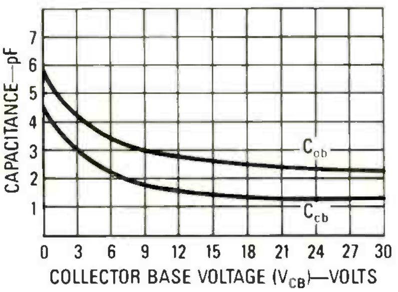


FIG. 2—THE OUTPUT AND INPUT JUNCTION CAPACITANCES can be read directly from curves provided in the data sheet.

current specifications to allow more wafer/dies to pass quality inspection.

On the other hand, leakage current caused by channels created by mobile impurities in the oxide (primarily sodium) tend to change with time and can lead to a progressive increase in leakage current. That can render the device useless for a specific application. Distinguishing between sources of leakage current can be difficult; that is one reason why devices designed for military use require HTRB (*H*igh *T*emperature *R*everse *B*ias) and burn-in testing. Even for commercial applications a leakage-current limit should be included in any complete device specification.

DC parameters such as h_{FE} and C_{ob} (output capacitance) need little comment. (Typically, for RF devices h_{FE}. Instead, AC gain at the desired operating frequency is specified). Keep in mind, however, that DC beta (h_{FE}) is related to AC beta (functional gain). AC beta will usually track DC beta, particularly at the lower RF frequencies. Generally, RF device manufacturers do not like to have tight limits placed on h_{FE}. That's because:

a. The specification is unrelated to performance

b. Difficulty in control in wafer processing

c. Other manufacturing constraints, dictated by the device's AC specifications, preclude specific limits for h_{FE}.

A good rule of thumb for h_{FE} is to set a maximum to minimum ratio of not less than 3, with the minimum h_{FE} value selected to assure you of an adequate AC gain margin.

Output capacitance is an excellent indicator of relative device size (base area), provided that the major portion of the output capacitance is created by the base-collector junction and not parasitic capacitance arising from bond pads and other top metal of the die. Keep in mind that junction capacitance will vary with voltage (Fig. 2), while parasitic capacitance is unaffected by voltage variations. Also, in comparing devices, it's important to note the voltage at which a given capacitance is specified. No industry standard exists. The preferred voltage at Motorola, for instance, is the transistor's V_{CC} rating; i.e., 12.5 volts for 12.5-volt transistors, 28 volts for 28-volt transistors, etc.

Maximum ratings

Maximum ratings, such as those shown in Fig. 3 for a typical RF power transistor, tend to be the most frequently misunderstood group of device specifications. Ratings for *maximum junction voltages* are straightforward and simply reflect the minimum values set forth in the DC specifications for breakdown voltages. If the device in question meets the specified minimum breakdown voltages, then voltages less than the minimum will not cause junctions to reach reverse-bias breakdown, with the potentially destructive current levels that can result.

On the other hand, a maximum rating for power dissipation (P_d) is closely entwined with thermal resistance (θ_{jc}). In reality, maximum P_d is a fictitious number—a kind of figure of merit—because it is based on the assumption that the case temperature is maintained at 25°C. However, providing that everyone arrives at the value in a similar manner, the maximum P_d rating is a useful tool for comparing devices.

Thermal resistance

The rating begins with a determination of the thermal resistance of the die to its case. Knowing θ_{jc}, and assuming a maximum die temperature, one can easily determine maximum P_d (based on the previously stated case temperature of 25°C). Measuring θ_{jc} is normally done by monitoring the case temperature (T_c) of the device while it operates at or near rated output power (P_o) in an RF circuit. Simultaneously, the die temperature (T_j) is measured by an infrared microscope (see Fig. 4) that has a spot-size resolution as small as 1-mil. Normally, several readings are taken over the surface of the die and an average value is used to specify T_j.

It is true that temperatures across a die will typically vary over the range of 10–20°C. Normally, the die uses ballasting to insure that the heat is dispersed more or less evenly across the die's surface. Without ballasting the heat would be concentrated near the middle of the die. Ballasting is a technique that reduces the emitter current to the transistors in the middle of the die below the emitter current of the transistors located at the edges of the die. In that way the middle transistors dissipate less heat than those at the edges, and the heat dissipation is spread more or less evenly across the die. A poorly designed die—one with improper ballasting—could result in worst-case hot-spot temperatures that vary between 40–50°C. Likewise, poor die bonds (see Fig. 5) can result in hot spots.

By measuring the DC and RF T_c and T_j, along with P_o and P_{in}, it's possible to calculate θ_{jc} from the formula:

$$\theta_{jc} = \frac{T_j - T_c}{P_{IN} - P_O}$$

Typical values for an RF power transistor might be $T_j = 130°C$; $T_c = 50°C$; $V_{CC} = 12.5$ Volts; $I_C = 12$ amperes; P_{in} (RF) = 10 watts; P_o (RF) = 80 watts. Thus:

$$\theta_{jc} = \frac{130 - 50}{10 + (12.5 \times 12) - 80} = \frac{80}{80} = 1°C/W$$

Several reasons dictate a conservative value be placed on θ_{jc}. First, thermal resistance increases with temperature (and we realize $T_c = 25°C$ is *not* realistic). Second, T_j is not a worst-case number. And third, by using a conservative value of θ_{jc} a realistic value is determined for $P_{d(max)}$. Generally, Motorola's practice is to publish θ_{jc} numbers approximately 25% higher than that determined by the measurements previously described, or for the case illustrated, a value of $\theta_{jc} = 1.25°C/W$.

Now a few words about die temperature: Reliability considerations dictate a safe value for an all Au (gold) system (die top metal and wire) to be 200°C. Once $T_{j(max)}$ is determined along with a value for θ_{jc}, maximum P_d is:

$$P_{D(MAX)} = \frac{T_{j(max)} - 25°C}{\theta_{jc}}$$

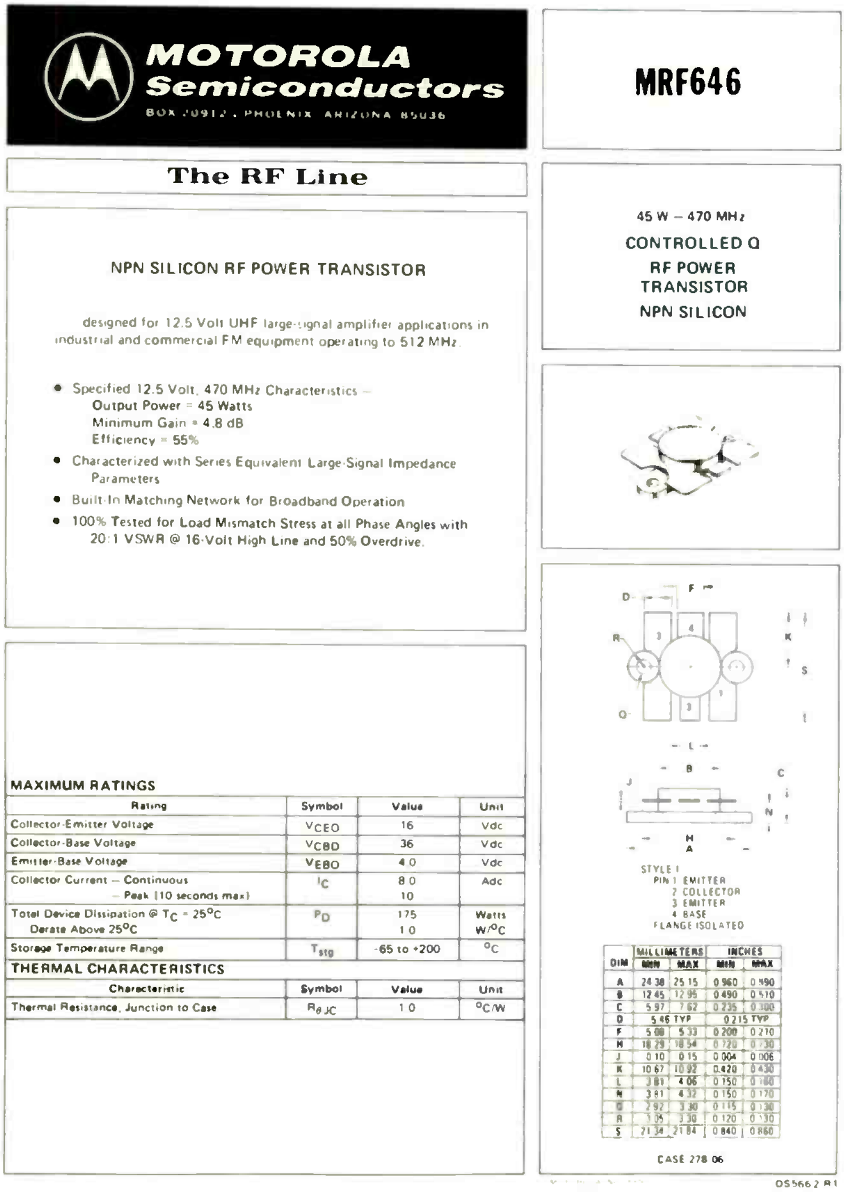
Specifying maximum P_d for $T_c = 25°C$ makes it necessary to derate maximum P_d for any value of T_c above 25°C. The derating factor is simply the reciprocal of θ_{jc}.

Maximum collector current

Maximum collector current (I_c) is probably the most subjective maximum rating on RF-transistor data sheets. It can, and is, determined in a number of ways—each leading to different maximum values. Actually, three possible current limitations can exist in RF transistors. One is package-related, one is wire-related, and a third is die-related. Collector current in most older, lower-frequency transistors is wire-and/or package-limited, which is why those parts generally have $I_{c(max)}$ determined by collector voltage (or by BV_{CEO} for added safety). Higher-voltage parts (such as 28 and 50 volts) tend to be wire-limited; when operated at lower voltage those components can safely handle sizable amounts of current. Lower voltage parts (such as 7.5 and 12.5 volts), however, tend to be package-limited; those should have $I_{c(max)}$ determined by power-dissipation considerations.

Most modern, high-frequency transistors are die-limited because of high current densities that result from their very small current-carrying conductors; those densities can lead to metal migration and premature failure. For those type of transistors, $I_{c(max\%)}$ is determined by using Black's equation for metal migration. That equation calculates a *m*ean-*t*ime-*b*etween-*f*ailures (MTBF) based on current density, temperature, and the type of metal. At Motorola, MTBF is generally set at greater than 7 years, and maximum die temperature is set at 200°C. For plastic-packaged transistors, maximum T_j is set at 150°C and $I_{c(max)}$ is calculated using the resulting current density along with a knowledge of the die geometry and top-metal thickness.

It is up to the transistor manufacturer to specify an $I_{c(max)}$ that is based on the appropriate limitation (die, wire, package). Note, however, that the limitation depends to some extent on the application. Circuit designers should consult the manufacturer for addi-



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designed for 12.5 Volt UHF large-signal amplifier applications in industrial and commercial FM equipment operating to 512 MHz.

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- Characterized with Series Equivalent Large-Signal Impedance Parameters
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45 W – 470 MHz
CONTROLLED Q
RF POWER
TRANSISTOR
NPN SILICON

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector-Emitter Voltage	V_{CEO}	16	Vdc
Collector-Base Voltage	V_{CBO}	36	Vdc
Emitter-Base Voltage	V_{EBO}	4.0	Vdc
Collector Current — Continuous — Peak (10 seconds max)	I_C	8.0 10	Adc
Total Device Dissipation @ T_C = 25°C Derate Above 25°C	P_D	175 1.0	Watts W/°C
Storage Temperature Range	T_{stg}	-65 to +200	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.0	°C/W

STYLE 1
PIN 1 EMITTER
2 COLLECTOR
3 EMITTER
4 BASE
FLANGE ISOLATED

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	24.38	25.15	0.960	0.990
B	12.45	12.95	0.490	0.510
C	5.97	7.62	0.235	0.300
D	5.46 TYP		0.215 TYP	
F	5.08	5.33	0.200	0.210
H	18.29	18.54	0.720	0.730
J	0.10	0.15	0.004	0.006
K	10.67	10.92	0.420	0.430
L	3.81	4.06	0.150	0.160
N	3.81	4.32	0.150	0.170
Q	2.92	3.30	0.115	0.130
R	3.05	3.30	0.120	0.130
S	21.34	21.84	0.840	0.860

CASE 278-06

DS5662 R1

FIG. 3—MAXIMUM RATINGS AND THERMAL CHARACTERISTICS are also provided by the data sheet.

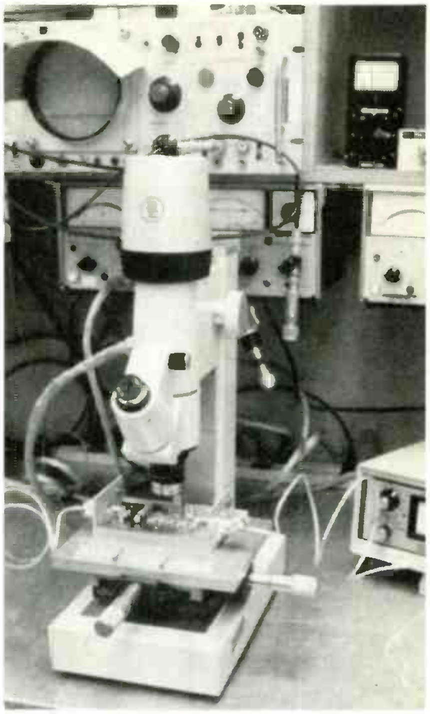


FIG. 4—AN INFRARED MICROSCOPE is used to measure the temperature of various spots on the die.

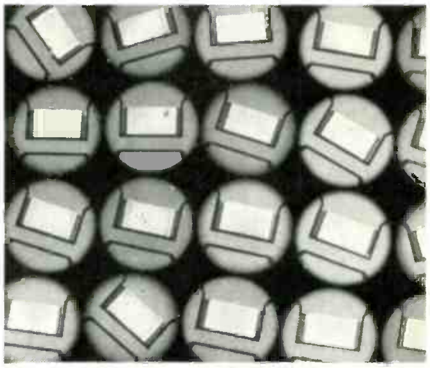


FIG. 5—AN X-RAY PHOTO SHOWS some transistor-cells that are poorly bonded to the die, which will result in hot-spots.

tional information if $I_{c(max)}$ for a specific application.

Storage temperature

Storage temperature is another maximum rating that is frequently not given the attention it deserves. A -55°C to 200°C range has more or less become the industry standard. For single, metal, hermetic-packaged devices, an upper limit of 200°C creates no reliability problems. However, plastic encapsulated or epoxy-sealed devices should not be subjected to temperatures above 150°C.

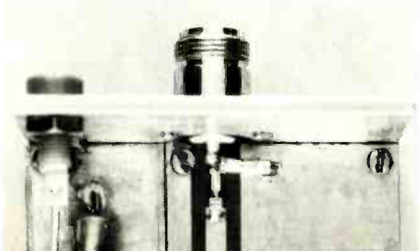


FIG. 6—AN ACTUAL WORKING TEST CIRCUIT is used to determine the parameters of an RF power transistor,

Functional characteristics

The functional characteristics of an RF transistor are by necessity tied to a specific test circuit, such as the one shown in Fig. 6, because without specifying a circuit, parameters like gain, reflected power, efficiency—even ruggedness—are meaningless. Furthermore, most test circuits that are used by RF-transistor manufacturers today (even those used to characterize devices) are designed to allow for easy insertion and removal of the device under test. For mechanical reasons, that sometimes limits device performance, which explains why the performance attained by users frequently exceeds that indicated in data-sheet curves. On the other hand, a circuit used to characterize a device is usually narrowband and tunable, which results in higher gain than attainable in a broadband circuit. Unless otherwise stated, it can be assumed that curves such as *P_o vs. frequency* are generated on a point-by-point basis by tuning a narrow-band circuit across a band of frequencies and, thus, represents what can be achieved at a specific frequency of interest with proper impedance matching.

