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**Tests Per Minute** (Benchmark Performance)

<table>
<thead>
<tr>
<th>Character I/O &amp; 7210</th>
<th>NAT4882 &amp; 7210</th>
<th>NAT-488 &amp; Turbo488</th>
<th>NAT4882 &amp; Turbo488</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.47</td>
<td>8.54</td>
<td>5.03</td>
<td>6.60</td>
</tr>
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<thead>
<tr>
<th>Parameter</th>
<th>Si9120</th>
<th>3844/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-up Circuit Power Dissipation</td>
<td>0.004 W</td>
<td>1.400 W</td>
</tr>
<tr>
<td>Supply Current</td>
<td>1.5 mA</td>
<td>17.0 mA</td>
</tr>
<tr>
<td>Reference Accuracy</td>
<td>±2.0%</td>
<td>±3.2%</td>
</tr>
<tr>
<td>Current Limit Delay Time</td>
<td>150 ns</td>
<td>300 ns</td>
</tr>
</tbody>
</table>

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Instrumentation amplifiers are finding increasing application in today's complex systems. Minor modifications can yield significantly better performance by improving common-mode rejection. In addition, these changes may let you use low drift amplifiers.—R Mark Stitt, Burr-Brown Corp

Real-time programming—Part 4

In constructing a requirements model, you should strive to make it independent of the specific methods that might be employed to achieve the requirements. Once you come to design an implementation model, however, you want to reveal the methods so that they can be analyzed and ultimately coded. The remainder of this series is concerned with implementation. This part of the series is devoted to the central issue of the implementation model: tasking.—David L Rippe, Industrial Programming Inc

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—Richard A Quinnell, Regional Editor

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C++ software development tool

PRODUCT UPDATES

Low-cost industrial PC family

Dual-channel VMEbus, audio-interface board

VMEbus-compatible CPU

Rugged, nonvolatile data card

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Discrete logic chips have had their day, being replaced repeatedly by programmable logic chips. Even to an old-time digital designer, that's the way it should be.

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Designers of computer games are expert programmers, successful managers, and still kids at heart.—Jay Fraser, Associate Editor

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MAC FAMILY TREE BEARS NEW FRUIT; PRICES CUT TO THE CORE

Price has been a barrier for many potential users of Macintosh computers from Apple Computer (Cupertino, CA, (408) 996-1010). The introduction of three low-cost Macs is lowering that barrier, as are price reductions of $1500 and $1000 for the Mac IIcx and Mac SE, respectively.

The Mac Classic includes a SCSI port, the Apple Desktop Bus with keyboard and mouse, two serial ports, and a sound port. It costs $999 with 1M bytes of memory, or $1499 with 2M bytes of memory and a 40M-byte hard-disk drive. The Mac LC offers color capability. It can use Apple's 12-in. monochrome or RGB monitors without additional hardware. It can expand its color and grayscale palettes by adding a memory card. A Mac LC with 2M bytes of memory and a 40M-byte hard-disk drive costs $2499 and will be available in January 1991. The Mac IIfs includes a floating-point processor and one expansion card modeled after either Nubus or the 030 bus. It costs $3769 with 2M bytes of memory and a 40M-byte hard disk.

—Richard A Quinnell

IN-CIRCUIT EMULATOR SERVICES TELECOMM PROCESSOR

Long a supporter of Hitachi's 64180 processor family, Softaid Inc (Columbia, MD, (301) 964-8455) has introduced an in-circuit emulator for the 64180S, a telecomm version of the µP. The 64180S UEM-Series emulator can trigger on 131,072 breakpoints and allows you to define complex trigger conditions with as many as five levels. It can display trace data from its 4k-word trace buffer in C, PL/M, or assembly language. A logic-analyzer mode captures trace data on each clock cycle instead of each machine cycle. The emulator also incorporates a real-time performance analyzer with 256 variable-width bins so you can root out those laggard chunks of code that always seem to gum up the works. With 128k bytes of emulation RAM, the emulator costs $5495. Larger memory options are available.—Steven H Leibson

ESD DETECTION SYSTEMS FOLLOW YOUR PRODUCT

An electrostatic discharge (ESD) detection system that mounts permanently or temporarily on circuit boards, assemblies, containers, or PCs is available from Zero Corp (Burbank, CA, (818) 846-4191). The unit has a 1-in² footprint. When it detects an ESD event, it latches on and changes the color of your LCD display. The unit remains latched until you reset it. Current beta test units have sensitivities of 500 to 800V, and the manufacturer plans to expand the sensitivity range to 300 to 5000V. Beta test units cost less than $150 each in small quantities.—Doug Conner
NiCd BATTERIES MORE POWERFUL THAN COMPETING PRODUCTS

The growing popularity of portable equipment continues to force battery vendors to pack ever higher storage capacity in standard cell shapes. Gates Energy Products Inc (Gainesville, FL, (904) 462-3911) claims that several members in its Ultramax family of NiCd cells up the ante in rechargeable batteries by storing 50 to 70% more charge than existing products. The AA-, Cs-, CsC-, and C-size batteries store 800, 2000, 2300, and 2800 mAh, respectively. Two more family members, the ¾Af and D cells, match the highest capacities available for those two sizes: 1000 and 5000 mAh, respectively. All cells in the line charge in 3 to 5 hours and accept a 1-hour fast charge. The batteries cost $1.25 to $6 (250,000), depending on the cell size.

—Steven H Leibson

CONFERENCE SHOWCASES EASE OF TEST DEVELOPMENT

Though much new hardware was introduced at the International Test Conference in Washington, DC, last month, many attendees thought that the stars of the show were the workstation-based test-development software packages shown by several automatic-test-equipment firms. Teradyne (Boston, MA, (617) 482-2700) has enhanced the Image software that runs on its A500 series of linear and mixed-signal device testers. LTX (Westwood, MA, (617) 461-1000) introduced a package called Envision, and Schlumberger (San Jose, CA, (408) 437-5128) announced software called ASAP. ASAP runs on the company's ITS 9000 family of sequencer-per-pin logic test systems, including the Typhoon, which the company is developing jointly with Motorola. Though there are significant differences among the packages, all of them let engineers develop IC test protocols by linking standardized tests from a library. The engineers can then customize the tests by clicking on a test icon to open a window that contains a form, for example. The form has blanks where engineers specify test conditions and limits. According to Bruce Webster, an applications engineering manager at Teradyne, semiconductor test engineers and ATE system developers have dreamed about such simplified test-development techniques for years. Only since the availability of workstations with high-resolution graphics and copious memory has the approach been practical.

On the hardware front, several companies were talking about integrated pin-electronics chips. Brooktree (San Diego, CA, (619) 452-7580) announced the Bt698 load/driver/dual-comparator for 100-MHz logic testing. The $130 (100) IC is fabricated with a complementary-bipolar process. It performs the functions of multichip hybrid circuits and discrete-component assemblies in less space, with less heat dissipation, with higher reliability, and at lower cost. Credence (Fremont, CA, (415) 657-7400) plans to sell its CMOS V-chip only as part of its test systems. Thanks to the chip, the firm's entire SC212 256-pin 50-MHz (pattern)/100-MHz (clock) VLSI tester is no larger than competitors' test heads. The system will sell for approximately $2000 per pin—roughly one-fourth the price of many VLSI testers. Shipments will start in the first quarter of 1991.—Dan Strassberg

STD BUS COMPUTER SUPPORTS MULTIPLE BUS-MASTER OPERATIONS

You can use the ZT8901 from Ziatech (San Luis Obispo, CA, (805) 541-0488) as a single-board computer in a standard STD-80 bus or for multiple bus-master operations using up to six additional ZT8901s on the STD 32-bus. The computer is based on the NEC V55 µP operating at 16 MHz. The processor is code compatible with 80286s and offers up to 20% higher throughput at the same clock rate. The board
40 MHz
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CIRCLE NO. 212
NEWS BREAKS

supports up to 1M bytes of onboard memory and has 48 digital I/O lines arranged as six 8-bit ports with 12-mA current-sinking capability. The board also has two RS-232C/485 ports and a math-coprocessor socket.

When the computer is used in multiple bus-master applications, it requires an arbiter board, the ZT89CT39, to coordinate bus control. Any computer board can become the bus master and access STD-32 bus memory and I/O in a fixed or rotating memory scheme. Unlike the STD-80 bus, the STD-32 bus has signal lines defined for bus-master request, master acknowledge, and bus lock to support complete control of multiple bus-master operations. Multiple bus-master operations on the STD-80 bus require nonstandard signal assignments causing incompatibility with other STD-80 products. STD DOS, a ROM-based DOS that allows programmers familiar with PC DOS to develop applications quickly, supports the computer. Other software support includes STD ROM, for ROM-based non-DOS applications, STD LADDER, and VRTX 32 for real-time operations. Single boards are $975.—Doug Conner

1-CHIP FAX MODEM ACHIEVES 14.4k-BPS OPERATION

The $60 (10,000) R144EFX 1-chip fax modem from Rockwell International's Digital Communication Div (Newport Beach, CA, (714) 833-4600) achieves 14.4k-bps transmissions over the public switched telephone network. The device is pin compatible with the company's 9600-bps modem, thus simplifying hardware upgrades and fallback modes. This makes the IC compatible with existing Group 3 fax machines.

—Steven H Leibson

VARIABLE-GAIN AMPLIFIER COMBINES LINEARITY AND LOW NOISE

The NE5209 wideband variable-gain amplifier from Philips Components-Signetics (Sunnyvale, CA, (408) 991-4544) has a typical 3-dB 850-MHz bandwidth, and can amplify signals by a few decibels out to 1.5 GHz. The amplifier's gain and attenuation adjustment is linear over the part's dynamic range, which is at least 60 dB at 200 MHz. The amplifier's noise increases by 0.6 dB for each 1 dB in gain. Previous devices had a 1-dB noise increase with each decibel increase in gain. The amplifier includes internal compensation and doesn't need external networks to tune for a particular operating frequency. You control the amplifier's gain with a single 0 to 1V dc voltage. The amplifier runs on 5V and consumes 400 mA. Commercial temperature-range devices ($14.24 (100)) and extended temperature-range versions ($17.08 (100)) are available.—Anne Watson Swager

TWO NEW VERSIONS ADDED TO INSTRUMENTATION SOFTWARE

National Instruments (Austin, TX, (512) 794-0100) has beefed up its software-instrumentation products for both the IBM PC and Apple Macintosh. The $995 Virtual Instrument Developer Toolkit for the company's $695 Labwindows package provides C-language extensions that add predefined user-interface objects to a programmer's repertoire. These objects include controls (pushbuttons, rocker and thumbwheel switches, and text-entry windows) and readouts (digital numeric displays, simulated LEDs, and waveform displays) that simulate the controls and readouts you generally find on real instrument front panels.

For its existing Apple Macintosh product, the company has introduced a $495 runtime version of its $1995 Labview 2 package. The package will run systems
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developed with Labview 2 but will not allow a user to edit the system's definition.
The Labview 2 Run-Time System substantially reduces the cost of distributing multiple copies of systems developed with Labview 2.—Steven H Leibson

**CPU BOARD HOSTS STACK-ORIENTED, 12-MHZ, 16-BIT µP**

The SC/FOX VMEbus CPU board from Silicon Composers (Palo Alto, CA, (415) 322-8763) uses an 8- or 12-MHz RTX-2000 µP from Harris. The stack-oriented processor executes most instructions in a single clock cycle, including $16 \times 16$-bit multiplies. The board offers VMEbus slot-one master capability, and can operate in VMSbus slave mode as well. Other features include one parallel, one SCSI, and two RS-232C ports; 128k bytes of dual-ported static RAM and 32k to 512k bytes of single-ported static RAM; and 64k bytes of EPROM. The company includes its Forth development language in EPROM and software that supports Forth language development on a PC. A board with an 8-MHz µP and 32k bytes of memory is available now for $3695.

—Maury Wright

**FPGA COMPILER DELIVERS 20% BETTER GATE UTILIZATION**

Claiming a 20% improvement in gate utilization from its updated FPGA compiler, Plus Logic (San Jose, CA, (408) 293-7587) has upgraded claimed gate equivalencies for its existing FPGAs. The software package responsible for this progress, Plustran 2.0, compiles schematics generated by several third-party schematic-drafting packages and behavioral descriptions written in several PLD description languages into gate layouts for the company's programmable parts. This latest version of the compiler costs less than $2800 and runs on high-end IBM PCs and Sun workstations.

—Steven H Leibson

**ACTIVITY-SCHEDULING PROGRAM ORGANIZES PROJECTS**

If complex engineering projects require you to keep track of multiple meetings, tasks, and phone calls, you may be able to simplify and organize your work by using ACT 2.0 from Contact Software International (Carrollton, TX, (214) 418-1866). This $395 program includes an activity calendar, word processor, spell checker, alarm, telephone database, autodialer, calculator, and query capability. Its drop-down menus let you customize 29 data fields, generate form letters and expense reports, manage lists, access reference libraries, and conduct key-word or criteria searches. It maintains a data log for each person you contact and uses alarms to help you stay on schedule.—J D Mosley

**YET ANOTHER ELECTRONIC CAD VENDOR JOINS THE PLD CAUSE**

Chalk up another win for logic-compiler vendor Minc Inc (Colorado Springs, CO). Valid Logic Systems (San Jose, CA, (408) 432-9400) has integrated Minc's PLD and PGA design packages into its Logic Workbench tool kit. The tools, called SystemPLD and SystemPGA, allow you to insert fully defined PLDs and PGAs into your schematics so that you can perform thorough system simulations on your entire design. You can use schematics, behavioral descriptions, waveforms, state-machine descriptions, truth tables, and Boolean equations to define the programmable parts, and you can combine several methods within the same schematic. SystemPLD costs $13,500 and SystemPGA, which incorporates SystemPLD, costs $19,500.

—Steven H Leibson
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EDN October 25, 1990

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*units are not QPL listed
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**3KHz-800MHz from $3.25**

- **Case Style Number**: See opposite page

<table>
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<tr>
<th>MODEL NO.</th>
<th>O/RATIO</th>
<th>FREQUENCY MHz</th>
<th>INSERTION LOSS</th>
<th>PRICE $</th>
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</tr>
</tbody>
</table>

#### FOR A AND B CONFIGURATIONS

- **Maximum Amplitude Unbalance**: 0.1 dB over 1 dB frequency range
- **0.5 dB over entire frequency range**
- **Phase Unbalance**: 1.5° over 1 dB frequency range
- **5.0° over entire frequency range**

- **CIRCLE NO. 215**

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* Denotes 75 ohm models

* FOR A AND B CONFIGURATIONS

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C72-2 REV B
Signetics. Because com isn't just a product

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PRODUCT</th>
</tr>
</thead>
</table>
| Workstations | • Advanced BiCMOS Logic (ABT)  
|             | • High-Speed ASICs  
|             | • Futurebus+ Chip Set  
|             | • High Speed PAL-type Devices  
|             | • High Performance MCUs |
| Desk Top Video | • Video Data Converters  
| Personal Computers | • Digital Color Decoders  
|               | • High Density ASICs/PLDs  
|               | • DRAM Controllers  
|               | • OTP PROMs  
|               | • FLASH Memory |
| Peripheral Products | • 8-bit 80C51-based MCUs  
|               | • Zero Power PLDs  
|               | • Programmable Sequencers  
|               | • 3-State ECL Transceivers |

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who can't wait designs work.

you see in design is what you'll get in manufacturing. How so? Because our LASAR system is more accurate than other event-based simulators. LASAR's worst-case algorithms precisely simulate the operation of gate arrays, high-speed micros and time-multiplexed buses, including the effects of process variations. You can zero-in on trouble spots efficiently, and be confident that LASAR-verified designs will work—reliably and repeatably.

If you're in a hurry for results, you'll appreciate how easily Teradyne tools integrate into your current design process. EDIF, VHDL and commercial-tool interfaces let you build on existing databases. Then tie all your design and analysis tools running on PCs, Suns® or VAXs™ into one multiwindow design environment using Vanguard's graphical framework.

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Competition needed to improve education

I agree with many of Jon Titus's suggested remedies for improving education (EDN, June 7, 1990, pg 41). My own feeling is that there is too little competition in education. This situation is partly due to unionization of teachers and partly due to lack of choice among schools. It is also due to parents who are occupied with things other than the mental education of their children—as opposed to their physical participation in competitive sports. After all, how much does a top scientist earn compared with a sports hero?

The fact that competition among schools is important is borne out by the fact that while the US falls behind the Japanese in public education, the US does better in higher education where schools are more competitive. I support the Educational Choice Initiative here in Oregon, which, if voted in, would allow parents to direct school funds to schools of their choice.

George Sayer, RE
Hillsboro, OR

Flexible and changing pattern needed in education

At first I read Jon Titus's editorial "Education is everyone's business" (EDN, June 7, 1990, pg 41) with pleasure, [thinking] "We are not the only ones with the problem." Then I realized that this comfort was misplaced. The fact that you in the US have the same concerns that we have in Great Britain could result in neither of us getting our retirement funds.

Although the answers to this problem are manifold, they can be broken down into some simple solutions. One aspect is pinpointed by your "risk taking." Our young people have an absolute need to learn to handle risk in relatively safe situations, but adventure of this nature is so often squashed at the source. Is it a fear among our teachers of the students becoming better than they are? We must develop risk-control skills.

Another area is the duty of parents to take ownership in the risk situation in which they have put their children. The risk that the children will be illiterate cannot be owned solely by the teacher. The parents are involved and must actively take their place in the process. Providing a home and money is not enough.

Teachers must move from their prepared and static content to a flexible and changing pattern so they do not use "the same questions year after year." Subject matter
must be made to live in today's world and compete with the ease of television-viewing.

Finally, the students must have the right signals to encourage them. Learning involves competition, and some students will do better than others. Competition is part of life and will continue to be so. What we have to do is ensure there are no losers.

The push in education cannot be single-directional, just "grass roots," but it must be continual from all concerned.

From someone still learning at 48.
Mike Grunberg
Chelmsford, Essex, CM1 5LN, UK

Tribute to Irwin Feerst
I have never met Irwin Feerst. Yet, as I read of his incapacity in Frances Feerst's letter (EDN, June 21, 1990, pg 47), I feel a profound sense of loss, as if he were a close personal friend.

I've read Irwin's CCEE Newsletters for many years, always with ambivalent feelings. I disagreed with him as often as I agreed. I voted for him for several IEEE offices but feared that he might win. I sent him donations but was repulsed by his personal attacks on the leadership. I wished for a gentler messiah.

Of one thing there is no doubt. Irwin has always been solidly on the side of the working engineer. I know that I speak for many of us when I say: Thank you, Irwin. You were our friend and supporter. Your efforts have helped us to stand a little bit straighter and to shed a little of our wimpish image. In time, just maybe, we can finish the job and gain the rewards that our contributions earn us. If so, your efforts will not have been in vain. Meanwhile, your work on our behalf will be sorely missed.

I know I speak for all engineers when I wish Mr Feerst a long, comfortable, and productive life. May God be gracious to him as he struggles with his crippling disease.
Fred D Campbell, PE
Nipomo, CA

(Ed Note: Unfortunately, Irwin Feerst died in late August, before we could print this letter. See News Breaks in the September 17, 1990, issue for his obituary.)

Problems encountered in 50 years of engineering
Jon Titus's editorial, "No shortage of engineers" (EDN, July 5, 1990, pg 39), should be required reading for every educator and top engineering manager.

I have been in engineering for more than 50 years (my latest patent was just issued), and am still producing—when my "leaders" permit it. It seems that the engineers who can produce, do, and those who can't, go into some area of management. Then they pass off the paperwork that they don't like to the engineers, creating the "shortage."

I wish that were the only problem. Some of our ill-informed engineering managers who decided how most US TV sets should be designed decided that the 4.5-MHz video bandwidth set by the FCC on a sound technical basis wasn't needed—that about 2.5 MHz was enough, thus creating out-of-focus pictures. (The small number of manufacturers who tried to live up to FCC specs were forced out of business because of modestly increased costs.)

We've also had a problem in the RF input stages of TVs that radio amateurs (hams) have taken the rap for. A coupled (inductive) circuit having one coil tuned, and the second untuned, can be overcoupled, with the result that strong neighborhood signals can corrupt low-channel pictures. Critical coupling occurs when the coupling coefficient is the reciprocal of the square root of the "Q" of the tuned circuit. This problem is severely aggravated with input circuits using bipolar transistors. The problem is significantly less with FETs and tubes, but it still can be serious.

IEEE leadership is to a large extent responsible for these conditions, as the publish-or-perish syndrome kills too many creative papers, and the bottom-line syndrome kills our competitiveness. Can't, or won't, anyone do something about it? The creativity resides in individuals, and innovation can only occur there. Does EDN comprehend that in their new program?
Keats A Pullen Jr
Kingsville, MD

Correction
In the listing of Innovation Finalists (EDN, September 3, 1990, pg 56), the phone number for Applied Microsystems is incorrect. The correct number is (206) 882-2000.

IT'S EASY TO HAVE YOUR SAY
EDN's Signals & Noise column provides a forum for readers to express their opinions on issues raised in the magazine's articles or on any topic that affects the engineering industry. You can use one of several easy ways to reach us. First, there's always the mail. Send your letters to Signals & Noise Editor, EDN Magazine, 275 Washington St, Newton, MA 02158. Or, send us a message via MCI mail at EDNBOS. Finally, EDN's bulletin-board system is ready for use—and it's free (except for the phone call). You can reach us at (617) 558-4241 and leave a letter in the EDITORS Special Interest Group. You'll need a 2400-bps or less modem and a communications program that is set for eight data bits, no parity, and one stop bit, or 2400, 8N1 in shorthand.

34
EDN October 25, 1990
M SERIES
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- All outputs:
  - Adjustable
  - Fully regulated
  - Floating
  - Overload and short circuit proof
  - Overvoltage protected
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  - System inhibit
  - Load proportional DC fan output
- Options include:
  - Auto range for continuous input operation
  - Power fail monitor
  - Independent pilot bias
  - Cover
  - Fan cover
  - Active surge limit
  - Power factor/UPS prep

MODEL SELECTION

Input modules are available in ratings of 400, 500, 600, and 750 watts with corresponding code letters A through D. See Power Codes chart opposite.

Output modules are available in four types J, K, M and N in nominal power outputs of 75, 150, 500, and 750 watts respectively. Type M or main output modules are variable power rated depending upon the power level of the input module. This is reflected in the rating table opposite which shows the corresponding multiplier applicable to the output current ratings of the M module as a function of the power rating of the input module. For example, when used with a 750 watt input module, the M type will produce a nominal 600 watts of output. The ratings of output modules are given in the table of output types. Ratings in shaded areas are stocked for fast delivery.

HOW TO ORDER

To form the proper model number defining a custom requirement, start with the letter M to designate the series, then choose the desired configuration of output modules and list the configuration code. Insert the power code letter for the power level desired and follow with the output code numbers for each specific output desired. Enter a dash and from the option table insert the sum of the option codes corresponding to the desired options. See example below:
M SERIES SELECTION CHARTS

<table>
<thead>
<tr>
<th>Input Module Power Codes</th>
<th>Output Module Types</th>
<th>M Type Main Module Ratings</th>
<th>Options</th>
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<tr>
<td>A</td>
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<tr>
<td>N</td>
<td>Double Main</td>
<td>750W 1.20</td>
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Output Modules

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<th>K Amps</th>
<th>M Amps</th>
<th>N Amps</th>
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<tr>
<td>0</td>
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Options

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<td>01</td>
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<tr>
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<td>Auto Ranger</td>
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<td>Pilot Bias</td>
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<td>08</td>
<td>Active Surge Limit</td>
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<tr>
<td>16</td>
<td>UPS/FFP Prep</td>
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<tr>
<td>32</td>
<td>Cover</td>
</tr>
<tr>
<td>64</td>
<td>Fan Cover</td>
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</tbody>
</table>

For multiple output modules of a given type, voltages are arranged in ascending order by magnitude in the same sense as the output number sequence. Shaded ratings are standard, others available on special order. Non tabulated intermediate voltages have current ratings equal to straight line interpolation between the current ratings of the voltages that bracket it.

M SERIES DIMENSIONS

The boxes above are diagramatic representations of the power supplies as viewed from the output end. The two digit numbers above the boxes are the configuration codes.
**SPECIFICATIONS**

**INPUT**
90-132 VAC or 180-264 VAC, 47-440 Hz. Strappable.

**INPUT SURGE**
Less than 68 Amps peak from cold start.

**HOLDUP TIME**
20 milliseconds from loss of nominal AC power.

**OUTPUTS**
See model selection table.

**ADJUSTABILITY**
±5% trim adjustment.

**OUTPUT POLARITY**
All outputs are floating from chassis and each other and can be referenced to each other or ground as required.

**LINE REGULATION**
Less than ±0.1% or ±5mV for input changes from nominal to min. or max. rated values.

**LOAD REGULATION**
±0.2% or ±10mV for load changes from 50% to 0% or 100% of max. rated values.

**MINIMUM LOAD**
Main output requires a 10% minimum load for full output from auxiliaries.

**REMOTE SENSING**
On all outputs except type J modules.

**RIPPLE & NOISE**
1% or 100mV pk-pk, 20 MHz bandwidth.

**OPERATING TEMPERATURE**
0-70°C. Derate 2.5% °C above 50°C.

**COOLING**
A min. of 10 LFS cooling air directed over the units for full rating. Two test locations on chassis rated for max. temperature of 90°C.

**TEMPERATURE COEFFICIENT**
±0.02%/°C.

**EFFICIENCY**
80% typical.

**SAFETY**

**DIELECTRIC WITHSTAND**
3750 VRMS input to ground.
3750 VRMS input to output.
700 VDC output to ground.

**SPACING**
8 mm primary to secondary.
4 mm to grounded circuits.

**LEAKAGE CURRENT**
0.75 mA at 115 VAC 60Hz. input.

**EMISSIONS**
Units meet FCC 20780 Part 15 Class A and VDE 0871/6.78 Class A for conducted emissions. Compliance with Class B limits by use of additional external filter.

**DYNAMIC RESPONSE**
Peak transient less than ±2% or ±200mV for step load change from 75% to 50% or 100% max. ratings.

**RECOVERY TIME**

**AC UNDERVOLTAGE**
Protects against damage for undervoltage operation.

**OVERVOLTAGE PROTECTION**
Standard on all outputs.

**REVERSE VOLTAGE PROTECTION**
All outputs are protected up to load ratings.

**OVERLOAD & SHORT CIRCUIT**
Outputs protected by duty cycle current foldback circuit with automatic recovery. Auxiliaries have additional backup fuse protection.

**THERMAL SHUTDOWN**
Circuit cuts off supply in case of local over temperature. Units reset automatically when temperature returns to normal.

**SOFT START**
Units have soft start feature to protect critical components.

**FAN OUTPUT**
Nominal 12 VDC @ 12 watts maximum.

**INHIBIT**
TTL compatible system inhibit provided.

**SHOCK**
MIL-STD 810-D Method 516.3, Procedure III.

**VIBRATION**
MIL-STD 810-D Method 514.3, Category 1, Procedure I.

**MECHANICAL**
400 W / 500 W - 2.5" H x 5.05" W x 9.00" L.
600 W / 750 W - 2.5" H x 5.20" W x 9.63" L.

**POWER FAIL MONITOR**
Optional circuit provides isolated TTL and VME compatible power fail signal providing 4 milliseconds warning before main output drops by 5% after an input failure.

**AUTO RANGER**
Optional circuit provides automatic operation at specified input ranges without strapping.

**PILOT BIAS**
Optional circuit provides SELV output of 5 volts at 75 milliamps independent of the main power converter. Output isolation compliant to safety specifications referenced above.

**ACTIVE SURGE LIMIT**
Limits input surge to less than 18 Amps, and provides rapid reset.

**COVER**
Optional flat cover recommended when customer supplied fan cooling is directed through the length of the unit.

**FAN COVER**
Optional cover with brushless DC fan which provides the required air flow for full rating of Moduflex power supplies.

**UPS**
Accessory battery backup system provides uninterruptible service in case of brownout or blackout of utility power. Requires nominal 48 VDC lead acid or Gel cell. Unit has 3 state charger to keep battery fully charged. Will support up to 1000 watts output.

**POWER FACTOR CORRECTOR**
Accessory active converter produces power factor of 0.99 for up to 2000 watts output at high input range, or 1000 watts at low input range. Provides automatic auto ranging.
If you've always felt something important was missing when it came to proving the effectiveness of advertising, this ad speaks powerfully to you. The Affinity Index is a revolutionary new guide to media buying that goes beyond circulation numbers, and beyond reader preference studies. Now for the first time, The Affinity Index measures the relationship between reader and publication. It measures how a reader's feeling for a particular magazine influences the response to your ad in that magazine.

At last, prove how your ad affects readers within a magazine's editorial environment. And where your ad stimulates your customers' greatest interest. The Affinity Index, using techniques created by Simmons Market Research Bureau, Inc. in a two year project sponsored by Cahners Publishing Company, is reliable, usable, and available now. For details and a complete brochure contact: Cahners Publishing Company, 275 Washington Street, Newton, MA 02158. Phone: 617-558-4425.
When it comes to PCs, workstations, printers, and other computer-related products, end-users want smaller systems, maximum memory storage, and minimum power consumption. And they want it now. Which creates several problems for you. How do you reduce system size and power consumption yet increase memory capacity? And be first to market with your product? Oki offers some flexible solutions.

To begin with, our pin-for-pin compatible 4-Megs provide 4X the memory storage of a 1-Meg — without increasing space. Plus our 4-Megs have the lowest power consumption of any 4-Meg, making them ideal for laptops and other memory-intensive, power-hungry systems. Choose from a variety of packages too: DIP, SOJ, ZIP — and, later in 1990, an ultrathin TSOP, for even more space-saving advantages.

For higher density applications, select from Oki's packaging-efficient family of SIMMs: 4-Megx8s, 4-Megx9s, and 1-Megx36s. Or we'll work with you to design a custom SIMM that meets your unique specifications. All our 4-Megs and SIMMs are available now; so we're ready to help accelerate your design time and your product's time-to-market.

Call Oki today for qualification samples. See why so many companies are demanding Oki's low-power, space-saving 4-Megs and SIMMs — and getting their leading-edge computer products to market so quickly.

Transforming technology into customer solutions
Demand Oki 4-Megs and SIMMs

Oki's 4-Meg Product Line-Up

<table>
<thead>
<tr>
<th>Device</th>
<th>Organization</th>
<th>Access Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSM514100-XXYY</td>
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<td>Fast Page</td>
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<tr>
<td>MSM514101-XXYY</td>
<td>4M x 1</td>
<td>Nibble</td>
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<tr>
<td>MSM514102-XXYY</td>
<td>4M x 1</td>
<td>Static Column</td>
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<tr>
<td>MSM514400-XXYY</td>
<td>1M x 4</td>
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<tr>
<td>MSM514402-XXYY</td>
<td>1M x 4</td>
<td>Static Column</td>
</tr>
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</table>

Speed Options (XX) Include:
- 70 = 70ns (RAC)
- 80 = 80ns (RAC) 20ns (CAC)
- 90 = 90ns (RAC) 25ns (CAC)
- 10 = 100ns (RAC) 25ns (CAC)

Packaging Options (YY) Include:
- JS = 350 mil SOJ
- RS = 400 mil DIP
- ZS = 400 mil ZIP

SIMMs

<table>
<thead>
<tr>
<th>Device</th>
<th>Organization</th>
<th>Access Mode</th>
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<td>MSC2340-XXYS9</td>
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<td>MSC2350-XXYS12</td>
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</table>

Speed Options (XX) Include:
- 70 = 70ns (RAC)
- 80 = 80ns (RAC) 20ns (CAC)
- 10 = 100ns (RAC) 25ns (CAC)

EDN October 25, 1990

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Here's one reason that over half of all SCSI devices sold are NCR.

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Meet NCR's SCSI development team. In 1983, they gave the computer industry its first SCSI device. By providing easy connectability and significantly reducing time to market, a new product era was born.

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Today SCSI is becoming the leading I/O standard — adopted by industry giants like Apple, IBM, HP, and DEC. And no one is selling more SCSI chip level products than NCR. In fact, no one even comes close.
Here's another.

The NCR 53C700 SCSI I/O Processor…
So good, Electronic Design named it the product of the year.

"You can't tell a good SCSI chip just by looking at it…” and according to Electronic Design, NCR’s 53C700 is the best there is.

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As the first SCSI I/O processor on a chip, the 53C700 allows your CPU to work at maximum speed while initiating I/O operations up to thousands of times faster than any non-intelligent host adapter. DMA controllers can burst data at speeds of up to 50 Mbytes/s. This new chip cuts down system time hookup to a fraction of what it has been.

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Structured Analysis & Design (seminar), Atlanta, GA. Visible Systems Corp, 950 Winter St, Waltham, MA 02154. (617) 890-2273. FAX (617) 890-8909. November 5 to 7.


Total Quality Management (short course), Irvine, CA. University of California—Irvine Extension, Box 6050, Irvine, CA 92716. (714) 856-7774. FAX (714) 725-2090. November 13 to 16.

MEGA MEMORY.

SONY HIGH-DENSITY SRAMS

<table>
<thead>
<tr>
<th>MODEL</th>
<th>CONFIG.</th>
<th>SPEED (ns)</th>
<th>PACKAGING</th>
<th>DATA RETENTION</th>
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<td>CXK581100TM*</td>
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<td>TSOP</td>
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<td>35/45/55</td>
<td>SQJ 400 mil</td>
<td>L</td>
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</tbody>
</table>

*Extended temperature range available. L = Low power. LL = Low, low power.

MEGA COMMITMENT.

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- FLEX-FTI™ dual compliant pin design allows front or rear removal and replacement.

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- Unique contact geometry reduces per contact insertion force to 1.5 oz. (avg.), but maintains high normal force of 75 g. (avg.).

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- meets MIL-STD-202 tests
- rugged hermetically-sealed pin models
- BNC, Type N; SMA available
- surface-mount
- over 100 off-the-shelf models
- immediate delivery

low pass dc to 1200MHz

<table>
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<tr>
<th>MODEL</th>
<th>PASSBAND, MHz (loss &lt;1dB)</th>
<th>Fco, MHz (loss 3dB)</th>
<th>STOP BAND, MHz (loss&gt;20dB)</th>
<th>VSWR pass-band typ.</th>
<th>PRICE</th>
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high pass dc to 2500MHz

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<th>Fco, MHz (loss 3dB)</th>
<th>STOP BAND, MHz (loss&gt;20dB)</th>
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<th>PRICE</th>
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<td>DC-2000</td>
<td>450</td>
<td>780</td>
<td>1200</td>
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<td>PHP-600</td>
<td>DC-2400</td>
<td>545</td>
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<td>1500</td>
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<td>PHP-700</td>
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<td>1200</td>
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<td>DC-3000</td>
<td>680</td>
<td>1280</td>
<td>2450</td>
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<td>DC-3600</td>
<td>720</td>
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<td>2800</td>
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bandpass 20 to 70MHz

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<tr>
<th>MODEL</th>
<th>CENTER FREQ. MHz</th>
<th>PASS BAND, MHz (loss &lt;1dB)</th>
<th>STOP BAND, MHz (loss &gt;20dB)</th>
<th>VSWR total band typ.</th>
<th>PRICE</th>
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<tbody>
<tr>
<td>PBF-21.4</td>
<td>21.4</td>
<td>18</td>
<td>25</td>
<td>4.9</td>
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<td>PBF-30.0</td>
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<td>35</td>
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<td>PBF-45.0</td>
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<td>49</td>
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<td>58</td>
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<td>70</td>
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<td>82</td>
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narrowband IF

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<tr>
<th>MODEL</th>
<th>CENTER FREQ. MHz</th>
<th>PASS BAND, MHz l.L. 1.5dB max.</th>
<th>STOP BAND, MHz l.L. &gt; 20dB</th>
<th>STOP BAND, MHz l.L. &gt; 35dB</th>
<th>VSWR</th>
<th>PRICE</th>
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<td>9.5-11.5</td>
<td>7.5</td>
<td>15</td>
<td>0.6</td>
<td>50-1000</td>
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<td>PNB-21.4</td>
<td>21.4</td>
<td>19-23.6</td>
<td>15.6</td>
<td>29</td>
<td>30-1000</td>
<td>1.7</td>
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<tr>
<td>PNB-30.0</td>
<td>30.0</td>
<td>27-33.0</td>
<td>22</td>
<td>40</td>
<td>32-9900</td>
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<tr>
<td>PNB-40.0</td>
<td>40.0</td>
<td>36-46.0</td>
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<td>58</td>
<td>48-18000</td>
<td>1.7</td>
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<td>53-77.0</td>
<td>44</td>
<td>84</td>
<td>66-19300</td>
<td>1.7</td>
</tr>
</tbody>
</table>

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**CIRCLE NO. 94**
Goodbye, TTL

My early logic circuits used both RTL and DTL integrated circuits—families of devices that today are forgotten. Designing with RTL and DTL ICs wasn’t difficult, but there was little variety from which to choose. As a result, complex designs grew rapidly. It was a pleasure to move on to the 7400 family of TTL devices, and its cornucopia of logic building blocks, in 1970. If you needed a specialized function, more than likely you could find one in the 7400 family.

It’s sad to see the demise of such a rich family of devices, but the end is at hand. For example, most computer circuit boards today are teeming with PLDs, which replace literally hundreds of discrete logic chips. Although programmable logic has been available for many years, we’ve reached the point at which PLDs and field-programmable gate arrays (FPGAs) are economical substitutes for most logic functions. It just doesn’t pay to use discrete TTL ICs unless you need a very special function.

I remember discovering “programmable logic” in a roundabout way. One of my colleagues started using fuse-programmable ROMs as programmable decoders on microprocessor boards. The PROM wasn’t what we think of today as a true programmable logic device. However, one PROM IC took the place of several TTL devices. It gave us the flexibility to change our memory and I/O-port arrangements. It also gave us the space we needed to fit the computer on a given board. By today’s standards, that application sounds crude and trite, but it solved a problem. We also used a PROM and a few external components to build a small state machine—as we called it. That crude form of programmable logic—and later true PLDs—found places in our designs.

Today’s designers can choose from such a broad range of PLDs and FPGAs that few of them will need as many individual TTL chips as we did 15 years ago. Sure, there will always be a need for a few extra gates or special driver ICs, but today’s logic designs rely heavily on programmable devices. These designs simply follow the trend toward putting more functions in a chip and letting the users select or program the functions they want.

In a way, it’s sad to see the death of massive breadboards crammed with 7400-series ICs. Those prototypes let us put scope and logic-analyzer probes on circuits that are virtually inaccessible in today’s PLDs and FPGAs. We could almost always find a spare gate, flip flop, or inverter on the board to patch in as needed during debugging. We also kept a wire-wrapping gun handy. In retrospect, though, it wasn’t easy. Nor was it enjoyable. Tracing my way through a maze of red, blue, yellow, and white 30-gauge wire was no fun—particularly when the schematic wasn’t up to date with the circuit revisions. Faced with the prospect of using TTL devices, I’ll take PLDs and FPGAs. Today’s design, development, and testing tools make digital engineering a lot less work. And, those same tools give today’s engineer much more time for creativity than we had 15 years ago. Long live programmable logic.

By the way, does anyone know what a 74LS261 is? I found one over the weekend in my collection of odds-and-ends chips. No fair looking it up.
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<table>
<thead>
<tr>
<th>Intel Microprocessors</th>
<th>NEC Microprocessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>8086/88/C86/C98 10 MHz</td>
<td>V20/50 10 MHz</td>
</tr>
<tr>
<td>80186/188/C186 16 MHz</td>
<td>V40/50 10 MHz</td>
</tr>
<tr>
<td>80286 16 MHz</td>
<td>V25 16 MHz</td>
</tr>
<tr>
<td>80386 25 MHz</td>
<td>V33 16 MHz</td>
</tr>
<tr>
<td>80386SX/376 16 MHz</td>
<td>V60 16 MHz</td>
</tr>
</tbody>
</table>

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EDN October 25, 1990
Portable PCs tackle instrumentation tasks

In the decade since the IBM PC’s introduction, personal computer-based instrumentation has grown from a novelty to a mature industry offering a range of hardware and software tools. At the same time, portable PCs have become powerful enough to rival their desk-bound cousins. With care, you can combine the two technologies to work in, and beyond, the laboratory.

Portable PCs offer a number of advantages over desktop models in instrumentation tasks. They are typically smaller, occupying less of your already crowded lab bench. They are also lighter and more easily moved from bench to bench or to a field site.

Because they are weaned from the wall outlet, battery-powered portable PCs offer additional advantages. They are immune to the power glitches and line noise found in generator-driven or heavy-industrial sites. They cannot create the power-cord ground loops often found in test setups. And in medical applications, battery-powered units are safer than desktop PCs; with only dc power they present no patient-shock hazards.

The light weight of some portable PCs may also be advantageous in a field application. One hang-glider company, for example, uses a laptop PC to measure wing stress during test flights. Not even a long extension cord could help a desktop unit perform that task.

To obtain the benefits of portability in your PC-based instrumentation, you have three choices: you can buy a portable PC and add plug-in cards, buy a system already assembled, or use portable instruments having a PC link. Unless you have only occasional use for portable instrumentation, however, that first choice may not be your best.

It seems simple enough to buy a portable PC and add plug-in cards, but it’s not. You’ll have to choose carefully to work around the PC’s limitations. You must consider the PC’s expansability, its available power, and its display and memory characteristics. You must also match the plug-in card’s size and power requirements to the PC’s expansion capability.

Most portable PCs have some form of expansion capability, but many use proprietary bus and card designs in order to meet packaging limitations. Unless you intend to design your own plug-ins, you’ll have to go with PCs that offer industry-standard plug-in slots. Table 1
Is your equipment meeting conducted EMI standards?

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Portable PC instruments
gives a sampling of portable PCs with standard card slots.
Mere possession of a standard expansion slot, however, does not guarantee that a portable PC will accept whatever plug-in card you may wish to use. You must consider the PC's power capability. The PC may have a scaled-down power supply, imposing limits on the amount of current you may draw to run your plug-in card. Exceeding those limitations can seriously damage the supply.
Battery-powered PCs have additional limitations. The PC's battery capacity may not be sufficient to drive a power-hungry plug-in device for a useful amount of time. Further, a battery-powered system may not provide the −12V normally available on a PC's expansion slot.
After expandability and power, the next consideration when choosing a portable PC for instrumentation is the PC's display type. Many portable PC displays are simply monochromatic LCDs with 600 × 200-pixel resolution. All are limited in size to <12 in. Such display limitations may prevent you from taking full advantage of instrumenta-
tion software's graphical capabilities. (Many portable PCs have video ports for driving external, higher-resolution color monitors, but carrying around a CRT probably defeats your purpose for using a portable PC in the first place.)
Finally, consider the speed of the computer, its memory capacity, and its disk data-transfer rate. These three factors will determine how much data you can collect and how fast. The computer's CPU speed determines how fast it can acquire and display data; the disk speed and memory size determine its maximum recording capacity at a given sample rate. Most data-acquisition

<table>
<thead>
<tr>
<th>Company</th>
<th>Model no.</th>
<th>Plug-in slots</th>
<th>RAM memory standard/maximum (M bytes)</th>
<th>Hard-disk capacity standard/optional (M bytes)</th>
<th>Display</th>
<th>Starting price</th>
<th>Battery capacity</th>
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<td>LA-30A</td>
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<td>Snap 1+1</td>
<td>1 XT, ½ size</td>
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<td>Gridcase</td>
<td>1 AT</td>
<td>1/8</td>
<td>40100</td>
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<td>Micro Express</td>
<td>Lyte-Byte</td>
<td>1 AT, ½ size</td>
<td>1/5</td>
<td>40100</td>
<td>640×400 gas plasma four levels of gray</td>
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<td>1 AT, ½ size</td>
<td>1/5</td>
<td>40200</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5 Ahr optional battery</td>
</tr>
</tbody>
</table>
TECHNOLOGY UPDATE

Portable PC instruments

boards can acquire information much faster than the PC can store such information.

Portable PCs for instrumentation

As discouraging as these considerations seem, there are portable PCs that will handle engineering instrumentation applications. Bitwise Designs, for example, offers an entire line of ac-powered portable PCs for engineers, called the VP series. Each member of the series features two full-size AT-bus-compatible expansion slots, a 200W power supply, and a gas-plasma monochrome VGA display with color mapped to 16 shades of gray. The top-of-the-line unit, the 433/VP, features a 33-MHz 80486 CPU, 4M bytes of RAM, and a 200M-byte, 16-msec hard-disk drive. Prices range from $2695 for a 12-MHz 80286 version to $11,995 for the 433/VP.

If you need a battery-powered unit, you can use the Gridcase 1535 EXP from Grid Systems. This unit uses a 12.5-MHz 80386 CPU and has a 640 x 400-pixel backlit LCD display. It costs $5525.

Finding a PC is only half of the problem; you must still find a plug-in card to match your PC. Literally hundreds of plug-in boards exist that will turn your PC into any type of instrument you desire (Ref 1), but few have been designed with portable PCs in mind. Many data-acquisition boards require -12V, which is often unavailable on portable PCs. Further, most portable PCs will only accept half-size cards.

One of the rare breed of plug-in boards designed to account for a portable PC’s limitations is the DT2814 data-acquisition board from Data Translation ($345). The DT2814 provides 16 single-ended data channels and digitizes to 12 bits with a sample rate as great as 40 kHz. The board occupies a half-card standard XT expansion slot, and it draws <138 mA at 5V and <50 mA at +12V. It uses a charge pump to generate its own -12V.

Integrated PC systems

If the business of selecting a portable PC and plug-in device is more of a hassle than a help, you may choose to purchase an integrated system. These systems have the advantage of using plug-in cards that are matched to their computer. The system designers have addressed power and size constraints for you, as well as factors such as heat, electrical noise, and providing software.

Several such systems are available, depending on the type of environment you expect to encounter. Elexor's TD-4000, for example, is a relatively low-cost (<$2000) system for average environments. The TD-4000 is a modified Toshiba T-1000 battery-powered laptop computer. It provides both analog and digital I/O ports, a 720k-byte floppy-disk drive, and 512k bytes of RAM. The system comes with MS-DOS in ROM and Elexor's data-acquisition and display software, MACS, on disk.

The system's analog input port provides 16 single-ended or eight differential data channels, samples as fast as 10 kHz, and provides 12 bits of resolution. Faster and more precise converters are available as options, as is a 2-channel 12-bit D/A output port. The digital port provides eight bidirectional and two timer/counter I/O lines.

The Techstation, from Onsite Instruments, handles more rugged conditions. The battery-powered system, including the 40M-byte hard-disk drive, will operate continuously under vibrations as great as 5G. Its cost is also more rugged; prices start at $17,750 for a basic system.

Onsite starts with a Gridcase 1535, then adds its own expansion box with memory, antialiasing filters, and an 80186-based data-acquisition card. The card's CPU handles all of the data conversion and storage, leaving the computer's CPU to handle display functions.
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TECHNOLOGY UPDATE

Portable PC instruments

and perform FFTs for spectral analysis. The result is data acquisition on 16 channels at a sustained 100,000 samples/sec with bursts as great as 250,000 samples/sec.

If your interests are more digital than analog, you may choose the Orion Instruments Omnilab II. It offers a 48- or 96-channel logic analyzer, 24-bit digital output generator, 100-MHz digital sampling oscilloscope (DSO), arbitrary waveform generator, and frequency counter in an ac-powered portable PC. Prices start at $12,800.

Because the Omnilab’s instruments are integrated into a single package, you can combine their functions. For example, you can capture an analog waveform with the DSO, edit it with the PC, then play it back through the waveform generator as a test stimulus. You can also trigger the logic analyzer with analog signals and get time-aligned digital and analog displays.

You may need the portability and ease-of-use available with an integrated system, yet require more capability than you can fit into a PC chassis. In that case, you can use a portable instrument that links to a PC for control, display, and data storage. Such instruments use either an interface card that plugs into the PC's expansion slot or an RS-232C link to the PC.

For simple data acquisition, you could use the Tektronix Model 222 handheld digital oscilloscope. The $2350 unit features an RS-232C link to a PC, allowing you to transfer stored waveforms and setup files between the two. If you use the CAT200 software package from National Instruments ($350), your PC can become an extension of the oscilloscope, allowing you to control the instrument and view data, using the PC display to duplicate the oscilloscope’s front panel. Any portable PC running MS-DOS and having a serial port and EGA-resolution graphics capability can run CAT200.

For more elaborate data acquisition, you can use an instrumentation front end that you configure with plug-in cards. For example, the Helios series from Fluke runs from 12 or 24V dc power and can handle as many as 1000 data channels at speeds as great as 1000 channels/sec. You control the unit through an RS-232C or RS-422 link, using Fluke’s CIM-PAC software or National Instruments’ Labtech Notebook. A base unit costs $2500, with plug-in cards ranging from $100 to $1200.

Keithley’s Metrabyte/DAC division also offers a flexible data-acquisition and control unit, the Model 500P, for portable applications. The unit connects to your PC through a half-size expansion card and provides an analog measurement module with slots for nine other modules. You can obtain analog-input and -output, digital-input and -output, power-control, and motion-control modules for the system.

The Model 500P uses a dc/dc converter to power its modules. The unit will also power your portable PC, providing 2.5A at 12V ±2%. You can choose a 9.5 to 18V version.

Add sensor, will travel should be the motto of these PC-based systems. The TD-4000 (a) from Elezor Associates and the Techstation (b) from Onsite Instruments are complete analog data-acquisition and processing stations, including software.
Are you missing the big picture in digital oscilloscopes?

There's more of everything with the Nicolet 400 Series.

Any way you look at it, competitors just can't touch the Nicolet 400 Series when you consider memory and vertical resolution.

The closest major competitor's per-channel memory is four times less. Vertical resolution—four times less again. And when memory and vertical resolution are combined, the nearest offering is 80 times less! Clearly no match.*

Now add other 400 Series advantages like the choice of two or four channels, with 64K to 256K memory in each. Single ended or differential inputs. A 3½" or 5¼" floppy drive. One to 200 MS/s digitizing rates. The unique 44 MB removable hard disk or 40 MB internal disk. Plus dual timebase, choice of 8 or 12 bit digitizing resolution (separate or combined); built in MS-DOS drive; LEARN mode for automated test sequences; FFT and averaging.

More individual features, more combined memory and vertical resolution, more of everything. Get the picture?

Call today about the Nicolet 400.

*Based upon known specifications as of 7/90.

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Nicolet
INSTRUMENTS OF DISCOVERY

Nicolet 430E: 256K Memory-Channel, 12 bits vertical resolution.

LeCroy 9450:
80 times less resolution
(5 times less horiz.,
16 times less vert.)

Tektronix 7A4602:
208 times less resolution
(13 times less horiz.,
16 times less vert.)

Hewlett-Packard 54112D:
256 times less resolution
(4 times less horiz.,
64 times less vert.)

Fluke PM 3323:
256 times less resolution
(64 times less horiz.,
4 times less vert.)

EDN October 25, 1990
CIRCLE NO. 101
Don’t Compromise!
'486 Portable Computer
with Workstation Performance
and
PC-Based Logic Analyzer
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-33 MHz 80486-based VGA Portable
-Runs MS-DOS, Unix, OS/2
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-The Fastest Portable in the World!
A Full Line of 286, 386, and 486 Portables, Workstations, and Networks.

Capture...
GENERAL CIRCUITBUG

Portable PC instruments

drawing 10A or an 18 to 36V version drawing 5A, at prices starting from $1850. The device comes with Keithley’s KDAC500/I software for programming the instrument in Basic. You can also use National Instruments’ Labtech Notebook software to control the instrument.

The many options you have demonstrate that portable PCs are viable instruments, despite their limitations. And those limits are changing. The next generation of portable PCs, for example, is likely to offer full-color VGA displays, removing the display limitation. Ultimately, only size and power capacity will limit what you can add to and do with a portable PC. That, and your imagination.

Reference

Article Interest Quotient (Circle One)
High 515 Medium 516 Low 517

For more information...

For more information on the portable PCs and instruments discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use EDN’s Express Request service. When you contact any of the following manufacturers directly, please let them know you saw their products in EDN.

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Circle No. 665

Onsite Instruments Inc
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FAX (415) 864-8808
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in WA, (206) 226-6100
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in CA, (415) 361-8883
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Taunton, MA 02780
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Circle No. 667

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(900) 426-2200;
in OR, (503) 690-3900
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FAX (404) 564-5555
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Circle 13 for Computers
Circle 14 for Logic Analyzers

EDN October 25, 1990
The Perfect Waveform Synthesizer for an Imperfect World

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In a world full of glitches, spikes, noise, aberrations and distortion, waveform synthesis must be flexible enough to emulate nature itself. With unprecedented speed, accuracy, and memory depths, Analogic’s 2020, 2040, and 2045 Polynomial Waveform Generators readily simulate the complex waveforms demanded in today’s test environments. The Data Precision waveform generators feature:

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CIRCLE NO. 102
BEFORE YOU CHOOSE P
BETTER CHECK

Things aren’t always what they seem.

Some people would have you believe FPGAs are faster and denser than MAX™ EPLDs.

Funny how they never mention in-system performance, though. When they talk about speed, they quote 100MHz flip-flop toggle rates. When they talk about density, they recite raw gate counts.

Which could make your high-performance design highly disappointing.

But if you want to do more than just spin your wheels, consider MAX. It’s the first family of programmable logic devices to provide both high speed and high logic density where it counts. At the system level.

Which means MAX can handle just about all your logic needs. In fact, a single 64-macrocell EPM5064...
can integrate anything from simple system glue logic right up to complex graphics coprocessors and LAN and memory controllers.

Or take the 68-pin MAX EPM5128. It's up to 50% faster and 100% denser than comparable FPGAs, thanks to its high-performance architecture and superior logic routability. But don't take our word for it—just take a look at the competition's benchmarks.

Best of all, MAX gives you this unbeatable performance in record time. With powerful, easy-to-use MAX+PLUS™ software, design compile times are measured in minutes. Not hours or days.

So if you’re looking to redefine system performance, talk to the folks who invented the EPLD. Call Altera today at (408) 984-2800.

We’ll make sure you’ve got plenty of horses under the hood.

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IN THE ERA OF MegaChip™ TECHNOLOGIES

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With more than 50 BiCMOS logic functions from Texas Instruments, you can beat tough bus-interface design challenges. Our free SamplePacs will show you how.

Specially designed for use in bus-interface applications, our growing BiCMOS logic family can make the difference in getting data on and off the bus faster. These advanced functions that combine the best of bipolar and CMOS can help you attain higher system performance levels.

Lowering power, maximizing speed
For example, our BiCMOS devices can help you minimize power dissipation and maximize speed. Disabled currents are reduced by as much as 95% and active currents by as much as 50% compared to advanced bipolar equivalents.
In fact, your system power savings can amount to more than 25%, and you should experience reduced switching noise as well. Yet you can maximize system speed. Switching speeds are comparable to advanced bipolar devices and provide the high drive current required for today's industry-standard buses (48/64 mA commercial, 24/48 mA military).

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If you need even lower power and higher speeds, our submicron Advanced BiCMOS (ABT) family is the choice for you. Planned devices include 8-, 9-, and 10-bit buffers/drivers, transceivers, latches, registers, and registered and latched transceivers. Our broad BiCMOS family also includes unique functions that can help you more quickly meet the design challenges involved with incident wave switching, driving MOS memories, and system testability.

Assuring incident wave switching
Wider word widths and additional cards on backplanes are requiring higher drive currents to assure incident wave switching. Our BiCMOS family delivers. With our low-impedance line drivers, you get more "instantaneous" current even when impedances are as low as 25 ohms. You minimize transition "flat" spots that can degrade speed or cause oscillation at the receiving devices.

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MOS memory array interfaces create the high-capacitive loading environments that can result in overshoot and undershoot conditions. As a result, system reliability suffers. To handle this situation, our BiCMOS memory drivers incorporate a series damping resistor output structure that delivers advanced system performance when driving 256K, 1M, and 4M DRAMs.

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It is becoming more difficult to accurately test today's highly integrated boards and systems, but TI's BiCMOS family contains your solution: SCOPE™ (System Controllability and Observability Partitioning Environment) octals.

Used in place of standard octals, SCOPE devices allow specific circuitry within an assembled module, board, or system to be isolated for verification and debugging without manual probing. Currently, our BiCMOS family includes an octal buffer, transceiver, D-type latch, and D-type flip-flop.

TI's SCOPE products are the first to conform to the Joint Test Action Group (JTAG) specifications adopted by the IEEE 1149.1 Test Standards Committee.

Get your free SamplePac and sample our BiCMOS difference; call 1-800-336-5236, ext. 3008
You can take your choice of our BiCMOS SamplePacs containing a free BiCMOS device, our latest advanced logic brochure, plus appropriate product data. Just call the number given above, or use the return card to let us know which SamplePac you need to begin applying TI's BiCMOS difference.

CIRCLE NO. 104
Remember when... There were no lights in Wrigley Field? Eight megabytes of RAM was only $320,000?

Take a stroll with NEC
down Memory Lane.

1893 Grover Cleveland sworn in as president. William Wrigley, Jr. introduces Juicy Fruit and Spearmint gum at 5¢ a pack, its price for the next 78 years.
1916 Wrigley buys Chicago Cubs.
1971 Wrigley's son Philip grudgingly increases price of gum to 7¢ a pack.
1975 Chewing gum is 15¢ a pack. Eight megabytes of RAM is $320,000. 1K DRAMs are $5.
1985 NEC introduces made-in-America 256K DRAMs.
1988 Lights go on in Wrigley Field (8/8/88). NEC 1-megabyte SIMMs retail for $400. Chewing gum is a quarter.
1989 NEC ships 4-megabit DRAMs in high volume.
1990 NEC 1-megabyte memory modules (SIMMs) begin the year at less than $100. George Bush throws out first ball. NEC samples 60-nanosecond 4-megabit DRAMs in 300-mil SOJ packages.
1993 U.S. president sworn in. NEC ships 16-megabit DRAMs from its Roseville, California, submicron line. Cubs win World Series.

If the price of chewing gum had dropped as fast as memory prices, you could buy 667 packs for a quarter. For the latest information on NEC SIMMs and 4-megabit DRAMs in 300-mil SOJ packages, remember to call NEC.
Programmable logic always has been a give-and-take affair. If you wanted speed, the price was power—lots of it. And, if you tried to cut power, you lost the speed. It seems you could have either one or the other—but not both. **NOW YOU CAN HAVE THE BEST OF BOTH WORLDS.**

Announcing the **AT22V10-15**—the no compromise 22V10.

Talk about fast. A blazing 15 nanoseconds. That’s fast enough for those advanced 32-bit systems you’re designing today for tomorrow’s machines.

And it’s cool. When you plug in the AT22V10 you won’t even think it’s on. It typically draws a stingy 55 milliamps and never asks for more than 90 milliamps.

So, if you’re tired of having to compromise. Don’t. Call Atmel, the home of the no compromise 22V10. If you’re not sure yet that we make the best CMOS 22V10 in the whole world drop us a note on your company’s letterhead, and we’ll send you one. Or in the U.S. call us at **1-800-292-8635.**

"See Us At Electronica, Booth 19C01A"
HLL CROSS-DEBUGGERS

Cross-debuggers verify high-level programs

Debugging used to mean doing little more than first sprinkling your code with PRINT statements and then spending endless hours single-stepping through it. Code debugged this way met, at best, a minimal standard for programs: It would stumble along without crashing.

A collection of incremental improvements to cross-debuggers for high-level languages (HLLs) adds up to software tools that transcend mere debugging. Now you can perform the software equivalent of “corner testing.” That is, as you construct each element of your program, you can wring it out thoroughly. The result should be bulletproof, efficient code.

Hardware engineers have long followed corner-testing practices. Their corner testing proceeds in stages corresponding to the stages of bottom-up implementation; beginning with components, progressing to subassemblies, and finishing with final-systems tests, using only the highest and lowest values of certain important parameters (hence the name corner testing). For example, hardware engineers check responses for all combinations of extreme values for input-signal levels, power-supply voltages, and temperature excursions.

Software engineers call this “unit testing” or “regression testing.” As you write each function or subroutine, you verify its responses to a small but comprehensive set of extreme input values. You perform this testing at each stage of development as you write each subroutine, integrate subroutines into subprograms, and integrate subprograms into your final program.

Cross-debuggers, sometimes called “symbolic debuggers,” offer features whose power transcends merely accessing your target-system program’s vari-

Because its tools have to interoperate over a complete range of hardware and software cross-development tools, Intel’s compilers’ cross-reference file format, OMF, has become a de facto standard for debuggers’ inputs.
AN APPLICATIONS EXAMPLE.
While the following example is for aircraft, it could apply to any air, land, sea or space system.

SEQUENCE ONE: The four-pushbutton display reads “ENGINE START,” “BATTERY OK,” “FUEL OK,” “OXYGEN OK.” The operator selects “ENGINE START.”

SEQUENCE TWO: The four-pushbutton display now changes to read “ENGINE OK,” “HYDRLC OK,” “POWER OK,” “CHECK LIST.” The operator selects “CHECK LIST.”

SEQUENCE THREE: The four-pushbutton display now reads “CHECK ICE,” “CHECK FLAPS,” “CHECK BRAKE,” “SYSTEM OK.” In this manner, the designer can program in as many sequences as required.

Design flexibility: The programmable display system.

Vivisun Series 2000, now the leading programmable display pushbutton system, interfaces the operator with the host computer. The user-friendly LED dot-matrix displays can display any graphics or alpha-numeric and are available in green, red or amber. They can efficiently guide the operator through any complex sequence with no errors and no wasted time.