Broadband, fixed-tuned test circuits are best for testing the functional performance of an RF transistor. Fixed-tuning is particularly important in assuring the manufacturer, and the user of product consistency; i.e., that the devices made tomorrow will be identical to the devices made today.

Tunable, narrow-band circuits have led to the requirement that users and manufacturers use "correlation units" to assure product consistency over a period of time. Fixed-tuned circuits minimize (if not eliminate) the need for correlation, and that compensates for the increased constraints they place on the manufacturer of the device. On the other hand, manufacturers like tunable test circuits because they allow adjustments that can compensate for variations in die fabrication and/or device assembly. Unfortunately, gain is normally less in a broadband circuit than it is in a narrowband circuit, so transistor manufacturers often use narrow-band circuits to improve product specifications for competitive reasons (that is called "specsmanship"). A good compromise for transistor manufacturers is to use narrow-band circuits with all tuning adjustments "locked" in place. The moral to all of that is that data-sheet readers should be careful to note the test circuit used when comparing specific parameters.

Ruggedness

For RF power transistors, the parameter of *ruggedness* takes on considerable importance. Ruggedness is the transistor's ability to withstand extreme mismatch conditions in operation, which causes large amounts of output power to be "dumped" back into the transistor, without altering its performance or reliability. In many circuits, impedances presented to a device are variable and unpredictable and can abruptly change. In portables, the antenna may be placed against a metal surface; in mobiles, perhaps the antenna is broken off or inadvertently disconnected from the radio. An RF power transistor must be able to survive such load mismatches. A realistic possibility for mobile radio transistors (although not a normal situation) is the condition whereby the RF power device "sees" a worst-case load mismatch (an open circuit, any phase angle), along with maximum V_{CC}, and greater-than-normal input drive—all at the same time. Thus, the ultimate test for ruggedness is to subject a transistor to a test wherein RF P_{in} is increased up to 50% above that value necessary to create the rated P_o; V_{CC} is increased about 25% (from 12.5 volts to 16 volts for mobile transistors), and then the load-reflection coefficient is set at a unity while its phase angle is varied through all possible values from 0° to 360°.

Testing ruggedness

Ruggedness tests come in many forms. Many older devices (and even some newer ones) simply have no ruggedness specification. Others are said to be "capable of" withstanding load mismatches. Still others are guaranteed to withstand load mismatches of 2:1 VSWR to ∞:1 VSWR at *rated output power*. A few truly rugged transistors are guaranteed to withstand 30:1 VSWR at all phase angles (for all practical purposes, 30:1 VSWR is the same as ∞:1 VSWR) with both overvoltage and overdrive. Once again, it is up to the user to match his circuit requirements against device specifications.

Then, as if the whole subject of ruggedness is not confusing enough, manufacturers "muddy the waters" further by stating what constitutes *passing the ruggedness test*. The words generally say that after the ruggedness test the device under test "shall have no degradation in output power." A better phrase would be "no measurable change in output power." But even that is not the best because, unfortunately, the device under test can be damaged by the ruggedness test and still have "no degradation in output power." As stated earlier, today's RF power transistors consist of up to 1000 or more small transistors connected in parallel. Emitter resistors—ballasts—are placed in series with groups of those transistors in order to better control power sharing throughout the transistor's die. It is well known by semiconductor manufacturers that a high percentage of an RF power transistor's die (say up to 25–30%) can be destroyed and the transistor will still able to deliver its rated power at its rated gain, at least for some period of time. If a ruggedness test destroys a high percentage of transistor-cells in an RF power transistor, then it is likely that a second ruggedness test (by the manufacturer or by the user while in his circuit) would result in additional damage, leading to premature failure of the device.

A more scientific measurement of "passing" or "failing" a ruggedness test is called ΔV_{re}—the change in emitter resistance before and after the ruggedness test. V_{re} is determined largely by the net value of emitter resistance in the transistor die. Thus if cells are destroyed, emitter resistance will change with a resultant

continued on page 126

POOR MAN'S STORAGE SCOPE

DUKE BERNARD

With nothing more than an oscilloscope, a video camera, and a VCR, hobbyists can have many of the advantages of fancy logic analyzers and digital storage scopes.

WHEN A NEWLY DESIGNED PIECE OF ELECTRONICS equipment or an existing piece of equipment that has gone bad is being debugged, it's common practice to trace signal paths by using an oscilloscope. With digital equipment, logic analyzers are often used to check timing and even store the waveforms on floppy disk for future evaluation. Such equipment is very convenient to use, but very expensive.

When professional designers do a thorough job of evaluating a new design, they record the waveforms at each major node in the system. Traditionally, that has been done by taking Polaroid photographs of oscilloscope traces. The process requires fastening the scope probe to a circuit trace on a printed circuit board long enough to take the photograph, developing the print, recording the appropriate oscilloscope scales, and then moving on to the next location to repeat the process. Things proceed in an orderly manner when documenting a new design that is working properly, though it surely helps to have an assistant. However, when either a new design or an existing system is faulty, circuit tracing usually becomes less orderly, with the scope probe stuck here and there looking for suspect signals.

Life gets even more interesting when the system works perfectly 99% of the time, but has a glitch that causes an error every few hours or so. In industry, troubleshooting such a glitch generally calls for powerful logic analyzers that can be triggered by the fault condition and then recall the signals that preceded the error. Unfortunately, the hobbyist and the small-business electronics professional generally cannot afford the tens of thousands of dollars that such equipment costs.

With a little ingenuity, however, commercially available video equipment can be made to do many of the tasks of much more expensive equipment, and in some cases do it better. Unlike most commercial logic analyzers, which record only one's and zero's, the technique described in this article works well for either digital or analog signals. It was first used by the author to find an intermittent failure in an asynchronous coupled multi-CPU digital system. It has subsequently been used for debugging simpler systems. It can also be used to turn a simple oscilloscope into a storage scope for reviewing transient waveforms.

The concept is simple and rather straightforward. All that is required is a VCR with top-quality special effects; that is, clean, jitter-free stop frame, fast forward and reverse, and slow motion such as that provided by the top-of-the-line four-head units or the new digital VCR's that feature digital frame storage. A video camera and a video monitor complete the list of required equipment.

A word about the video camera: A high-end unit is not required; a simple black-and-white surveillance camera will do fine. However, if an expensive color camera is used, to prevent burning the image tube care should be taken not to leave the camera pointed at a very bright trace on the scope for long periods of time. That is less of a concern if the camera uses a solid-state imager.

More savings

In addition to the obvious savings in equipment cost, it's interesting to compare the number of oscilloscope traces that can be recorded on a two hour roll of VCR tape versus the cost of trying to capture the same amount of information on film. Assume that for recording the waveforms of a new system, each point in the system is recorded for 10 seconds. That is generally enough time to record the scope settings and what point in the circuit is being monitored on the voice track. That yields six traces recorded per minute, or 720 in two hours. At about 50 cents a print for instant film, to record as many traces the cost would be $360. Compare that to the cost of even the highest quality T120 tape. At even faster recording speeds an even greater savings can be realized.

While hard copies are often desired in addition to the tape recordings, the taped waveforms can be reviewed at leisure and the most important ones photographed off the TV monitor, although with some lim-

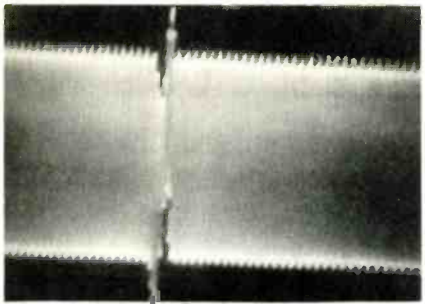


FIG. 1—USING A VCR, this glitch in the system clock waveform was found.

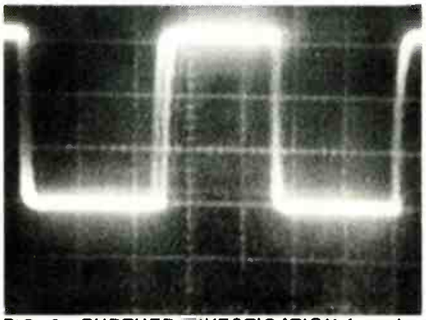


FIG. 2—FURTHER INVESTIGATION found a waveform with a timing shift during alternate leading edges.

itations. Meanwhile, a very extensive set of waveforms have been captured, which can be reviewed later if the system develops a problem.

A typical application

The problem that initiated the effort to record oscilloscope traces with a VCR was one of those periodic, hard-to-trace glitches that had cropped up during the testing of a new design. In frustration, we decided to record various oscilloscope waveforms with a VCR until one was found that changed appreciably just before the system being tested recorded an error (since the system being tested had a real time clock, it was possible to let it run to give an indication of when an error occurred).

Once an error was noted, the VCR tape was advanced to the approximate time of the error and the waveforms were examined. Finally, a glitch was found on the system's clock waveform; that is shown in Fig. 1. At first, the glitch was thought to be the direct cause of the error, but it wasn't. However, by knowing what to look for, the same conditions that created the glitch in the clock waveform (several high-current devices switching simultaneously) were programmed, and more waveforms were recorded.

The waveform shown in Fig. 2, a sub-clock signal, was found to be the culprit. As shown by the dual-trace leading edge, the signal's timing changed on alternate leading edges during the time that the system clock had the disturbance, causing a synchronization problem. That timing change was further traced to ringing on the waveform, as shown in Fig. 3.

Budget storage scope

Having found the VCR so useful in recording occasionally occurring waveform disturbances for future review, we looked into using a VCR as a "poor-man's" storage oscilloscope. Events that happen as a transient rather than a repetitive occurrence are hard to capture on an ordinary oscilloscope. One example is speech. With so much interest in speech synthesis and speech recognition, it's often necessary to observe the patterns created by different words and compare their similarities and differences. But since speech waveforms are transient in nature, it's hard to do comparative work using only a standard scope.

FIG. 3—RINGING ON THE WAVEFORM was finally found to be the cause of the problem.

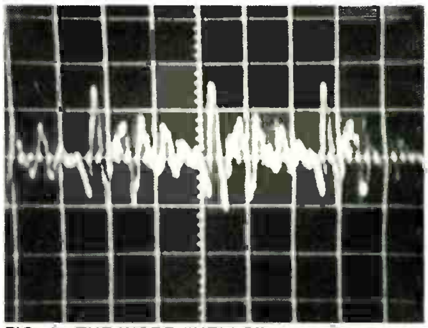


FIG. 4—THE WORD "HELLO" as captured by a video camera and a VCR. The varying intensity of the trace is caused by using a time base longer than a single TV field (about 16 milliseconds).

Recording a waveform on a VCR and then playing it back a frame at a time allows the repetitious patterns in certain speech sounds to be observed. Part of the word "hello" as captured by a VCR is shown in Fig. 4. Note the non-uniform appearance of the trace. That is caused by using a time base that is longer than the TV field rate of 16 milliseconds (1/60 second). Then, the camera can not capture a trace in a single field; instead it does so over two or more fields, causing a stroboscopic effect. The fainter parts of the image are seen only because of image persistence on the CRT screen and/or in the camera pickup. That does not prevent you from examining the waveform, since you can use the frame advance to examine the event one frame at a time, but it does make it difficult to obtain a good hard copy (photograph) from the monitor, as evidenced by Fig. 4.

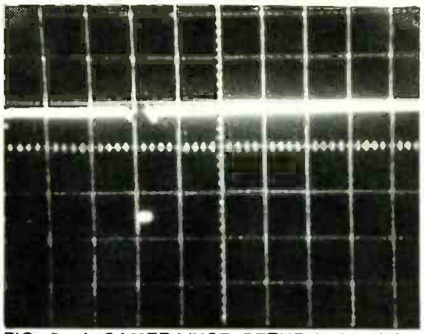


FIG. 5—A CAMERA/VCR SETUP is ideal for viewing short duration transients, such as a voltage interruption caused by a relay's contact bounce.

To get good results when using a VCR's frame-advance feature as a poor-man's storage scope requires some experimenting to obtain the proper trace intensity. Since most video cameras can accomodate fairly low light levels, a trace barely visible when viewed directly may show up quite well when viewed on a TV monitor. To set intensity, then, repeatedly trigger the scope, adjusting the trace intensity until it looks right on the monitor.

Let's close out our discussion by looking at a simple application. One problem that plagues circuit designers is that of contact bounce, a mechanical problem that all mechanical switches and relays are subject to.

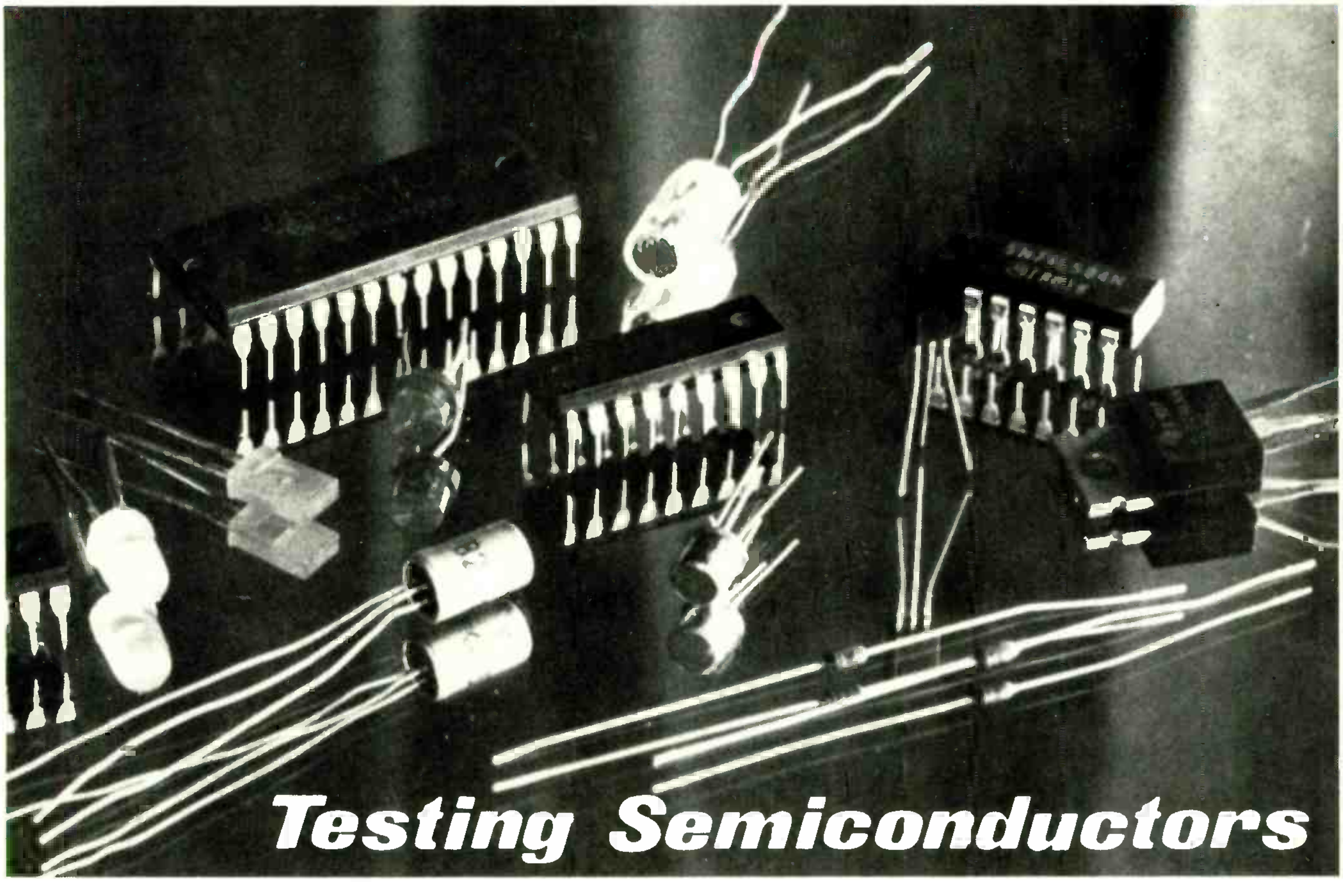
Figure 5 shows the output waveform from a relay. When the contacts close, the voltage goes high, triggering the scope. A few milliseconds later, however, the contacts bounce open and closed, creating a momentary voltage interruption.