They also simplify operator training as well as control panel design. One Vivisun Series 2000 programmable display system can do the work of 50 or more dedicated switches. In short, Vivisun Series 2000 gives the design engineer more control over the design.

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Vivisun Series 2000
programmable displays. The intelligent communications system.
HLL Cross-Debuggers

ous entities by their symbolic names. They now automate what used to require considerable operator intervention. The simplest example of such a powerful feature is the "watchpoint."

A watchpoint is a combination of a breakpoint followed by a formatted dump of a selected data entity—a register variable, a memory variable, an array, or a structure. The watchpoint lets you shift your attention from the program's execution to its effects.

With watchpoints, you can employ the normal troubleshooting mindset, identifying anomalous results and working back to their causes. Simply single-stepping your program or running it to breakpoints forces you to identify the cause first.

Note that even the simplest debuggers allow you to break and then examine memory. The key to the watchpoint's utility is that it combines, in one command, what formerly were a tedious string of commands.

Other key features of the newer cross-debuggers are the ability to capture and edit a string of commands (a "session") and the ability to invoke a prerecorded file of commands ("batch mode"). Operating in batch mode, the debugger's scope enlarges beyond on-line testing to encompass automated testing. The simplest example of automated software testing is "babysitting," or letting a program run for extended periods until the debugger detects a fault.

Another important feature is the ability to redirect I/O, because without it, running subroutines and subprograms in isolation would be difficult. With this feature, you can force your program to take unusual branches, enhancing code-coverage testing and branch-flow analysis. You can even test around missing hardware. For example, Intermetrics's SXDB 5.0 ($2400) combines the company's XDB debugger with an IBM PC hardware-simulation board bearing an Intel 80X86 or Motorola 68XXX µP. You can use it to try out your software if your target system isn't available.

When you crunch up sets of these and other useful debugger commands into one custom command, you are, in effect, creating custom test suites. The more easily the cross-debugger allows you to construct such suites, the more likely you are to test your software thoroughly.

Command languages tend to C

Cross-debuggers vary in the command languages they provide to allow you to construct these elaborate command strings. The trend is toward using the same command constructs as the C programming language. Writing a debugging session is therefore virtually the same as

How to become a "power user"

With a cross-debugger, you can pass through the lower stages of computer-user evolution and achieve the status of a "power user." At the first stage of computer-user evolution, you poke around using the debugger's menus. After mastering all the menus, you begin zipping around using commands or a mouse. Finally, you ascend to power-user status when you begin combining commands into strings of your own devising.
writing a small C program. So, be careful about claims that a debugger interfaces to languages other than C. The debugger may work with a non-C compiler if the compiler outputs a standard cross-reference file, such as an Intel OMF cross-reference file. But the debugger's command language will probably still be C.

Some cross-debuggers can also link intimately with powerful debugging hardware such as ROM emulators, in-circuit emulators, and logic analyzers. Such tools offer both nonintrusive, real-time performance and the promise of penetrating below the resolution of high-level statements to the machine-language level.

Cross-debuggers have seen upgrades at each of their three ports (Fig 1): the interface between the host system and the target system; the interface between the compiler and the debugger; and the interface between the software engineer and the debugger.

**Target interface**

As Table 1 shows, you have four choices for linking a host-resident cross-debugger to your target system. Each link has six important characteristics:

- How much command and control it can exert over your target system
- Which software events it can capture in real-time vs those it must evaluate after halting the code under test
- How much it interferes with the target system's operation
- How many target-system resources it usurps
- How fast it communicates
- How much it costs.

The tool you select to debug your code depends heavily on the class of bug you are looking for. For example, you could exorcise most logical bugs (which are in your program's command flow and data structures) right on your host computer using a software simulator. Runtime problems (which pop up when you first try to bind your software to the target hardware), on the other hand, obviously require a cross-debugger. Real-time problems (which bedevil you as you try to make your hardware/software system respond properly to hard-

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**Table 1—Target-system/debugger links**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Monitor</th>
<th>Codetap</th>
<th>ROM emulators</th>
<th>In-circuit emulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solves optical problems</td>
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<td>•</td>
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<td>*</td>
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<tr>
<td>Visibility</td>
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<td>Debugging</td>
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<td>Runtime execution</td>
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<tr>
<td>Diagnostics</td>
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<tr>
<td>Solves runtime problems</td>
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<td>Doesn't use memory</td>
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<tr>
<td>Doesn't use IO</td>
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<td>Doesn't require code match</td>
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<td>Elaboration transparency</td>
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<td>*</td>
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<tr>
<td>Solves real-time problems</td>
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<tr>
<td>Time stamp</td>
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<td>Trace</td>
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<td>Ovverlay memory</td>
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<tr>
<td>Compiler breakpoints</td>
<td>•</td>
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<tr>
<td>Execution transparency</td>
<td>•</td>
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<tr>
<td>Buffering</td>
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<tr>
<td>Cost</td>
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* = optional
The Aries Chip Set

Why disk drive designers call it the eliminator.

The ARIES Chip Set does away with many significant design headaches, that's why. It collapses virtually all disk drive electronic functions onto just 4 chips, so you can accomplish your hard disk drive design in less space. And get your finished product to the market a lot sooner.

Packed inside ARIES are the 32R4610 Read/Write Amplifier, the 32P4620 Pulse Detector/Data Separator, the 32H4631 Servo and Motor Speed Controller, and the 32C4650 Combo AT Controller.

ARIES appreciates your ongoing need for shrinking footprints and high 24-Mbit/s performance. Plus it equips you with low-power +5 volt only operation.

In other words, the ARIES Chip Set is a revolutionary idea that just might help you eliminate your competition. For more on ARIES, contact your nearest Silicon Systems representative. Or call us for literature package SPD-2.

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Fax (44) 79-881-2117
HLL Cross-Debuggers

Monitor makers have added more powerful routines for chores such as filling memory or performing checksums. For example, Xray does checksums on memory at halts to see if the program has run away and overwritten illegal memory locations. The result is that the monitors now execute complicated operations without a constant stream of chatter between the target and host systems.

Emulators evolve

Monitor vendors aren’t the only ones modifying their products to suit cross-debuggers. Some emulator manufacturers are changing their emulator’s event-capture hardware so that their instruments match up better to cross-debuggers. For example, Pentica System's Mime-600 emulators for Motorola 68XX single-chip µPs incorporate two changes over earlier models.

First, the capture hardware breaks execution before executing an instruction that has a breakpoint set on it. Previous emulators broke after executing such instructions. The newer emulators now stop execution right at the beginning of a string of machine-level instructions that correspond to a HLL statement, rather than partially executing the string. The old behavior was acceptable for assembly-level debugging; the new behavior suits HLL debugging better.

Pentica has also shifted from word-recognizer hardware to “shadowbits” for recognizing software events. Earlier emulators depended on a limited number of digital comparators, or word recognizers, to signal the occurrence of a software event. The newer instruments have an extra bit, or bits, appended to each byte of emulation memory. These extra bits serve as qualifiers that the emulator’s hardware can set, before execution, and then test.

Monitor makes bugs

Generally speaking, the lowest-cost link between the debugger and the target is a serial line and a target-resident, debugging-monitor ROM. Such a link is also the slowest but has the least command and control over your-target system, usurps the most target-system resources, and can capture the fewest software events in real time.

The monitor functions by substituting a software-trap instruction for instructions in your program. Thus, unlike hardware-based links, the only software event a monitor can recognize is an instruction fetch from RAM.

But even this link has seen substantial improvements. Cross-debugger and monitor-ROM vendors have worked together to modify existing monitors, or have developed their own. Older monitors toiled with simple ASCII terminals. Consequently, their serial-communications streams were verbose and slow. Their command languages suited human operators. The new monitors use terse, binary communications and have command languages that suit computerized debugging operations. For example, Microtec Research's monitor for its Xray debugger optionally uses the Kermit protocol for communications. Concurrent Sciences quotes data-transfer rates of 200k bytes/minute for binary files using its Soft-Scope debugger.

Monitor makes bugs

Modern windowing interfaces, such as this one for Intermetrics’s RMSCB 5.0, can correlate your source program to software elements in the target system such as assembly code, stack contents, and data structures.
New Directions for MIPS RISC
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I. RISC Technology and Application Trends
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II. Performance Analysis
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EDN October 25, 1990
CIRCLE NO. 108

HLL Cross-Debuggers
during execution, to recognize software events.
A complex HLL debugging session can soon exceed the limited resources of a word-recognizer-based emulator. The shadow-memory scheme lets the cross-debugger preset a breakpoint, or other software events, on every emulation-memory location, not just in RAM.
In-circuit emulators provide the highest resolution, least-intrusive link between your debugger and target system. In the past, the best cross-debuggers could do to provide an interface to an in-circuit emulator was to pop out of the debugger's normal human interface into a virtual terminal for the in-circuit emulator's native control language. In other words, the debugger and the emulator didn't really communicate.
Many debuggers now integrate selected in-circuit emulators' event-recognition and breakpoint circuitry directly into the debuggers' arsenal. One debugger, Emulogic's Slice, can handle any in-circuit emulator. It can also decompile the trace of the program's execution captured by an emulator, correlating the captured trace with your HLL program in an interleaved display.

Applied Microsystem's Codetap 386 for Intel 80386 µPs has a subset of the features of an in-circuit emulator. The instrument lacks the emulation memory and trace buffer that hardware engineers need. But it retains an emulator's nonintrusive target-system link, replacing the target µP with a probe. The instrument costs approximately one-fifth the price of an 80386 in-circuit emulator.

ROM emulators, such as the Orion Instruments' 8620 ($6280) or the Embedded Support Tools' ROMport ($1095) (which interfaces to Intermetrics's XBD cross-debugger), offer a relatively low-cost way to link your cross-debugger to your target system without using the target system's serial port. ROM emulators provide some of the features of an in-circuit emulator. But, unlike in-circuit emulators, ROM emulators require a target-resident monitor program.

Compiler-interface arcane
The interface between a compiler and a debugger is the most arcane of the three interfaces. Compilers are far more complex than just simple macro expanders. Good compilers perform many operations that obscure any one-to-one correspondence between your HLL file and the compiled code in your target system. They recognize certain combinations of HLL code, generating compressed and rearranged assembly code. Compilers add hidden overhead routines to access variables, structures, and the stack. They use covert filing systems and nomenclature to keep track of objects you've defined. Optimizing

Kernel debuggers embrace Ethernet
Real-time-kernel vendors, unlike cross-debugger vendors, have adopted Ethernet as a target-system link. The cross-debugger vendors see Ethernet drivers as large and intrusive.
Wind River Systems—first—and Ready Systems—lately—have introduced sophisticated debuggers for their real-time kernels. While a conventional applications programmer doing host development would find the notion of an operating-system debugger absurd, real-time programmers need the same visibility and control over their real-time operating systems as they do over the code in their real-time tasks.
The latest real-time-kernel debuggers benefit from improved kernels and cleaner organization.
First, kernel vendors added debugging kernel calls to their kernels. Next, they put the debugger up as a task running under the kernel's scheduler. Finally, they gave the debugger task an Ethernet connection, or "socket."
With the new debuggers, you can send debugging commands to the debugger task. The debugger task, in turn, uses kernel calls to obtain visibility of the real-time system's state as well as control of the kernel and individual tasks. Look for kernel vendors to integrate HLL debuggers so that you can use one debugger for both the real-time kernel and the code in your real-time tasks.
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HLL Cross-Debuggers

compilers rearrange your code's execution order, move variables into registers, and cut useless instructions out.

A good compiler presents a formidable challenge to a debugger that wants to correlate the actual program running on your target system with your HLL file. But establishing that correspondence is one of the most important features of recent debuggers.

The compiler must do its part; the most powerful symbolic debugger cannot make up for incomplete documentation from the compiler. The compiler must supply extensive documentation of all its tricks, particularly optimizations, to the debugger. The debugger must be perfectly aware of all of a compiler's customary habits. Not all compilers supply debuggers with enough cross-reference information.

Happily, some debugger and compiler vendors have spent long hours hammering out details to improve communications. You can expect that eventually all debuggers will be able to handle optimized code. Right now, many debugger vendors advise you to debug only code compiled with the compiler's optimization switch turned off.

In the past, cross-debuggers would only work with compilers from vendors who designed their compilers to interface with debugging hardware. Intel, for example, offers its own complete suite of development tools, from compilers to in-circuit emulators. Intel's compilers and their comprehensive OMF cross-reference files set the standard for the debugger industry.

Now, many compilers produce comprehensive debugging-information files set to standards such as Intel's OMF, Microsoft's Codeview, and ANSI COFF.

Intel, in particular, has responded to suggestions from debugger makers. For example, Concurrent Sciences requested better information so that its Soft-Scope debugger could traverse chains of indirection (pointers to pointers to pointers ...). Intel's latest version of OMF provides such details.

However, the existence of different versions of Intel's OMF should warn you to examine closely any claims that a debugger is "OMF compatible." Take your cue from such past claims as, "Centronics compatible," "RS-232C compatible," or "IBM PC compatible." Emulogic claims that Slice can work with any compiler; but other debuggers are more choosy.

Human interface

Had low-cost, integrated programming environments such as Turbo Pascal or Quick C not come along, cross-debugger makers would probably not have adopted the latest fashion in human interfaces. But, having basked in the luxury of an editor, compiler, and debugger all operating together under a slick windowing interface, software engineers now demand—and are getting—similar features from cross-debuggers.

In fact, Z-World, a maker of Z80 development tools, offers a cross-programming environment for the IBM PC that functions exactly like native-programming environments such as Turbo C or Quick C. The key to Z-World's environment is a clever use of its ICEPROM ($790) ROM emulator. The company's compiler compiles your program directly into the ROM emulator over a parallel link. The environment's debugger uses the same link for communications and control.

Right now, your chances of getting a compiler, debugger, and target-system interface (be it debugging monitor, ROM emulator, or in-circuit emulator) vary widely, depending on which host computer, compiler, debugger, link, and tar-
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TECHNOLOGY UPDATE

HLL Cross-Debuggers

get processor you choose.

Providing a comprehensive, correlated list of host computers, compilers, debuggers, links, and target processors is a daunting task that is well beyond the scope of this article. To make matters worse, the situation changes daily. If a combination that suits your application isn’t available now, the clear trend is that you will have it soon.

Immediate concerns

Someday, such advanced software-engineering techniques as CASE (computer-aided software engineering) or object-oriented programming (OOP) may revolutionize the way you write your programs. Right now, however, you ought to think about getting a good debug-

ger to make the program you’re working on run.

References


For more information . . .

For more information on the debugging aids discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use EDN’s Express Request service. When you contact any of the following manufacturers directly, please let them know you saw their products in EDN.

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Bill Travis, Contributing Editor

Brawny amps stretch small-signal limits

If your application needs an amplifier that delivers more voltage than the traditional ±15V swing, or more current than the classical ±100-mA limit of small-signal op amps, you could add an output booster or a unity-gain buffer to an ordinary op amp. However, you'll save on circuit-board real estate, and often on cost, if you instead select one of the many available high-voltage or high-current op amps.

Many applications—for example, cable driving—demand a hefty current-drive capability. For instance, a ±10V signal in a 50Ω cable entails ±200-mA drive current. On the other end of the spectrum, such devices as piezoelectric transducers don't require much current but do need voltage-drive levels far beyond ±15V. Finally, some systems such as magnetic-resonance imagers and vibration tables need both very high voltages and enormous currents.

Some recently introduced ±15V devices cross the ±100-mA threshold. Comlinear Corp's CLC207—which, like all the company's amplifiers, uses a current-feedback architecture (Ref 1)—delivers ±150 mA to its load. The $56 (100) hybrid op amp is notable for its speed: The -3-dB bandwidth is 170 MHz, slew rate is 2400V/µsec, and output settles to within ±0.1% error band in 22 nsec.

Though two other new devices from Comlinear are designed as output amplifiers, or drivers, they do classify as op amps of the current-feedback type because they offer differential inputs and resistor-settable, user-definable gains. The CLC560 and CLC561 offer peak output currents to ±250 mA, and respective bandwidths of 120 and 150 MHz. A unique feature of these amplifiers is that the feedback-network resistors set both the gain and the output impedance. The latter aspect can be valuable because it allows you to match the output to the load impedance without sacrificing half the output swing, as happens in the classical op-amp configuration with a series matching resistor. Both devices cost $99 (100).

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High-voltage/high-current op amps

output-current capability further. Model LM6313 supplies ±300 mA peak, ±220 mA continuous. The amplifier, which is housed in a 16-pin DIP, furnishes a 250V/µsec slew rate, a 35-MHz gain-bandwidth product, and a 200-nsec settling time to within ±0.1%. Underlining the device’s suitability for driving 50Ω and 75Ω video lines, its data sheet specifies typical differential-gain and -phase figures of 0.1% and 0.1°, respectively. The op amp costs $3.50 (100).

High output currents are also available from National Semiconductor’s LM759 and LM77000. These monolithic devices deliver guaranteed peak output currents of ±325 and ±250 mA, respectively. The LM759 ($2.15 to $2.67 (100)) comes in a TO-8-style metal can or in a single-in-line plastic package with a heat-sink tab; the LM77000 is available only in the latter package. National claims the devices’ internal short-circuit-current limiting and thermal-overload protection make them virtually indestructible. The LM77000CP costs $1.07 (100).

If you’re designing a system that needs several amperes of drive current, you face the choice of configuring your own amplifier or designing in one of several available power op amps. Often, your choice will hinge on economic factors, one of them being the expensive, TO-3-type metal package used for many power op amps. For these units, the obvious way to get the cost down is to develop plastic packaging.

That’s the solution Burr-Brown Corp adopted for its OPA541 power op amp. This device works from power supplies to ±40V and delivers output currents to ±10A peak. Priced from $18.06 (100) in a TO-3 metal package, the monolithic device delivers true op-amp performance—its open-loop gain is 90 dB min, and offset voltage is ±1 mV max. FET inputs keep the input bias currents to 50 pA max.

Putting the OPA541 in an 11-pin, single-in-line plastic package cuts the price to $9.95 (100), but some spec compromises accompany the plastic-packaged devices. For example, the maximum offset-voltage spec rises from ±1 to ±10 mV, the maximum permissible power-supply span drops from 80 to 70V, and the only temperature-range option is −25 to +85°C vs the −55 to +125°C available with the metal-can devices.

Burr-Brown also offers a dual version, designated the OPA2541. The $28.95 (100) device comes in a TO-3-type metal package. A dual op amp from Apex Microtechnology Corp offers pin compatibility with the OPA2541. Apex’s $21.25 (100) PA25 also comes in a TO-3-type metal can. In some spec areas, the device offers performance improvements compared to the OPA2541. For example, its permissible common-mode input-voltage range is within 2V of the positive supply and 0.3V of the negative rail vs 6V for both supplies with the OPA2541.

Other improvements include enhanced output-voltage swing—to within 3V of each supply at 2.5A output vs 4.5V at 2A for the OPA2541. The PA25’s class-AB output stage cuts crossover-induced harmonic distortion to 0.02% at 100-mW output vs approximately 0.15%. Finally, the PA25 incorporates both an internal current limit and automatic thermal shutdown. The OPA2541 offers current limiting only.

Some compromises in performance go along with the PA25’s cited improvements. For example, the best-grade model’s offset voltage is 4 mV max vs 1 mV. Input bias current is 250 nA max vs 50 pA, and the open-loop gain is 80 dB min vs 90 dB. Two other dc compromises attend the PA25. Its maximum power-supply span is 40V vs the OPA2541’s 70V, and the dc junc-
High-voltage/high-current op amps

High-voltage swingers

Some applications—for example, driving CRT displays—demand both wide voltage swings and high speed. A hybrid op-amp family from MS Kennedy Corp meets these requirements. The MSK600/610/650 Series offers slew rates to 5000V/µsec, peak currents to 250 mA, and output-voltage swings to 150V p-p.

The $195 MSK600 uses ±80 V supplies on separate terminals to its output stage to deliver ±70V min output swing. Its output slews at 3000V/µsec min, and settles to within ±0.1% in 1 µsec typ. Designed for positive output swings, the $195 MSK610 delivers 110V min to a load. Its slew rate is 4000V/µsec min. Finally, the $150 MSK650 uses ±35 V supplies to deliver ±30V min to a load. This device slews at 2000V/µsec min and settles to within ±0.1% in 350 nsec typ.

The PA89 from Apex Microtechnology uses ±600 V max supplies to furnish over 1100V output swing to a load; the company claims this is the highest voltage op amp in the world. It comes in a square, hermetically sealed package that takes up less than 3 in.² of board space. The power bandwidth is typically 5 kHz. The enormous output-voltage capability doesn't entail any sacrifices in dc precision. Input bias current and offset voltage for the best-grade devices are 10 pA max and 0.5mV max, respectively. The PA89 costs $310.50 (100).

In configuring linear amplifiers, the transition from watts to kilowatts often entails costly and bulky water-cooling schemes. Pulse-width modulation (PWM), also called class-D operation, offers a way to provide power amplification in the

Claimed by its manufacturer to be the highest voltage op amp available, the PA89 from Apex Microtechnology delivers an 1100V output swing to its load. Along with high output voltage, the device offers precision dc specs.

For more information . . .

For more information on the high-current and -voltage op amps discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use EDN's Express Request service. When you contact any of the following manufacturers directly, please let them know you saw their products in EDN.

Apex Microtechnology Corp
5980 N Shannon Rd
Tucson, AZ 85741
(800) 421-1865
FAX (602) 888-3229
Circle No. 700

Burr-Brown Corp
Box 11400
Tucson, AZ 85734
(602) 746-1111
FAX (602) 889-1510
Circle No. 701

Comlinear Corp
4800 Wheaton Dr
Fort Collins, CO 80525
(303) 225-6500
FAX (303) 225-0564
Circle No. 702

Copley Controls Corp
375 Elliot St
Newton, MA 02164
(617) 965-2410
FAX (617) 965-7315
Circle No. 703

MS Kennedy Corp
8170 Thompson Rd
Clay, NY 13041
(315) 699-9201
FAX (315) 699-8023
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Santa Clara, CA 95052
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CIRCLE NO. 114
TECHNOLOGY UPDATE

High-voltage/high-current op amps

Designed for output-driver applications, the CLC560 and CLC561 from Comlinear allow you to set both gain and output impedance by judicious choice of the feedback network. Because the impedance-matching maneuver entails no series resistor, the full output-voltage swing is available to the load.

kilowatt range without the need for such elaborate cooling systems.

A giant, PWM-based amplifier from Copley Controls Corp offers output-voltage ratings to ±160V at ±230A continuous (±400A peak) output. Model 232 delivers a stream of width-modulated output pulses at 81 kHz to lowpass filters that remove the 81-kHz component and its harmonics. Two power-MOSFET half-bridges constitute the 81-kHz output stages; the load connects to the outputs in a differential (bridge) configuration.

Employing power MOSFETs in the 232 allows the use of the 81-kHz switching frequency. Thanks to its high switching rate, the amplifier’s 3-dB bandwidth is 5 kHz. Master/slave connections allow you to connect as many as 20 units in parallel to increase power capacity. For example, a 20-unit ensemble delivers 1800A at 110V rms for 0.2 MW; ±5000A peak at ±160V translates to 0.8 MW peak power. The unit doesn’t come cheap—$7500. However, you must consider the development time and costs to design and produce such a behemoth in-house.

This cost-study factor figures in all the amplifiers mentioned here. In looking at some of the prices, you might draw the conclusion that you can roll your own for much lower costs. But be careful—you must take into account many factors in a cost analysis. Some of the factors (for example, parts cost) might seem obvious, but others are more subtle. The cost of pc-board real estate, the design and implementation of an efficient heat-removal system, and current-limiting and thermal-shutdown schemes are only a few considerations that can lead to unpleasant surprises in the final cost of an amplifier system.

Reference

Article Interest Quotient
(Circle One)
High 500 Medium 501 Low 502

EDN October 25, 1990
Like you, Woody Newman will go to any length to become a better designer. This time he went into another dimension.
Woody Newman has vanished into the mountains to get a better look at his designs.

POSTCARD

A DIFFERENT POINT OF VIEW. The Modulation Domain provides designers with a unique opportunity to directly see a signal's frequency, phase, or time-interval versus time.

Dear Brad,

Just a note to say I won't be at work for a while. I came to the realization that I can't fully characterize my designs using conventional measurements.

Don't get me wrong, scopes and spectrum analyzers are great. They just can't give me the whole picture.

But I think I've found the answer. I've discovered a place called the Modulation Domain. No life form as we know it, only thousands of species of waveforms floating around!

I'll keep you posted. Hi to the gang.

Woody
Recently, a design engineer named Woody Newman was working against a deadline when he found himself in a familiar predicament: To get the performance he wanted from his design, he needed a better understanding of his prototype. Like many modern designers, Woody knew the information he needed would be revealed if he could just see the dynamic behavior of frequency agile signals, study the transient response of phase-locked loops, or understand potential sources of jitter. But conventional measurement techniques simply couldn't give him the right perspective.

Where could he get a view like that? In his search for the answer, Woody found the Modulation Domain. A place unknown to most engineers, where changes in frequency, phase or timing can be measured with respect to time. There, he saw things he had never seen before. Like characterization of frequency agile signals in secure communications and advanced radar systems. Quantification of jitter in high-performance disk drives and digital communications systems. And single-shot analysis of step response in phase-locked loops and VCOs. It was just what he was looking for.

Join Woody in his search to become a better designer. Call your local sales office or circle the reader service number for more information on the Modulation Domain and what you can expect to find there.

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The control logic of the LMD18200 connects both sides of the H-Bridge. Which eliminates crossover problems and makes it easy to use. Plus, its rugged design and process makes it extremely reliable. The device operates at supply voltages from +12V to +55V with continuous output of 3A. Or peak to 6A.

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EDN October 25, 1990
Electronica 90 Products

Electronica 90: What you'll see . . . See pg 112 in EDN's October 11 issue for a complete look at the technology topics that will be covered in depth at the Electronica 90 trade fair in Munich, Germany, on November 6 through 10. For a preview of the vast number of products that will be displayed at the show, see the descriptions below.

Calibration-Accuracy
Alternating-Voltage DVM
Model 4920 alternating-voltage digital voltmeter calibrates top-end calibration instruments. Voltage ranges extend from 300 mV to 1 kV, and frequencies range from 1 Hz to 1.25 MHz. The meter has 7½-digit resolution. Total measurement uncertainty for signals in the range of 0.9 to 11 V and 40 Hz to 30 kHz is ±28 ppm (1 year, ±5°C ambient). An ac/dc transfer mode improves uncertainty to ±14 ppm. The meter provides simultaneous readout of voltage and frequency. Extra ranges down to 1 mV are optional. Settling time is <2.5 sec for frequencies greater than 100 Hz. Model 4920M has an extended frequency range with an uncertainty of 0.2% at 20 MHz. Both models interface via IEEE-488.2. Model 4920, $9995; millivolt option, $1495.

Hyperstone Electronics GmbH, Robert-Bosch-Strasse 11, 7750 Konstanz, West Germany. Phone (7531) 67789. FAX (7531) 51725.

32-Bit Microprocessor
The Hyperstone is a 25-MHz microprocessor with separate 32-bit data and address buses. Registers include 18 global and 64 local, which can reconfigure to a stack of variable frame lengths of 2 to 16 registers. The majority of instructions are single cycle and operate on 16-bit data. Multiply and divide instructions require multicycle operation. Using dynamic RAMs with 40-nsec page-mode cycle times sustains a 25-MIPS burst rate without external memory caches. Benchmarks yield 38,000 Dhrystones/sec. Support includes an emulator that links to your PC by RS-232C, and an MS-DOS cross-assembler and debugger. Introductory price is $150 (1000).

Hyperstone Electronics GmbH, Robert-Bosch-Strasse 11, 7750 Konstanz, West Germany. Phone (7531) 67789. FAX (7531) 51725.

Logic Analyzers
The PM 3580 and PM 3585 logic analyzers allow simultaneous acquisition of state and timing data on 96 channels using one probe per channel. The analyzers record 50-MHz state and 200-MHz timing data into 2k of memory per channel. Probe loading is 7 pF per channel. It has 8-level state triggering. Timing resolution is 5 nsec, and glitch capture operates to 3 nsec. Outputs include a parallel printer port, an RS-232C port, and a video driver for a VGA monitor. The 32-channel PM 3580 records 32 channels of 50-MHz state and 32 channels of 100-MHz timing data into a 1k-deep memory. $4250. The PM 3585 records 96 channels of 50-MHz state and 96 channels of 200-MHz timing data into 2k of memory. $10,950.


CMOS Communications Chip Set
The DBS 800 family of chips suits the audio and auxiliary stages of mobile radio communications equipment. The family comprises the FX802 codec, three audio processors (FX803/FX805/FX806), and the FX809 modem. All chips have a 5-line serial interface that links to an external microcontroller. This interface transfers commands and data throughout the system at a clock rate of up to 500 kHz. The FX806 audio processor handles routing, gain control, and filtering of all audio signals from receiver and microphone inputs, and to transmitter and speaker outputs. This processor links directly to the FX803 codec, which digitizes or reconstitutes analog audio signals. The codec embodies a dynamic RAM (DRAM) controller, which stores digitized data in a separate 4M-byte DRAM.
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The FX803 provides in-band tone signaling and DTMF encoding. The FX805 deals with out-band signals for squelch control, using continuous-tone or digitally encoded techniques. The FX809 modem chip operates in half-duplex mode at 1200 baud. A development system, consisting of a chip set and microcontroller mounted on three pc boards, lets you evaluate and design using these chips. The system includes support software and an RS-232C interface for linking to an IBM PC or compatible. FX806 £4.22 (10,000). Other processors, from £5 to £9. Samples of FX802 and FX806 available now; others due second quarter of 1990.

Consumer Microcircuits Ltd, 1 Wheaton Rd, Witham CM8 3TD, UK. Phone (376) 513833. FAX (376) 518247. Hall 25, stand A04.

Circle No. 808

DSP PC Plug-In Card

The DSP96002 is a DSP system board based on a Motorola 96002, which plugs in to your IBM PC or compatible. In addition to interfacing with the PC bus, the board provides two other fast interfaces from ports A and B of the 96002. Port A connects via a 16-bit, 150-nsec cycle-time, parallel link to other proprietary boards for interfacing digital audio and multiple-channel ADCs and DACs. Port B feeds to a parallel 32-bit interface, which links up to four similar boards. Arbitration logic allows any one of the four to be bus master on a sequential basis. The two ports equally split 320k bytes of 32-bit static RAM. You can expand this memory capacity to 1088k words.

Dual analog inputs feed sigma-delta ADCs, which sample at up to 100 kHz or 400 kHz, with a linearity of 16 or 12 bits, respectively. Processed data passes to twin 16-bit DACs, producing two channels of analog output. Optional in-line fourth-order Butterworth filters allow partial signal reconstitution. Additional onboard logic and support software exercises the 96002’s on-chip emulation facility for debugging work. Other backup consists of Intermetrics’ 96002 C compiler, assembler, and high-level debugging tools. Support also includes an interface library to allow your Microsoft programs to control the board. £3495. Showing on Motorola’s booth.


Circle No. 809

PC-Board Press-Fit Connectors

The Har-press range of connectors uses press-fit terminations for straight and angled entry to a pc board. A variety of models exists, based on a 0.1-in. pin spacing, in up to three rows of 16 or 32 pins. Standard current rating per pin is 2A, although a 4A version is available in limited sizes with pin spacings of 0.20×0.15 in. Connectors conform to DIN 41612. Fully gold-plated wrap posts are optional. A 64-pin connector with gold-plated, male, angled terminations, DM 3.65 (1000).

Harting Elektronik GmbH, Postfach 1140, D-4992, Espelkamp, Germany. Phone (5772) 470. FAX (5772) 47461. Hall 2, stand C05.

Circle No. 811

VMEbus CPU Card With Plug-In I/O

The SYS68K/CPU-40 is a 68040-based VMEbus CPU card that accepts daughter boards for memory or other functions. Daughter boards let you add SCSI, Ethernet, floppy-
Electronica 90 Products

disk, or VME-subsystem-bus interfaces. The base card provides four serial configurable RS-232C, RS-242, or RS-485 channels, an 8-bit parallel I/O channel, a real-time clock, and one 8- and two 24-bit timers. Standard memory includes up to 1M byte of 32-bit-wide, 200-nsec EPROM; 128k bytes of battery-backed static RAM; and boot EPROM. The memory daughter board holds either a 16M-byte dynamic RAM or a 4M-byte static RAM. DM 7995.

Force Computers GmbH, Prof-Messerschmitt-Strasse 1, D-8014 Neubiberg, Munchen, Germany. Phone (89) 608140. FAX (89) 6097793. Hall 19, stand A11.

Circle No. 812

CMOS Telephone Chip Set

A chip set for an analog telephone includes the AS2501 line adapter, AS2562B melody generator, and AS2575 feature dialer. The line adapter develops stabilized power sources from the telephone line supply, while preserving line impedance for transmission. The melody generator performs tone-ringer functions. An internal sequencer produces 10 melodies from three basic frequencies. A serial interface loads an 8-bit register, which selects melodies, as well as 10 volume settings and 10 repetition rates. The feature dialer allows you to select operating modes, such as last-number redial, direct dial, and storage of twenty 20-digit numbers, from the telephone keypad. This chip interfaces to EEPROM and drives the serial interface for the

Erasable Programmable Logic Device

The GAL16V8S-20EB1 electrically erasable programmable logic device emulates many 20-pin PLDs. The device has a maximum propagation delay of 20 nsec and requires a maximum supply current of 27 mA. Operation offers preload and power-on reset of all registers. Guaranteed specifications include 100% programming yield and a minimum data-retention period of 20 years. On-chip ESD protection functions to 3 kV. $2.70 (1000); 25-nsec version, $2.50 (1000).


Circle No. 814

Double-Diode Module

The BYT230P1 family of diode pairs has repetitive peak reverse voltages to 1 kV. Each diode has an average maximum current rating of 30A, which develops a forward drop of 1.8V when the junction temperature is 100°C. Reverse recovery time is <100 nsec with a switch-off rate of 50A/µsec when operating at 1A. The module attaches directly to your heat sink; breakdown voltage is 2.5 kV rms. Measuring 1 x 1.5 in., the solderable screw and push-on connector versions are 0.5 and 0.8 in. high, respectively. Gld 11 (1000).

Philips Components, Box 218, 5600 MD Eindhoven, The Netherlands. Phone (40) 724324. FAX (40) 724825. Hall 11, stand B16.

Circle No. 815

Computing DMM

The 8047 AT consists of a 7½-digit multifunction digital voltmeter combined with a 12-MHz IBM PC/AT-compatible computer. The unit has a 210 x 130-mm black-and-white LCD; you control it by making window selections using cursor keys. DC voltage input ranges from 100 mV to 1 kV. Accuracy at 10V is 9 ppm for 1 year at 23°C, ±5°C.

The meter reads rms alternating voltages ranging to 700V and at frequencies of 20 Hz to 1 MHz. At 1 to 100V, 40 Hz to 1 kHz, rms accuracy is 340 ppm. The device also measures resistance, alternating and direct current, and temperature using a platinum resistance sensor. The computer section houses a 1M-byte RAM and a 3½-in. 1.44M-byte floppy-disk drive. A scanning option provides twenty 4-pole inputs. The relay inputs scan at 5 Hz and accept signals to 125V pk and 3A pk. DM 17,560; scanner option, DM 19,520.


Circle No. 816
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Electronica 90 Products

16-bit ADC With Track And Hold
The AD 1382 is a 16-bit, 500-kHz sampling ADC in a 48-pin ceramic DIP. Analog input range is ±5 or ±10V into a 2.5-kΩ input impedance. Differential nonlinearity is 0.6 ppm, and input noise is 6 µV rms. The chip requires a 10-MHz TTL clock and supplies of ±5V at 165 mA and ±15V at 77 mA. DM 1300.

Analog Devices Inc, 831 Woburn St, Wilmington, MA 01887. Phone (617) 935-5191. FAX (617) 932-9159. Hall 19, stand A16.

Circle No. 817

32-Bit DSP For ASICs
The ST18932 is a DSP for ASIC integration with a library of standard-cell components. The processor operates on real or complex numbers using a 32-bit ALU, which can perform 26 million complex multiplications/sec. In a cycle time of 77 nsec, the device can read two operands, multiply and store, set three address pointers, and handle an I/O operation. The circuit has an operational power dissipation of 350 mW and a standby dissipation of 0.5 mW. The processor is compatible with the CB12000 library of standard cells. Development support includes an assembler/linker, C compiler, VHDL model, and real-time emulator. ASICs that embody this processor cost $20 (10,000).

SGS-Thomson Microelectronics, ZI de Rousset-BP2, 13106 Rousset Cedex, France. Phone (4225) 8800. FAX (4229) 0068. Hall 24, stand B12.

Circle No. 818

Mixed Analog And Digital ASICs
The PDM system enables you to design, capture, evaluate, and verify mixed-signal ASICs before committing to silicon. The system consists of a reconfigurable logic module, an analog design tablet, an analog component kit, and software. An IBM PC/AT or workstation is necessary to control the system. The circuit is designed by using analog and digital macros from the software library. PDM mapping software configures the logic module and assigns interface channels to the analog tab-

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EDN October 25, 1990
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let. After inserting analog components into the tablet, a complete hardware model exists to enable testing and development of the design. To study complete system operation, input transducers and output actuators can be wired to the tablet. The software library currently contains 50 characterized analog macros, which also exist in the component kit. Plessey delivers prototype ASICs four weeks following receipt of your design on floppy disk or cartridge. £15,000.

Plessey Semiconductors Ltd, Cheney Manor, Swindon, Wiltshire SN2 2QW, UK. Phone (793) 518000. FAX (61) 688 7898. Hall 25, stand B08. Circle No. 819

Waterproof Connector

The Buccaneer range of cable connectors provides chassis/panel, in-line, bulkhead, and low-profile mountings. Pin counts of 2, 3, 4, 6, 7, and 9 and coaxial BNC inserts are optional. The connectors accept cables from 5 to 9 mm in diameter, and offer dust and moisture protection to IEC 529 specification. Maximum current rating is 10A at 250V. In-line 3-way versions have NATO stock numbers. Three-way in-line plug/socket, £8.23 (25).

A F Bulgin + Co PLC, Bypass Rd, Barking, Essex IG11 0AZ, UK. Phone (01 594) 5588. FAX (01 591) 6913. Hall 7, stand A5. Circle No. 820

Photomultiplier Power Supply

The Model 3479N miniature dc/dc converter produces an output that's programmable from 50V to 1.7 kV (1 mA). Input supply is either 12 or 24V at a maximum input current of 220 mA. The supply achieves an input and load regulation of 0.05% and an output ripple of 75 mV. The package has flange fixings, and it measures 95.2 x 40.2 x 25.0 mm. £144.


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input of 5 or 12V. The converters deliver 500 mW in a 70°C ambient temperature without heat sinks and at an efficiency of 50%. Input-to-output isolation voltage is 500V dc. Load regulation is 1.5% max for a 10 to 100% full-load variation. The device comes in a single-in-line package for pc-board mounting and measures 19.5 x 6.0 x 10.0 mm high. A control pin enables output voltages to drop to approximately 1.2V, specifically for flash-EPROM applications. £5.50 (100).

**Newport Components Ltd, Tanner's Dr, Blakelands N, Milton Keynes, MK14 5NA, UK. Phone (908) 615232. FAX (908) 617545. Hall 1, stand A05. Circle No. 822**

**Surface-Mount Transistors**

Transistors FMMT449 (npn) and FMMT549 (pnp) offer a continuous Ic rating of 1A in a surface-mount SOT23 package. Both types feature a VCESAT of 0.3V typ at 1A Ic. HFE is a minimum of 40 at the peak Ic rating of 2A, and increases to 100 at 0.5A Ic. At a 25°C ambient temperature and mounted on a 0.6-mm substrate of 80 mm², the transistors can dissipate 425 mW. £0.14 (100).

**Zetex PLC, Fields New Rd, Chadderton, Oldham, OL9 8NP, UK. Phone (61) 6275105. FAX (61) 6275467. Hall 24, stand A24. Circle No. 823**

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**Varta Batterie AG, Am Leineufer 51, D-3000 Hannover 21, Germany. Phone (0511) 79031, FAX (0511) 790 3622. Hall 21, stand A07. Circle No. 825**

Heat-Sink Wirewound Resistors

The HS range of heat-sink-mounted, wirewound resistors has values from 0.005 to 62 kΩ. Maximum power rating in the range is 75W in 25°C ambient without additional heat sinking. This rating increases to 300W with additional heat sinking. You can specify inductive or noninductive windings and resistance tolerance from 1 to 10%. Terminations cater to solder, threaded, or fast-on connections. 300W type, DM 84 (100).

**Arcol UK Ltd, Threemilestone Industrial Estate, Truro, Cornwall TR4 9LQ, UK. Phone (872) 77431, FAX (872) 222002. Hall 24, stand B21. Circle No. 826**

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**Melcher AG, Ackerstrasse 56, Postfach 248, CH-8610 Uster, Switzerland. Phone (1944) 8111, FAX (1940) 9858. Hall 12, stand A06. Circle No. 827**

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CIRCLE NO. 87
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Circle No. 828

Single-Board XT Computer

The SBC-XT is a single-board computer with IBM PC/XT compatibility. It employs an 8088 processor and can accommodate a matching coprocessor. Memory capacity extends to 640k bytes. The board contains controllers for hard and floppy-disk drives, and supports CGA graphics. The board includes two RS-232C interfaces, one parallel port, and provisions for IBM PC bus and iSBX expansion. Additional items include a battery-backed clock and watchdog timer. A 5V at 800 mA power supply is required. The board measures 5.75 x 7.75 x 0.85 in. £550 (10).

Nevin Developments Ltd, 48 Charlton Rd, Andover, Hampshire SP10 3JL, UK. Phone (264) 332122. FAX (264) 332125. Hall 24, stand B13A. Circle No. 829

Fiber Transceiver

The DLX2040 is an optical-fiber transceiver for interfacing ECL signals to and from the 1300-nm band at 170M bps. A maximum output power of 28 µW provides 5-km transmission distance. The unit typically consumes 120 mA from a 5V source. A duplex FDDI Media Interface Connector accepts your fiber terminations. The enclosure measures 2.91 x 1.18 x 0.47 in., and links to your pc board by a pair of to DSOs, some companies
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Aries Electronics (Europe), Unit 3 Furtho Court, Towcester Rd, Old Stratford, Milton Keynes MK19 6AQ, UK. Phone (908) 260007. FAX (908) 260008. Hall 16, stand F9. Circle No. 831

Embedded VXI Computers
The VXIpc-386/1 20-MHz, IBM PC/AT compatible occupies a single-width C-size slot in your VXI rack. The module contains a 20M- or 40M-byte hard disk and up to 8M bytes of RAM. The computer drives a VGA monitor, two RS-232C serial ports, and a parallel port. The unit houses an IEEE-488.2-compatible interface and a controller for an external floppy-disk drive. The VXIpc-386/2 is a 2-slot version with an integral 1.44M-byte floppy-disk drive and a 40M-, 80M-, or 210M-byte hard disk. Support software for both models includes a VXI revision 1.3 resource manager, a VXI interactive control program, a driver function library, and IEEE-488.2 control programs. Either model with 1M-byte RAM and a 40M-byte hard disk, $9000.
National Instruments, 6504 Bridge Point Parkway, Austin, TX 78730. Phone (512) 794-0100. FAX (512) 794-8411. Hall 19, stand F12. Circle No. 832

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Integrated tool set makes software development in C++ easier

Objectworks/C++ Release 2 is an integrated tool set for object-oriented programming (OOP) that helps you develop software in C++ language. The key component is an object-oriented database shared by all of the tools; this database provides a window-oriented user interface that links the tools to give you four different views of your program.

The inheritance browser draws class-inheritance trees and supports multiple inheritance. The call-relationship browser draws caller/callee relationships among functions. The program-structure browser draws the program-structure tree to the level of granularity at which classes, functions, and global variables are defined. The error browser lists errors that the compiler has detected and for each error places you in the appropriate file at the statement that caused the error.

Code is reusable only if it is findable. These browsers find all instances of a specified class and show you the associated C++ code. Thus, you can quickly identify classes whose behavior meets some or all of the requirements of another application.

For debugging, the process inspector gives you five subviews of the program that help you debug the code and correct errors. Because module-dependencies are stored in the object-oriented database, any changes that you make to a class or function automatically propagate themselves to all affected modules when you recompile.

To improve the portability of your programs, Objectworks/C++ includes the latest version of the AT&T C++ compiler (currently release 2.1); you can therefore develop and test your software on the Sun-3 or SPARCstation host, and then transport the source code to any target system whose C++ compiler is 100% compatible with the AT&T 2.1 compiler.

However, you don't have to use the AT&T compiler; you can use the development system in conjunction with third-party compilers, source-code-control systems, profilers, and debuggers. To increase the consistency and portability of your programs, the vendor offers the optional ObjectKit/C++, a class library that includes AT&T's standard library and standard library extension, as well as translations of selected Smalltalk class libraries and an X-Windows graphical user interface called Interviews. Objectworks/C++ costs $3000, and the optional ObjectKit/C++ costs $500.—Chris Terry

ParcPlace Systems, 1550 Plymouth St, Mountain View, CA 94043. Phone (415) 691-6700. FAX (415) 691-6715. Circle No. 730
Low-cost industrial PC family draws little power and fits in a small space

System designers often adapt PC components for embedded-system needs. However, motherboard designs for desktop applications don’t generally have industrial operating-temperature ratings. And their layout presumes the spacious accommodations of a computer cabinet rather than the close confines of industrial enclosures. PC compatibility allows you to develop and test your application on a PC, and then transfer your code directly to your target system without change.

The Micro-PC line of board-level computer components delivers IBM PC compatibility with small size, low cost, and low-power operation to designers of industrial systems. Two CPU cards form the core of this industrial PC family. The Model 5000 PC control card incorporates an NEC V20 µP running at 10 MHz; sockets for a 256k- or 1M-byte single-inline memory module and a 1M-bit flash EPROM or static RAM; a BIOS ROM; a watchdog timer; and the 8-bit IBM PC bus interface.

The Model 5010 PC control card adds two serial ports and a parallel I/O printer port. Without memory chips, the Models 5000 and 5010 cost $195 and $345, respectively. For $75, you can add instant-on capability by plugging in a special BIOS ROM that includes DOS. In quantities of 1000, the cost of the controller cards drops to $99 and $189, respectively. Using 1M bytes of RAM, the boards draw less than 230 mA on the 5V power supply. The Model 5010 also requires 20 mA from a 12V power supply for the serial ports.

In addition, the company offers a large number of accessory I/O cards to support these two controllers. For example, the $295 Model 5400 EGA card provides standard PC video graphics. The $195 Model 5800 floppy- and hard-disk cards add support for 5¼- and 3½-in. floppy-disk drives and hard-disk drives with IDE (integrated-drive-electronics) interfaces.

For industrial applications, you can obtain several more exotic I/O cards. The $195 Model 5300 counter/timer I/O card has six 16-bit timer/counters (three with optically isolated inputs); two programmable timebase generators with frequency ranges of 122 Hz to 4 MHz and 0.0005 to 2 MHz, respectively; and eight general-purpose digital I/O lines. The $195 Model 5600 digital I/O card provides 96 I/O lines and can drive as many as four Opto module racks. The racks accept optically isolated control modules originally developed by Opto 22 (Huntington Beach, CA).

The Micro-PC family also includes some rather specialized members. For example, the $395 Model 5328 motion-control card provides the system with a self-contained PID (proportional, integral, derivative) analog control system. The card accepts signals from a quadrature encoder, processes that position information using 16-bit coefficients, and generates the appropriate analog feedback signal to drive a motor controller. It does all this without help from the CPU once the coefficients are provided. You can add a second control channel to the card for $150.

Similarly, the $345 Model 5329 motion-control card provides PID control for motor controllers that require pulse-width modulated signals. The 2-channel version of that card costs $150 more than the 1-channel version. The line also includes relay cards, analog I/O cards, a RAM- or ROM-disk card, and a serial I/O card.

Although it uses the standard 8-bit PC bus, the entire Micro-PC card line uses a proprietary form factor. Micro-PC cards will plug into PCs (using a standard PC end plate) so you can use them during development on a desktop machine, but commodity expansion cards marketed for desktop PCs will not

Advanced Filter Designer is an interactive design aid giving you the ability to design and analyze active filters. Features include a menu-driven interface, hard copy report summaries and plots, cascading multiple designs, and interfaces to PSpice and SWITCAP.

Advanced Filter Designer uses a well established methodology in applying classical approximations to your filter specification. Available filter types include low pass, high pass, band pass, and band reject, all of which may be synthesized by Butterworth, Chebyshev, Inverse Chebyshev, and Elliptic (Cauer) functions. There is also the capability to synthesize arbitrary transfer functions and delay equalization filters.

A full editing capability allows you to insert, delete, and reorder stages, and modify coefficient values. These editing features allow a filter expert to fine tune a design, or quickly make a small modification to an existing design.

Advanced Filter Designer supports both active RC and switched-capacitor biquad filter structures. The components may be scaled or resized to center the values in preferred ranges.

Both Bode and pole-zero plots are available. Normally, you can determine the acceptability of your design by the inspection of its Bode plot. The Advanced Filter Designer plots gain, phase, and delay vs. frequency. For sampled data designs, you can plot your choice of the s- or z-domain transfer function. Pole-zero plots allow you to inspect the roots of the transfer function in either the s-domain or z-domain.

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UPDATE

fit in a Micro-PC's card cage. Micro-PC cards measure 4.9 x 4.2 in. (excluding the edge connector).

The company uses this strategy for several reasons. First, the standard card-mounting technique employed by the original PC isn't really up to the shock and vibration requirements of industrial applications. So the company developed a different mounting method that uses a nonstandard end plate and two mounting screws. This scheme provides a more solid mechanical arrangement.

Second, the large number of PC bus boards on the market hinder a company's effort; one company really can't provide support for every board that plugs into the bus. Rather than provide support for a cut-rate I/O card of unknown quality, the company uses a nonstandard form factor and physically excludes such boards from Micro-PC systems. Further, most Micro-PC boards operate over a -20 to +70°C temperature range, and commodity PC boards do not. Building a mixed system could compromise the Micro-PC's reliability.

To accommodate the cards' special form factor, the company offers card cages with backplanes and power supplies. The 3-, 4-, and 8-slot cages cost $45, $75, and $105, respectively. Power modules that draw power from several ac and dc sources range from $135 to $235. The power modules all feature MTBF ratings of at least 120,000 hours. The company also offers a variety of cables, keypads, alphanumeric displays, and terminal blocks for the various Micro-PC cards to ease system assembly.

—Steven H Leibson

Octagon Systems Corp, 6510 W 91st Ave, Westminster, CO 80030.
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CIRCLE NO. 92
Dual-channel VMEbus, audio-interface board encodes and compresses data in real time

The two compact-disk-quality digital audio channels on the MMI-210 VMEbus board suit applications in professional studios, realistic flight simulators, and sonar signal processors. Firmware on the board includes a number of data-compression and encoding algorithms that the board can execute in real time. The board has 4W power amplifiers on each channel, as well as a digital I/O interface compatible with workstations from Next Inc (Palo Alto, CA).

The MMI-210 incorporates a Motorola 56001 DSP µP for each output channel. The 27-MHz processors each have access to private $32k \times 24$-bit arrays of program memory and private $32k \times 24$-bit arrays of data memory. The board also has a socket for a $128k$-byte EPROM. A $1M$-byte RAM memory array stores sound data. The multiplexed design allows access to the memory array from both DSP chips and the VMEbus interface.

The board implements a 32-bit slave interface to the VMEbus and also supports 8- and 16-bit, and non-aligned transfers. A VMEbus host can communicate directly with either DSP µP via a dedicated host port. The host passes data to the processors via the $1M$-byte memory array. During VMEbus read and write transfers, the board latches data to minimize VMEbus cycle time. The board also provides a VMEbus interrupter.

The DSP ICs combined with a 16-bit Delta-Sigma A/D converter and a 16-bit D/A converter on each channel provide the compact-disk-quality digital recording and playback of sound. The channels sample at a maximum 100-kHz rate, and you can program the sample rate to a value as low as 8 kHz. The programmable sample rate allows you to make tradeoffs of sound quality and storage requirements.

The board features a dynamic range of 96 dB and a bandwidth of 20 Hz to 45.5% of the sampling frequency. You can program the output level from 0 to -72 dB. The board accepts $2V$ p-p input signals and outputs a $2V$ p-p signal of 4W into 8Ω.

Firmware on the board offers a choice of 4-bit ADPCM (adaptive differential PCM), 16-bit linear PCM, 8-bit µ-law, and 8-bit A-law data encoding and compression. The audio-data capacity the board offers varies according to the sampling rate and encoding scheme you use. For example, the board requires 960k bytes of memory to store 10 sec of sound, using 16-bit PCM encoding sampled at 48 kHz.

On the other hand, a 10-sec recording sampled at 8 kHz, using 4-bit ADPCM requires only 40k bytes of memory.

Users who want to develop proprietary algorithms for audio or general-purpose DSP applications can disable the onboard firmware and download code to the DSP µPs.

The board costs $3925, and samples are available. You can use the board with Microware’s (Des Moines, IA) Rave multimedia user interface for the OS/9 real-time operating system.—Maury Wright


Circle No. 732

ADPCM, PCM, µ-law, and A-law data-encoding choices, and a programmable sampling rate allow users of the MMI-210 VMEbus audio board to trade off audio-data capacity and sound quality.
Zilog's integrated universal serial communication controller (Z16C31™) combines two 32-bit full duplex DMA channels with a powerful single-channel USC cell. And that means efficient bus access, sophisticated buffer management, higher throughput, a greatly reduced CPU workload, and considerably lower cost for complex data communications applications.

Fast, multi-protocol operation.
Zilog's USC cell gives you 10 Mbits/sec speed for multi-protocol operation. It also gives you 52-byte RX and TX FIFOs for improved latency and up to 32-byte block moves. There's a Time Slot Assigner for multiplexing in ISDN/TI applications, a flexible 16-bit bus interface — multiplexed or non-multiplexed — for easy CPU interconnect, and a daisy-chain interrupt structure for simpler interrupt handling. And, best of all, the USC can reduce the CPU workload as much as 60%.

Integrated buffer management.
The USC's two 32-bit DMA channels provide for 32-bit addresses and 16-bit data word transfers... and they allow full duplex operation at 10 Mbits/sec. The two simple DMA modes, normal and buffered, mean your design can be tailored to common buffer management schemes. The two chained DMA modes, array chained and link array chained, reduce CPU overhead in advanced buffer management schemes. The daisy-chain DMA priority structure makes it easy to design multiple USC systems.

Versatility and reliability.
The USC's flexible, multi-protocol design lets you adapt your system to a variety of networks as interconnect standards evolve. The USC supports ten protocols and eight data encoding formats, including asynchronous, bit and byte synchronous, HDLC, isochronous, Ethernet and MIL-STD 1553B. And it all comes to you off the shelf, backed by Zilog's proven quality and reliability.

To find out more about the USC or any of Zilog's growing family of Superintegration™ products, contact your local Zilog sales office or your authorized distributor today. Zilog, Inc., 210 Hacienda Ave., Campbell, CA 95008, (408) 370-8000.
VMEbus-compatible CPU and storage modules implement a complete 80486-based system

Two VMEbus modules, collectively measuring 6 x 9 x 3.2 in. (two VMEbus slots), make up a complete IBM-compatible 80486-based computer system offering 20-MIPS performance. The EPC-5 embedded PC includes a CPU module and a mass-storage module; it targets applications as a front-end computer and operator interface for embedded-computer applications. The modules also provide the EXMbus for local expansion and for expansion and multiprocessing on the VMEbus.

The EPC-5 CPU module offers a choice of a 25- or a 33-MHz 80486 µP. The module also provides as much as 16M bytes of dynamic RAM, two RS-232C ports, a parallel port, a VGA graphics controller, a battery-backed clock, and a speaker. The CPU contains Award Software's 486 BIOS. An 8-layer PCB board, five custom gate arrays, and 4M-bit RAM chips enabled the company to fit the complete motherboard into the VMEbus form factor.

The mass-storage module includes a 3½-in. floppy-disk drive that's accessible from the VMEbus front panel, and a slot for a 3½-in. hard disk. You can specify a hard disk with capacity ranging from 40M to 100M bytes. Furthermore, you can use the EXMbus for additional expansion requirements. The company offers Ethernet, solid-state disk, floppy-disk, SCSI, IEEE-488, modem, RS-232C, and RS-422 expansion modules. Two EXMbus expansion slots fit within the CPU module form factor.

The VMEbus interface supports master and slave modes and can operate with an 8-, 16-, or 32-bit data bus. The board can generate and receive all seven VMEbus interrupts and includes full VMEbus slot-1 capability. The CPU board also provides byte-swapping circuitry to perform little-endian (Intel) to big-endian (Motorola) data conversions.

The device runs industry-standard operating systems such as MS-DOS, OS/2, and Unix. In addition, the system can run a number of real-time operating systems including VRTX-PC from Ready Systems and OS-9000 from Microware. Industrial application software available for the board includes Wonderware's Intouch, Iconic's Genesis, and Labtech's Labtech Control.

The company also offers its EPConnect software with the EPC-5 system. The software provides system-development and runtime packages that simplify the development of MS-DOS (including Microsoft Windows), OS/2, and Unix-based systems.

The company expects to ship the EPC-5 in November at a base price of $7495. Mass-storage modules start at $990, and the base price for EXMbus modules is $370. The EPC-5000 system-development kit costs $11,510 and includes the CPU module, a mass-storage module with a 100M-byte disk drive, MS-DOS, Windows 3.0, EPConnect, a keyboard, a mouse, and a data-migration facility.

—Maury Wright
Radisys Corp, 19545 NW Von Neumann Dr, Beaverton, OR 97006. Phone (503) 690-1229. FAX (503) 690-1228.

Circle No. 733

The 6 x 9 x 3.2-in. 80486-based VMEbus EPC-5 suits applications as a front-end computer in industrial control and other embedded-computer applications.
Synthesizer performance... priced to generate some waves.

The HP 3324A Synthesized Function/Sweep Generator.

The attractive price of this generator is bound to generate some waves. It's much less than you'd expect to pay for a function generator that has 5 ppm frequency accuracy, 9-digit frequency resolution and multi-interval sweep capabilities too.

Put it to work in testing filters and amplifiers where you need synthesizer accuracy, stability and signal purity. Tap its high linearity and multi-interval sweep features for A/D converter testing and for simulating rotating signals. Simplify the creation of phase-related signals for PLL or navigation-system testing with the new automatic phase-calibration options.

And there's more. Such as the high-stability frequency-reference option, and a high-voltage output option for making really big waves. Call 1-800-752-0900 today Ask for Ext. 1598 or mail the reply card and we'll send a brochure and application information.

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EDN October 25, 1990

CIRCLE NO. 94
Because you’re thinking fast...

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PRODUCT UPDATE

Rugged, nonvolatile data card features alloy contacts

A data card that tolerates harsh environments and lasts 5 to 10 times longer than similar products now expands your options for controlling users' access to critical equipment or data. The 5-pin, credit-card-sized 3.37 x 2.125-in. DS6300 CyberCard includes a unique 64-bit electronic serial number and at least 1k bits of static RAM. You can also order a 4M-bit DS64000EV CyberCard or a smaller, key-sized 2.375 x 1.12-in. 64-bit ROM DS6200 CyberKey. Ultrasonic welding makes these devices impervious to contaminants.

Electronic data keys are often characterized by such mechanical weaknesses as easily bent pins, high insertion-force requirements, and rapidly worn-away, gold-plated contact surfaces. The Cyber series uses contacts made of a solid-metal alloy that is more durable than gold. Each contact is 6000 mils thick and withstands 50,000 insertion/extraction cycles—a figure that’s 5 to 10 times higher than the specifications of competing products.

In addition, the card requires 1.5 lbs of insertion force, whereas other cards need 18 lbs of force. To enhance reliability, the receptacles for the Cyber series provide 250g of retention force per connector, as opposed to the 45g used by competitors' products.

To increase the MTBF, this card has five pins rather than the 68 connectors often used by competing data cards. The reduced pin count was made possible by its serial-transfer scheme and 1M-bps transfer rate. Internal cyclic-redundancy-check circuitry monitors and validates the serial data transmissions to detect any connection problems.

The Cyber series uses an internal converter to control data access via the device’s clock, data, and reset signals. An extended ground pin protects data integrity by ensuring that every insertion first provides a path to ground, thereby discharging any static electricity before the signal and power pins make contact.

Prices range from $3.50 for a 64-bit CyberKey to $250 (100) for a 4M-bit CyberCard EV. Flush-mounted or recessed receptacles for the Cyber series range from $3.90 to $4.50 (100).—J D Mosley

Dallas Semiconductor, 4401 S Beltwood Pkwy, Dallas, TX 75244. Phone (214) 450-0448.

Circle No. 731
The newest system through space-time.

The AMP Z-Pack Interconnection System is a scalable, high-density board-to-board/cable-to-board system for nanosecond and subnanosecond applications, in 2 mm and .100" grid sizes to accommodate global packaging requirements.

The fastest members use stripline technology, introducing reference planes between pin columns to retain maximum pin counts in a controlled impedance interface.

The design advantages are immediate: Z-Pack .100" stripline connectors accommodate 250 ps edge rates with no sacrifice in signal density: four rows = 40 lines per inch.

High-temp materials for SMT compatibility.
Twin-beam receptacles, 2 mm wipe.
Sequenced mating up to four levels.
2 mm versions accommodate two traces between lands.
Stripline versions isolate pin columns for 50 ohm interface.
Reliable compliant-pin versions available.
Space: 40 lines/inch.  
Time: 250 ps.