The transient caused by the bounce can disrupt the proper operation of a circuit and is often difficult to eliminate. But by using a VCR to record the scope trace, you can study the waveform at leisure, allowing you to be certain that your fix is working properly.

Other uses

As you can see, a VCR can make collecting and analyzing data over long periods of time much easier, especially if you can't afford an expensive logic analyzer or a storage scope. And a VCR can be used to record any instrument's readings over time.

For example, the author has used a VCR to record changes in an oscillator's frequency versus temperature. After connecting them to the circuit under investigation, a frequency meter and an electronic thermometer were placed side-by-side and their readings were recorded by a VCR as the circuit was warmed. Fast-forward scanning was later used to find appropriate temperature intervals, allowing the oscillator frequency-versus-temperature data points to be recorded very quickly. **R-E**



Testing Semiconductors

This time we examine the AC characteristics of the op-amp.

TJ BYERS

Part 7 LET'S BEGIN WITH AN op-amp characteristic that is measured under DC conditions, but that relates directly to AC characteristics: open-loop voltage gain, or A_{VOL}. Often you see A_{VOL} referred to as the large-signal voltage gain. Basically, it is the gain of the amplifier with no feedback.

Open-loop voltage gain is defined as the ratio of the change in output voltage to the voltage difference between the differential inputs. It is measured by applying a voltage between the two inputs and noting the change in output voltage.

Open-loop gain is important because it reflects the overall quality of the amplifier. Ideally, A_{VOL} should be infinite, but when we come to real-world devices, it's not. As open-loop gain decreases, there is a corresponding deterioration in drift, stability, input impedance, output impedance, and bandwidth.

Although op-amp manufacturers specify large-signal gain for a DC input, A_{VOL} is generally measured with a 5-Hz AC signal. Doing so greatly simplifies the measurement, and the frequency is low enough that the A_{VOL} obtained by that method approximates DC A_{VOL} so closely that any discrepancy is negligible.

Open-loop gain can be measured with the test setup shown in Fig. 1. First, we must cancel the effects of input-offset voltage and current (V_{OS} and I_{OS}, respectively) by flipping the function switch to the TEST position and adjusting R7 until the DC voltmeter indicates zero.

Then place S1 in the CAL position and adjust the signal generator until the AC voltmeter reads 10 volts. Return S1 to the TEST position and record the measurement as V_{IN}. Then calculate A_{VOL} as follows:

$$A_{VOL} = (1/V_{IN}) \times 10^4$$

The value of A_{VOL} is likely to exceed 50,000, and that makes it convenient to express it as a ratio between output volts and input millivolts. A value of 50,000, for example, corresponds to 50V/mV.

In fact, you can measure the value expressed by the ratio directly by setting the input voltage to 100 mV (rms) and reading the value on the 10-volt scale of the AC meter (in the CAL position). A reading of 1 volt indicates a ratio of 10V/mV, and a reading of 10 volts represents 100V/mV.

Manufacturers often specify A_{VOL} in decibels. To convert the amplification factor into decibels, use the following formula:

$$A_{VOL}\,(\mathrm{dB}) = 20 \log A_{VOL}$$

The value of A_{VOL} on the right-hand side of the equation is measured as described above.

Be aware that most data sheets list A_{VOL} with a specific load attached to the output—which usually is the minimum impedance of the instrument that is used to make the measurement. Typically, you will find the value of R_L to be 2000 ohms or greater.

Bandwidth

As the frequency of the input signal increases, open-loop gain decreases. Many reasons are cited for that, but the major cause is reduced performance by the transistors in the op-amp.

What occurs, in essence, is that the output voltage of the operational amplifier remains stable up to a point. After that point, open-loop gain drops off rapidly, as shown in Fig. 2. It is generally agreed that

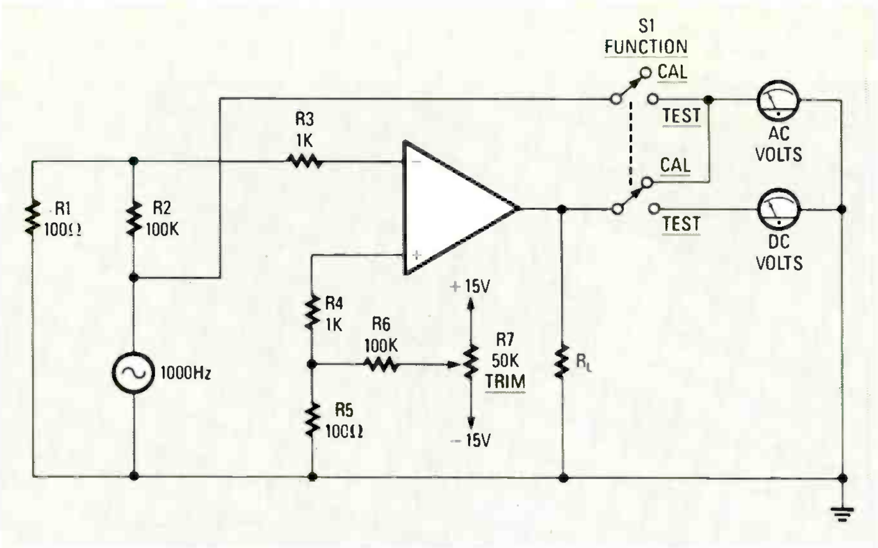


FIG. 1—MEASURE OPEN-LOOP GAIN (A_{VOL}) after adjusting R7 for null output.

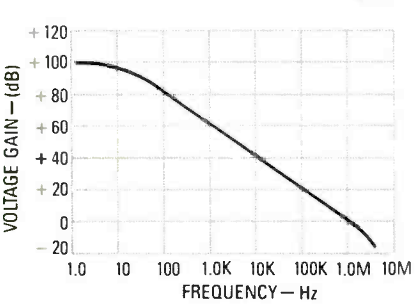


FIG. 2—FREQUENCY RESPONSE of an op-amp is constant up to a point, after which it drops off at a rate of 6 dB per octave. Cutoff frequency (f_T) is reached when the amplitude of the output voltage equals that of the input signal.

after the gain decreases by 3 dB (i. e., falls to 70% of its original value), the decline in performance makes it undesirable for many applications. Consequently, the open-loop bandwidth, BW_{OL}, is specified at the −3-dB point.

Further increases in input frequency cause further reduction in output voltage at the rate of 6 dB per octave. Eventually a point is reached where the amplifier's gain equals one (unity gain). That is, the amplitude of the output signal equals that of the input signal. Not surprisingly, that is called the unity-gain-bandwidth factor.

Sometimes unity-gain bandwidth is simply listed as BW, implying total bandwidth, rather than the −3-dB bandwidth. But more often than not, it is described as f_T. Continuing increases in input frequency beyond that point result in negative amplification, or attenuation.

Both bandwidth parameters can be measured using the circuit shown in Fig. 1. First stabilize the amplifier by compensating for any offset values—you do that using the procedure outlined earlier. It is not necessary for the amplifier's DC output to be at exactly zero volts, but too much of an offset will give a false reading. Next, set the generator to deliver a 5-Hz signal, and adjust the generator's output so that the meter reads 1 volt. Now increase the input frequency until the meter reads 0.707 volt. That is the 3-dB bandwidth point, or BW_{OL}.

Continue sweeping the frequency while keeping your eyes on the meter. You will notice a pronounced decline in output as you do. When the output voltage decreases to about 1/1000 of the input (1 millivolt) you have reached the unity-gain bandwidth, f_T. For an accurate measurement, you must make sure that the input voltage remains constant during the frequency sweep.

Gain-bandwidth product

Another commonly specified op-amp characteristic is called *G*ain-*B*and*W*idth product, GBW. Essentially, it is the product of the small-signal open-loop gain and the frequency at that gain. It is expressed by the formula:

$$GBW = A_{VOL} \times f.$$

There is no standard frequency at which GBW is measured, but most manufacturers arbitrarily specify GBW somewhere around 100 kHz. The actual test frequency may vary and can range from as low as 1 kHz to as high as 10 MHz.

Slew rate

Whereas bandwidth indicates how the op-amp is able to handle small-signal analog inputs, it provides little information on how the amplifier can handle digital and large-signal inputs.

Digital pulses are unique in that, even though the frequency of the waveform (actually, its repetition rate) may be low, bandwidth requirements are quite high. It is not unusual for digital pulses to have risetimes on the order of five nanoseconds; a five nanosecond risetime corresponds to a frequency of 200 MHz!

The op-amp experiences similar problems when trying to process large output signals. Amplifiers used as high-voltage drivers are particularly susceptible to being unable to handle large-signal inputs.

The problem lies within the output stage of the op-amp. Because of design requirements, the output transistors experience a high degree of charge retention. In other words, it takes a while for them to change from one phase to the next.

Let's say, for example, that we have a squarewave input that has been adjusted to give us a squarewave output that swings the entire ± voltage range. The moment the input signal changes states, the output tries to follow. However, inter-element capacitance (and inductance) prevent it from making the transition instantaneously. Consequently, the output pulse takes longer to reach its plateau than the original input signal did.

The time it takes for the output voltage to correspond to the input voltage is called the slew rate. Slew rate is expressed in volts of change per microsecond.

Slew rate is a linear function. If, for example, the slew rate is 2 volts per microsecond, then it will take 5 microseconds for the output to change 10 volts. No matter how quickly the input signal may rise, the output can not respond any faster.

Slew rate (designated S_R) is measured using the circuit shown in Fig. 3. Notice that the op-amp is configured as an inverting amplifier. The input is a low-frequency squarewave of about 100 Hz. The amplitude of the input signal is adjusted

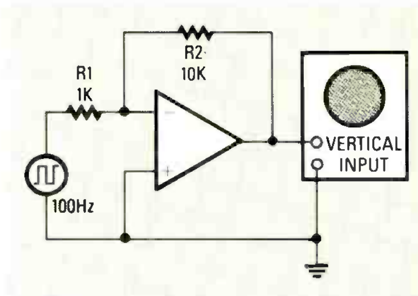


FIG. 3—SLEW RATE is defined as the amount of time it takes for the output voltage to correspond to a change in the input voltage. The slew rate is expressed in volts of change per microsecond.

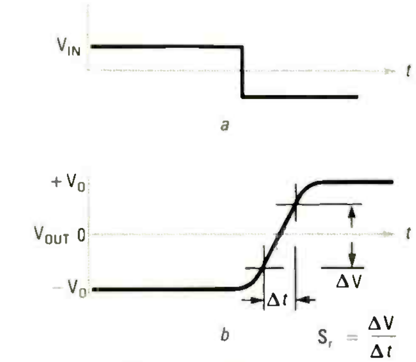


FIG. 4—SLEW RATE is determined by measuring how long a signal takes to rise from 20% to 80% of the total voltage swing.

so that the output swings over the entire ± power-supply voltage. S_R is measured on an oscilloscope by noting the amount of time it takes for the waveform to pass through the 20% and 80% points on the waveform, as shown in Fig. 4.

Settling time

A closely related parameter is settling

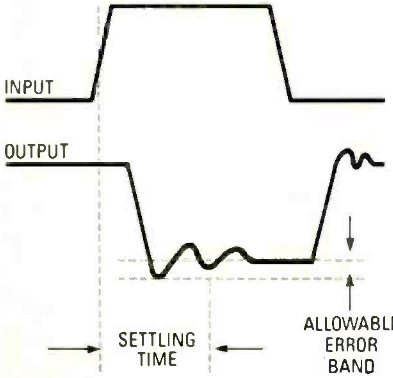


FIG. 5—SETTLING TIME is defined as the amount of time the output signal takes to stabilize at its final value.

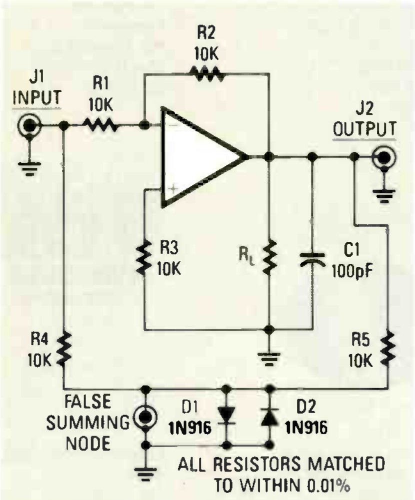


FIG. 6—SETTLING TIME is measured on an oscilloscope using a false summing node.

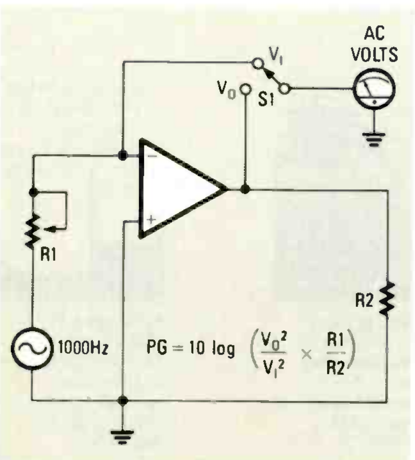


FIG. 7—POWER GAIN is the ratio of the signal power developed at the output to the signal power applied to the input.

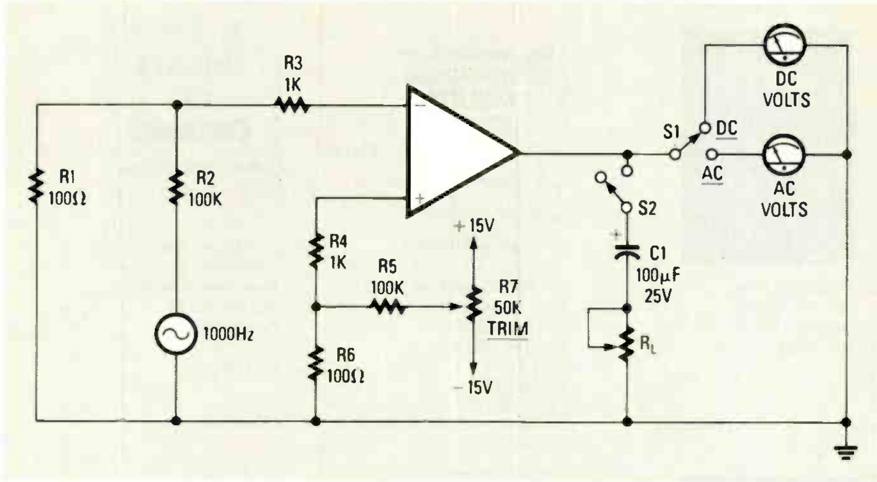


FIG. 8—OUTPUT IMPEDANCE may be determined by first nulling the op-amp for zero offset error and then adjusting R_L for one-half output. The value of R_L equals the output impedance.