2 mm stripline versions (500 ps) require just one pin row for reference, and open pin field versions in both centerlines handle 1.8 ns rise-times with a 3:1 signal/ground ratio. Standard spacing minimizes board redesign, and system modules stack end-to-end with no loss of signal positions, offering true form/performance scalability in Futurebus-like applications.

For more information on the Z-Pack Interconnection System, call our Product Information Center at 1-800-522-6752. AMP Incorporated, Harrisburg, PA 17105-3608.

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A 40¢ component can stop what nature throws at you.

Every so often, nature throws your system a surge. And whether it’s lightning, static or a simple crossed line, it can destroy the most expensive system with a single blow.

About 40¢ is all it takes to protect your design from this cruel fate. Thanks to the full line of surge suppression devices from Harris.

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Harris offers the broadest line of MOVs in the industry. From 5V to 3500V. Up to 70,000 peak amps. And up to 10,000 joules.

Inventor of Surjector.

Surjector devices combine a thyristor and a zener into one reliable cost-effective device. At low voltages the Surjector device is off. But the instant its clamping voltage is exceeded, the Surjector turns on. Within nanoseconds, the surge is shunted safely to ground, protecting your circuit from sure destruction.

Because Surjector devices respond so quickly and can shunt lots of energy away from the circuit, they’re perfect for protecting expensive components from all kinds of transients. Lightning strikes, load changes, switching transients, commutation spikes, line crosses—all the things nature throws your system’s way.

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What your vision of the future demands. Today.
Digital storage oscilloscopes (DSOs) that cost less than $8000 are plentiful and incorporate many of the features of their high-priced siblings. If $8000 doesn't seem to be low cost, don't be dismayed. You'll find many products in the $2000 to $4000 range. And don't assume low cost means low performance. The DSOs in Table 1 have bandwidths of at least 50 MHz, and several have bandwidths that range from 300 to 500 MHz.

When comparing DSOs among themselves or with similarly priced analog scopes, you should understand the available features. These features vary considerably from scope to scope. Look around until you find the DSO or analog oscilloscope that has the feature combination you need for your application.

The most basic function of a DSO is acquiring and storing waveforms. If you need to acquire a signal that only happens once or is very infrequent, a DSO's single-shot, or real-time, performance will be your primary concern.

A DSO's maximum sample rate determines the bandwidth of a signal you can reasonably expect to acquire in the single-shot mode. The rule of thumb is that the DSO's sample rate should be at least 10 times the bandwidth of the signal you want to acquire. Of course, the single-shot bandwidth must not exceed the bandwidth of the DSO's input amplifiers. Although this rule of thumb holds for the DSOs in Table 1, some DSOs filter the input and use nonlinear waveform reconstruction techniques to push this bandwidth limit higher.

For example, Hewlett-Packard states that the single-shot bandwidth of its HP 54502 is 100 MHz with a maximum sample rate of 400M samples/sec. A lowpass filter limits signals going into the DSO's converter to 100 MHz for single-shot acquisitions. The 100-MHz bandwidth limit in conjunction with the 400M-samples/sec sampling rate is below the Nyquist limit and, therefore, prevents aliasing.

Not all DSOs automatically guard against aliasing at the maximum sample rate. Some have selectable bandwidth-limit filters, and others require you to limit a signal's bandwidth before the signal goes into the DSO.

Another important consideration for single-shot acquisitions is the number of digitizers. DSOs with one digitizer can only sample at their maximum rate on one channel. If you need to use two channels, the maximum sample rate divides in half.

If the event you are trying to acquire happens only once or is very infrequent, you need to be certain you acquire all the information you need. Some DSOs have long memories to make sure you don't miss any information. You should be aware of several factors when considering DSOs with long-record-length memories.

DSOs with long record lengths can't always capture maximum-length records at the maximum sample rate. Sometimes you can...
The rule of thumb for digitizing single-shot waveforms is to sample at a rate at least 10 times the bandwidth of the signal.

use the maximum record length only at slower sweep speeds, and sometimes the DSO must divide the memory when you want to record more than one channel.

For example, the LeCroy 9410 has two 10,000-point records, one for each of its two channels, no restrictions. The Panasonic VP-5710A offers a 64k-point record length on one channel. If you're using all four channels of the VP-5710A, you're down to a record length of 16k points per channel—still the longest record length of the DSOs in Table 1. A third example is Philips's PM3323, which has a record length of 4k points per channel at low sampling rates. When sampling at 500M samples/sec (the fastest sampling speed of the DSOs in Table 1), the scope limits you to 512 points per channel.

One benefit of long-record-length memories you might overlook is that you can operate the DSO at its maximum sample rate when you slow down the timebase. Front-end filters that prevent aliasing when sampling at the maximum sample rate become ineffective if the sample rate is reduced. A DSO with a 500-point record length will let you record as much as five microseconds of data at 100M samples/sec before you need to reduce the sampling rate. A 10,000-point record length lets you record 100 microseconds of data before you need to reduce the sampling rate.

Don't lose narrow pulses
Regardless of the record length, acquiring short pulses when a DSO is operating in single-shot mode can be problematic because a short pulse can fall between samples. You're probably sensitive to the possibility of missing a pulse shorter than the time between samples at the maximum sample rate, but you have to remember that a relatively long microsecond pulse can go unseen on a low timebase setting. Many DSOs will miss a 1-µsec pulse at a timebase of 1 msec/div.

A long-record-length memory helps you acquire short pulses by extending the period of time you can record without reducing the sample rate. At some timebase settings, however, the DSO will have to reduce the sample rate to fit the full time period into memory. When the DSO reduces its sampling rate, several strategies can help you avoid missing a short pulse.

Some DSOs have a glitch-capture mode to detect peaks between samples. Another way to make sure you aren't missing short pulses is to trigger on them. Glitch triggering is a type of time-qualified triggering. It lets you look for pulses that are shorter or longer than a set limit or that fall between two time limits.

Triggering to get the data you need
DSOs' timebases and delayed-trigger functions vary considerably. Delayed sweep and dual timebases are common on many analog scopes, and you'll find them on some DSOs, too. If a DSO is missing these features, that doesn't necessarily mean you can't perform the same or similar functions. DSOs often compensate for the lack of dual timebases by having long delayed trigger capability. Some offer delay by event, a feature that lets the DSO count events to line you up with a desired event.

A long-delay capability is often called post-trigger delay or just trigger delay. Most DSOs have some type of post-trigger delay. Some delays can be as long
as several seconds or thousands of divisions, depending on how the manufacturer specifies it. A long delay lets you see an event that happens long after the trigger with high resolution.

A long delay doesn't necessarily mean you get two timebases and can look at a temporally expanded image on one trace. However, you can often accomplish that goal in a different way. Some DSOs provide a magnified window that lets you expand one trace 10 or 20× for a limited dual-timebase capability.

Most DSOs let you look at pretrigger data. Typically, you can put the trigger point anywhere from the left side of the display to the right side. If you put the trigger point on the right side, you get 10 divisions of pretrigger information. Hewlett-Packard's DSOs and some DSOs from Philips let you view more pretrigger data.

**Resolution: Buyer beware**

If you've got a DSO with a sample rate adequate to acquire a single-shot waveform and sufficient memory to capture the event, then consider whether you have sufficient voltage resolution for your application. Almost all of the A/D converters on low-cost DSOs have 8-bit resolutions.

The resolution of the converter only tells you part of the story because it does not take into account noise and nonlinearity in the front-end of the DSO. These sources of nonlinearity include the input amplifiers, sample-and-hold methods, and the converter itself. The effective-bits measurement (Ref 1) probably gives the most accurate measure of DSO resolution vs signal bandwidth. That data is not available from most manufacturers and, therefore, is not included in **Table 1**. Until manufacturers agree on a meaningful measure of resolution—or users demand one—the effective resolution of most DSOs will remain a mystery.

If you're trying to capture a repetitive signal, you can get relief from low resolution by using averaging. Not all DSOs offer averaging, but those that do let you reduce noise by averaging signals acquired from multiple triggers. In fact, the whole playing field changes when you use averaging to look at repetitive signals. Sampling-rate and resolution requirements are not as stringent. That's why DSOs like the HP 54503A can offer a 500-MHz bandwidth yet sample at a maximum rate of only 20M samples/sec.

The secret of acquiring high-bandwidth waveforms at low sampling rates is repetitive, or equivalent-time, sampling. Note in **Table 1** that not all DSOs offer repetitive sampling. If a DSO doesn't offer repetitive sampling, then the bandwidth of the DSO portion of the scope (some of these DSOs have conventional analog oscilloscope capability) will be limited to the single-shot bandwidth.

Repetitive sampling is a method of using data acquired after each trigger to build up the complete waveform (Fig 1). This sampling method enables a DSO to acquire a waveform whose bandwidth is not restricted by the sample rate. The DSO's sample rate does, however, determine how fast the scope will acquire a reasonably complete image of the waveform. For example, the HP 54503A has a sample rate of 20M samples/sec. When operating at a timebase of 5 nsec/div, the DSO will acquire one point every time it triggers. Philips's PM3323 sampling at 500M samples/sec will acquire 25 points every time it triggers.

Using repetitive sampling at fast sweep speeds may mean a DSO is acquiring on the average only a fraction of a point each time it triggers. At these sweep speeds,
Repetitive sampling lets a DSO acquire a waveform whose bandwidth is not restricted by the sample rate.

The trigger-rearm dead time and display-update time both affect how quickly you can get a display of the waveform.

In fact, update rates are one area in which DSOs and conventional analog oscilloscopes differ noticeably. When a DSO operates in repetitive sampling mode, you get much finer timing resolution than you do in single-shot acquisition mode. However, you may notice some delay in acquiring and displaying a signal.

However, analog scopes can be difficult to use on

## Table 1—Representative low-cost DSOs

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Price</th>
<th>Channels</th>
<th>Bandwidth (MHz)</th>
<th>Maximum sample rate (M-samples/sec)</th>
<th>Number of channels at maximum sample rate</th>
<th>A/D converter resolution (bits)</th>
<th>Record length (words)</th>
<th>Dual timebases</th>
<th>Summation</th>
<th>Display data points with linear interpolation</th>
<th>Display data points with nonlinear interpolation</th>
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Notes: * Each RAM card holds 15 waveforms.
† 1000 setups per memory card
1. L=Limited
2. O=Option
3. 512k words per memory card
low-repetition-rate signals because the display is too dim to see clearly. Analog scope users often have to use hoods to see low-repetition-rate signals or extremely fast signals. DSOs don't have display brightness problems.

Despite the fact that update rate is an inherent DSO feature, few DSO manufacturers provide information on it. The problem isn't just that DSO manufacturers want to downplay a negative aspect of DSOs. The update rate often depends on many factors including timebase, voltage-attenuator setting, and processing methods, such as averages and automatic measurements, that might be happening simultaneously. Because no standards exist for specifying the update rate, most manufacturers ignore it. Getting a feel for the update rate and whether you consider it acceptable is one reason you should try a DSO before buying it. You just can't get all the information you need from the data sheets.

Cursor measurements are a start

One of the most attractive features of DSOs—whether they're operating in single-shot mode or repetitive sampling mode—is their ability to make measurements. Every DSO in Table 1 has cursors for making timing and voltage measurements. Cursor measurements are a useful feature because they let you make measurements faster and usually more accurately than counting divisions on the display. Cursor measurements aren't unique to DSOs. Many low-cost analog scopes also provide them.

For example, the 2100R from Leader is a 3-channel, 100-MHz analog oscilloscope that offers delayed sweep, cursor measurements, and timebase autoranging for $2195. The cursor measurements are ±3% accurate. You can find analog scopes with similar capabilities from most of the manufacturers in Table 1 as well as from other companies. Higher-performance analog oscilloscopes, such as Tektronix's $5550 400-MHz 2465B, offer pushbutton waveform measurements on repetitive signals for such parameters as rise time, fall time, pulse width, frequency, and voltage.

Some products are beginning to blur the distinction between standard analog oscilloscopes and DSOs. Tektronix recently announced the 100-MHz-bandwidth 2252, an analog oscilloscope that is part digital—it has cursors, a digital voltmeter, a 200-MHz counter/timer, and automatic setup. The oscilloscope can digitize repetitive signals with 12-bit vertical resolution and has a 500-point record length. It can provide hardcopy output to a printer through a Centronics interface and is fully programmable over an IEEE-488 interface. The $3495 oscilloscope does not, however, offer single-shot acquisition.

Automatic measurements, unlike cursor measure-
Low-cost digital storage oscilloscopes

Measurements, are more common among DSOs than among analog oscilloscopes. They are much faster and more repeatable than cursor measurements, and they are independent of the user. But many low-cost DSOs don’t make automatic measurements. Some DSOs make so few automatic measurements, such as only frequency and peak-to-peak voltage, that the value of these measurements is limited.

In addition to peak-to-peak voltage and frequency, automatic measurements often include pulse width, period, rise time, and fall time. Some DSOs can average multiple measurements. Others can give you additional measurement statistics such as minimum and maximum value for repetitive measurements.

Automatic measurements can be a big plus on any oscilloscope if you often make quantitative measurements or if you want to use the DSO in an automated test application. The automatic-measurement features each manufacturer puts into its DSOs varies. Gould, Hewlett-Packard, LeCroy, Philips, and Tektronix put considerable automatic measurements into some or all their models. Manufacturer’s data sheets can help you figure out which automatic measurements a DSO can make.

Another measurement concern is whether a DSO can make measurements on stored—as opposed to live—waveforms. Making measurements on stored waveforms is important both when examining a stored single-shot waveform and when you have saved a repetitive waveform and wish to make additional measurements at a later time.

With a 64k-point record length on one channel, the 20M sample/sec, 100-MHz VP-5710A from Panasonic can record long events. Two- or 4-channel operation results in proportionately shorter record lengths.

DSOs also vary in the way they display information. First, the size and quality of the displays varies. LeCroy’s 9410 has an impressive 4000 × 4000-pixel display. Scopes with less spectacular displays can do a fine job, but you should note that DSOs often display more information than analog oscilloscopes do. In addition to standard waveform, timebase, vertical-attenuator, and cursor readouts, DSOs sometimes display menus and other information that use up screen area.

DSOs typically display waveform data using one of three formats, although all three may be available on a given DSO. The most straightforward format is showing the data points as they are acquired. The points-only display is sometimes awkward to work with because the rising and falling edges of pulses may have few or no points, which makes pulses difficult to see.

The second display format avoids the invisible-edge problem by using linear interpolation to fill in the line between data points. Linear interpolation makes the rising and falling edges of pulses visible. This display format also lets you see when you are starting to push the time resolution of the DSO in single-shot mode. The linear segments between points have pronounced angular junctions when your sample rate is too low for the signal bandwidth.

In an attempt to clean up the angular display you get with linear interpolation, some DSOs use nonlinear interpolation to reconstruct a curve through the data points. Some manufacturers also use nonlinear interpolation to push the single-shot bandwidth of the DSO. If single-shot performance is important in your applica-
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CIRCLE NO. 96
tion and you want to push the bandwidth beyond one tenth the sample rate, you may want to use a DSO that offers nonlinear interpolation. You'll want to check out the scope on some test waveforms to get an idea of what kinds of signals you can acquire at the higher bandwidths and how repeatable the reconstruction is.

**Seeing a waveform change over time**

Some DSOs let you see how a waveform changes over time. In envelope mode, the display shows the limits of the waveform over time. At each horizontal time position, the DSO stores the maximum and minimum voltage values and displays them as an envelope.

A feature called persistence also lets you see how a waveform varies over time. Instead of storing only the minimum and maximum values, the DSO stores all horizontal and vertical values in persistence mode. The DSO displays the data points for the set persistence time and then erases them. If you choose infinite persistence, all points stay visible until you clear the screen.

Infinite persistence can show some conditions the envelope mode can't, such as eye patterns. You can acquire infrequent events by leaving the DSO running in either mode. For example, a pulse that is occasionally longer or shorter than average will show up in either mode.

**Features that affect ease of use**

Ease of use is often a concern for new DSO users. The features that make a DSO easy to use—or not—depend on what you're familiar with. Most scope users are familiar with analog oscilloscopes, so many manufacturers of low-cost DSOs have made the controls mimic those of an analog scope.

Dedicated controls for timebase, voltage attenuation, and delays make changing DSO settings quick and easy. Adjusting controls through the menu system takes longer. Unlike most analog oscilloscopes, you don't necessarily have to adjust all DSO controls manually.

About half the scopes in Table 1 feature automatic setup. Using automatic setup, you can get a timebase, voltage range, and trigger level acceptable enough to get an image on screen. You may have to adjust the delay or other parameters to get exactly the information you're looking for, but automatic setup will help you get close quickly.

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Low-cost digital storage oscilloscopes

Panel settings is using setup memories. You can save setups you use often in setup memories on some DSOs and use them to immediately set specific front-panel configurations.

Differences in computer control

Setup memories are also useful if you will be using a DSO remotely through a computer interface. Table 1 shows whether IEEE-488 connections or RS-232C interfaces are available on a given DSO. Some scopes include one or both of these interfaces as standard, some scopes offer them as options, and a few DSOs aren't available with any computer interface. You can also use these interfaces to connect a DSO to printers or plotters for hardcopy output.

Not all DSOs with computer interfaces support computer-controlled operations. For example, some interfaces only let you transfer data to or from the DSO—they don't let you control the front panel and operate the DSO remotely. Furthermore, data-transfer rates vary considerably among the different interfaces. LeCroy's fastest interface has a 380k-bps transfer rate.

One final question you might ask when looking at low-cost DSOs is what do you get by going to higher-priced DSOs. The typical features you pay for in higher-priced DSOs are higher sample rates, higher bandwidths, and higher resolution. On higher-priced DSOs, you'll also find that the automated measurements available on a few of the low-cost DSOs are virtually standard. Of course, you could also say that some DSOs with those high-performance features already have low prices.

Reference


Manufacturers of low-cost DSOs

For more information on low-cost DSOs such as those described in this article, circle the appropriate numbers on the Information Retrieval Service card or use EDN's Express Request service. When you contact any of the following manufacturers directly, please let them know you saw their products in EDN.

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<td>FAX (216) 328-7400</td>
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<td>Tektronix Inc</td>
<td>Box 1700</td>
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A PERSPECTIVE ON DESIGN ISSUES:
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**Leitch Video**

**Challenge:** Design a compact, cost-efficient direct broadcast satellite TV descrambler for consumer use.

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**Challenge:** Build a modem for high-speed data transmission between computers; allow flexible operation and minimize data errors.

**Solution:** Our TLC32040 Analog Interface Circuit (AIC). A product of our Advanced LinCMOS process, the AIC combines programmable filtering, equalization, and 14-bit A/D and D/A converters with such digital functions as control circuitry, program registers, and a DSP interface.

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All of these examples point to one conclusion: TI's Advanced Linear functions are adding an analog edge to many system designs. They are contributing significantly to the enhanced system performance that marks a market winner.
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EDN October 25, 1990

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CIRCLE NO. 129
Good bridge-circuit design satisfies gain and balance criteria

Bridge circuits are among the most elemental and powerful electrical tools. They are used in measurement, switching, oscillator, and transducer applications. This guide will help you choose the most appropriate circuit for your application. Part 1 of this 2-part series discusses dc and pulsed methods for bridge-circuit signal conditioning. Part 2 will discuss ac signal-conditioning methods.

Jim Williams, Linear Technology Corp

Bridge circuits are the electrical analog of the mechanical beam balance as well as the predecessor of all electrical differential techniques. The basic resistor bridge (Fig 1) is usually credited to Charles Wheatstone, although S H Christie—who demonstrated this circuit in 1833—almost certainly preceded him. Wheatstone apparently had a better public relations agency, namely himself.

In the resistor bridge, if all resistor values are equal, the differential voltage is zero. The excitation voltage does not alter this relationship because it effects both sides of the bridge equally. When the bridge is unbalanced, the excitation's magnitude sets the output sensitivity. With a single variable resistor, the bridge's output is nonlinear. Two variable arms (such as \( R_e \) and \( R_p \)) also produce a nonlinear output, although the sensitivity doubles. Linear outputs are made possible by complementary resistance swings in one or both sides of the bridge.

The Wheatstone bridge has attracted a great deal of attention. Designers have applied an almost uncountable number of tricks and techniques to enhance the linearity, sensitivity, and stability of the basic configuration. Transducer manufacturers are especially expert at adapting the bridge to their needs (see box, "Strain-gauge bridges"). Carefully matching the transducer’s mechanical characteristics to the bridge’s electrical response can provide a trimmed, calibrated output. Similarly, circuit designers have altered performance by adding amplifiers to the bridge, excitation source, or both.

A primary concern with bridge circuits is accurately determining the differential output voltage. In bridges operating at the null point, the absolute scale factor of the readout device is normally less important than its sensitivity and zero-point stability. Bridge amplifiers extract the bridge's differential...
Designers have given a great deal of attention to the Wheatstone bridge. A variety of tricks and techniques enhance its basic linearity, sensitivity, and stability.

Output from its common-mode level. An amplifier’s ability to reject a common-mode signal is critical. A typical strain-gauge transducer operating from a 10V source produces only 30 mV of signal riding on 5V of common-mode level. A 12-bit resolution of this signal has an LSB of only 7.3 µV, which is almost 120 dB below the common-mode signal. Other significant error terms include offset voltage (including its shift with temperature and time), bias current, and gain stability.

Instrumentation amplifiers make good bridge amplifiers. These devices are usually the first choice for bridge measurement, and their performance is adequate for most applications. In general, instrumentation amplifiers feature fully differential inputs and internally determined stable gain. The absence of a feedback network results in inputs that are essentially passive, and no significant bridge loading occurs. Table 1 lists performance data for some specific instrumentation amplifiers. Table 2 summarizes some options for de-bridge signal conditioning by presenting various approaches and their pertinent characteristics. The constraints, freedoms, and performance requirements of the particular application define the best approach.

DC bridge-circuit applications

Fig 2 shows a typical bridge application and details signal conditioning for a 350Ω transducer bridge. The specified strain-gauge pressure transducer produces a 3-mV output for each volt of bridge excitation. The LTC1021 reference, buffered by IC1A and IC2, drives the bridge. This potential also supplies the circuit’s ratio output, permitting ratiometric operation of a monitoring A/D converter. Instrumentation amplifier IC3 extracts the bridge’s differential output at a gain of 100; IC1B supplies additional trimmed gain.

You can adjust this configuration for a precise 10V output at full-scale pressure. The trimming adjustment at the bridge sets the zero-pressure scale point. The RC combination at the input of IC1B filters noise and determines the system’s lowpass cutoff frequency. Noise may originate as residual RF line pickup or transducer responses to pressure variations. In cases where noise is relatively high, you may want to filter ahead of IC1A, thereby preventing any possible signal infidelity caused by nonlinear IC2 operation. Saturation, slew-rate components, and rectification effects can produce such undesirable outputs.

When filtering ahead of the circuit’s gain blocks, remember to allow for the effects of bias-current-induced errors caused by the filter’s series resistance. This resistance can be a significant consideration because large-value capacitors, particularly electrolytic types, are not practical. If bias-current-induced errors rise to appreciable levels, you may need FET or MOS input amplifiers.

To trim this circuit, apply zero pressure to the transducer and adjust the 10-kΩ potentiometer until the output just comes off 0V. Next, apply full-scale pressure and trim the 1-kΩ adjustment. Repeat this procedure until both points are fixed.

Fig 3 shows a way to reduce errors caused by the bridge’s common-mode output voltage. IC1 biases Q1 to provide a servo action that forces the bridge’s left mid-

Table 1—Instrumentation-amplifier performance data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LTC1100</th>
<th>LTC1101</th>
<th>LTC1102</th>
<th>LTC1043 (Using LTC1050 amplifier)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>10 µV</td>
<td>160 µV</td>
<td>500 µV</td>
<td>0.5 µV</td>
</tr>
<tr>
<td>Offset drift</td>
<td>100 nV/°C</td>
<td>2 µV/°C</td>
<td>2.5 µV/°C</td>
<td>50 nV/°C</td>
</tr>
<tr>
<td>Bias current</td>
<td>50 pA</td>
<td>8 nA</td>
<td>50 pA</td>
<td>Resistor programmable</td>
</tr>
<tr>
<td>Noise</td>
<td>2 µV-p-p</td>
<td>0.9 µV</td>
<td>2.8 µV</td>
<td>Resistor limited, 0.001% possible</td>
</tr>
<tr>
<td>Gain</td>
<td>100</td>
<td>10,100</td>
<td>10,100</td>
<td>Resistor limited, &lt;1 ppm/°C possible</td>
</tr>
<tr>
<td>Gain error</td>
<td>0.03%</td>
<td>0.03%</td>
<td>0.05%</td>
<td>Resistor limited, 1 ppm possible</td>
</tr>
<tr>
<td>Gain drift</td>
<td>4 ppm/°C</td>
<td>4 ppm/°C</td>
<td>5 ppm/°C</td>
<td>160 ppm/°C possible</td>
</tr>
<tr>
<td>Gain nonlinearity</td>
<td>8 ppm</td>
<td>8 ppm</td>
<td>10 ppm</td>
<td>160 ppm/°C possible</td>
</tr>
<tr>
<td>CMRR</td>
<td>104 dB</td>
<td>100 dB</td>
<td>100 dB</td>
<td>Single, dual 44V max</td>
</tr>
<tr>
<td>Power supply</td>
<td>Single or dual, 16V max</td>
<td>Single or dual, 16V max</td>
<td>Single, dual 44V max</td>
<td></td>
</tr>
<tr>
<td>Supply current</td>
<td>2.2 mA</td>
<td>105 µA</td>
<td>5 mA</td>
<td>2 mA</td>
</tr>
<tr>
<td>Slew rate</td>
<td>1.5 V/µsec</td>
<td>0.07 V/µs</td>
<td>25 V/µs</td>
<td>1 mV/µs</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>8 kHz</td>
<td>33 kHz</td>
<td>220 kHz</td>
<td>10 Hz</td>
</tr>
</tbody>
</table>

Fig 1—Usually credited to Charles Wheatstone, the basic resistor bridge is widely used in measurement applications.
Strain-gauge bridges

In 1856, Lord Kelvin discovered that applying strain to a wire shifted its resistance. This effect is repeatable and is the basis for electrical-output strain measurement. Early devices were wires suspended between two insulated points. The mechanically measured force biased the wire, thus changing its resistance. Modern devices utilize foil-based designs (Fig Aa) in which the conductive material is deposited on an insulated carrier. Physically, these designs take many forms and allow a variety of applications. The gauges are usually configured in a bridge circuit and mounted on a beam, thus forming a transducer.

A useful transducer must be trimmed to a zero reference point, adjusted for gain, and compensated for temperature sensitivity. Fig Ab shows a typical arrangement. Trimming adjustments set the zero point and the gain. The gain trims include modulus gauges to compensate for the temperature sensitivity of the beam material. Arranging these trims and completing the mechanical assembly involves a fair amount of artistry and is best left to specialists.

Semiconductor-based strain-gauge transducers utilize resistive shift in semiconducting materials. These monolithic devices are smaller in size and considerably less expensive than manually assembled foil-based strain gauges and have more than 10 times the sensitivity. However, semiconductor-based transducers are more sensitive to temperature and other effects and suit less demanding applications. Although a semiconductor-based transducer’s impedance levels are about 10 times higher than foil-based designs, the devices have electrically similar bridge configurations.

Fig Ac shows the construction of a semiconductor-based device that uses a piezoresistive effect to provide strain-gauge action. The diaphragm is anisotropically etched from a silicon substrate. The piezoresistive element is a single, 4-terminal strain gauge. It is located at the midpoint of the edge of the square diaphragm at an angle of 45°. This orientation maximizes the device’s sensitivity to shear stress.

Excitation current passes longitudinally through the resistor (pins 1 and 3), and the pressure that stresses the diaphragm is applied at a right angle to the current flow. The stress establishes a transverse electric field in the resistor. Pins 2 and 4, which are the taps located at the midpoint of the resistor, sense this field as an output voltage. In a sense, the single-element, shear-stress strain gauge is the mechanical analog of a Hall-effect device.

The piezoresistive pressure transducer presents several advantages over the Wheatstone bridge configuration: improved linearity and a more consistent offset.

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**Fig A—Modern strain gauges utilize foil-based designs (a); a simplified schematic shows trimming adjustments to set the zero point and the gain (b). This semiconductor-based device (c) uses a piezoresistive effect to provide strain-gauge action.**
point to zero under all operating conditions. The 350Ω resistor ensures that IC₁ will find a stable operating point with 10V of drive delivered to the bridge. This arrangement lets IC₂ take a single-ended measurement, thus eliminating all common-mode-voltage errors. The approach works well and is often a good choice for high-precision work. The amplifiers in this example, which are CMOS chopper-stabilized units, essentially eliminate offset drift with time and temperature. Compared with an instrumentation-amplifier bridge circuit, this circuit is more complex and requires a negative supply.

Fig 4 is similar to Fig 3, except that it uses low-noise bipolar amplifiers. This circuit trades slightly higher dc offset drift for lower noise and is a good candidate for stable resolution of small, slowly varying signals.

Fig 5 employs chopper-stabilized IC₁ to reduce Fig 4's already small offset error. IC₁ measures the dc error at IC₂'s inputs and biases IC₁'s offset pins to force the offset to a few microvolts. The offset-pin biasing at IC₂ is such that IC₁ will always be able to find the servo point. The 0.01-µF capacitor rolls off the gain of IC₁ at low frequencies; IC₂ handles high-frequency signals. Returning IC₂'s feedback string to the bridge's midpoint eliminates IC₂'s offset contribution. Without this connection, IC₄ would require its own offset-correction loop. Although complex, this circuit achieves a drift of less than 0.05 µV/°C, less than 1 nV/√Hz noise, and a CMRR exceeding 160 dB.

These common-mode suppression circuits require a negative power supply. Often, such circuits must function in systems where only a positive rail is available. Fig 6
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Instrumentation Amplifier Diagram" /></td>
<td>Best general choice. Simple, straightforward. CMRR typically &gt;110 dB, drift 0.05-2 μV/°C, gain accuracy 0.03%, gain drift 4 ppm/°C, noise 10nV/√Hz~1.5 μV for chopper stabilized types. Direct ratiometric output.</td>
<td>CMRR, drift, and gain stability may not be adequate in highest precision applications. May require second stage to trim gain.</td>
</tr>
<tr>
<td><img src="image2" alt="Oscilloscope Diagram" /></td>
<td>CMRR &gt;120 dB, drift 0.05 μV/°C. Gain accuracy 0.001% possible. Gain drift 1 ppm with appropriate resistors. Noise 10nV/√Hz~1.5 μV for chopper stabilized types. Direct ratiometric output. Simple gain trim. Flying capacitor commutation provides lowpass filtering. Good choice for very high performance—monolithic versions (LTC1043) available.</td>
<td>Multipackage—moderately complex. Limited bandwidth. Requires feedback resistors to set gain.</td>
</tr>
<tr>
<td><img src="image3" alt="OP Amp Diagram" /></td>
<td>CMRR &gt;160 dB, drift 0.05-0.25 μV/°C, gain accuracy 0.001% possible, gain drift 1 ppm/°C, with appropriate resistors plus floating supply error, simple gain trim, noise 1nV/√Hz possible.</td>
<td>Requires floating supply. No direct ratiometric output. Floating supply drift is a gain term. Requires feedback resistors to set gain.</td>
</tr>
<tr>
<td><img src="image4" alt="OP Amp Diagram" /></td>
<td>CMRR &gt;140 dB, drift 0.05-0.25 μV/°C, gain accuracy 0.001% possible, gain drift 1 ppm/°C, with appropriate resistors plus floating supply error, simple gain trim, noise 1nV/√Hz possible.</td>
<td>No direct ratiometric output. Zener supply is a gain and offset term error generator. Requires feedback resistors to set gain. Low-impedance bridges require substantial current from shunt regulator or circuitry that simulates it. Usually poor choice if precision is required.</td>
</tr>
<tr>
<td><img src="image5" alt="OP Amp Diagram" /></td>
<td>CMRR &gt;160 dB, drift 0.05-0.25 μV/°C, gain accuracy 0.001% possible, gain drift 1 ppm/°C with appropriate resistors, simple gain trim, ratiometric output, noise 1nV/√Hz possible.</td>
<td>Requires precision analog-level shift, usually with isolation amplifier. Requires feedback resistors to set gain.</td>
</tr>
<tr>
<td><img src="image6" alt="OP Amp Diagram" /></td>
<td>CMRR = 120-140 dB, drift 0.05-0.25 μV/°C, gain accuracy 0.001% possible, gain drift 1 ppm/°C with appropriate resistors, simple gain trim, direct ratiometric output, noise 1nV/√Hz possible.</td>
<td>Requires tracking supplies. Assumes high degree of bridge symmetry to achieve best CMRR. Requires feedback resistors to set gain.</td>
</tr>
<tr>
<td><img src="image7" alt="OP Amp Diagram" /></td>
<td>CMRR 160 dB, drift 0.05-0.25 μV/°C, gain accuracy 0.001% possible, gain drift 1 ppm/°C, simple gain trim, direct ratiometric output, noise 1nV/√Hz possible.</td>
<td>Practical realization requires two amplifiers plus various discrete components. Negative supply necessary.</td>
</tr>
</tbody>
</table>
Bridge-output amplifiers can extract the bridge's differential output from its common-mode level.

shows one way to achieve this goal. IC₁ biases the LT1054 positive-to-negative converter. The LTC1054's output pulls the bridge's output negative, which causes IC₁'s input to balance at 0V. This local loop lets a single-ended amplifier (IC₂) extract the bridge's output signal. The 10-kΩ, 1-µF RC network filters noise, and IC₂'s gain provides the desired output scale factor. Circuit biasing permits 8V to appear across the bridge, which requires the 100-mA-capable LT1054 to sink about 24 mA. You can use the ratio output to reference a monitoring A/D converter.

**Switched-capacitor amplifier**

Switched-capacitor methods are another way to provide signal conditioning for bridge outputs. Fig 7 uses such a method in a high-precision scale application. This circuit for weighing human subjects resolves 0.01 lb at 300 lbs full scale.

The strain-gauge-based transducer platform is excited at 10V by the LT1021 reference, IC₁, and IC₂. The LTC1043 switched-capacitor block combines with IC₃ to form a differential-input, chopper-stabilized amplifier. The LTC1043 alternately connects the 1-µF capacitor between the output of the strain-gauge bridge and the input to IC₃. A second 1-µF capacitor stores the LTC1043 output, maintaining IC₃'s input at dc. The LTC1043's low charge injection maintains a differential-to-single-ended transfer accuracy of about 1 ppm at dc and low frequencies. The 0.01-µF capacitor sets the commutation rate to approximately 400 Hz. IC₃'s scaled gain provides 3.0000V for a 300.00-lb full-scale output.

The extremely high resolution of this scale requires filtering to produce useful results. Even slight body movement acting on the scale's platform can cause significant noise in IC₃'s output. This fact is dramatically apparent in Fig 8's tracings. The total force on the platform is equal to gravity pulling on the body (the weight) plus any additional accelerations within or acting upon the body. Trace B of Fig 8 shows that each time the heart pumps, the acceleration of the blood moving in the arteries shows up as weight. To prove this theory, the subject gets off the scale and runs in place for 15 seconds. When the subject returns to the platform, the
Fig 7—Using switched-capacitor techniques, this weight-scale circuit can resolve 0.01 lb at 300 lbs full scale.

Fig 8—These tracings show the effects of a subject on the weight-scale platform of Fig 7. Trace B shows the subject at rest; trace A shows the effects after the subject has exercised.

heart should be working harder. Trace A confirms this prediction. The exercise causes the heart to work harder, forcing greater acceleration per stroke.

Another source of noise is body motion. As the body moves around, its mass doesn’t change but the platform picks up the instantaneous accelerations and reads them as weight shifts. These fluctuations might seem to make a 0.01-lb measurement meaningless, but filtering the noise yields a time-averaged value. A simple RC lowpass filter will do the job, but it requires excessively long settling times to filter noise fundamentals in the 1-Hz region. Another approach works much better.

In Fig 7, IC₄, IC₅, and their associated components form a filter that switches its time constant from short to long when the output approaches the final value. With no weight on the platform, IC₅'s output is zero. IC₄'s output is also zero, IC₅₆B's output is indeterminate, and IC₅₆A's output is low. The MOSFET optocoupler's LED turns on, putting the RC filter into a short-time-constant mode. When someone gets on the scale, IC₅₆A goes high, but IC₅₆B trips low, which keeps the RC filter in its short-time-constant mode. The 2-µF capacitor charges rapidly, and IC₄ quickly settles to a final value plus or minus body motion and
Instrumentation amplifiers, which have fully differential inputs and internally determined stable gain, often make good bridge amplifiers.

heartbeat noise. IC3B’s negative input sees 1% attenuation from IC3; its positive input does not. This condition causes IC3B to switch high when IC4’s output arrives within 1% of its final value. The optocoupler goes off, and the filter switches into a long-time-constant mode, thus eliminating noise in IC4’s output. The 39-kΩ resistor prevents overshoot, ensuring monotonic outputs from IC4.

When the subject steps off the scale, IC3 quickly returns to zero, and IC2A immediately goes low, turning on the optocoupler. This action quickly discharges the 2-µF capacitor, which rapidly returns IC1’s output to zero. The bias string at IC1A’s input maintains the scale in the short-time-constant mode for weights less than 0.50 lb. This condition permits the circuit to respond rapidly when small objects (or persons) are on the platform. To trim this circuit, adjust the zero potentiometer for a 0V output with no weight on the platform. Next, set the gain adjustment for a 3.0000V output for a 300.00-lb platform weight. Repeat this procedure until both points are fixed.

Another example of using optical techniques to enhance performance is the circuit in Fig 9. This switched-capacitor-based instrumentation amplifier can handle transducer signal conditioning where high common-mode voltages exist. The circuit features low offset and drift because of the LTC1150 chopper-stabilized op amp (IC1). The design also incorporates a switched-capacitor front end to achieve some specifications not available in a conventional instrumentation amplifier.

The common-mode rejection ratio at dc for the front end exceeds 160 dB. The amplifier operates over a ±200V common-mode range; gain accuracy and stability are limited only by external resistors. Chopper-stabilized IC1 sets the offset drift at 0.05 µV/^\circC. The high common-mode voltage capability of the design enables it to withstand transient and fault conditions often present in industrial environments.

The bridge’s output feeds two LED-driven, optically coupled MOSFET switches, S1 and S2,
which are in series with two similar switches, \( S_3 \) and \( S_4 \). CMOS logic functions, clocked from IC'\(^1\)'s internal oscillator, generate nonoverlapping clock outputs that drive the LEDs. When the acquire pulse is high, \( S_1 \) and \( S_2 \) are on, and \( C_2 \) acquires the differential voltage at the bridge's output. During this interval, \( S_3 \) and \( S_4 \) are off. When the acquire pulse falls, \( S_1 \) and \( S_2 \) begin to go off. After a delay to allow \( S_1 \) and \( S_2 \) to fully open, the read pulse goes high, turning on \( S_3 \) and \( S_4 \).

Capacitor \( C_1 \) acts as a ground-referred voltage source, which IC\(^1\) reads. \( C_2 \) lets IC\(^1\)'s input retain \( C_1 \)'s value when the circuit returns to the acquire mode. IC\(^1\) provides the circuit's output; its gain is set in normal fashion by feedback resistors. The 0.33-\( \mu \)F feedback capacitor sets the rolloff. The differential-to-single-ended transition that the switches and capacitors perform prevents IC\(^1\) from ever seeing the input's common-mode signal. The breakdown specification of the optically driven MOSFET switch enables the circuit to operate at common-mode levels of \( \pm 200 \)V. In addition, the optical drive to the MOSFETs eliminates the charge-injection problems common to FET switched-capacitor networks.

Platinum resistance temperature detectors (RTDs) are frequently used in bridge configurations for temperature measurement. Fig 10's circuit is highly accurate and features a ground-referred RTD. The ground connection is highly desirable for reducing noise. A current source drives the bridge's RTD leg; the opposing bridge branch is voltage biased. The current drive lets the voltage across the RTD vary directly with the device's temperature-induced resistance shift. The difference between this potential and the potential of the opposing bridge leg is the bridge's output.

IC\(_{1A}\) and instrumentation amplifier IC\(_2\) form a voltage-controlled current source. IC\(_{1A}\), biased by the LT1009 voltage reference, drives current through the 88.7\( \Omega \) resistor and the RTD. IC\(_2\) senses voltage differentially across the 88.7\( \Omega \) resistor and closes a loop back to IC\(_{1A}\). The 2-k\( \Omega \), 0.1-\( \mu \)F combination sets the amplifier rolloff for this stable configuration. Because IC\(_{1A}\)'s loop forces a fixed voltage across the 88.7\( \Omega \) resistor, the current through \( R_P \) is constant. IC\(_1\)'s operating point is primarily fixed by the 2.5V LT1009 reference.

The constant current through the RTD forces the voltage across it to vary with the RTD's resistance, which has a nearly linear positive temperature coefficient. The degree of nonlinearity could cause an error of several degrees over the circuit's 0 to 400°C operating range. The bridge's output feeds instrumentation amplifier IC\(_3\), which provides differential gain while correcting nonlinearity. The correction is implemented by feeding a portion of IC\(_3\)'s output back to IC\(_1\)'s input via the 10- and 250-k\( \Omega \) divider. This correction causes the current through \( R_P \) to slightly shift with the resistor's operating point, which compensates sensor nonlinearity to within \( \pm 0.05^\circ \)C. IC\(_{1B}\) provides additional scaled gain and furnishes the circuit output.

To calibrate this circuit, substitute a precision decade box, such as the General Radio (Lincoln, NE) 1432K, for \( R_P \). Set the box to the 0°C value (100.00\( \Omega \)) and adjust the offset trim for a 0.000V output. Next, set the box for a 140°C value (154.26\( \Omega \)) and adjust the gain trim for a 3.500V output reading. Finally, set the box to 400.00°C (249.0\( \Omega \)) and trim the linearity adjustment for a 10.000V output. Repeat this sequence until all three points are fixed. Total error over the entire range will be within \( \pm 0.05^\circ \)C. The resistance values in parentheses are for a nominal 100.00\( \Omega \) (0°C) sensor. You can use
Chopper-stabilized CMOS amplifiers can help eliminate offset drift with time and temperature.

Sensors that deviate from their nominal value by factoring in the deviation from 100.000. This deviation, which the manufacturer specifies for each individual sensor, is an offset term caused by winding tolerances during RTD fabrication. The gain slope of the platinum is primarily fixed by the purity of the material and has a very small error term.

Digitally corrected RTD bridge

The previous example relies on analog techniques to achieve a precise, linear output from the platinum RTD bridge. The circuit in Fig 11 uses digital corrections to obtain similar results. A microprocessor corrects any residual RTD nonlinearities as well as the bridge's inherent nonlinear output.

The LT1097 drives the bridge with 5V. Instrumentation amplifier IC₁ extracts the bridge's differential output. IC₁'s output is fed to the LTC1290 12-bit A/D converter via gain-scaling stage IC₂. The A/D converter's raw output codes reflect the bridge's nonlinear output vs temperature. The processor corrects the converter's output and produces linearized, calibrated output. You calibrate the circuit as you would the platinum RTD circuit but with the linearity trim deleted.

Thermistor bridge

Another temperature-measuring bridge, Fig 12, uses a thermistor as a sensor. The LT1034 excites the bridge. The 3.2-kΩ and 6250Ω resistors are supplied with the thermistor sensor. The network's overall response is linearly related to the thermistor's sensed temperature. The network forms one leg of a bridge, and the resistors make up the opposing leg. Trimming this opposing leg sets the bridge output to zero at 0°C. Instrumentation amplifier IC₁ provides gain, and IC₂ provides additional trimmed gain to supply a calibrated output. You calibrate the circuit as you would
duces the bridge current to less than 700 µA by using a semiconductor-based bridge transducer. The input resistance of these devices is significantly higher than that of resistance-based bridges. This higher input resistance minimizes current drain and power dissipation. Semiconductor-based pressure transducers are less expensive than bonded strain-gauge types, but they have reduced accuracy and stability.

Fig 14 was derived directly from the Fig 6 circuit and illustrates a simple way of reducing power without sacrificing the bridge's output signal level. The technique applies when continuous output is not a requirement. This circuit can sit in the quiescent state for long periods with relatively brief on times. A typical application would be obtaining remote weight information for storage tanks where weekly readings are sufficient. Quiescent current is about 150 µA with an on-state current of 50 mA typ.

With Q1's base unbiased, all circuitry is off except the LT1054 plus-to-minus voltage converter, which draws 150 µA of quiescent current. When Q1's base is pulled low, its collector supplies power to IC1 and IC2. IC1's output then goes high, turning on the LT1054. The LT1054's output (pin 5) heads toward −5V, and Q2 comes on, which permits the bridge current to flow. To balance its inputs, IC1 servo controls the LT1054 to force the bridge's midpoint to 0V. The bridge ends up with approximately 8V across it, requiring the 100-mA-capable LT1054 to sink about 24 mA. The 0.02-µF capacitor stabilizes the loop. The IC1-LT1054 loop's negative output sets the bridge's common-mode voltage to zero, allowing IC2 to take a single-ended measurement. The output-trim adjustment scales the circuit for 3-mV/V strain-bridge transducers, and the 100-kΩ, 0.1-µF combination provides noise filtering.

Fig 15, an obvious extension of Fig 14, automates the strobing into a clocked sequence. Circuit on time is restricted to 250 µsec at a clock rate of approximately 2 Hz. This restriction limits the average current drain to approximately 200 µA. Oscillator IC1A produces the 250-µsec clock pulse every 500
Switched-capacitor instrumentation amplifiers can provide effective signal conditioning where high common-mode voltages exist.

msec. A filtered version of this pulse feeds Q₁₁, whose emitter provides a slew-limited bridge drive. IC₁₁₆'s output also triggers a delayed pulse produced by the 74C221's one-shot output. The timing is such that the pulse occurs well after the IC₁₁₅-IC₂ bridge-amplifier output settles. A monitoring A/D converter, triggered by this pulse, can acquire IC₁₁₅'s output.

The slew-limited bridge drive prevents the strain-gauge bridge from seeing a fast rise pulse, which could cause long-term transducer degradation. To calibrate this circuit, trim the zero and gain controls for appropriate outputs.

Fig 16 extends the sampling approach to include a continuous output. The circuit accomplishes this end with an additional sample-and-hold stage at its output. Q₂ is off when the sample command is low. Under these conditions, only IC₂ and the LTC201 receive power, and the current drain is less than 60 µA. When the sample command pulses high, Q₂'s collector goes high, providing power to all other circuit elements. The 10Ω, 1-µF RC combination at the input of the LT1021 prevents the strain-gauge bridge from seeing a fast-rise pulse, which could cause long-term transducer degradation. The LT1021-5 reference's output drives the strain-gauge bridge, and instrumentation amplifier IC₁ provides gain for the bridge's output signal. Simultaneously, S₁'s switch-control input ramps toward Q₂'s collector. At approximately 0.5 mV, S₁ turns on, and C₁ stores IC₁'s output.

When the sample command drops low, Q₂'s collector falls, the bridge and its associated circuitry shut down, and S₁ goes off. C₁'s stored value appears at gain-scaled IC₂'s output. The RC delay at S₁'s control input ensures glitch-free operation by preventing C₁ from updating until IC₁ has settled. During the 1-msec sampling phase, the supply current approaches 20 mA; a 10-Hz sampling rate cuts the effective drain to less than 250 µA. Slower sampling rates will further reduce drain, but C₁'s droop rate (about 1 mV/100 msec) sets an accuracy constraint. The 10-Hz rate provides adequate bandwidth for most transducers. The gain trim lets you calibrate 3-mV/V slope-factor transducers. You should rescale this trim for other transducer types. This circuit's effective current drain is about 250 µA, and IC₂'s output is accurate enough for 12-bit systems.

Remember that this circuit is a sampled system. Although the output is continuous, information is collected at a 10-Hz rate. You should keep the Nyquist limit in mind when interpreting results.

Fig 17 is a special case of a continuous-output sampled-bridge drive. The circuit is intended for applications requiring extremely high-resolution outputs from a bridge transducer. This circuit puts 100V across a 10V, 350Ω strain-gauge bridge for short periods of time. The high pulsed-voltage drive proportionally increases the bridge output without forcing excessive dissipation. In fact, although this circuit is not intended to reduce power, the average bridge current is far below the normal 29 mA obtained with 10V dc excitation.

The key to the high resolution obtainable with this circuit is combining the 10 x higher bridge gain (300 mV full scale vs the normal 30 mV) with a chopper-stabilized amplifier in the sample-and-hold output stage. When oscillator IC₁₁₆'s output is high, Q₆ turns on, and IC₂'s negative input is pulled above ground.
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Typically, an A/D’s spurious signal levels show a variation with input signal power. Swept-Power testing demonstrates that these spurs remain at levels acceptable over the complete range of input signal amplitudes. The test measures “worst-case” spurious signal levels as the input is decreased in very small increments from an over-driven amplitude to near the ADC noise level.

Figure 1
IC₃'s output goes negative, which turns on Q₁. Q₁'s collector then goes low, robbing Q₂'s base drive and cutting it off. Simultaneously, IC₃ enforces its loop by biasing Q₂ into conduction, which turns on Q₆. Under these conditions, the voltage across the bridge is essentially zero.

When IC₁ₐ's output is low, RC-filter-driven Q₆ responds by cutting off slowly. Now, only the current through the 3.6-kΩ resistor affects IC₂'s negative input. The input begins to head negative, causing IC₂'s output to rise. Q₆ comes out of saturation, and Q₆'s emitter voltage rises. Initially, this action is rapid, but feedback to IC₃'s negative input closes a control loop, and a 1000-pF capacitor restricts the rise time. The 72-kΩ resistor sets IC₂'s gain at 20 with respect to the LT1004 2.5V reference, and Q₆'s emitter servo controls to 50V. IC₃ responds to the bridge's biasing by moving its output in the negative direction. Q₆ tends toward cutoff, increasing Q₆'s conduction. IC₃ biases its loop to maintain the bridge midpoint at zero. To bias its loop, IC₃ must produce a complementary output to IC₂'s loop. IC₃'s loop rolloff is considerably faster than IC₂'s, ensuring that it will faithfully track IC₂'s loop action. Similarly, IC₂'s loop is slaved to IC₃'s loop output and produces no other outputs. Under these conditions, the bridge sees 100V for the 1-msec duration of the clock pulse.

IC₁ₐ's clock output also triggers the 74C221 one-shot circuit. This circuit delivers a delayed pulse to Q₁, which turns on and charges the 1-µF capacitor to the bridge's output voltage. With IC₅ forcing the bridge's left-side midpoint to zero, Q₆, the 1-µF capacitor, and IC₄ see a single-ended, low-voltage signal. The complementary, controlled rise times of the control loops prevent high-transient common-mode voltages.

IC₄, which has gain, provides the circuit output. The 74C221's pulse width ends during the bridge's on time, thus preserving the integrity of the sampled data. When oscillator IC₁ goes high, the control loops remove the bridge's drive, returning the circuit to quiescence. The 1-µF capacitor maintains IC₄'s output at dc. IC₁ₐ's 1-Hz clock rate is adequate to prevent a deleterious charge droop on the 1-µF capacitor, but slow enough to limit the bridge's power dissipation. The controlled rise and fall times across the bridge prevent possible long-term transducer degradation by eliminating high ΔVΔT-induced effects.

When using this circuit, remember that it is a sampled system. Although the output is continuous, information is collected at a 1-Hz rate. The Nyquist limit applies and must be taken into account when interpreting results.

**Author's biography**

Jim Williams, staff scientist at Linear Technology Corp (Milpitas, CA), specializes in analog-circuit and instrumentation design. He has served in similar capacities at National Semiconductor, Arthur D Little, and the Instrumentation Development Lab at the Massachusetts Institute of Technology. A former student of psychology at Wayne State University (Detroit, MI), Jim enjoys art, collecting antique scientific instruments, and restoring old Tektronix oscilloscopes.

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Instrumentation amplifiers are finding increasing application in today's complex systems. Minor modifications can yield significantly better performance by improving common-mode rejection. In addition, these changes may let you use low drift amplifiers.

R Mark Stitt, Burr-Brown Corp

Modern systems are placing ever greater demands on instrumentation amplifiers. When standard instrumentation amplifiers can't deliver the performance you require, consider using enhanced versions. Operating the input amplifiers of a classical 3-op-amp instrumentation amplifier from common-mode-driven subregulated power supplies will dramatically improve their performance.

Instrumentation amplifiers amplify low-level differential signals while rejecting unwanted common-mode signals. Common-mode rejection (CMR) is an important feature of instrumentation op amps. CMR in ac is especially important because common-mode signals are inevitably dynamic—ranging from the 60 Hz of power-line interference to the hundreds of kilohertz of switching-power-supply noise. By using common-mode-driven subregulated supplies, you can improve an instrumentation amplifier's ac and dc CMR. You'll also get improved ac and dc power-supply-noise rejection as an added bonus.

When you need high gain, input-offset-voltage drift is critical. In some applications, chopper-stabilized op amps provide the best solution because of their low input-offset-voltage drift. Unfortunately, because many chopper-stabilized op amps use low-voltage CMOS processes, you can't operate them on standard ±15V power supplies. On the other hand, you can operate them from common-mode-driven, subregulated ±5V supplies without restriction in ±15V systems.

To understand the technique for maximizing rejection, first consider the 3-op-amp instrumentation amplifier (Fig 1). The design comprises an input-gain stage driving a difference amplifier. The difference amplifier consists of op amp IC3 and ratio-matched resistors R1 through R4. If the resistor ratio R2/R1 exactly matches R3/R4, the difference amplifier will boost differential signals by a gain of R2/R1 while rejecting common-mode signals. Resistor mismatch will almost certainly limit the difference amplifier's CMR if IC3 is a high-performance op amp. If the input-stage gain is 1, a unity-gain difference amplifier will require a 0.01% resistor match for CMR of 86 dB.

Add gain ahead of the difference amp

There are significant drawbacks in using a single-op-amp push-pull-to-single-ended converter with gain (difference amplifier) to amplify small signals superim-
Because most chopper-stabilized op amps are built with low-voltage CMOS processes, you can't operate them on ±15V supplies.

- Fig 1 — A 3-op-amp instrumentation amplifier boosts differential signals by a gain of \( R_2/R_1 \), if \( R_2/R_1 \) matches \( R_1/R_2 \).

posed on common-mode voltages. First of all, any imbalance in the source resistance will alter the resistor match and degrade the CMR. To avoid this problem, many instrumentation amplifiers precede the difference amplifier with a differential-input, differential-output gain stage consisting of two amplifiers (IC1 and IC2 of Fig 1) and three resistors. The gain of this stage is \( 1 + 2 \cdot R_2/R_1 \), and the instrumentation amplifier's overall gain is \( (1 + 2 \cdot R_2/R_1) \cdot R_2/R_1 \).

The CMRR is the ratio of differential gain to common-mode gain. Using buffer amplifiers to add gain ahead of a difference amplifier increases an instrumentation amplifier's CMR (if the buffer amplifiers' CMR is better than that of the difference amplifier). That's why instrumentation amplifier data sheets usually specify one CMR at gain = 1 and a much higher CMR at higher gains.

Most high-performance op amps have better CMR than difference amplifiers do. However, be careful when selecting an input op amp. High-grade versions of the venerable 741 op amp have a minimum dc CMR of 80 dB, and the popular LM324 has a minimum dc CMR of only 70 dB. High-performance bipolar-input op amps have the best CMR. The OPA177, for example, has a minimum dc CMR of 130 dB. FET-input op amps usually don't offer quite as much CMR performance. For example, the Burr-Brown OPA627 FET-input op amp has a minimum dc CMR of only 106 dB.

Driving the input op amp's power-supply from subregulated power supplies referenced to the instrumentation-amplifier common-mode-input voltage improves the dc CMR of a standard instrumentation amplifier. The device mismatch and thermal feedback that occur as an op amp's inputs change limit its CMR. (Similar effects also limit the amplifier's power-supply rejection ratio.) Varying the power supply to track the common-mode input signal inhibits changes and reduces errors, which can degrade CMR.

The input amplifier's ac response limits the instrumentation amplifier's ac CMR. The outputs of the input amplifiers in the instrumentation amplifier follow the common-mode input signal. As the frequency of the common-mode signal increases, the input op amp's loop gain diminishes, which causes differential gain errors to increase and CMR to fall off.

For large common-mode signals, the input op amp's slew rate can limit the function of the instrumentation amplifier. The instrumentation amplifier will fail to function completely when the maximum rate of change of the common-mode signal exceeds the op amp's slew-rate limit. For a sine wave, where the maximum rate of change occurs at the zero crossing, the derivation of the slew-rate limit is

\[
V = V_p \cdot \sin(2\pi ft),
\]

\[
dV/dt = 2\pi f \cdot V_p \cdot \cos(2\pi ft).
\]

At \( t = 0 \),

\[
dV/dt = 2\pi f V_p, \text{ therefore the slew-rate limit} = 2\pi f_{\text{MAX}} V_p,
\]

where

\[
V = \text{common-mode voltage vs time (t)},
\]

\[
V_p = \text{peak common-mode voltage},
\]

\[
\text{slew-rate limit} = \text{maximum } dV/dt,
\]

\[
\text{and } f_{\text{MAX}} = \text{maximum common-mode frequency at amplitude } V_p \text{ beyond which a standard instrumentation amplifier will fail to function due to the slew-rate limit of the input op amp.}
\]

Driving the power supply of the input op amps from
common-mode-referenced subregulated supplies improves ac CMR as well as dc CMR. Because neither the amplifier's inputs nor output change relative to the subregulated power-supply rails—at least in the ideal case—nothing within the amplifier moves in response to the common-mode signal. No current flows in the phase-compensation capacitors, which disables the slew-rate-limiting phase compensation for common-mode response.

Fig 2 shows a complete circuit for an enhanced instrumentation amplifier. As you can see, this enhanced instrumentation amplifier contains the 3-op-amp instrumentation amplifier from Fig 1 plus a buffered common-mode voltage generator and ±5V subregulated power supplies.

The 3-op-amp instrumentation amplifier in Fig 2 uses an INA106 gain-of-10 difference amplifier, which contains a precision op amp and ratio-matched resistors \( R_1 \) through \( R_4 \) pretrimmed for 100-dB min CMR. Because the INA106 already contains ratio-matched resistors, you don't have to match critical resistors to build a precision instrumentation amplifier.

The resistor divider network \( (R_5 \) and \( R_6 \)) creates the common-mode signal that drives the subregulated supplies. The instrumentation-amplifier inputs drive the network through unity-gain-connected op amps IC\(_4\) and IC\(_5\). These buffer amplifiers preserve the instrumentation amplifier's high input impedance. Some applications don't require such impedance. In those applications, the impedance of the \( R_5, R_6 \) network may be connected directly to the instrumentation-amplifier inputs. Fig 3 shows a circuit without buffer amplifiers IC\(_4\) and IC\(_5\). The signal at the \( R_5, R_6 \) connection of the resistor divider is the common-mode or average voltage of the two instrumentation-amplifier inputs.

The negative subregulator consists of IC\(_6\), \( R_7 \), \( C_1 \), and a 100-\( \mu \)A current source. Since no current flows in the op-amp input, 100 \( \mu \)A flows through the 50-k\( \Omega \) resistor, \( R_7 \), forcing a −5V drop from the op-amp input to its output. The op amp forces the negative input to be at the same potential as the positive input. The result is a −5V floating-voltage reference relative to the op-amp noninverting-input terminal. The positive subregulator is the same as the negative subregulation except for the current-source connection's polarity.

The circuit in Fig 3 only connects the positive and
An input op amps' slew rate can limit the ability of an instrumentation amplifier to produce large, common-mode signals.

The subregulated-supply voltage limits the common-mode input range of the enhanced instrumentation amplifier. The outputs of the subregulator amplifiers (IC₆ and IC₇) must swing the common-mode voltage as well as the subregulator voltage. The larger the subregulator voltage, the smaller the common-mode input range. A subregulator voltage of ±5V is low enough to give good input common-mode range and high enough to allow full performance from almost any op amp. The reduced power-supply voltages lower power dissipation in the input op amps. They also improve the instrumentation amplifier's performance by reducing thermally induced low-frequency noise.

In all semiconductor packages, thermocouples exist at dissimilar conductor interfaces. Matched-seal metal, side-brazed ceramic, cerdip, and many plastic packages use Kovar leads. Thermocouples exist between the lead plating and the Kovar. Thermocouples also exist between the leads and the solder connections to the printed circuit.

If thermal gradients are properly matched at the amplifier inputs, the thermocouple errors will cancel one another out. In practice, mismatches occur. Even under laboratory conditions, a mismatch may produce several tenths of a microvolt—well above low-noise-
amplifier levels. In the output of a high-gain amplifier, errors appear as low-frequency noise or short-term input-offset errors.

In signal op amps, package leads conduct away much of the heat. The resulting thermal difference between the package and the printed circuit can be a major source of error. Operating the op amp on ±5V supplies instead of ±15V supplies decreases quiescent power dissipation and its associated temperature rise by at least 300%. This decrease also provides a commensurate reduction in thermally induced errors.

The common-mode input range of an enhanced instrumentation amplifier is equal to that of most integrated-circuit instrumentation amplifiers. Because an enhanced instrumentation amplifier uses a gain-of-10 difference amplifier rather than a unity-gain difference amplifier, input amplifiers don't limit a difference amplifier's common-mode range. The common-mode input range of both an enhanced instrumentation amplifier and a standard instrumentation amplifier is ±7V. With a 10V output, the common-mode input of a standard instrumentation amplifier is only ±7V, not ±10V as is commonly believed.