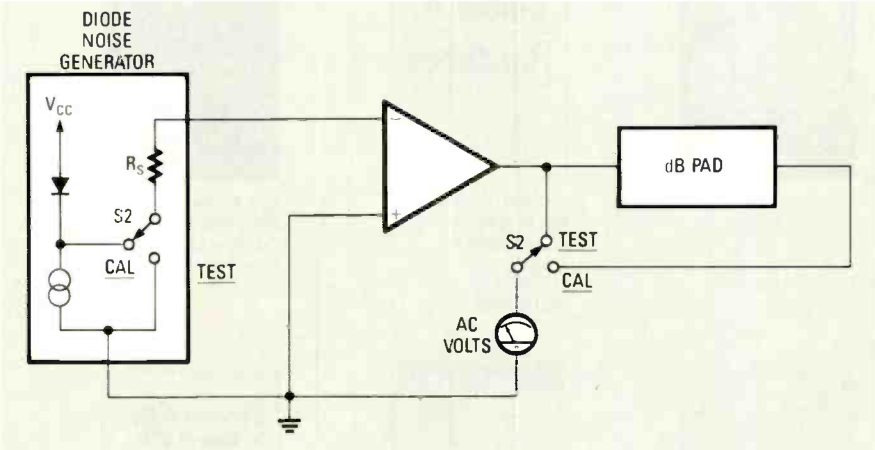


FIG. 9—NOISE FACTOR (NF) is measured with a diode noise source and a 3-dB attenuation pad.

time, which is defined as the time required, after the application of a step voltage (such as squarewave), for the output voltage to settle and remain within a specified error band around the final value.

As you can see in Fig. 5, a normal step function causes the output to swing wider than it should, both overshooting and undershooting the final value, in a gradually reducing series of damped oscillations. Eventually the signal arrives at the proper output voltage. The time it takes to accomplish that feat is called the settling time of the op-amp.

You can measure settling time using the circuit shown in Fig. 6. To measure the settling time of the op-amp accurately, a "false summing node" has been created. Although it might seem that the best place to measure settling time would be at the output of the op-amp, stray capacitance on the test probe makes it impossible to resolve settling time to better than 0.1 percent. The false node eliminates the error by isolating the oscilloscope from the amplifier under test. However, because of the voltage divider composed of R4 and R5, only one-half the actual error voltage appears at the false-summing node—a factor that must be taken into account.

Settling time (t_S) which is sometimes listed as step response, is measured according to the tolerance of the overshoot bandwidth. Typically, settling-time responses are measured in steps, beginning with 10 percent. That is, when the ringing (the damped oscillation) has contained itself within 10 percent of the target value, settling time has been reached. In high-precision circuits, tolerances of 0.1 and 0.01 percent are not uncommon.

The lower the loop gain, the faster the settling time. Settling time depends on feedback from output to input, so the higher the loop gain, the longer it takes for the amplifier to overcome external influences within the loop.

Power gain

The *Power Gain* (PG) of an op-amp is expressed in decibels. It is the ratio of the signal power developed at the output to the signal power applied to the input.

Power gain may be measured using the circuit shown in Fig. 7. The test is made by adjusting the value of R1 so that the input voltage to the amplifier under test is one-half the voltage output of the signal generator. Because R1 is in series with the

continued on page 130

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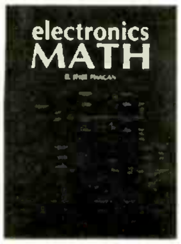

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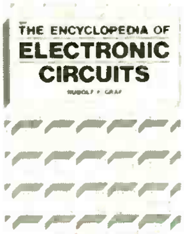

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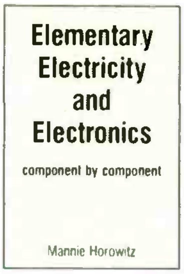

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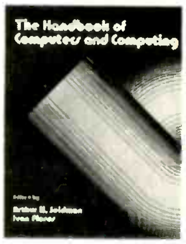

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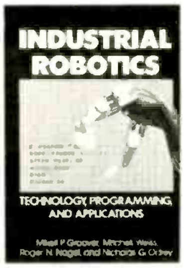

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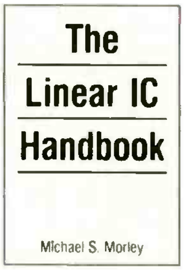

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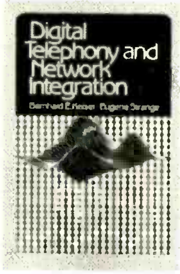

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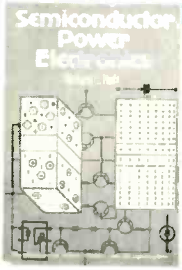

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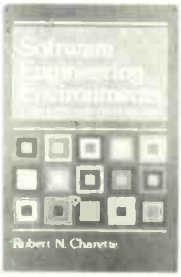

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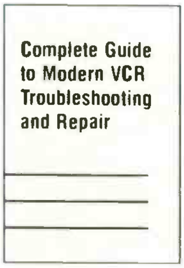

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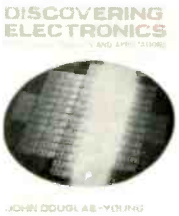

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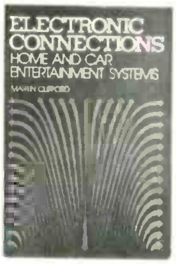

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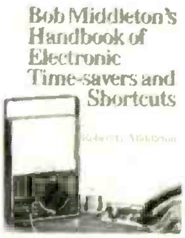

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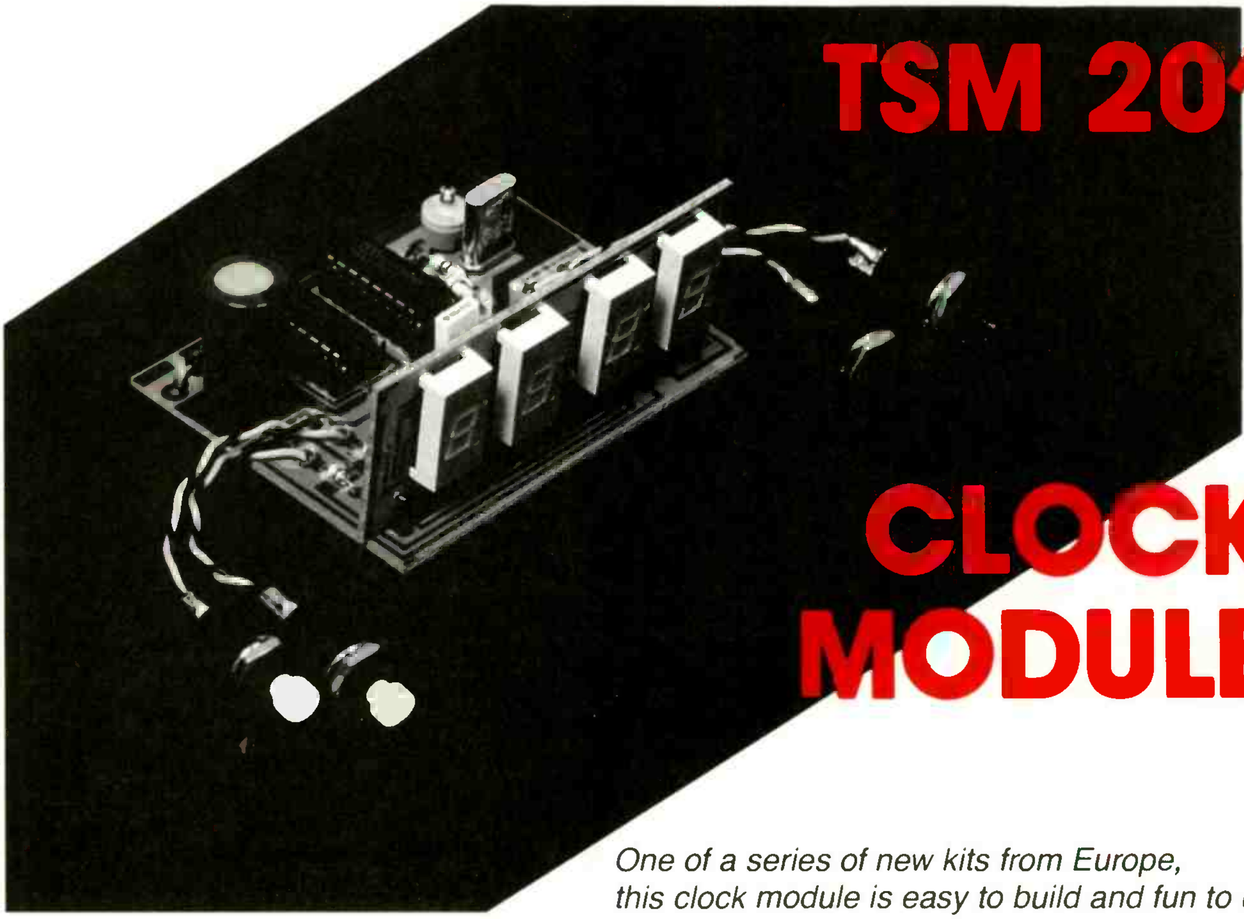


TSM 201 CLOCK MODULE

One of a series of new kits from Europe, this clock module is easy to build and fun to use.

IN EUROPE, THE NAME TSM IS SYNonymous with educational and useful electronics kits for the hobbyist. Now, some of their products are available in this country. Because the kits fill an important need for hobbyists, especially beginning ones, we'd like to take some time to introduce them to you. In this article, we'll look at one that's typical of the line—an easy-to-build, versatile crystal-controlled clock module.

Use it anywhere

The TSM *201* clock module is exceptionally adaptable. Powered by AC or DC, it can be installed virtually anywhere—in another piece of equipment; in the dash of a car, truck, or boat; or even in a cabinet by itself. The device features an alarm output that can be used to control another circuit, or to sound the optional TSM *114* buzzer. Time readout is provided by four 8-mm 7-segment LED displays, which can easily be seen from across a room, or on the road at night.

A schematic diagram of the circuit is shown in Fig. 1. The heart of the circuit is IC3, a custom Texas Instruments TMS 3899 clock IC that provides all of the clock and alarm functions, and the display driver. **Note that the IC is a proprietary device and that it is available in the U.S. only as part of the *201* kit.**

The circuit includes two other IC's: One, IC2, is a CD4060 ripple counter, which is configured as a crystal oscillator. Trimmer C5 allows precise tuning of the oscillator frequency. The other, IC1, a CD4027 dual J-K flip-flop, divides the output from IC2 to provide IC3 with the proper time-base signal.

The clock and alarm functions are controlled by four pushbutton switches. The hour and minute settings are set using S3 and S4; the alarm is set using S2; and the alarm is turned on or off with S1.

A half-wave rectifier made up of D5 and C1 allows the unit to operate from either an AC or a DC power supply. For DC operation, use a 12- to 24-volt power source. For AC operation, use a step-down transformer to provide a 9–12-volt input.

Building the circuit

All components, except the pushbutton switches, are mounted on two PC boards. The *201* kit, available from the suppliers mentioned in the Parts List, includes two etched and drilled PC boards, with all component locations clearly indicated. The patterns also are shown in PC Service.

The circuit is extremely easy to build; the most difficult task is making sure all components are oriented correctly. A parts-placement diagram for the main board is in Fig. 2; the parts-placement diagram for the display board is in Fig. 3.

Since most of the components mount on the main board, let's start there. First, mount the five jumpers; note that one runs beneath the socket for IC1. Stuff the board with the remaining parts, starting with the low-profile devices. Be sure to use IC sockets for the IC's. Connect the pushbuttons to the appropriate points on the board using wires.

The four 7-segment displays are located on the display board. Before mounting them, however, be sure to install the two jumpers.

The two boards are normally connected using a right-angle male header. However, just about any scheme can be used.

Setup and use

Apply power, being careful to observe the proper polarity. A flashing display indicates that the clock is working correctly.

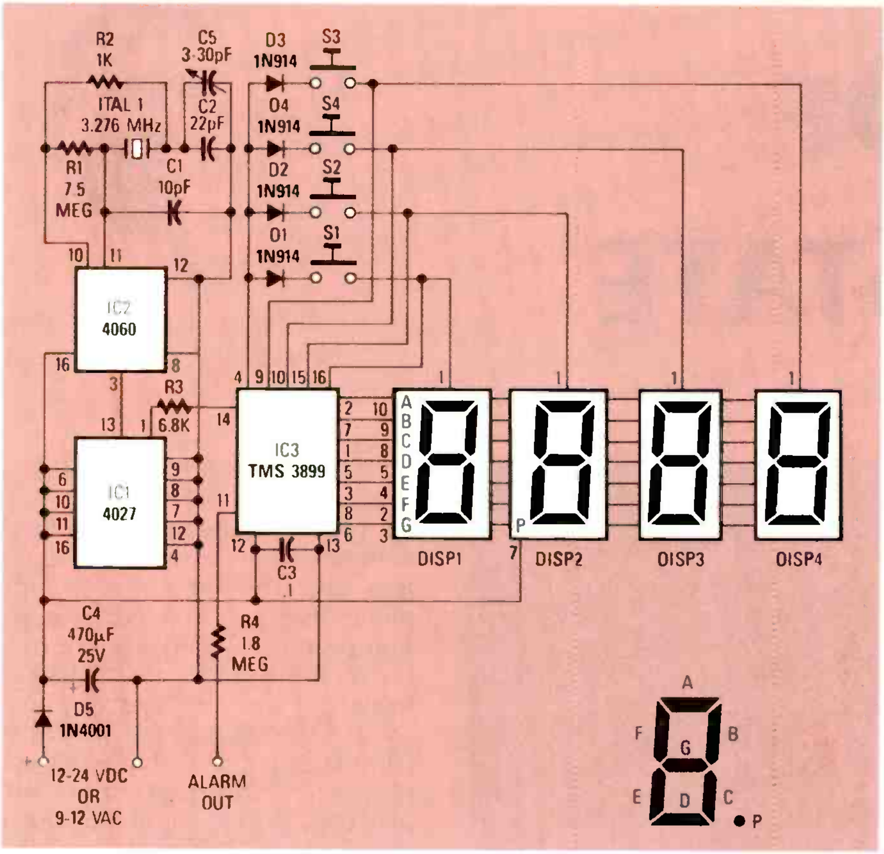


FIG. 1—THE HEART OF THE CLOCK CIRCUIT is IC3, a proprietary clock IC. Note that it can be obtained in the U.S. only as part of the TSM *201* kit.

Set the correct time using S3 and S4. If you have a frequency counter, connect it between pin 11 of IC2 and ground. Then adjust C5 for a frequency of 3.2768 MHz. If you don't have a counter, set C5 to midrange and allow the clock to run for a day or so. Then, compare the time display to the actual time. If the clock is running fast, decrease the capacitance of C5 slightly; if it is slow, increase the capacitance. Allow the clock to run another day, then check again. Repeat until the displayed time and the actual time correspond.