An input amplifier's output swing limits the common-mode swing of a standard instrumentation amplifier. The output swing of subregulator amplifiers limits the common-mode range of an enhanced instrumentation amplifier.

Standard instrumentation amplifiers use unity-gain difference amplifiers for practical reasons. Since standard instrumentation amplifiers are general-purpose devices, they must be adjustable to unity gain. Because maintaining the resistor ratio necessary for good difference-amplifier CMR is difficult, standard instrumentation amplifiers usually contain a fixed unity-gain difference amplifier. Gain adjustment is made with the input amplifiers, where matching is not critical for good CMR. Also, the more gain placed ahead of the difference amplifier, the better the instrumentation amplifier's CMR.

To investigate the limits on the instrumentation amps' input common-mode range, assume the op amps' inputs can all swing to within 3V of their power-supply rails (±12V when operating on ±15V power supplies). In a standard instrumentation amplifier with a unity-gain difference amplifier, the input amplifiers must provide a differential 10V output to produce a 10V difference amplifier output. If the input amplifiers have equal gains, each must deliver one-half of the 10V differential signal. With a common-mode input of 7V, an input amplifier must deliver 7V common mode plus 5V differential mode in order to bring it up to its 12V-swing limit.

The enhanced instrumentation amplifier also has a ±7V common-mode input limit. Its subregulators are set at ±5V from the input common-mode signal. With a 7V common-mode input, a subregulator's output will be at its 12V-swing limit.

In an enhanced instrumentation amplifier using a gain-of-10 difference amplifier, the buffer amplifiers must provide a differential output of only 1V to produce a 10V instrumentation-amplifier output. If the input amplifiers have equal gains, each must deliver one-half of the 1V differential signal. With a common-mode input of 7V, one input amplifier must deliver 7V common mode plus 0.5V differential for a total output of 7.5V. Obviously, producing the 7.5V is no problem since the $V_{\text{in}}$ is 12V (5V subregulated plus 7V common mode).

Fig 4 offers a performance comparison between a standard instrumentation amplifier and an enhanced-instrumentation amplifier. In Fig 2, IC$_1$ and IC$_2$ are OPA177 amplifiers; IC$_3$ is an INA106 gain-of-10 difference amplifier; and IC$_4$ to IC$_7$ is an OPA404 quad op amp in the enhanced circuit. This instrumentation amplifier's overall gain is set at 1000V/V. The OPA177 is an improved version of the industry-standard OP-07. It offers 10-µV max $V_{\text{os}}$ and 0.1-µV/°C max $V_{\text{os}}$/dT. The OPA404 provides high speed and low bias current.

The FET inputs of the OPA404 don't add loading at the inputs of the instrumentation amplifier. Their speed is higher than the OPA177's, yielding an improvement in CMR vs frequency. An HP4194A gain-phase analyzer with an input signal to the instrumentation amplifier of 9 dBm made the CMR plots. The

![Fig 4](image-url)
An input amplifier’s output swing limits the common-mode swing of a standard instrumentation amplifier.

Enhanced plot shows a dramatic CMR vs frequency boost. At 2 kHz, for example, the CMR of the standard instrumentation amplifier is about 80 dB. At 2 kHz, the CMR of the enhanced instrumentation amplifier is more than 120 dB—an improvement of more than two orders of magnitude.

The scope photos of Fig 5 show similar instrumentation amplifiers using LTC1050 chopper-stabilized op amps for IC₁ and IC₂. When V₀sdT is critical, chopper-stabilized op amps may be the best choice because they offer 5-µV maximum V₀sd over temperature. With a ±2.5V, 2-kHz input signal, chopper noise limits CMR to about 56 dB. The enhanced circuit improves the usable CMR to about 82 dB with the common-mode input shown in Fig 5b.

A difference amplifier will limit CMR performance in enhanced instrumentation amplifiers. The more gain you add ahead of a difference amplifier, the better the potential for improvement. For example, with a gain of 100V/V ahead of the difference amplifier, an improvement in CMR of as much as 40 dB is possible. The actual performance boost depends on impedance matching and parasitics in the devices you select.

How fast are your amplifiers?

Of course, the way CMR varies with frequency depends on the dynamic performance of all the amplifiers in the circuit. Improvement in dynamic CMR will be most dramatic when the speed of the amplifiers IC₁ to IC₇ is much higher than the speed of IC₁ and IC₂.

You can easily implement high-voltage instrumentation amplifiers using the enhanced instrumentation-amplifier configuration. Use standard-precision signal-level op amps for the input amplifiers and less critical op amps for the high-voltage chores. For example, use OPA445 op amps for IC₆, IC₇, and IC₃ (the difference amplifier). To boost the voltage rating of the current sources in the subregulated supplies, place two REF200 current-source sections in series. If you use 1% resistors for difference resistors R₁ to R₄, you may need a potentiometer to adjust CMR. The resulting instrumentation amplifier will provide outstanding performance on power supplies up to ±45V.

Author’s biography

R Mark Stitt received his BSME from the University of Arizona and joined Burr-Brown Corp (Tucson, AZ) in 1969. He has been an analog design manager since 1980, working on instrumentation amplifiers, operational amplifiers, and voltage references. Mark has 14 US and numerous foreign patents.

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Understanding the complexity of tasking in real time

In constructing a requirements model, you should strive to make it independent of the specific methods that might be employed to achieve the requirements. Once you come to design an implementation model, however, you want to reveal the methods so that they can be analyzed and ultimately coded. The remainder of this series of articles is concerned with implementation. This part of the series is devoted to the central issue of the implementation model: tasking.

David L Ripps, Industrial Programming Inc

Tasking is the distribution of the functional requirements (as contained in the requirements model) among concurrently executing programs (the tasks). The problem of tasking in real-time work is akin to structural organization (distribution of functions to subprograms) in traditional programming. Many of the same concerns and principles apply in both cases. Nevertheless, real-time tasks run concurrently and can be started, suspended, and terminated individually. This imposes even stronger design restraints than would be necessary for a singly threaded traditional program.

In real-time work, the problem of tasking is more than just the assignment of the application’s functions to various concurrent tasks. You also have to select the method by which the task will be activated and receive its inputs, as well as the function the task will perform once it is active.

Despite the importance of proper tasking, there are only a few general rules that can be set down to guide the newcomer. Fig 1 gives eight rules. (This list is an expanded version of a six-rule set [Ref 1].) The rules are almost too obvious to be called basic principles. But any more specific rules would have to be hopelessly complex, if they could be expressed at all.

Use tasking to aid development and maintenance

The first rule warns the designer not to complicate a task by including several separate and functionally independent components. The memory overhead for each task is the size of an internal task-control block (about 300 to 400 bytes for MTOS-UX) plus the size of the task stack. While this overhead is significantly more than that for just another subprogram, the designer should not be afraid to create a separate task if it clarifies the overall logic of the application.

Separating main functions into different tasks is especially important because changes in specifications inevitably become necessary. Ideally, the alterations generated by a single change in the functional specifications should not extend beyond a single task.

By the same reasoning, it is preferable that closely related functions and functions that deal with the same inputs, data, or outputs be kept in the same task. Closely related functions are those that have operations that must be logically consistent; that is, a change in one is likely to lead to a change in the other.

Unfortunately, in embedded, real-time applications, all functions are somewhat intertwined since they share interrelated goals and common data. Judgment with respect to the particular application dictates what are distinct main functions (that should be in separate tasks) and what are closely related aspects of the same function (that should be in a single task). This category of rules is amply covered...
in numerous books on principles of good structured programming (Refs 2, 3, 4, and 5).

Take advantage of concurrency

The next rule is unique to real-time work. Most often a task will specify that the operating system is to block the task until a requested service is completed. (If a task needs input from a peripheral it usually cannot proceed until the input is available.) Thus, if we have Task TkAB designed as shown in Fig 2, the processor cannot even begin to get input B until it has finished with A. There is no problem if another task can keep the processor busy until A comes in. But if there is no such task work to do, the processor must be idle. In that case, if the processing of B does not depend upon A, a more productive organization would be that depicted in Fig 3. Now you are utilizing the benefits of task concurrency.

Respect differences in functional attributes

The final category of rules provides the strongest constraints on tasking within a real-time application.

Every major function has three attributes that determine how it is to be implemented in terms of tasks. These are its method of activation, its level of urgency, and its time scale. The rules state that functions which do not have the same attributes should not be housed in the same task.

As a simple example, suppose that there were just one task for all emergency processing in a certain application. Suppose further that this task had already been started by a safety violation when a power failure occurs. Since the task is busy, it cannot be restarted immediately to respond to the power failure, even though power failure has the highest level of urgency. Unless you complicate the processing of safety violations by frequent checks for power failure, the system may shut down before the power failure interrupt is ever serviced.

To better appreciate these rules, you must understand the four basic ways in which a task can become active. The first could be called periodic self-activation. A task PdSA is started initially. (The details of the initial start are not relevant.) PdSA performs its part of the application. When that function is complete, it issues an OS service call to terminate it with restart after a given interval (say, 15 msec) based on its last start time. Thus, PdSA takes the form of Fig 4.

MTOS-UX computes the time at which the task should be restarted as the sum of the last start time plus the given interval. If it is already at or past the restart time, the task begins immediately. Otherwise, the task is suspended until the computed time arrives. In either case, the task restarts back at its entry point, ready to begin a new cycle.

A. Obey the rules of structured design to help make the application easy to design, implement, test, and maintain:
1. Each main (functionally distinct) activity should be assigned to at least one separate task.
2. Closely related functions should be kept in the same task. “Closely related” means that they perform operations that must be logically consistent; that is, a change in one is likely to engender a change in the other. However, in cases where it is desired to perform the same function but other considerations dictate separate tasks, the desired consistency can be achieved by using common subprograms or even common task code.
3. It is preferable that functions that deal with the same inputs, data, or outputs be kept in the same task.

B. Try to keep the processor (or processors) always busy with productive work:
4. Try to isolate as a separate task any subfunctions that frequently encounter significant delays such as wait for peripheral I/O to be completed, pause to allow mechanical or electrical events to occur, and wait for information produced within another functional component.

C. Functions that have different attributes must be assigned to different tasks:
5. Functions that are initiated or coordinated by different means must be assigned to separate tasks.
6. It is preferable that functions that are initiated or coordinated by the same means must be assigned to the same task.
7. Functions that have significantly different levels of urgency must be assigned to separate tasks.
8. Functions that proceed at different time scales must be assigned to separate tasks.

Fig 1—Rules for real-time tasking serve as a general guideline. More specific rules would be hopelessly complex.
PdSA is a periodically active task, with 15 msec as its period. (Assume that PdSA runs at sufficiently high priority to complete its execution within the given interval.) It is self-activated; its own request to terminate carries with it the order for its next restart. Because PdSA starts itself, it does not receive any information when it begins. As you will see shortly, a task that is started at the request of another task may receive parameters, in a way analogous to a simple subprogram call.

An input scanning task (INPS) is usually periodic. Typically, it runs with a short interval (5 to 20 msec) and very high priority (200 to 250). It scans external inputs that are mapped into memory bits or are read from hardware ports. When it finds a change, INPS reports the change to other tasks by means to be described shortly. This arrangement allows INPS to complete the scan cycle quickly, leaving it to the other tasks to process the changes more slowly and with lower priority.

Another use for periodic tasks is for summary reporting. Now, a typical period is 1 hour to 1 day, and the priority is often rather low. (Commonly, all you need is sufficient priority to complete the processing before the time for the next cycle.) Such a task would produce a summary report and output it to a printer or to another computer. Input for such tasks is usually already in memory or is obtained from records left on a disk.

The scanning and reporting functions would have to be in separate tasks: by Rule 7 because they have different priorities and by Rule 8 because they have different time scales. If there were two different summaries produced, one output every 30 minutes and the other every hour, the designer would have a choice. On the one hand, two tasks may be the simpler and clearer arrangement (Rule 1). Furthermore, if there is appreciable peripheral input or output, Rule 4 would also favor two tasks so that one could proceed while the other waits for I/O. On the other hand, if both reports use similar data or similar algorithms, Rule 2 implies that both be produced in one 30-minute task, with a counter to skip alternate periods for the hour report.

The description of the scanning task mentioned that it passes change-of-input information on to other tasks. One possibility is for INPS to have the OS start that other task. The MTOS-UX start service is the second method of task activation. It permits the requesting

![Fig 2](image-url) - Parallel processing of real-time inputs improves on Fig 2's serial approach. In this example, in which the processing of B doesn't depend on A, the processor can get B without waiting for A.

![Fig 3](image-url) - Parallel processing of real-time inputs improves on Fig 2's serial approach. In this example, in which the processing of B doesn't depend on A, the processor can get B without waiting for A.

![Fig 4](image-url) - Periodic self-activation is one way a task can become active. When the task completes its function, it issues a call to the operating system to terminate itself and to restart itself after a given interval, in this case 15 msec.

EDN October 25, 1990
task to select a particular task to start (the “target,” TskT), to pass parameters to TskT, to set the priority at which TskT begins to run, and to queue the start request automatically if TskT happens to be still running, among other options.

In embedded, real-time applications, all functions are somewhat intertwined.

It is quite common for fast, high-priority input-capture or preprocessing tasks to start other tasks that complete the processing at lower priority. Task INPS would normally select the target and its priority based on the type of input (Fig 5). For the start request to be honored immediately, the target task must be currently Dormant. Otherwise, the request is queued internally to be completed when the target terminates without timed restart; that is, *via exit*.

With start, activation involves the full restart of the target from its entry point. There is an alternate class of activations that do considerably less. To employ this class, TskT must be organized as a cyclic task, but not a periodic one (Fig 6). In this form, TskT never terminates. Instead, after a possibly empty initialization section, it enters an endless loop. It waits for input, using any of several mechanisms such as wait for any length message at a mailbox, wait for a 4-byte or 6-byte message at a message buffer, or wait for 1 to 16 bits of coordination data at an event-flag group. (Which mechanism to use is the subject of several subsequent parts of this series. At this point, our interest is only in the tasking, which transcends the details of the wait facility. To be concrete, we will employ a message buffer.)

If TskT reaches the wait before the message, the OS blocks it until the message arrives. If the message gets there first, it is queued awaiting the task. If need be, the message queue can be very long. Fig 7 gives the corresponding form for INPS. In the alternate formulation, activation means start the next cycle rather than start the whole task. That is a minor detail.

Of the two task couplings, message activation is faster than full start. Thus, for a scan-type task, the message is preferable.

There are also many cases in which start is the method of choice. Scan is special; it starts other tasks, but does not wait to coordinate with them. Suppose, however, that an application function is being processed by a certain task (TskO). At some point, the work is to be continued by one or more other tasks, say, for reasons of structural clarity (Rule 1) or improved CPU utilization (Rule 4). Often, TskO must know when these concurrent sections are completed. As Part 5 will show, start has the option of coordinating with the termination of the target task. Furthermore, it is easy to have TskO start several tasks, continue on, and later request that it be blocked until all those tasks have finished. It is not so easy to arrange this with messages alone. Thus, when coordination with the end of a subfunction is needed, start can have advantages over other tasking arrangements.

This discussion has still not exhausted the methods of activating a task available under MTOS-UX. This operating system contains a set of internal programs, known as drivers, that perform peripheral I/O. They service task-level requests for peripheral I/O. Drivers can also handle unsolicited input, such as text that is typed at a console without a corresponding read request having been given.

A common response to unrequested input is to activate a task to process it. Debuggers and command-line interpreters are often started in this way. Normally, the driver selects which task to start (if any) based on the first character of the unrequested text.

A simple tasking example

You can illustrate the rudiments of task design by working out the tasking for the shared-bridge control system discussed in Part 3 of this series.

Assume that the four car-present sensors are

---

**Fig 5**—This typical input-scanning task is periodic. It runs every 15 msec, and it starts another task to process any change-of-input information.
mapped into a 4-bit register. On some computers the register value would be input by reading a "port"; on other computers the same value would be obtained by reading a certain location in memory. In each case, a bit value of 1 means that a car is over the sensor, while a 0 means that no car is present. You also know that typically when a car passes over a sensor, the bit is on for 100 to 300 msec. However, the beginning and end of the on period is somewhat ragged so that smoothing is needed to prevent counting a noise spike as a car.

A good way to handle noisy data input is to have a cyclic scanning task that reads the status bit for each sensor, performs data smoothing, and presents the other tasks with a consistent view of the sensor inputs. Note that the input scanning function is assigned to a separate task since it is the only function that deals directly with the raw sensor inputs (Rule 3). It is also the only function that must act periodically (Rule 6). However, the sampling time scale for each sensor is the same, and it is preferable to synchronize all changes of sensor data. Applying Rules 2, 3, and 6, there will be only one scanning task ("SCAN") that runs, say, every 20 msec.

You now have to decide whether there will be one or two tasks to perform the main control functions. On the one hand, if you consider control of the left-bound and right-bound traffic as closely related functions, they should be kept in the same task (Rule 2). On the other hand, if you consider the control of each side as functionally distinct activities, by Rule 1 they should be in separate tasks. The requirements model strongly suggests separating each direction; this example will follow that suggestion. Consequently, tasks C_LB and C_RB will control left-bound and right-bound traffic, respectively. You can make sure that the two control algorithms are kept consistent by calling common subprograms from the two separate tasks.

The two control tasks will compete for the right to send cars over the bridge. The competition will involve gaining exclusive access to the bridge, as represented by the semaphore ACCS. While either task is waiting for the semaphore, it cannot be restarted to maintain its corresponding Cars tally. However, you can easily assign maintenance of the Cars tallies to task SCAN.

The value of the Cars tallies will change asynchronously with respect to any actions that tasks C_LB and C_RB may be taking. Hence, the control tasks must be careful how they use the information within the tally for its direction. Fortunately, what a control task is really interested in is not the value of the tally per se, but in the binary information: Is the tally zero or nonzero? For example, C_RB must become active when LB_Cars becomes nonzero (that is, when the first left-bound car approaches the bridge). Later, C_LB needs to wait until LB_Cars becomes zero again.

![Fig 6: A cyclic task never terminates. In this example, it simply waits for input—in this case a message in a buffer—from another task. Use of this cyclic task contrasts with the approach taken in Fig 5, in which an input-processing task gets restarted with each new input.](image)

![Fig 7: This message-based formulation of an input task passes a message regarding changed inputs to the processing task of Fig 6.](image)

![Fig 8: Tasking and coordination are at the heart of controller applications. This example shows tasks that control left-bound and right-bound traffic on a 1-lane bridge. Event-flag group 'STAT' keeps a tally of cars. Semaphore 'ACCS'—which only one task at a time can "own"—grants task access to the bridge.](image)
(signifying that the last left-bound car has cleared the bridge). As a result, you can hide the actual tallies within task SCAN and employ only the binary zero/nonzero information for coordination.

MTOS provides an easy mechanism to have a task wait until a binary bit is set: the event-flag group. You can create an event-flag group (STAT) within which you assign two bits for each direction. SCAN sets one bit when the corresponding tally is zero and the other when the tally is nonzero. (The event-flag wait function only waits until flags are set; there is no wait until reset. This restriction is easily overcome with dual bits.)

Fig 8 pictures the overall tasking and coordination mechanisms for the shared-bridge control application. Fig 9 shows a more detailed implementation model for the LB control task. (The corresponding RB task would use bits 2 and 3 of STAT.) The implementation model for the SCAN task is outlined in Fig 10. To complete the tasking, there would normally be an initialization task (INIT) whose only function is to create all the support objects for the application (ACCS, STAT, C_LB, and C_RB), start the other tasks, and then terminate itself (Fig 11).

More tasking examples

Available literature on the subject of tasking has not been generous in supplying examples of the steps that lead to a design model for real-time applications. An exception is a detailed description of the design of a robot controller presented by H Gomma (Ref 6). In this example, Gomma employs his "Design Approach for Real-Time Systems" (DARTS).

DARTS starts with a requirements model formu-

A common response to unrequested input is to activate a task to process it.

---

**Fig 9**—This implementation model shows details of a task that controls left-bound traffic on a 1-lane bridge. The details are hidden in Fig 8, which shows only overall tasking and coordination.

**Fig 10**—Details of the scanning task that appears only as a block in Fig 8, are shown in this implementation model.
lated as a data-flow diagram. The diagram shows data stores (repositories) connected through transformations that carry out the functions of the system. The transformations must be analyzed to determine which of them may run concurrently and which must be run sequentially. Gomma gives six rules to help guide the analysis. Gomma's rules are not identical to those given in Fig 1. Nevertheless, they seem to arise from similar experiences and are generally alternate statements of equivalent concepts.

In summary, tasking includes both the distribution of the functions specified in the requirements model among concurrent programs (tasks) and the selection of the coordination mechanisms among the tasks. Tasking is the central issue in the design of a real-time application.

There are eight heuristic rules that can guide the functional distribution (Fig 1). These rules have been employed to outline a design model for the shared-bridge example from Part 3 of this series. A pictorial representation of the resulting design hides the details of the required OS services until they can be described in subsequent parts.

This part of the series has introduced some of the factors that a designer must consider in planning the tasking of a real-time application. A full appreciation of the options available requires much more knowledge of the facilities provided by the OS. The remainder of the series is concerned with these issues.

References

Article Interest Quotient (Circle One)
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Companion disk offer
All of the C examples in this series, plus applications of your own, can be run on a PC with a set of demonstration disks available from Industrial Programming Inc. The disks contain a full version of MTOS-UX for an IBM PC/AT or compatible. An application program is edited, compiled, linked, and loaded under MS-DOS. The MTOS-UX then takes over the hardware to execute the program in real time. At any time, you can enter an alt/dlt command from the console to return control to MS-DOS.

The demonstrator requires an AT with at least 512k bytes of RAM and a hard disk with 2M bytes available for MTOS libraries and scratch storage. Program preparation requires the Microsoft C compiler/linker, version 5.0 or later. Microsoft tools are not included with the MTOS-UX demonstrator.

The demonstrator version has all of the features and facilities of standard MTOS-UX. However, there is a limit of six of each type (six tasks, six mailboxes, six semaphores, and so forth). The disk set costs $25; unlimited versions are also available. For more details, call the IPI sales department at (800) 365-6867.

Fig 11—The initialization task creates all the elements of Fig 8's overall tasking and coordination and then terminates itself.
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<table>
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<tr>
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<th>SUN SPARCstation 1+</th>
<th>IBM 320/520</th>
<th>DECstation 5000 cx</th>
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(1) All data normalized to DECstation 3100. Comparable configurations tested. Geometric mean used to combine results. Performance will vary depending on applications and environment. (2) Graphics and windowing data measured using X11 perf benchmark. CPU Integer and Floating Point performance measured from running SPEC V1.0 workload. (3) SPEC performance estimate based on SUN 4/330 results published by Sun Microsystems, Inc.

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Commutating amp multiplies precisely

Moshe Gerstenhaber and Frank J Ciarlone
Analog Devices, Wilmington, MA

By using a pulse-width-height modulation technique, the circuit in Fig 1 implements a 0.015%-accurate multiplier. The circuit’s output equals \( V_x V_y / 10 \). An AD581 voltage reference, an AD630 commutating amplifier, and an integrator comprising an AD707 op amp, 2000-pF capacitor, and 150-kΩ resistor first generate a precision triangle wave. For a given state of the AD630’s output—\(+V_{\text{REF}}\) at TP1, for example—the integrator ramps until its output reaches \(-11\) V. Then, TP1 changes state and the integrator begins ramping toward \(+11\) V. The triangle wave’s period is \(4.4RC\) or \(1.32\) msec, where \(R\) and \(C\) are the values of the integrator components.

The circuit uses a second AD630 driven by the variable \(V_x\) to compare the triangle waveform at TP2 to the signal at \(V_y\). The duty cycle, \(T_1 + T_2\), at the output of this second commutating amplifier is as follows:

\[
T_1 = \frac{2RC(11 - V_y)}{10}, \quad \text{and} \quad T_2 = \frac{2RC(11 + V_y)}{10}.
\]

During \(T_1\), the voltage at TP4 equals \(-1.1V_x\). During the remaining period, \(T_2\), the pulse height will equal \(+1.1V_x\). \(V_{\text{OUT}}\) is the average, obtained by lowpass filtering, of this \(T_1\) and \(T_2\) combined waveform and equals

\[
V_{\text{OUT}} = \frac{-1.1V_x T_1 + 1.1V_x T_2}{T_1 + T_2} = \frac{V_x V_y}{10}.
\]

You can use a higher bandwidth filter and a higher carrier frequency to build a faster multiplier.

(EDN BBS /DL_SIG #900)

To Vote For This Design, Circle No. 746
RAM test program prevents crashes

Christopher M. Petersen  
Applied Biometrics Inc, Eden Prairie, MN

Most embedded systems must perform power-on self tests to ensure their integrity. Testing the RAM is a significant part of this procedure. One major difficulty with the RAM test is that the same RAM under test is used simultaneously by the system. A crash can occur if the program or stack tries to use a location that is currently under test. Writing a C program to adequately test RAM while not using the stack or any memory for variable storage is virtually impossible.

A solution is to use a routine (Listing 1) that doesn’t use the stack, holds all working variables in registers, and restores the RAM to its original state after the test. You can call the 8088 assembly language program from C to test a 64k block of RAM located anywhere in memory. You must shut off all interrupts before beginning the test. Listing 1’s programming concept is also valid for use with any high-level language using a CPU that has a number of general-purpose registers.

To Vote For This Design, Circle No. 747

Listing 1—RAM Test Program

```
.MODEL SMALL
.CODE

; The following procedure performs a test of memory.
; Calling format from C is:
; int ramtest(unsigned int segment, unsigned int offset_start,
;  unsigned int offset_stop);
; Return codes: 0-no error, 1-error occurred
; Notes:
; o The first memory location is used to detect addressing problems.
; o The last memory location tested is offset_stop - 1.
; o This routine is limited to testing one 64k segment at a time. Use multiple calls to test larger memory arrays.
; o All interrupts must be turned off before running this procedure.
; o offset_stop - offset_start must be greater than 1.
;
; Register usage:
; ds Segment of memory to be tested
; bx Current location of test
; dx Ending location of test
; ax Used to move and compare data
; ch Save data under test for later restoration
; cl Save first byte (used for detection of addressing errors)
; di Starting location of test
; bp Pointer to stack
;
PUBLIC _ramtest

_ramtest PROC
push di ; Program begins here
push bp
push cx
push ds
push dx
mov bp,sp
mov ax,[bp+12]
mov ds,ax
POP BP
```

(Ed Note: To download Listing 1 directly, use the EDN Bulletin Board System.)
Listing 1—RAM Test Program (continued)

```assembly
; Get starting offset
mov ax,[bp+14]
mov bx,ax ; Save in bx
mov ax,[bp+16] ; Get ending offset
mov dx,ax ; Save in dx

; Test begins here
mov cl,ds:bx ; Save first memory location
mov al,5ah ; Use 0x5a in 1st loc. to id
; addressing problems
mov ds:bx,al ; Save in first location
mov di,bx ; Remember location
inc bx ; Bump to first location to test

ramloop: mov ch,ds:bx ; Save data at byte to be tested
    mov al,55h ; Test pattern is 0x55
    mov ds:bx,al Write out to test location
    cmp ds:bx,al Same?
    jne ramerror No, report error and exit
    mov al,0aah ; Test pattern is now 0xaa
    mov ds:bx,al ; Write
    cmp ds:bx,al Same?
    jne ramerror

; Now perform a "walking ones" test on this location
    mov ah,1 ; Start at d0 = 1
walking.ones: mov ds:bx,ah ; Write test pattern
    cmp ds:bx,ah Same?
    jne ramerror ; No, report error and exit
    cmp ah,80h ; Done?
    je test done
    rol ah,1 ; Rotate one to next position
    jmp walking.ones ; Loop to continue with test

; Test successfully completed at byte
    test.done: mov ds:bx,ch ; Restore original data byte
    inc bx ; Bump pointer to next test byte
    cmp bx,dx ; Is this the last location?
    jne ramloop ; No, test this byte

; Main test is completed, now go back and verify that the first byte was
; not changed. A changed byte would indicate addressing problems
    cmp BYTE PTR ds:di,5ah ; Has byte changed?
    jne ramerror1 ; Yes, report error

; Test is finished - no problems
    sub ax,ax ; Return code of 0 in ax
    jmp exit.test ; Restore registers

ramerror: mov ds:bx,ch ; Error - Restore test data byte
ramerror1: mov ax,1 ; Set return code to 1
exit.test: mov ds:di,cl ; Restore 1st byte
    pop dx ; Restore registers
    pop ds
    pop cx
    pop bp
    pop di
    ret ; Return with status

ENDP ; End of procedure
```
Three ICs produce pure sine waves

Bruce Saldinger
Maxim Integrated Products, Sunnyvale, CA

A TTL counter, an 8-channel analog multiplexer, and a fourth-order lowpass filter can generate 1- to 25-kHz sine waves with a THD better than -80 dB (Fig 1). The circuit cascades the two second-order, continuous-time Sallen-Key filters within IC₃ to implement the fourth-order lowpass filter. Two resistive dividers connected from ground to V_DD and ground to V_SS provide bipolar dc inputs to the multiplexer.

To operate the circuit, you first must choose the filter’s cutoff frequency, f_c, by tying IC₃’s D₀ through D₆ inputs to 5V or ground. The cutoff frequency can be at 128 possible levels between 1 and 25 kHz depending on those seven digital input levels. Because Fig 1 ties D₀ through D₆ to ground, f_c equals 1 kHz. The 100-kHz potentiometer adjusts the output level anywhere from 1.5V below V_DD to 1.5V above V_SS.

The clock input frequency must be eight times higher than the filter’s f_c. The multiplexer then produces an eight-times oversampled staircase approximation of a sine wave. Eight-times oversampling greatly simplifies the smoothing requirements of the lowpass filter by pushing the first significant harmonic out to seven times the fundamental. All higher-order harmonics are removed by IC₃, which includes an uncommitted amplifier for setting the output level.

Fig 2’s scope photo illustrates the effect of filtering

Fig 1—The output of Fig 1’s multiplexer (trace A) emerges from the lowpass, continuous-time filter as a clean sine wave (trace B).