The clock is now ready for use. If you wish to take advantage of the alarm function, connect the TSM *114* buzzer circuit, or anything else that you wish to control, between the positive side of the supply and the alarm output.

Impressions

With a catalog of over 200 kits, TSM is one of Europe's leading suppliers of kits.

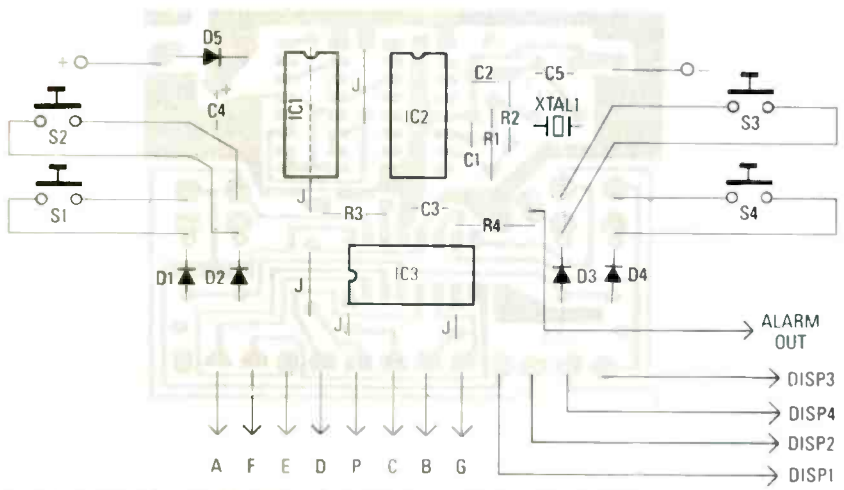


FIG. 2—MOST OF THE COMPONENTS mount on the circuit's main board.

PARTS LIST

All resistors ¼ watt, 5% unless otherwise noted
R1—7.5 megohms
R2—1000 ohms
R3—6800 ohms
R4—1.8 megohms
Capacitors
C1—10 pF
C2—22 pF
C3—0.1 µF
C4—470 µF, 25 volts, electrolytic
C5—3 pF–30 pF, trimmer, PC mount
Semiconductors
IC1—CD4027 dual J-K flip-flop
IC2—CD4060 14-stage binary ripple counter
IC3—TMS 3899 clock IC (Texas Instruments)
D1–D4—1N914 or equivalent
D5—1N4001 or equivalent
DISP1–DISP4—7-segment LED display, common cathode
Other components
XTAL1—3.2768-MHz quartz crystal
S1–S4—pushbutton switch, momentary contact, normally open
Miscellaneous: PC boards, wire, solder, etc.
NOTE: The TSM *201* kit is available for $26.77, plus $1.50 shipping and handling, from the following suppliers: TSM in America, Inc, 2065 Boston Post Road, Larchmont, NY 10538; Nutron Computer Electronics, 821 E. Roosevelt Road, Lombard, IL 60148; Auto Sound Systems, 1269 East Main St., El Cajon, CA 92021. The optional TSM *114* Buzzer Kit is available for $7.38, plus shipping and handling, from the same suppliers. Include proper state sales tax, if appropriate. The *201* kit does not include battery, AC power transformer, or case.

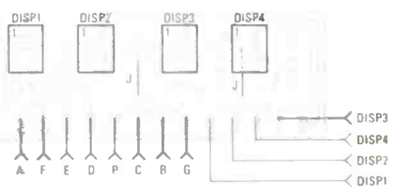


FIG. 3—MOUNT THE FOUR DISPLAYS on the display board. Note that one of the jumpers runs beneath DISP4.

If the *201* is any indication, they should enjoy similar success in this country. Those who purchase the kit will be pleased to note that it is professionally prepared and packaged. Further, its designed to be used with little modification in almost any timekeeping or timing application. The only negative is that the instructions are a little rough around the edges due to translation problems. Despite that, they are easily followed. **R-E**

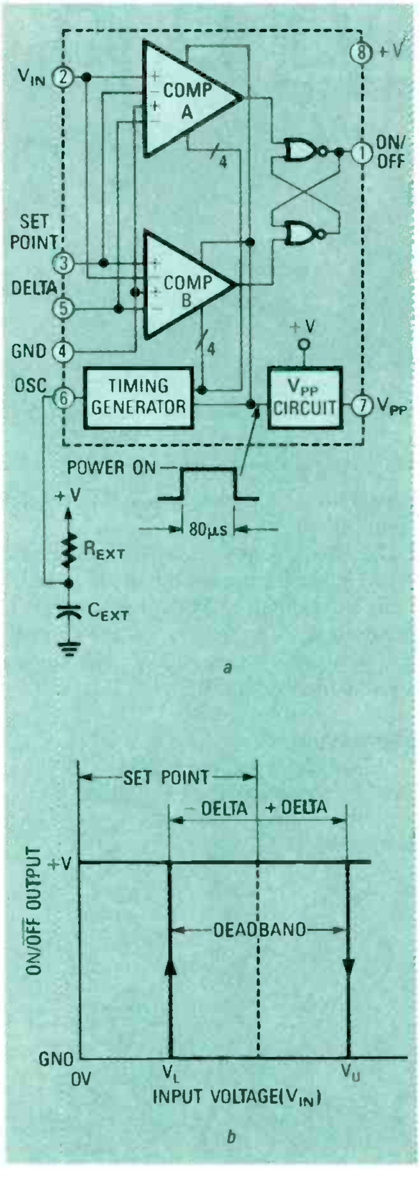
STATE OF SOLID STATE

A bang-bang IC

ROBERT F. SCOTT,
SEMICONDUCTOR EDITOR

A NEW AND INTERESTING MONOLITHIC device for process-control applications is the LTC1041 "bang-bang" controller from Linear Technology Corp. That CMOS component takes its name from its ability to turn a control element either fully ON ("bang") or fully OFF ("-bang"), with no middle ground, to regulate the value of the parameter being controlled.

Figure 1-*a* shows an operational block diagram of the LTC1041 along with the pinout of its 8-pin DIP housing. The SET POINT input determines the average control value and the DELTA input establishes the "deadband". As show in Fig. 1-*b*, the deadband is centered on the set-point voltage and is twice the voltage at the DELTA input. An unusual sampling technology allows independent control of the deadband and the set point; there is absolutely no interaction between the two.



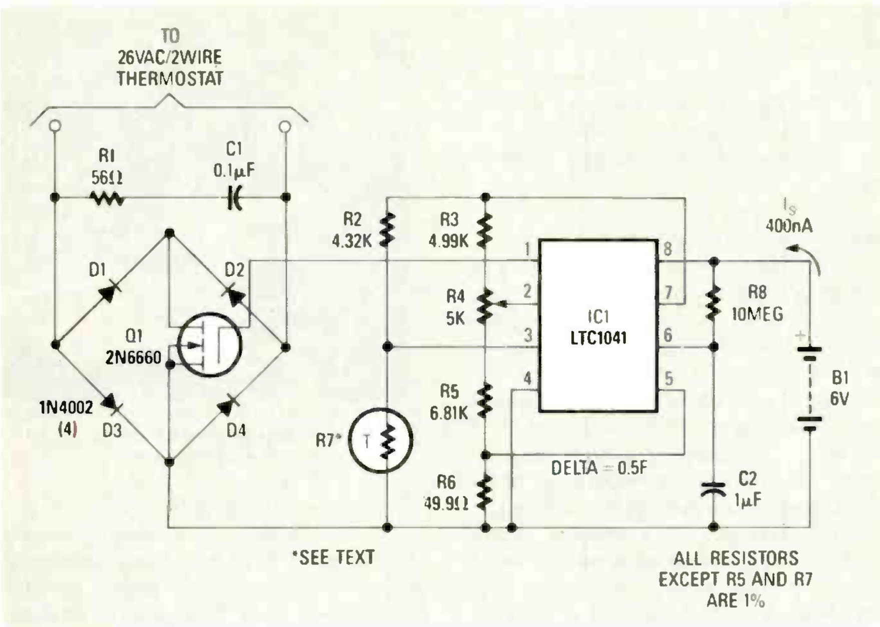
A series RC network, connected to pin 6, controls the oscillator frequency and therefore determines the sampling rate. Power is applied to the two on-board comparators for approximately 80 µs at the start of each sampling period. During that time, the inputs to the analog section are sampled and compared. Power is removed from the comparators as soon as they have completed their task. The CMOS logic holds the output continuously while consuming virtually no input power.

Each of the two comparators has two differential inputs. When the sum of the voltages on a comparator's inputs is negative, the output is low; a comparator's output is high when the sum of its inputs is positive. The inputs are interconnected so that the pin 1 voltage is low (the RS flip-flops are reset) when the pin 2 voltage (V_{in}) is greater than the set-point voltage plus delta and the pin 1 voltage is high when the pin 2 voltage is less than the set-point voltage minus the delta voltage. That action produces a very precise hysterisis loop with a deadband of twice the delta voltage centered around the set point as shown in Fig. 1-*b*. The LTC1041 has many applications in instrumentation and process control. Figure 2 shows how it can be used in an ultra-low-power (2.4 µW) thermostat. The circuit shown is suitable for temperature regulation over a range of +50°F to +100°F.

Complete specifications and additional applications, including a DC-motor control and a battery-charger control can be found in the *1986 LTC Linear Databook*. The LTC1041 costs approximately $5.50 each in small quantities. For additional information on the device and on the data book, write to **Linear Technology Corp.**, 1630 McCarthy Blvd., Milpitas, CA 95035-7487.

GaAs amplifier brief

Using the Anadigics ADA25001, DC–2.5-GHz Amplifier is the title of an applications technical brief giving detailed information on the use of GaAs (gallium-arsenide) monolithic amplifiers produced by Anadigics, Inc. It begins with a description of the ADA25001 DC-to-2.5-GHz amplifier, a GaAs device designed for high gain and wide bandwidth in high-data-rate fiber-optic systems, radar processors, high-speed pulse amplifiers, and clock-driver applications.



The application discussed in the brief is the layout of a single-stage amplifier using the ADA25001 to provide flat gain response from 100 kHz to 2.5 GHz over a temperature range of −55°C to +125°C. The layout includes a temperature-compensation loop. The brief is available upon request to Mr. Michael P. Gagnon, **Anadigics, Inc.**, 35 Technology Drive, Warren, NJ 07060.

Computerized FET databook

Designers who use small-signal FET's can now quickly select the best device for a given application by using the *Siliconix Computerized Data Book*, which provides full details on the company's FET product line on a 5¼-inch floppy disk for an IBM PC or PC-compatible computer. The disk also contains an updated version of the *MOSPOWER Computerized Data Book*, originally released in 1986.

The FET section prompts the user to select one of seven major application areas such as amplifiers, analog switches, current regulators, diodes, dual amplifiers, mixers/oscillators, and voltage-controlled resistors. A list of key parameters is then generated on the screen, and the user is instructed to enter a range of acceptable parameter values. In response to those entries, the type numbers of appropriate Siliconix FET's are displayed.

The data book on a floppy is free to Siliconix customers. Contact *Siliconix Telemarketing* at 800-554-5565 or 2200 Laurelwood Road, Santa Clara, CA 95054.

New tone ringer

The LS1240A is a recent addition to the SGS Semiconductor family of economical two-tone telephone-ringer devices. The new ringer has a high output-current capability (150-mA maximum), which is sufficient to drive low-cost dynamic transducers having impedances as low as 50 ohms.

The new ringer, which is pin-compatible with the standard LS1240, generates an alternating two-tone drive signal for the transducer. The tone frequency and the alternation rate are continuously variable and externally adjustable.

The required supply voltage is derived from the AC ring signal and the circuit is designed so that noise on the line or variations in the ringing signal current cannot affect correct operation of the ringer. An external polarity-guard bridge and a protection Zener diode allow direct connection to the telephone line. The IC's low current consumption permits up to four of the devices to be operated in parallel. The LS1240A comes in an 8-pin miniature DIP and requires only six external components. The price is $0.82 each, in minimum quantities of 1000. *SGS Semiconductor Corp.*, 1000 Bell Road, Phoenix, AZ 85022. **R-E**

POWER TRANSISTORS

continued from page 112

change in V_{ce}. Changes as small as 1% are readily detectable, with 5% or less normally considered an acceptable limit. Today's most sophisticated device specifications for RF power transistors use that criteria to determine "success" or "failure" in ruggedness testing.

Other specs

Data sheets for low-power RF transistors show such special characteristics as *noise figure* (NF), *maximum available gain* (GU_{max}) and *scattering* (S) parameters. The S parameter is normally taken with the device under test in a standard commercial fixture. Typically, they are given as functions of frequency and I_c.

NF and GNF likewise use commercial equipment such as the Eaton 4012 gain-noise analyzer, or the HP8970A noise figure meter. A transistor's NF will vary with input impedance match, and as a result is generally measured in a test fixture having input tuning. Usually, data is given with a circuit tuned initially for lowest possible NF, and then for a standard 50-ohm input. Measuring NF at a 50-ohm input impedance (Z_{in}) is more repeatable, but normally yields a higher NF. The 50-ohm measurement is preferred for production testing because it requires no tuning and can be done with automated test equipment: for that reason, it is frequently the value specified on data sheets. Likewise, gain is normally specified for best NF conditions and for a Z_{in} of 50 ohms.

Impedance parameters

RF power transistors are typically characterized by impedance parameters rather than small-signal S+ parameters. Both Z_{in} and Z_{out} of a device are determined in a similar way: i.e., place the device under test in a circuit and tune both the input and output circuit elements to achieve maximum P_o at the desired frequency of interest. At maximum output power, the impedances of the device under test will mathematically represent the input and output network impedances. Thus, terminate the input and output ports of the test circuit, remove the device and measure impedance looking from the device: first, toward the input to obtain the conjugate of Z_{in} and, second, toward the output to obtain Z_{OL}, which is normally given as the load required to achieve maximum P_o.

A network analyzer is used in the actual measurement process to determine the complex reflection coefficient of the circuit. A typical measurement setup for measuring impedance is shown in Fig. 7.

FIG. 7—RF POWER TRANSISTOR IMPEDANCES are determined by measuring the characteristics of a working circuit.

The entire impedance measuring process is somewhat difficult and time-consuming because it must be repeated for each frequency of interest, using a test circuit that will tune the frequency range. Different circuits must be designed and built for other frequencies, which explains why it is sometimes difficult to get a semiconductor manufacturer to supply impedance data for special conditions of operation, such as different frequencies, different power levels, or different operating voltages.

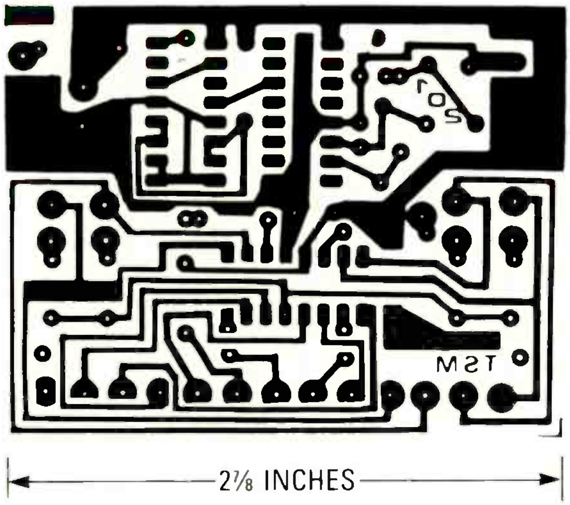
Tradeoffs in specifications

Gain and ruggedness are the most obvious device parameters for compromise in RF power specifications. Devices with high gain—high with respect to their figure of merit (emitter periphery/base area)—tend to be fragile; i.e., not rugged. By using materials with higher resistance, with a thicker epitaxial layer, and/or increased values of emitter resistance, ruggedness can be enhanced at the expense of gain. Likewise, to get higher gain, the user may be asked to accept lower collector/base breakdown voltages (BV_{CBO}, or BV_{CES} and BV_{CEO}) in order to reduce collector resistance and thereby increase gain. Transistors designed for operation at high frequencies can be used at lower frequencies to obtain increased gain, but such devices will usually be fragile at the lower frequency.

Summing up

The RF power transistor is an unusually complex semiconductor device and difficult to fully characterize. Not all information about RF-transistor characteristics have been explained in this article, nor are all usually covered in a data sheet. The circuit-designer should contact the manufacturer for more-detailed information whenever it is appropriate. Most, if not all, manufacturers of RF transistors have extensive applications support for the express purpose of assisting the circuit designer whenever and wherever assistance is needed. **R-E**

PC SERVICE



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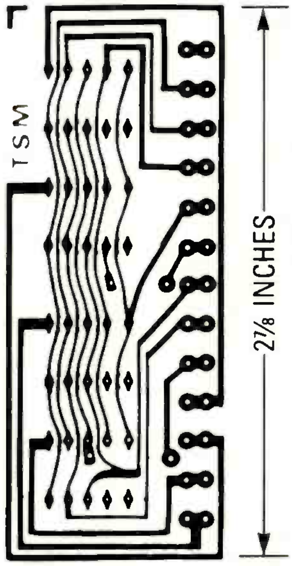

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An optional step, once you're satisfied that the artwork is clean, is to take a little bit of mineral oil and carefully wipe it across the back of the artwork. That helps make the paper transluscent. Don't get any on the front side of the paper (the side with the pattern) because you'll contaminate the sensitized surface of the copper blank. After the oil has "dried" a bit—patting with a paper towel will help speed up the process—place the pattern front side down on the sensitized copper blank, and make the exposure. You'll probably have to use a longer exposure time than you are used to.

We can't tell you exactly how long an exposure time you will need as it depends on many factors but, as a starting point, figure that there's a 50 percent increase in exposure time over lithographic film. But you'll have to experiment to find the best method for you. And once you find it, stick with it.

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BLUE BOX

continued from page 52

office to silence the ringing signal. When Pop released S4, the folks can talk to Junior without Junior getting charged because his AMA tape did not show his call was answered—the DC loop must be closed for at least three-seconds for the AMA tape to show Junior's call was answered. All the AMA tape showed is that Junior let the phone ring at the old homestead for almost 30 minutes; a length of time that no Bell Operating Company is likely to believe twice!

A modern Red Box is simply a conventional telephone that's been modified to emulate the vintage 1940 military field telephone. Aside from the fact that the operating companies can now nail every Red Box user because all modern billing equipment shows the AMA information concerning the length of time a caller let the target telephone ring, it's use has often put severe psychological strain on the users.

Does getting electronics mixed up with psychology sound strange? Well it isn't because it's what helped Ma Bell put an end to indiscriminate use of the Red Box. The heyday of the Red Box was the 1950's and 1960's. Mom and Pop were lucky to have finished high school, and almost without exception, both elementary and high schools taught honesty and ethics. Mom and Pop didn't have the chance to take college courses in *Stealing 101* that masqueraded under quaint names such as *Business Management*, *Marketing*, or *Arbitrage*. When Junior tried to get the old folks to use his "free telephone" they just wouldn't go along. So Junior installed the Red Box at his end. He gave one ring to notify the family to call back. When Pop called Junior, it was Junior who was using the Red Box. Problem was, Junior didn't know that the AMA tape for Mom and Pop's phone showed a 20- or 30-minute ringing. When Ma Bell's investigators showed up it was at the old homestead; and it was only then that the folks discovered their pride and joy had been taught to steal.

There are no hard facts concerning how many Red Boxes were in use, or how much money Ma Bell lost, but one thing is known: she had little difficulty is closing down Red Boxes in virtually all instances where the old folks were involved because Mom and Pop usually would not tolerate what to them was *stealing*. If you as a reader have any ideas about using a Red Box, bear in mind that the AMA (or its equivalent) will get you every time, even if you use a phone booth, because the record will show the number being called, and as with the Blue Box, the people on the receiving end will spill their guts to the cops. **R-E**

ELECTRONIC LOCK

continued from page 108

one for the common signal and electrical ground.

Build the encoder circuit on a small, piece of perforated wiring board, and, if possible, use a socket for IC2, because being a CMOS device, it can be damaged if you solder directly to its terminals, especially if you're using an ungrounded soldering iron. For the same reason, use a socket for the decoder's IC1.

As shown in Fig. 3, the small encoder assembly can be secured directly to one side of a DB-25-type connector hood using two 4-40 screws.

Testing

Testing is very simple. Connecting the key to the decoder should cause RY1's contacts to close. If the contacts don't close, it's more than likely the problem is an address mismatch between encoder and decoder. Check that they are exactly the same. If you connect an oscilloscope to pin 15 of IC2 should see a constant sequence of pulses being transmitted out of the encoder. If the pulses are missing check that resistors R4 and R5, and capacitor C3, are connected correctly. **R-E**

SEMICONDUCTORS

continued from page 117

input resistance of the op-amp itself, its value can be fairly large, especially when the op-amp has a JFET or MOSFET input. The output resistor (R2) should have a value that is equal to the output impedance of the op-amp. Now adjust the input voltage for a small-signal output voltage from the test amplifier. Calculate PG using the formula shown in Fig. 7.

Output impedance

Ideally, the output impedance of an op-amp should be zero. In real circuits, however, that's impossible. The actual output impedance may be measured using the circuit shown in Fig. 8. First compensate for offset errors as before. Then set the signal generator to deliver a 1-kHz 1-volt signal. Next close S2 and adjust R_L until the output drops to 0.5 volt. Open S2 and measure the resistance of R_L—that's the op-amp's output impedance, Z_O.

The measurement is valid because the impedance of the op-amp and that of the RC network behaves as a voltage divider, and a voltage divider delivers half the input voltage only when the impedances of both legs are equal.

Noise factor

Not all op-amp output is desirable, however. Some is noise that is generated in the op-amp's transistors. That noise is not isolated to any particular part or area. In fact, it is a collective phenomenon. The noise generated by the input transistors is amplified by the second stage, which adds noise of its own. The total is in turn further amplified—and more noise is added—by the output drivers. The overall effect is called the *N*oise *F*actor (NF).

Noise is measured using the circuit shown in Fig. 9. In that circuit a diode noise generator is used to measure the noise figure. With both switches in the TEST positions, measure and note the output voltage on the AC voltmeter. Now place the switches in the CAL position and increase the diode current until the meter reads the previous voltage level.

Then calculate the noise figure (in decibels) as follows:

$$NF = 10 \log 20 (IR_S)$$

where I is the diode current and R_S is the source impedance. The accuracy of the technique depends on the accuracy of the 3-dB attenuation pad and the diode's current source. **R-E**

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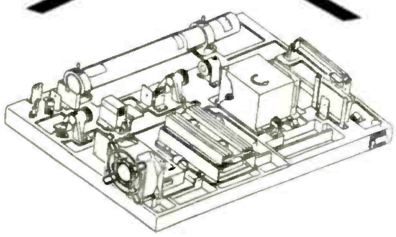

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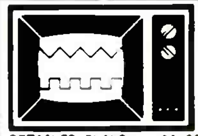

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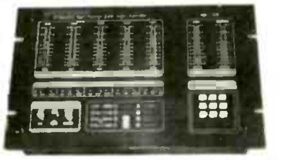

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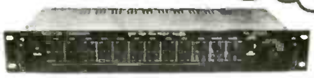

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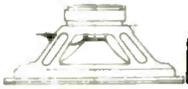

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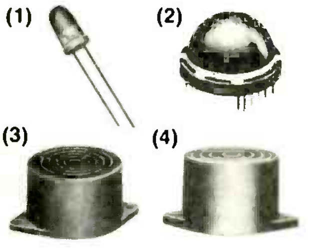

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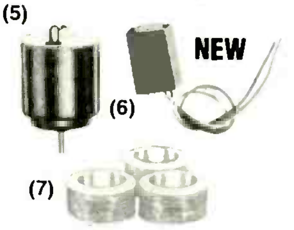

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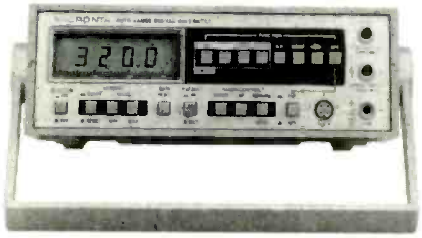

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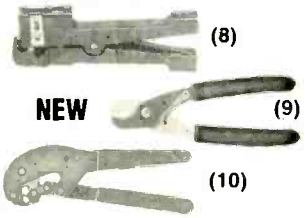

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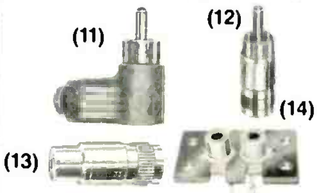


(11) Solderless 90° Plugs. Two red, two black. #274-383 . . . . Set of 4/1.59
(12) Shielded Plug. #274-339 . . . . Set of 2/1.49
(13) Shielded Jack. #274-338 . . . . Set of 2/1.49
(14) Dual Phono Jacks. Chassis mount. #274-332 . . . . . . Set of 2/1.19

Solder-Type "D" Submini Connectors

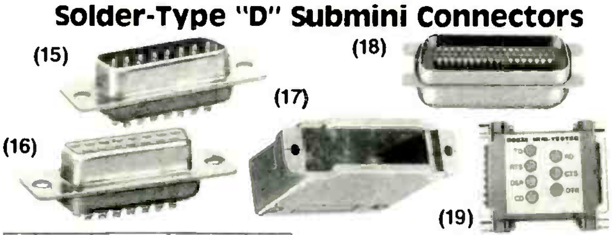
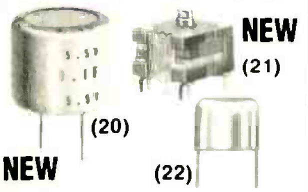


Fig	Type	Positions	Cat. No.	Ea.
15	Male	9	276-1537	1.49
16	Female	9	276-1538	2.49
17	Hood	9	276-1539	1.99

Type	Positions	Cat. No.	Ea.
Male	25	276-1547	1.99
Female	25	276-1548	2.99
Hood	25	276-1549	1.99

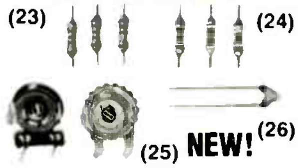
(18) Printer Connector. Solder type, 36-position. For parallel printers. #276-1534 . . . . 4.99
(19) RS232 Inline Tester. Diagnose interface problems without costly repair calls. #276-1401 . . . . 14.95

Hard-to-Find Parts



(20) CPU/RAM Backup Capacitor. For CMOS microprocessors. 0.1 farad, 5.5 WVDC. #272-1440 . . . . 2.95
(21) Dual-Ganged 335 pF Pot. PC mount. With knob, pinout. #272-1337 . . . . . . 4.95
(22) 6-50 pF Trimmers. PC/perfboard mount. #272-1340 . . . . Set of 2/1.59

Irresistables



(23) 1/8-Watt Carbon Film Resistors. 100 Asstd. #271-311 . . . . 1.98
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Inverting Hex Buffer	4049	276-2449	1.19
Quad Bilateral Switch	4066	276-2466	1.19

Description	Type	Cat. No.	Each
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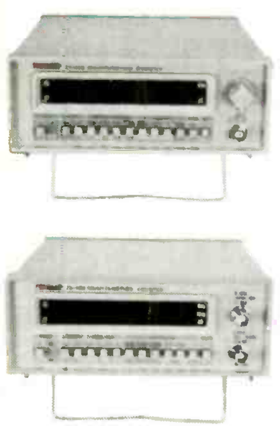

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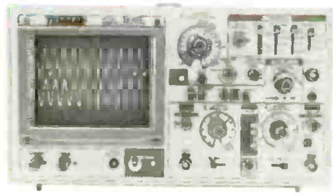

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■ Two 10:1 probes included ■ High brightness CRT with internal graticule ■ 6KV accelerating potential ■ 5x vertical and horizontal magnifiers ■ Delayed triggering sweep ■ Front panel electrical trace rotation ■ Alternate triggering permits viewing of asynchronous channel A and channel B signals **#72-330**

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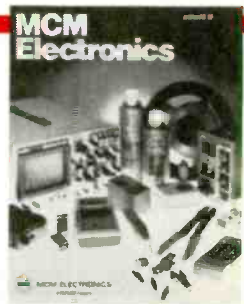

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HM6116-3	2048x8	(150ns)(CMOS)	1.85
HM6116LP-4	2048x8	(200ns)(CMOS)(LP)	1.85
HM6116LP-3	2048x8	(150ns)(CMOS)(LP)	1.90
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HM6264P-15	8192x8	(150ns)(CMOS)	3.89
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2764	8192x8	(450ns)(5V)	3.49
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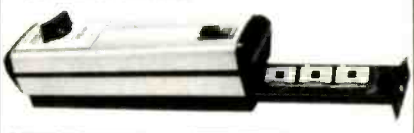

Model	Timer	Capacity Chip	Intensity (uW/Cm²)	Unit Price
PE-14	NO	9	8,000	$83.00
PE-14T	YES	9	8,000	$119.00
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1.0 MHz

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6520	1.95
6522	4.95
6526	26.95
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6581	34.95

2.0 MHz

6502A	2.95
6520A	2.95
6522A	5.95
6532A	11.95
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6800

1.0 MHz

6800	1.95
6802	4.95
6803	9.95
6809	5.95
6809E	5.95
6810	1.95
6820	2.95
6821	1.95
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4.032	1.95
5.0	1.95
5.0688	1.95
6.0	1.95
6.144	1.95
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6.0	4.95
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8.0	4.95
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12.480	4.95
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20.0	4.95
24.0	4.95

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74LS00

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74LS02	.17	74LS169	.95
74LS03	.18	74LS173	.49
74LS04	.16	74LS174	.39
74LS05	.18	74LS175	.39
74LS08	.18	74LS191	.49
74LS09	.18	74LS192	.69
74LS10	.16	74LS193	.69
74LS11	.22	74LS194	.69
74LS12	.22	74LS195	.69
74LS13	.26	74LS196	.59
74LS14	.39	74LS197	.59
74LS15	.26	74LS221	.59
74LS20	.17	74LS240	.69
74LS21	.22	74LS241	.69
74LS22	.22	74LS242	.69
74LS27	.23	74LS243	.69
74LS28	.26	74LS244	.69
74LS30	.17	74LS245	.79
74LS32	.18	74LS251	.49
74LS33	.28	74LS253	.49
74LS37	.26	74LS256	1.79
74LS38	.26	74LS257	.39
74LS42	.39	74LS258	.49
74LS47	.75	74LS259	1.29
74LS48	.85	74LS260	.49
74LS51	.17	74LS266	.39
74LS73	.29	74LS273	.79
74LS74	.24	74LS279	.39
74LS75	.29	74LS280	1.98
74LS76	.29	74LS283	.59
74LS83	.49	74LS290	.89
74LS85	.49	74LS293	.89
74LS86	.22	74LS299	1.49
74LS90	.39	74LS322	3.95
74LS92	.49	74LS323	2.49
74LS93	.39	74LS364	1.95
74LS95	.49	74LS365	.39
74LS107	.34	74LS367	.39
74LS109	.36	74LS368	.39
74LS112	.29	74LS373	.79
74LS122	.45	74LS374	.79
74LS123	.49	74LS375	.95
74LS124	2.75	74LS377	.79
74LS125	.39	74LS378	1.18
74LS126	.39	74LS390	1.19
74LS132	.39	74LS393	.79
74LS133	.49	74LS541	1.49
74LS136	.39	74LS624	1.95
74LS138	.39	74LS640	.99
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74LS147	.99	74LS670	.89
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74LS155	.49	74LS783	22.95
74LS156	.49	81LS95	1.49
74LS157	.35	81LS96	1.49
74LS158	.29	81LS97	1.49
74LS160	.29	81LS98	1.49
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74LS163	.39	26LS31	1.95
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74HC02	.59	74HC151	.89
74HC04	.59	74HC154	2.49
74HC08	.59	74HC157	.89
74HC10	.59	74HC158	.95
74HC14	.79	74HC163	1.15
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74HC27	.59	74HC240	1.89
74HC30	.59	74HC244	1.89
74HC32	.69	74HC245	1.89
74HC51	.59	74HC257	.85
74HC74	.75	74HC259	1.39
74HC85	1.35	74HC273	1.89
74HC86	.69	74HC299	4.99
74HC93	1.19	74HC368	.99
74HC107	.79	74HC373	2.29
74HC109	.79	74HC374	2.29
74HC112	.79	74HC390	1.39
74HC125	1.19	74HC393	1.39
74HC132	1.19	74HC4017	1.99
74HC133	.69	74HC4020	1.39
74HC138	.99	74HC4049	.89
74HC139	.99	74HC4050	.89

74HCT00

74HCT: Direct, drop-in replacements for LS TTL and can be intermixed with 74LS in the same circuit.

74HCT00	.69	74HCT166	3.05
74HCT02	.69	74HCT174	1.09
74HCT04	.69	74HCT193	1.39
74HCT08	.69	74HCT194	1.19
74HCT10	.69	74HCT240	2.19
74HCT11	.69	74HCT241	2.19
74HCT27	.69	74HCT244	2.19
74HCT30	.69	74HCT245	2.19
74HCT32	.79	74HCT257	.99
74HCT74	.85	74HCT259	1.59
74HCT75	.95	74HCT273	2.09
74HCT138	1.15	74HCT367	1.09
74HCT139	1.15	74HCT373	2.49
74HCT154	2.99	74HCT374	2.49
74HCT157	.99	74HCT393	1.59
74HCT158	.99	74HCT4017	2.19
74HCT161	1.29	74HCT4040	1.59
74HCT164	1.39	74HCT4060	1.49

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74F00	.69	74F74	.79	74F251	1.69
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74F08	.69	74F139	1.69	74F280	1.79
74F10	.69	74F157	1.69	74F283	3.95
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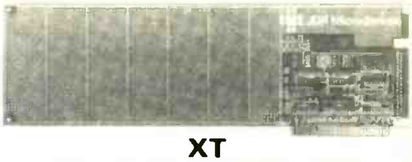

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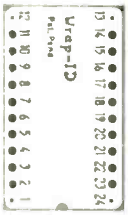

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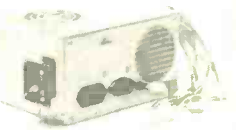

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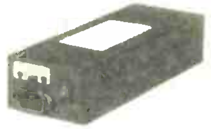

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PS-1558

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6.8	15V	.70	1.0	35V	.45
10	15V	.80	2.2	35V	.65
22	15V	1.35	4.7	35V	.85
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22	50V	.05	.001µf	50V	.05
27	50V	.05	.0022	50V	.05
33	50V	.05	.005	50V	.05
47	50V	.05	.01	50V	.07
68	50V	.05	.02	50V	.07
100	50V	.05	.05	50V	.07
220	50V	.05	.1	12V	.10
560	50V	.05	.1	50V	.12

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.01µf	50V	.14	.1µf	50V	.18
.047µf	50V	.15	.47µf	50V	.25

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4.7	50V	.15	22	16V	.14
10	50V	.15	47	50V	.20
47	35V	.18	100	35V	.25
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WBU-208

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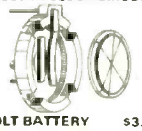

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7404	.29	.19	7489	2.05	1.95
7405	.35	.25	7490	.49	.39
7406	.39	.29	7493	.45	.35
7407	.39	.29	74121	.45	.35
7408	.35	.25	74123	.55	.45
7410	.29	.19	74125	.55	.45
7414	.49	.39	74126	.69	.59
7416	.39	.29	74143	3.95	3.85
7417	.39	.29	74150	1.35	1.25
7420	.35	.25	74154	1.35	1.25
7430	.35	.25	74158	1.59	1.49
7432	.39	.29	74173	.85	.75
7438	.39	.29	74174	.59	.49
7442	.55	.45	74175	.59	.49
7445	.79	.69	74176	.99	.89
7446	.89	.79	74181	1.95	1.85
7447	.89	.79	74189	1.95	1.85
7448	2.05	1.95	74193	.79	.69
7472	.89	.79	74198	1.85	1.75
7473	.39	.29	74221	.99	.89
7474	.39	.29	74273	1.95	1.85
7475	.49	.39	74365	.65	.55
7476	.45	.35	74367	.65	.55

74LS

74LS00	.29	.19	74LS165	.75	.65
74LS02	.29	.19	74LS166	.99	.89
74LS04	.35	.25	74LS173	.59	.49
74LS05	.35	.25	74LS174	.49	.39
74LS06	1.09	.99	74LS175	.49	.39
74LS07	1.09	.99	74LS189	4.59	4.49
74LS08	.29	.19	74LS191	.59	.49
74LS10	.29	.19	74LS193	.79	.69
74LS14	.49	.39	74LS221	.69	.59
74LS27	.35	.25	74LS240	.69	.59
74LS30	.29	.19	74LS243	.69	.59
74LS32	.35	.25	74LS244	.69	.59
74LS42	.49	.39	74LS245	.89	.79
74LS47	.99	.89	74LS259	.99	.89
74LS73	.39	.29	74LS273	.89	.79
74LS74	.35	.25	74LS279	.49	.39
74LS75	.39	.29	74LS322	4.05	3.95
74LS76	.55	.45	74LS365	.49	.39
74LS85	.59	.49	74LS366	.49	.39
74LS86	.35	.25	74LS367	.49	.39
74LS90	.49	.39	74LS368	.49	.39
74LS93	.49	.39	74LS373	.79	.69
74LS123	.59	.49	74LS374	.79	.69
74LS125	.49	.39	74LS393	.89	.79
74LS138	.49	.39	74LS590	6.05	5.95
74LS139	.49	.39	74LS624	2.05	1.95
74LS154	1.09	.99	74LS629	2.95	2.85
74LS157	.45	.35	74LS640	1.09	.99
74LS158	.45	.35	74LS645	1.09	.99
74LS163	.59	.49	74LS670	1.09	.99
74LS164	.59	.49	74LS688	2.39	2.29

74S/PROMS*

74S00	.29	74S188*	1.49
74S04	.29	74S189	1.69
74S08	.35	74S196	2.49
74S10	.29	74S240	1.49
74S32	.35	74S244	1.49
74S74	.45	74S253	.79
74S85	1.79	74S287*	1.49
74S86	.49	74S288*	1.49
74S124	2.75	74S373	1.49
74S174	.79	74S374	1.49
74S175	.79	74S472*	2.95

74F

74F00	.29	74F139	.69
74F04	.29	74F157	.69
74F08	.29	74F193	2.95
74F10	.29	74F240	.99
74F32	.29	74F244	.99
74F74	.39	74F253	.69
74F86	.39	74F373	.99
74F138	.69	74F374	.99

CD—CMOS

CD4001	.19	CD4076	.59
CD4008	.69	CD4081	.25
CD4011	.19	CD4082	.25
CD4013	.29	CD4093	.35
CD4016	.29	CD4094	.89
CD4017	.49	CD40103	2.49
CD4018	.59	CD40107	.49
CD4020	.59	CD40109	.79
CD4024	.49	CD4510	.69
CD4027	.35	CD4511	.69
CD4030	.29	CD4520	.75
CD4040	.65	CD4522	.79
CD4049	.29	CD4538	.79
CD4050	.29	CD4541	.89
CD4051	.59	CD4543	.79
CD4052	.59	CD4553	4.95
CD4053	.59	CD4555	.79
CD4063	1.49	CD4559	7.95
CD4066	.29	CD4566	2.49
CD4067	1.29	CD4583	.89
CD4069	.25	CD4584	.39
CD4070	.25	CD4585	.89
CD4071	.25	MC14411P	8.95
CD4072	.25	MC14490P	4.49

MICROPROCESSOR COMPONENTS

MISCELLANEOUS CHIPS

Part No.	Price
D765AC	4.95
WD9216	6.95

Z80, Z80A, Z80B SERIES

Part No.	Price
Z80	1.25
Z80-CTC	1.79
Z80-DART	4.95
Z80-PIO	1.79
Z80A	1.69
Z80A-CTC	1.79
Z80A-DART	4.95
Z80A-PIO	1.69
Z80A-SIO/0	5.75
Z80B	3.49
Z80B-CTC	3.95
Z80B-PIO	4.29

6500/6800/68000 SER.

Part No.	Price
6502	2.65
65C02 (CMOS)	8.95
6520	1.95
6522	3.95
6532	6.49
6551	4.49
65C802 (CMOS)	19.95
6800	1.95
6802	3.95
6810	1.25
6821	1.75
6840	3.95

6500/6800/68000 Cont.

Part No.	Price
6845	3.95
6850	1.95
6852	1.49
MC68000L8	11.95
MC68000L10	13.95
MC68010L10	49.95
MC68020RC12B	169.95
MC68881RC12A	149.95

8000 SERIES

Part No.	Price
8031	3.95
80C31	9.95
8035	1.95
8073	9.95
8080A	2.95
8085A	2.49
8086	5.95
8086-2	6.95
8087 (5MHz)	129.95
8087-2 (8MHz)	169.95
8088	6.49
8088-2	8.95
8116	4.95
8155	2.49
8155-2	3.49
8156	3.95
8202	5.95
8203	9.95
8212	1.49
8224	2.25

8000 SERIES Cont.

Part No.	Price
8228	2.95
8237-5	4.95
8243	2.25
8250A	6.49
8250B (For IBM)	6.95
8251A	1.89
8253-5	1.95
8254	4.95
8255A-5	1.89
8257-5	1.95
8259-5	2.25
8272	4.95
8279-5	2.95
8741	9.95
8748 (25V)	7.95
8748H (HMOS) (21V)	9.95
8749	9.95
8751	39.95
8755	14.95

DATA ACQUISITION

Part No.	Price
ADC0804LCN	3.19
ADC0808CCN	5.95
ADC0809CCN	3.95
ADC0816CCN	11.95
ADC1205CCJ-1	19.95
DAC0808LCN	1.95
DAC1008LCN	4.95
AY-3-1015D	4.95
AY-5-1013A	2.95

MICROPROCESSOR SALE!

Part No.		Price
MC68000L8	16-Bit MPU (8MHz)	$ 11.95
MC68000L10	16-Bit MPU (10MHz)	$ 13.95
MC68000L12	16-Bit MPU (12MHz)	$ 17.95
MC68008L8	32-Bit MPU (8-Bit Data Bus)	$ 19.95
MC68010L10	16-Bit MPU (10MHz)	$ 49.95
MC68020RC12B	32-Bit MPU (12MHz)	$169.95
MC68701	8-Bit EPROM Microcomputer	$ 14.95
MC68705U3L	8-Bit EPROM Microcomputer	$ 10.95
MC68881RC12A	Floating Point Co-processor	$149.95

DYNAMIC RAMS

Part No.			Price
4116-15	16,384 x 1	(150ns)	.89
4128-20	131,072 x 1	(200ns) (Piggyback)	3.25
4164-120	65,536 x 1	(120ns)	1.75
4164-150	65,536 x 1	(150ns)	1.25
4164-200	65,536 x 1	(200ns)	.99
TMS4416-12	16,384 x 4	(120ns)	3.49
8118	16,384 x 1	(120ns)	.49
41256-120	262,144 x 1	(120ns)	3.95
41256-150	262,144 x 1	(150ns)	3.25
50464-15	65,536 x 4	(150ns) (4464)	4.95
511000P-10	1,048,576 x 1	(100ns) 1 Meg	24.95
514256P-10	262,144 x 4	(100ns) 1 Meg	29.95

STATIC RAMS

2016-12	2048 x 8	(120ns)	1.69
2018-45	2048 x 8	(45ns)	6.95
2102-2L	1024 x 1	(250ns) Low Power	1.95
2114N	1024 x 4	(450ns)	.99
2114N-2L	1024 x 4	(200ns) Low Power	1.49
21C14	1024 x 4	(200ns) (CMOS)	.49
2149	1024 x 4	(45ns)	2.49
5101	256 x 4	(450ns) CMOS	1.95
6116P-3	2048 x 8	(150ns) CMOS	1.89
6116LP-3	2048 x 8	(150ns) LP CMOS	1.95
6264LP-12	8192 x 8	(120ns) LP CMOS	4.25
6264P-15	8192 x 8	(150ns) CMOS	3.49
6264LP-15	8192 x 8	(150ns) LP CMOS	3.75
6514	1024 x 4	(350ns) CMOS	3.49
43256-15L	32,768 x 8	(150ns) Low Power	11.95

EPROMS

TMS2516	2048 x 8	(450ns) 25V	6.95
TMS2532	4096 x 8	(450ns) 25V	6.95
TMS2532A	4096 x 8	(450ns) 21V	5.95
TMS2564	8192 x 8	(450ns) 25V	9.95
TMS2716	2048 x 8	(450ns) 3 Voltage	9.95
1702A	256 x 8	(1µs)	6.95
2708	1024 x 8	(450ns)	4.95
2716	2048 x 8	(450ns) 25V	3.75
2716-1	2048 x 8	(350ns) 25V	4.25
27C16	2048 x 8	(450ns) 25V (CMOS)	5.49
2732	4096 x 8	(450ns) 25V	3.95
2732A-20	4096 x 8	(200ns) 21V	4.25
2732A-25	4096 x 8	(250ns) 21V	3.95
27C32	4096 x 8	(450ns) 25V (CMOS)	5.95
2764-20	8192 x 8	(200ns) 21V	4.25
2764-25	8192 x 8	(250ns) 21V	3.75
2764A-25	8192 x 8	(250ns) 12.5V	3.95
2764-45	8192 x 8	(450ns) 21V	2.95
27C64-15	8192 x 8	(150ns) 21V (CMOS)	6.49
27128-20	16,384 x 8	(200ns) 21V	6.95
27128-25	16,384 x 8	(250ns) 21V	5.95
27128A-25	16,384 x 8	(250ns) 12.5V	5.25
27C128-25	16,384 x 8	(250ns) 21V (CMOS)	6.95
27256-20	32,768 x 8	(200ns) 12.5V	6.95
27256-25	32,768 x 8	(250ns) 12.5V	6.49
27C256-25	32,768 x 8	(250ns) 12.5V (CMOS)	8.95
27512-20	65,536 x 8	(200ns) 12.5V	13.49
27512-25	65,536 x 8	(250ns) 12.5V	11.95
68764	8192 x 8	(450ns) 25V	13.95

EEPROMS

2816A	2048 x 8	(350ns) 5V Read/Write	5.95
2817A	2048 x 8	(350ns) 5V Read/Write	7.95
2865A	8192 x 8	(250ns) 5V Read/Write	9.95
52B13 (21V)	2048 x 8	(350ns) 5V Read Only	1.49

COMMODORE CHIPS

Part No.	Price
WD1770	11.95
SI3052P	2.49
6502	2.65
6504A	1.95
6507	4.39
6510	9.95
6520	1.95
6522	3.95
6525	4.95
6526	14.95
6529	2.95
6532	6.49
6545-1	4.95
6551	4.49
6560	10.95
6567	14.95
6569	24.95
6572	8.95
6581 (12V)	14.95
6582 (9V)	14.95
8360	14.95
8501	10.95
8502	7.95
8563	15.95
8564	9.95
8566	24.95
8701	9.95
*8721	14.95
8722	9.95
*251104-04	10.95
318018-03	10.95
318019-03	10.95
318020-04	10.95
325302-01	10.95
*325572-01	24.95
*82S100PLA**	15.95
901225-01	11.95
901226-01	11.95
901227-03	11.95
901229-05	11.95

*No specs. available
**Note: 82S100PLA = U17 (C-64)

SATELLITE TV DESCRAMBLER CHIP

The MM5321 is a TV camera sync generator designed to supply the basic sync functions for either color or monochrome 525 line/60Hz interlaced and camera video recorder applications. COLOR BURST GATE & SYNC ALLOW STABLE COLOR OPERATION

MM5321N. $11.95

INTERSIL Also Available!

74HC HI-SPEED CMOS

Part No.	Price	Part No.	Price
74HC00	.25	74HC175	.69
74HC02	.25	74HC221	1.19
74HC04	.29	74HC240	.99
74HC08	.29	74HC244	.99
74HC10	.29	74HC245	.99
74HC14	.49	74HC253	.59
74HC30	.29	74HC259	.89
74HC32	.29	74HC273	.99
74HC74	.39	74HC373	.99
74HC75	.39	74HC374	.99
74HC76	.45	74HC595	1.29
74HC85	.79	74HC688	.99
74HC86	.39	74HC943	8.95
74HC123	.89	74HC4040	.99
74HC125	.49	74HC4049	.59
74HC132	.69	74HC4050	.59
74HC138	.49	74HC4060	.99
74HC139	.49	74HC4511	1.29
74HC154	1.49	74HC4514	1.79
74HC163	.65	74HC4538	.89
74HC174	.69	74HC4543	1.19

74HCT — CMOS TTL

74HCT00	.29	74HCT139	.59
74HCT02	.29	74HCT157	.69
74HCT04	.29	74HCT174	.69
74HCT08	.29	74HCT175	.69
74HCT10	.29	74HCT240	.99
74HCT32	.29	74HCT244	.99
74HCT74	.49	74HCT245	1.19
74HCT86	.49	74HCT373	1.19
74HCT138	.59	74HCT374	1.19

74C—CMOS

74C00	.29	74C174	.79
74C02	.29	74C175	.79
74C04	.29	74C221	1.79
74C08	.35	74C240	1.79
74C10	.35	74C244	1.79
74C14	.59	74C373	1.95
74C32	.35	74C374	1.95
74C74	.59	74C912	8.95
74C85	1.49	74C915	1.39
74C86	.35	74C920	6.95
74C89	5.49	74C921	6.95
74C90	.99	74C922	3.95
74C154	2.95	74C923	3.95
74C173	1.05	74C925	5.95

LINEAR

DS0026CN	1.95	LM1458N	.39
TL074CN	1.19	LM1488N	.49
TL084CN	.99	DS14C88N (CMOS)	1.19
AF100-1CN	8.95	LM1489N	.49
LM307N	.45	DS14C89N (CMOS)	1.19
LM309K	1.25	LM1496N	.89
LM311N	.45	MC1648P	3.49
LM317T	.79	LM1871N	1.95
LM318N	.99	LM1872N	1.95
LM319N	1.29	LM1896N-1	1.49
LM323K	3.95	ULN2003A	.79
LM324N	.39	XR2206	3.95
LM338K	4.95	XR2211	2.95
LM339N	.39	XR2243	1.95
LF347N	1.79	26LS29	3.95
LM348N	.69	26LS31	1.19
LM350T	2.95	26LS32	1.19
LF351N	.39	26LS33	1.49
LF353N	.49	LM2901N	.39
LF355N	.79	LM2907N	1.29
LF356N	.89	LM2917N (8 pin)	1.95
LF357N	1.09	MC3419CL	6.95
LM358N	.49	MC3446N	1.69
LM360N	2.19	MC3450P	1.95
LM361N	1.79	MC3470P	1.95
LM380N-8	.99	MC3471P	1.95
LM386N-3	.89	MC3479P	4.79
LM387N	.99	MC3486P	1.69
LM393N	.39	MC3487P	1.69
LM399H	2.95	LM3900N	.49
LF411CN	.79	LM3905N	1.19
TL497ACN	1.49	LM3909N	.99
NE540H (C540H)	2.95	LM3914N	1.95
NE555V	.29	LM3916N	1.95
XRL555	.59	NE5532	.69
LM556N	.49	NE5534	.69
NE558N	.89	7805K (LM340K-5)	1.29
LM565N	.99	7812K (LM340K-12)	1.29
LM567V	.79	7815K (LM340K-15)	1.29
NE592N	.89	7805T (LM340T-5)	.49
LM741CN	.29	7812T (LM340T-12)	.49
LM747CN	.59	7815T (LM340T-15)	.49
MC1350P	1.09	7905K (LM320K-5)	1.35
MC1372P	1.95	7905T (LM320T-5)	.59
MC1377P	2.29	75472	.59
MC1398P	8.95	75477	.89
LM1414N	1.29	MC145106P	3.25
		MC145406P	2.95

IC SOCKETS

Low Profile		Wire Wrap (Gold) Level #3	
8LP	.11	8WW	.59
14LP	.12	14WW	.65
16LP	.13	16WW	.69
24LP	.25	24WW	1.19
28LP	.27	28WW	1.39
40LP	.29	40WW	1.89

Soldertail Standard (Gold & Tin) & Header Plug Sockets Also Available

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THERE'S NO RISK.
With our full 90-day warranty, any purchase can be returned for any reason for full credit or refund.

5¼", 10Mb HARD DISK DRIVE

(IBM® Compat.)
Fits standard 5¼" spacing. Shock mtd. High speed, low power.
Mfr – Seagate/Tandon
Item #13250 **$159.00** New
Controller Card for above
Item #10150 **$89.00**

5¼" 1/2 HT. DISK DRIVES

48/96 TPI 1.2 Mb. (AT Compat.)
DS/single-double density; 80 track.
Mfr – Panasonic #JU-475
Item #10005 **$119.00** New
96 TPI, DS/Quad Density (DOS 3.2 Compatible)
Tandon TM55-4; DS/Quad
Item #1904 **$79.00**
2 for **$150.00**

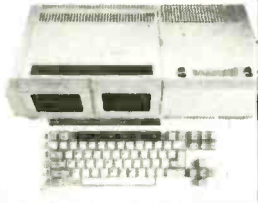
5¼" FULL HT. DISK DRIVES

48 TPI (IBM® Compat.)
Double sided/double density, full height drive. 48 T.P.I., 80 tracks.
Mfr – Tandon TM100-2
Item #7928 **$79.00**
2 for **$150.00**
96 TPI, DS/Quad Density
Mfr – CDC #9409T
Item #1893 **$99.00**

HIGH-RESOLUTION TTL MONITORS

12VDC. Mtd. in metal housing. Schematic supplied.
12", Green Phosphor
Item #6811 **$19.95** New
9", Amber
Item #14332 **$14.95** New

ADAM COMPUTER

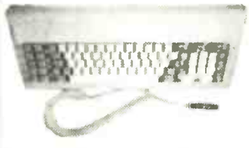


(Less printer)
No wiring nec. (just plugs together). Hook-up diagram included. Includes: Keyboard, 1 cassette digital data drive, 2 game controllers, power supply, and one cassette. Capable of running CP/M, has built-in word processor.
Item #7410 Complete – **$99.00**

MAGNIFYING LAMP

Multi position, 30", completely adjustable swing arm w/3-way metal C-clamp. Has 4" diopter magnifying lens, w/ruler. Porcelain lamp socket, & on/off switch; uses up to a 60W bulb. Color: Beige. UL listed.
Item #13136 **$24.95** New

IBM® PC/XT KEYBOARD



- Illuminated cap and number lock indicators.
- Low profile design.

Item #11041 **$49.95** New

ADC KITS . . .

IC Socket Kit
100 Ass't. Sockets! Consisting of 100 assorted IC sockets. From 14 to 40 Pin.
Item #5309 **$9.95** New

Components & Parts Kit
Hundreds of components! Consisting of Heat Sinks, Capacitor, Trimpots, Resistors, and MORE!
Item #7230 **$15.00** New

Switch Kit
35 Ass't. Switches! Consisting of 35 assorted: Dip, Toggle, Slide, and Sensitive Miniature and Standard Size Switches.
Item #5307 **$9.95** New

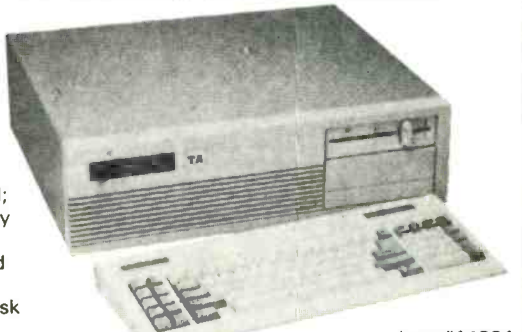
SWITCHING POWER SUPPLY

115 & 230V, 47–440 Hz.
Input: 90–135V/180–270V
Output: 5VDC @ 5.5A
+12VDC @ .4A
–12VDC @ .3A
Perforated metal case enclosure.
Dim.: 9½"L x 3½"W x 2"H.
Mfr – General Instrument
Item #7983 **$14.95** New

ADAM 5¼" DISK DRIVE

Gives your Adam fast, reliable data storage & retrieval. Can hold up to 160K bytes of information. Uses industry-standard SS/DD disks. Connects directly to your Adam memory console. Comes w/disk drive power supply, Disk Manager disk and owner's manual.
Mfr – Coleco, model 7817
Item #12830 *Like New* – **$199.00**

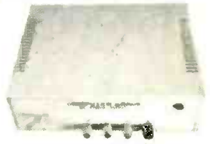
American's IBM PC/XT-COMPATIBLE COMPUTER . . .



Contains:
- 256K RAM;
- XT/AT Style Keyboard;
- 5¼" Full-Height Floppy Disk Drive
- 10Mb Full-Height Hard Disk Drive
- Hard Disk & Floppy Disk Controller Cards
- Color/Monochrome Monitor Card (monitor not included).

Item #14331
$549.95 New

COMPUTER GRADE POWER SUPPLY



Other uses–runs CB & car radios. Comes ready to plug in!
DC Output: –5V @ .5 amp.
+5V @ 3 amp.
+12V @ 6 amp.
Input 115V/60Hz. Dim.: 9¾"W x 3¾"H. (Rubber ft. incl.)
Item #9501 **$24.95** New

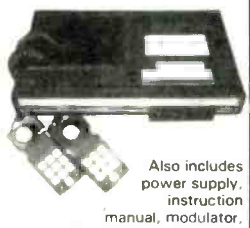
– BATTERIES – FANS – BLOWERS

ADAM PRINTER

Complete, less top cover plate. Friction feed. Takes standard paper 8½" x 11". (Customer returns; tested – operational.)
Item #8839 **$69.50**

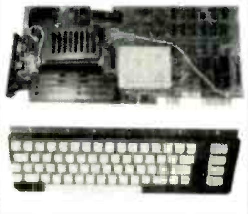
COLECOVISION GAME

(Factory returns – tested good!)



Also includes power supply, instruction manual, modulator, and one Donkey Kong cartridge.
Item #7411 **$29.95**

Insides of the COMMODORE COMPUTER



Commodore VIC 20 CPU board & mechanical keyboard. Guaranteed not to work. (For parts only.)
Item #12144 **$14.95** RFE

COMMODORE CARTRIDGES

C-64
Consists of 12 asstd. cartridges. Includes: *Number Nabber, Star Post, Financial Advisor, Radar Rat, Jupiter Land, Magic Compos, Viduzzles, Golf, Easy Calc, Simon Basic, Dragon's Den,* & *ABC Voice.* Item #13573
Set of 12 – **$49.95** New

C16 & +4
Consists of 9 asstd. cartridges. Includes: *Script+2, Calc Plus, Script+, Jack Attack, Pirate Adventures, Atomic Miss, Strange Odyssey, Financial Advisor,* & *Logo.* Item #13572
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Dim.: 5¼"L x 3¾"H x 2$\frac{1}{16}$"D
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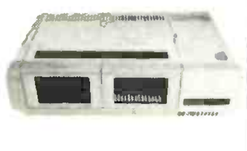
Adam Ribbon Cartridge – Item #13306 **$3.95**

COLECOVISION to *ADAM* Expansion Kit



This expansion module just plugs into your ColecoVision. With printer power supply and data drive (both included), you will have a working Adam Computer. Adam keyboard, one Smart basic cassette and hook-up diagram also included.
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EXPANSION MODULE #2
Play arcade quality driving & racing games on your ColecoVision. Incl. *Turbo* cartridge.
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DC Output: +5V @ 8 amps.
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Input: 110VAC/60 Hz., ±20%
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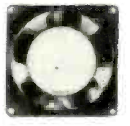

115VAC; 50/60Hz.; 12W. Low noise level fans, can be mtd. for blowing or exhaust.

1½" STANDARD
7 metal blades
Dim.: 3⅛" sq. x 1½" deep

NEW — Rotron #SU2A1
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LM350K	3.55	7805K	1.21	Z80A-PIO	1.75
LF353N	.53	7812K	1.21	Z80B	3.55
LF356N	.8D	7815K	1.21	Z80B-CTC	4.45
LM358N	.44	7818K	1.21	Z80B-PIO	4.45
LM380N	.80	7824K	1.21		
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LM566CN	1.25	79L15AC	.53	68705	9.95
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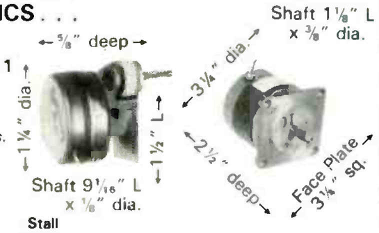

Item No.	Step Angle	Volts DC	Stall Torque oz/in	Type	Mfr. & Part No.	Fig	Price
5431	1	5	17	PM	N.A. Phillips A82310-M2	1	$9.95 ea. 2/$14.95
5275	1.8	1.8	72	PM	Superior Electric 2 Ø MO61-FF-6201B	2	$19.95 ea. 2/$37.50
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Mfr — Sola #63-13-114

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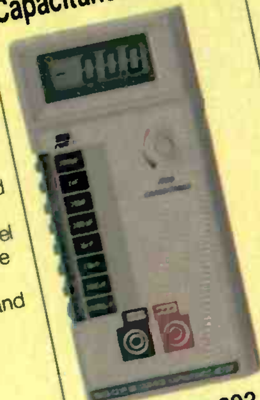

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