Fig 2—This circuit produces a pure, -80-dB THD sine wave with a frequency equal to the f_c of IC₃'s filter.
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SPECIFICATIONS

<table>
<thead>
<tr>
<th>YSW-2-50DR</th>
<th>dc-500MHz</th>
<th>500-2000MHz</th>
<th>2000-5000MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertion loss, typ (dB)</td>
<td>0.9</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Isolation, typ (dB)*</td>
<td>50</td>
<td>40</td>
<td>28</td>
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<tr>
<td>1dB compression, typ (dBm @ in port)</td>
<td>20</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>RF input, max dBm (no damage)</td>
<td>22</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>VSWR (on), typ</td>
<td>1.4</td>
<td></td>
<td></td>
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<tr>
<td>Video breakthrough to RF, typ (mV P-P)</td>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>Rise/Fall time, typ (nsec)</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*typ isolation at 5MHz is 80dB and decreases 5dB/octave from 5-1000 MHz

incredible!
a 1-kHz output from the multiplexer. The frequency domain offers another view of the filter's operation. Smaller harmonics in the multiplexer's output spectrum (Fig 3a) caused by inaccuracies in the voltage dividers are insignificant with respect to the larger-amplitude harmonics associated with the staircase approximation. In the filtered output (Fig 3b), all harmonics are lost in the noise floor of the spectrum analyzer. (EDN BBS /DL_SIG #898)

To Vote For This Design, Circle No. 748

Fig 3—The circuit's approximation process generates large harmonics in the multiplexer's output spectrum (a), which the filter attenuates to below the spectrum analyzer's noise floor (b).
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Models exhibit saturation and hysteresis

Donald B Herbert
Consultant, Lomita, CA

Many commercial versions of Spice2 include nonlinear transformer models, but Berkeley Spice has no such provision. You can build nonlinear-transformer models for use with Berkeley Spice using other built-in elements. Fig 1 and Fig 2 model 2- and 3-winding transformers that feature both saturation and hysteresis. Each of these transformers uses a basic core model (Fig 3). You must supply the models with four parameters: turns ratio, core-loss conductance, magnetizing inductance, and saturation current. All four parameter values are programmed external to the transformer model in the polynomial-controlled-sources feature in Spice2.

Fig 1 and Fig 2 show common equivalent circuits and their accompanying Spice2 listings for 2- and 3-winding ideal linear transformers, respectively. The secondary voltages developed by the E voltage-controlled voltage sources are related to the primary voltages by the product of the turns ratio. Likewise, the primary currents developed by the F current-controlled current sources are related to the secondary by the product of the turns ratio. You specify your particular turns ratio with an externally applied voltage which is typically constant.

These Spice models implement the voltage-controlled turns ratio by using product terms in the polynomial expressions for the controlled E and F sources. For example, the 2-dimensional polynomial P4 controls source ES in the secondary of the 2-winding transformer model. ES is a function of two voltage variables. The model defines the P4 coefficient term as the only nonzero term in the polynomial expression. This term forms the product V(5)·V(1,2). The node voltage V(5)
Actual size

Actual output

20 WATTS

Actually meets

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MIL-S-901C
MIL-STD-461C
MIL-STD-704D
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is the turns ratio by definition and V(1,2) is the voltage across the primary. **Fig 1**'s listing sets P4 to unity.

Similarly, the current in the primary’s current-controlled current source, FP, is the product 1MEG·I(VSENS)·I(VS) where P4 is 1MEG. The independent sources, VS and VSENS, sense current and consequently have voltage values of zero. Because the current in VSENS is V(5)/1MEG, the current product is equal to V(5)·I(VS), which is the product of the turns-ratio voltage times the secondary current. In **Fig 2**'s 3-winding model, FP forms the sum of the two turns-ratio secondary-current products by the use of a 3-dimensional polynomial function.

Both **Fig 1** and **Fig 2** use a subcircuit model for a saturating core with hysteresis. **Fig 3**'s core model uses an integrator comprising G6 in parallel with C6 to develop an equivalent magnetizing inductance (LM) equal to C6·RL/V(3). The model defines the C6·RL product as unity. Therefore, LM=1/V(3). V(3) is an externally applied dc voltage. Current-controlled current source FLM implements the magnetizing current I(VLM) in the transformer primary winding. V(6) is the integral of the primary voltage that develops across the magnetizing inductance, and V(6)/RL is the magnetizing current.

The diode-limiter circuit models the core's saturation. The core saturates when V(6) is less than -1000·V(5) or greater than 1000·V(5). V(5) is an externally applied voltage equal to the specified or measured core saturation current in milliamperes. When

---

**Fig 2**—The Spice2 model and listing of this 3-winding transformer and the model in **Fig 1** use 2-dimensional polynomials to implement the voltage-controlled turns ratio.
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the core saturates, the magnetizing inductance reduces to approximately LM/1000. The transconductance source GCLOSS models the core-loss conductance. This source’s current \( I(GCLOSS) \) equals \( V(1,2) \cdot V(4) \). Because the voltage at nodes 1 and 2 is the same, GCLOSS equals \( V(4) \), also an externally dc voltage. Core-loss conductance determines the hysteresis of the core, and is typically a function of the frequency of operation.

The primary function of the three 1000-MΩ resistors R3, R6, and R45 is to satisfy Spice’s requirement for a minimum of two elements connected to each node and a dc path to ground for every node. The parallel combination of R6 and C6 forms a first-order lag circuit with a corner at 1 mrad/s. However, the parallel combination of G6, C6, and R6 looks like an integrator at frequencies of 10 MHz and higher. Because of R6’s high value, it has minimal effect on the response of the integrator and provides for good dc and transient solution convergence.

An example of the use of these model is a full-wave rectifier circuit (Fig 4). (EDN BBS/DI_SIG #901)

**To Vote For This Design, Circle No. 749**

---

**Fig 3**—This saturating-core equivalent circuit (a) and model (b) include components that simulate core-loss conductance, magnetizing inductance, and current saturation using externally supplied dc voltages.
**DESIGN IDEAS**

![Diagram](image)

**FULL-WAVE RECTIFIER CIRCUIT EXAMPLE**

* SINUSOIDAL INPUT WITH AN AMPLITUDE OF 100 VOLTS-PEAK AT 20KHz

VIN 1 0 SIN (0 100 20K 0 0)

RS 1 7 1600

D1 8 2 DD

D2 9 2 DD

RL 2 0 10K

XFORMER 7 0 8 0 0 9 3 4 5 6 XFMR3

* SET TURNS-RATIO=0.25

VRATIO 3 0 DC 0.25

* SET RECIPROCAL MAGNETIZING INDUCTANCE TO 40 (LM=0.025H)

VLM 4 0 40

* SET CORE-LOSS CONDUCTANCE TO 0.2MMHOS

VGL 5 0 2M

* SET CORE SATURATION CURRENT TO 20MA

VSAT 6 0 20

.MODEL DD D

.TRAN 0.5US 100US 0.0 0.5US

.PRINT TR V(8) V(9) V(7) V(2)

(b) * INCLUDE CORE AND THREE-WINDING TRANSFORMER MODELS HERE

---

**PROM state machine adds outputs and states**

James C. Vandiver  
*Vandiver Electronics, Huntsville, AL*

The familiar PROM state machine in Fig 1, although inexpensive and easy to reprogram during development, has its restrictions. The circuit has only 8 bits to distribute between both outputs and state feedback lines. Generation of the data table for programming this circuit can also be tricky because output and next-state data must be contained in the same bytes.

By adding another latch and a flip-flop, Fig 2's circuit makes better use of the PROM address space by using both phases of the clock. This 2-phase state machine has eight outputs and allows for 256 possible states. Note that the size of the PROM limits the number of state transitions allowed in the table. Programming Fig 2's circuit is also easier because of the separation of the state and output data into odd and even bytes. The flip-flop generates a 2-phase clock for alternately latching state and output bytes. The circuit stores these state and output bytes in odd and even addresses, respectively. The flip-flop's Q output controls the least-significant address bit, S0, to select either state or output data for latching. Address bits S1

EDN October 25, 1990
DESIGN IDEAS

through $S_8$ are used for state feedback, and the higher address bits are used for inputs. As the input bits change, the machine addresses different parts of its state transition table, changing state and outputs as programmed with each 2-phase clock cycle. The input bits are synchronized with the state-latch clock so that the PROM address lines are stable while the circuit accesses a new state or output byte.

Many variations of this circuit are possible. You can expand the number of outputs by generating a 4-phase clock and adding two more latches. Or you can replace the PROM with an appropriately controlled and buffered RAM or EEPROM to provide for quicker changes to the state-transition and output tables. Almost any assembler can generate the state and output tables for this state machine if you first use the “define byte” or “define word” assembler directives and type the table in with an editor. The assembler can then use this text file to generate a hex or binary file for loading into the state machine PROM. The most important point to remember when setting up the state table is to fill unused bytes with the default values you need to allow proper start-up of the machine.

(EDN BBS /DL_SIG #899)

To Vote For This Design, Circle No. 750

Fig 1—This simple state machine is limited to 8 bits for both output and state-feedback lines.

Fig 2—By adding a latch and a flip flop, this 2-phase state machine uses both clock edges to make better use of the PROM address space.
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Simple supply powers large LCDs

Don Sherman
Maxim Integrated Products, San Jose, CA

Laptop computers often use large-screen LCDs, which require a variable and a negative supply to ensure maximum contrast. The circuit in Fig 1 operates from the system's positive battery supply and generates a digitally variable negative voltage to drive the display.

Fig 1's switching regulator creates a negative voltage from the battery supply. The microprocessor data bus drives a 4-bit DAC, which in turn varies the actual regulator output from -6.5 to -11.5V. This arrangement allows a staircase of 16 possible voltages between these limits. The circuit implements the DAC by using the rail-to-rail output-drive capability of a 74HC-series CMOS gate. A resistor divider network formed by the 240-kΩ resistor connected to the -V filter capacitor and the resistors referenced to the 5V supply control the MAX635 regulator. When the voltage at the V_FB pin is greater than ground, the switching regulator turns on and stores energy in the inductor. The inductor then dumps this energy into the -V filter capacitor. When the voltage at V_FB is less than ground, the regulator skips a cycle. The MAX635 regulates the voltage at the junction of the resistor divider to 0V. Thus, any resistor that the DAC connects to ground (logic 0) will not contribute any current to the ladder. Only the resistors that are at 5V (logic 1) will be part of the voltage-divider equation.

The entire switching-regulator supply draws less than 150 µA. You can place the circuit in an even lower power mode by interrupting the ground pin. The high-current path is from the battery input through the internal power P-MOS FET to the external inductor. Disconnecting the ground connection simply disables the gate drive to the FET and turns off the internal oscillator. (EDN BBS /DL_SIG #881)

To Vote For This Design, Circle No. 803

Fig 1—Using a resistor-ladder DAC and a voltage regulator IC, this circuit uses the system's positive battery supply to generate a digitally variable negative voltage.
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Charles H Small and Anne Watson Swager
Design Idea Editors

Software spawns slip-ups

The Design Idea, “C routine sets bit groups” (EDN, May 10, 1990, pg 160), contains two errors. The first error is that the routine cannot handle the special case of start_byte equaling stop_byte. Secondly, the loop following the comment “Set the intermediate results” sets one too many words. The index i should begin at start_byte +1 instead of start_byte. Listing 1 corrects these errors.

Edward L Calvin
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FAX (714) 532-4115

F/V converter picks up errors

My Design Idea, “F/V converter has variable slope” (EDN, March 15, 1990, pg 182), contains many errors. My figure was exchanged with the figure from Mr J Handy’s idea. The figure’s caption is wrong; it calls my circuit a V/F converter when it is an F/V converter. The components in the figure are not labeled Q1, Q2, and C. And in the circuit diagram I sent you, the resistor from the collector of the first transistors is not connected to Vc. In this situation, I have a very small chance of being the issue winner.

Cezary Rudnicki
Pereca 13/19-718
00-849 Warszawa
Poland

(Ed Note: We apologize for swapping your figure with that of another Design Idea and reversing the F and V. I suspect that most of our readers spotted the mistakes immediately and had little trouble resolving them. We do not label components in figures unless we refer to the components in the text. Our published figure matches your initial submission exactly. We did change your European-style UREF to our style, VREF (control voltage). Perhaps you are confusing VC with VCC. Given the monetary situation in Poland today, we certainly hope that you had the chance of winning that your circuit merited.)
Listing 1—Bit-setting C routine

```c
set_bits_in_array(start_number, stop_number, a_ptr)
int start_number;
int stop_number;
char *a_ptr;
/* set bits in an array of bytes */
/* The array is referenced by the pointer a_ptr and is indexed from 0 up. Bit 0 in the first byte is the rightmost bit, and bit 7 is the leftmost bit in the byte */
{
char start_byte; /* 0 relative */
char stop_byte; /* 0 relative */
char start_bit; /* 0 relative */
char stop_bit; /* 0 relative */
char start_mask; /* 0 relative */
char stop_mask; /* 0 relative */
int i;
/* Get the byte numbers by dividing by 8 */
start_byte = start_number >> 3;
stop_byte = stop_number >> 3;
/* get the start and stop bit numbers */
start_bit = start_number % 8;
stop_bit = stop_number % 8;
/* generate masks for the start and stop bytes */
start_mask = Oxff << start_bit;
stop_mask = Oxff >> (7 - stop_bit);
/* Special case when only one byte has to be modified */
if ( start_byte == stop_byte )
{
    *(a_ptr + start_byte) = start_mask & stop_mask;
    return;
}
/* Set the intermediate bits */
for ( i = start_byte + 1; i < stop_byte; i++ )
    *(a_ptr + i) = Oxff;
    *(a_ptr + start_byte) = start_mask;
    *(a_ptr + stop_byte) = stop_mask;
}
```
VCO internalizes linearization

On pg 174 in the May 24, 1990, issue of EDN, Antonio Tagliavini's "Current sink widens VCO's frequency range" uses an external current source to get a wider VCO-frequency range. As an extension of his idea, I suggest using the chip's internal MOS current-source transistor to do the job of his external transistor, Q1. Now, you need only the op amp as an additional external element to get almost the same linearizing effect (Fig 1).

Rainer Lackmann
Fraunhofer Institut
Finkenstrasse 61 41 Duisburg
West Germany

Author refutes assertions

In reply to Joseph M Lopez's letter (EDN, June 21, 1990, pg 274) about my Design Idea, "PLD adds flexibility to motor controller" (EDN, March 1, 1990, pg 177), I would like to clarify the following points:

1. My Design Idea's Table 1 gives information about the motor's phases, which are on at any instant for wave drive, two-phase drive, and hybrid drive. In the table, H indicates logic high and L indicates logic low. An H in the columns A through H of the table indicates which phase is on.

2. Lopez asserts that my controller allows rotation in one direction only. Not true! Column P of Table 1 indicates the rotation of direction, with an L signifying clockwise and an H counterclockwise. Note that P is an input term in the PLD equations in Table 2.

3. Lopez further asserts that my Table 1 does not show "actual states and next states." True enough, but such state information is in Table 2.

4. Though several stepper-motor controller chips are available from various manufacturers such as Lopez's Sprague as well as Ericsson, Philips, and more, these chips are not as flexible as PLD-based designs that can generate any type of drive sequence simply by programming the PLD. I had considered the three, standard drive-sequence examples of wave drive, 2-phase drive, and hybrid drive to illustrate the PLD-based design approach—though many other drive sequences are possible with my circuit. In fact, the two key points of my Design Idea are using a PLD for programmable drive sequences and eliminating discrete power transistors and free-wheel diodes by using the XR-2013.

V Lakshminarayanan, Technical Staff Member
Centre for Development of Telematics
SNEHA Complex, 71/1 Miller Rd
Bangalore-560 052, India
Phone 91-812-27890

Resistor slips decimal points

The value given for R2 in Greg Schaffer's "Cascaded video amps have high gain" (EDN, June 7, 1990, pg 136) is off by two orders of magnitude; it should be 965Ω not 99.65Ω.
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**ISSUE WINNER**

The winning Design Idea for the August 2, 1990, issue is entitled “Passive network is totally resistive,” submitted by Prayson Pate of BNR (Research Triangle Park, NC).

**FEEDBACK AND AMPLIFICATION**

**High-voltage amp needs more parts**
The circuit in “High-voltage amp drives transducers” (EDN, April 12, 1990, pg 183), requires two additional zener diodes and resistors for proper operation. The accompanying partial schematic illustrates their placement from gate to source of the high-voltage transistors. A 1N758A should be connected between the source and gate of Q3 and Q4 with the cathode of each diode connected to the gate of the FET. Also, a 10-kΩ resistor should be inserted between the cathode of each added diode and the cathode of D3 and D6, respectively. In addition, Scott Ellington should have been identified as co-author.

Don Michalski
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Scott Ellington
Senior Design Engineer
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1150 University Ave
Madison, WI 53706

(Ed Note: Although the authors submitted a revised schematic, EDN erred and reproduced their original schematic. Even though both authors had their names on the Design Idea writeup that they submitted, only one author completed and signed an entry blank. To get credit and be paid for a Design Idea, all authors must complete and sign an entry blank.)

![Diagram](attachment:edn_diagram.png)

EDN October 25, 1990
Designing with a New Family of Instrumentation Amplifiers

Jim Williams

A new family of IC instrumentation amplifiers achieves performance and cost advantages over other alternatives. Conceptually, an instrumentation amplifier is simple. Figure 1 shows that the device has passive, fully differential inputs, a single ended output and internally set gain. Additionally, the output is delivered with respect to the reference pin, which is usually grounded. Maintaining high performance with these features is difficult, accounting for the cost-performance disadvantages previously associated with instrumentation amplifiers.

Figure 2 summarizes specifications for the amplifier family. The LTC1100 has the extremely low offset, drift, and bias current associated with chopper stabilization techniques. The LT1101 requires only 105µA of supply current while retaining excellent DC characteristics. The FET input

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CHOPPER STABILIZED</th>
<th>MICROPWR</th>
<th>HIGH SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset</td>
<td>10µV</td>
<td>160µV</td>
<td>500µV</td>
</tr>
<tr>
<td>Offset Drift</td>
<td>100nV/°C</td>
<td>2µV/°C</td>
<td>2.5µV/°C</td>
</tr>
<tr>
<td>Bias Current</td>
<td>50pA</td>
<td>8nA</td>
<td>50pA</td>
</tr>
<tr>
<td>Noise (0.1Hz-10Hz)</td>
<td>2µVp-p</td>
<td>0.9µV</td>
<td>2.8µV</td>
</tr>
<tr>
<td>Gain</td>
<td>100</td>
<td>10,100</td>
<td>10,100</td>
</tr>
<tr>
<td>Gain Error</td>
<td>0.03%</td>
<td>0.03%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Gain Drift</td>
<td>4ppm/°C</td>
<td>4ppm/°C</td>
<td>5ppm/°C</td>
</tr>
<tr>
<td>Gain Non-Linearity</td>
<td>8ppm</td>
<td>8ppm</td>
<td>10ppm</td>
</tr>
<tr>
<td>CMRR</td>
<td>104dB</td>
<td>100dB</td>
<td>100dB</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Single or Dual, 16V Max</td>
<td>Single or Dual, 44V Max</td>
<td>Dual, 44V Max</td>
</tr>
<tr>
<td>Supply Current</td>
<td>2.2mA</td>
<td>105µA</td>
<td>5mA</td>
</tr>
<tr>
<td>Slew Rate</td>
<td>1.5V/µs</td>
<td>0.07V/µs</td>
<td>25V/µs</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>8kHz</td>
<td>33kHz</td>
<td>220kHz</td>
</tr>
</tbody>
</table>

LT1102 features high speed while maintaining precision. Gain error and drift are extremely low for all units, and the single supply capability of the LTC1100 and LT1101 is noteworthy.

The classic application for these devices is bridge measurement. Accuracy requires low drift, high common mode rejection and gain stability. Figure 3 shows a typical arrangement with the table listing performance features for different bridge transducers and amplifiers.

Bridge measurement is not the only use for these devices. They are also useful as general purpose circuit components, in similar fashion to the ubiquitous op amp. Figure 4 shows a voltage controlled current source with load and control voltage referred to ground. This simple, powerful circuit produces output current in strict accordance with the sign and magnitude of the control voltage. The circuit's accuracy and stability are almost entirely dependent upon resistor R. A1, biased by V(In), drives current through R (in this case 10Ω) and the load. A2, sensing differentially across R, closes a loop back to A1. The load current is constant because A1's loop forces a fixed voltage across R. The 10k-0.5µF combination sets rolloff, and the configuration is stable. Figure 5 shows dynamic response. Trace A is
the voltage control input while trace B is the output current. Response is clean, with no slew residue or aberrations.

A final circuit, Figure 6, combines the current source and a platinum RTD bridge to form a complete high accuracy thermometer. A1A and A2 will be recognized as a form of Figure 4’s current source. The ground referred RTD sits in a bridge composed of the current drive and the LT1009 biased resistor string. The current drive allows the voltage across the RTD to vary directly with its temperature induced resistance shift. The difference between this potential and that of the opposing bridge leg forms the bridge output. The RTD’s constant current drive forces the voltage across it to vary with its resistance, which has a nearly linear positive temperature coefficient. The non-linearity could cause several degrees of error over the circuit’s 0°C-400°C operating range. The bridge’s output is fed to instrumentation amplifier A3, which provides differential gain while simultaneously supplying non-linearity correction. The correction is implemented by feeding a portion of A3’s output back to A1’s input via the 10k-250k divider. This causes the current supplied to Rp to slightly shift with its operating point, compensating sensor non-linearity to within ±0.05°C. A1B, providing additional scaled gain, furnishes the circuit output. To calibrate this circuit, follow the procedure given in Figure 6.

Details of these and other instrumentation amplifier circuits may be found in LTC Application Note 43, “Bridge Circuits — Marrying Gain and Balance.”

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Borg quits at 26

Standard components launched in miniature

A relatively untrapped link in the miniaturisation of electronics — power supply — is now being exploited. A completely new concept has been launched that makes it possible to obtain power from a miniature standard component, which is both highly efficient and economically attractive.

Lech Walesa wins Nobel peace prize

The world's most prestigious award, the Nobel Peace Prize, has gone this year to Lech Walesa, outspoken leader of the Polish Solidarity movement.

Walesa plans to donate the prize money that accompanies the award to a cultural project in Poland.

Suhag kidnapped

One of Britain's best-known racehorses - Desert Eagle - has been kidnapped. He was owned by the former racing driver, now in jail in the United States.

French aid for Chad

As Libyan troops continue to occupy large areas of the country, France has stepped up its aid to the beleaguered government, already struggling to hold on to power in the civil war.

Britain told to belt up

A new directive from the European Community has been issued to member countries. The directive requires that all new cars be fitted with seat belts as standard equipment.

But Greens gain ground

The Christian Democrats, back in power after an absence of 16 years, Herr Kohl is well aware of the unpredictability of political life.

His immediate predecessor, Helmut Schmidt, was removed by the West German parliament without an election, after a period of uneasy alliance with the minority Free Democrats party.

The increasing popularity of the Greens is seen as a reflection of growing public concern with such issues as acid rain, water pollution and wider ecological issues.
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Tri-state: Available
Compatible Technology: CMOS and TTL

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Temperature Indicator

- Handles nine sensor types
- Measures to 3325°F

Model 500T temperature indicator has a multichannel feature, which allows the unit to measure as many as six inputs. A miniature rotary switch allows you to select between inputs. The indicator handles nine sensor types—seven thermocouples and two resistance-temperature detectors—which you can select with a switch mounted behind the front panel. The unit features a 0.1 to 1° automatic resolution capability. The meter has a 0.55-in.-high LED display and measures from -346 to +3325°F. The indicator also measures in either degrees F or C. A Form C 0.5A relay output is available for connecting external lamps, buzzers, or on/off control elements.

Fiber-Optic Converter

- Accommodates RS-422
- Handles 2.5-MHz data rates

The Model 270 will communicate 2.5-MHz full-duplex data rates over a distance of 2 km. The converter operates at an 850-nm wavelength and features a 10-dB optical power budget. The electrical interface to the RS-422 port is fully differential for transmit and receive. The fiber-optic ports employ ST connectors, and the RS-422 port is compatible with an Electrovert/Phoenix-type 8112 connector. The unit is optimized for 62.5/125 µm fiber cable, but it will accommodate other cable sizes. A small wall-mounted transformer, which produces 9V ac, supplies power to the adapter. $152.

Photoelectric Controls

- Feature a variety of scanning techniques
- Scan to 10m

FE7D Series photoelectric controls are available in through-, polarized-reflective-, and diffuse-scan versions. Respective maximum scan distances in clean air equal 10, 3, and 0.7m. The controls operate with supply voltages of 10.8 to 264V dc or 21.6 to 264V ac. They have a spst relay output rated for 1A at 250V ac or 30V dc. At full output, they are rated for 350,000 operations. Each control is self-contained. The retroreflective- and diffuse-scan versions have a pulsed-LED emitter, phototransistor receiver, and amplifier in one package. Through-scan models have separate packages for the emitter and receiver/amplifier. The units are housed in 45 x 45 x 20-mm ABS plastic housings, which comply with IP66 sealing standards and operate over a range of -20 to +60°C. $80 for diffuse and polarized-reflective models; $112 for through-scan units.

High-Density Sockets

- Feature 0.025-in. contact spacings
- Available in 100- and 132-pin versions

Micro-Pitch plastic quad flatpack (PQFP) sockets feature 0.025-in. contact spacing and a 0.375-in. mounted profile. Available in 100- and 132-pin versions, the sockets consist of a housing and a plastic cover. The PQFP easily inserts into the relay terminals, positioned at the rear of the instrument, provide hookup for NO or NC operation. $398.

Beckman Industrial Corp, 3883 Ruffin Rd, San Diego, CA 92123. Phone (619) 495-3200. FAX (619) 268-0172. Circle No. 408

Micro Switch, 11 W Spring St, Freeport, IL 61032. Phone (815) 235-6600. Circle No. 410

EDN October 25, 1990
the cover, which contains protective slots for aligning and separating IC leads. Visual and mechanical polarization features properly orient the cover and housing during mating. Spring latches in each corner secure the cover to the housing. The tin-plated socket contacts exert a 200g normal force. The sockets' solder legs are arranged on a 0.075 × 0.100-in. 3-row grid to ease trace routing. The high-temperature housing materials withstand the rigors of reflow, vapor phase, and infrared soldering. The sealed bottom prevents flux and solder from entering the contact area, and standoffs prevent flux buildup between the socket base and the pc board. $8.62 and $10.35 (1000) for the 100- and 132-pin versions, respectively. Delivery, four to six weeks ARO.

AMP Inc, Box 3608, Harrisburg, PA 17105. Phone (800) 522-6752.

Circle No. 411

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- Provide current or voltage outputs
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Electro-Numerics Inc, 1811 Reynolds St, Irvine, CA 92714. Phone (714) 250-1501. FAX (714) 250-0958.

Circle No. 412

EMI Filter
- Meets MIL-STD-461
- Attenuates 40 dB
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- Come in 1- and 3-output versions
- Have an 80% efficiency

K2200 single- and triple-output dc/dc converters have a 25W power rating. The 1-output models offer 5, 12, or 15V outputs while the 3-output units offer 5 and ±12 or ±15V. Input levels equal 20 to 60V or 36 to 72V. All models are short-circuit and overvoltage protected. Line and load regulation equals ±1% for the main output and ±5% for auxiliary outputs. Ripple and noise measure 1% and 2% max, respectively, and input-to-output isolation equals 500V dc. All models switch at 200 kHz, have an 80% typ efficiency, and operate over a -20 to +70°C range with no derating. The converters are housed in a 3×3×0.7-in. metal package, that features six-sided shielding. $92 for single-output models; $110 for triple-output versions.

Intronics Inc, 150 Dan Rd, Canton, MA 02021. Phone (617) 828-4992. FAX (617) 828-5050. Circle No. 416

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full international safety agency approvals, dual-input voltage ranges, and overload protection. An optional power-fail circuit provides a user-accessible signal upon loss of ac input. The supply is housed on a 2.5 × 5 × 10.5-in. L-bracket and is available with an optional cover. $207 (100).

Astec America Inc, 401 Jones Rd, Oceanside, CA 92054. Phone (619) 439-4280. FAX (619) 439-4243. Circle No. 417

Electronic Thermostats
• Have a ±1°C accuracy
• Operate to 85°C
The TP Series solid-state, board-mountable temperature switches are electronic thermostats that will trip at either one or two specified temperatures with ±1°C accuracy. The unit comes in a 0.48 × 1.2-in. single in-line package and operates over a −20 to +85°C range. They can be mounted perpendicular or parallel to the cooling air stream. The switches feature hysteresis-free operation and are available in normally open or normally closed versions for 5 to 24V operation. Switch output is compatible with TTL, CMOS, and other logic families. The units are built into headers that have a 0.1-in. pin spacing, allowing you to mount them into a connector. From $4.95 (10,000).

Cambridge Aeroflo Inc, 900 Mount Laurel Circle, Shirley, MA 01464. Phone (508) 425-2346. FAX (508) 425-2338. Circle No. 418

Slot-Bypass Boards
• Act as RFI shields
• Designed for VXIbus systems
The Slot-Bypass boards are made of an aluminum construction and are designed to fill an open or spare slot in a VXIbus system. They also act as an RFI shield when installed between boards. Jumpers are provided in the P1-connector position to daisy-chain the BUSGRANT and IACK signals. A front panel is provided to create a finished appearance. Each board includes an air baffle on each side to maintain efficient air flow. The boards are available in all VXIbus-specified sizes. From $34.

Dawn VME Products, 47073 Warm Springs Blvd, Fremont, GA 94539. Phone (415) 657-4444. FAX (415) 657-3274. Circle No. 419

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CIRCLE NO. 68
Keylocks Offer Top Quality
Standard Grigsby's family of keylock switches features high performance, a variety of design options and competitive pricing.

P.C. or solder lug terminations are available. Terminals are gold-plated over silver-plated brass. Users may specify a variety of security levels and circuits. Anti-static versions offer protection to 20 KVDC. Stops are fixed with indexing angles of 36°, 45° and 90°. Life is rated at 25,000 cycles.

The SG Series KL keylocks are priced at $10.00 in lots of 250 pieces, with delivery in 8 to 10 weeks. Standard Grigsby, Inc., (708) 556-4200.

Membrane Switching Offers Many User Options. Sugar Grove, IL—Membrane switches from Standard Grigsby Inc. provide many design options for use in a variety of applications including: test instrumentation, point-of-sale equipment, medical electronics and weight measurement.

Users may select flexible or PC board construction, x-y matrix or common bus, and flat or tactile feel. PC board construction can incorporate LED's, diodes, displays, IC sockets, resistors and capacitors. ESD, EMI, and RFI shielding is available. Terminals may be gold or tin plated.

Overlay colors may be matched to PMS or Federal standards, or to color chips as supplied by the customer. Full key or ridge-only embossing is offered.


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Just .865" square, the MMP/REL rotary switch from Standard Grigsby, Inc. offers standard code (hexadecimal, BCD, gray) and custom code options.

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The switches are $5.00 ea. in lots of 500 pieces. Delivery is 6 to 8 weeks. Standard Grigsby, Inc., 708/556-4200
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NEW PRODUCTS

CAE & SOFTWARE DEVELOPMENT TOOLS

Ada Cross-Compiler For 88000 RISC Systems
- Runs on VAX/VMS host computers
- Performs extensive in-lining and code optimization
The Telegen2 Ada cross-development package runs on VAX/VMS host computers and generates code for target systems that are based on the Motorola 88000 RISC (reduced-instruction-set computer) processor. The package consists of the optimizing cross-compiler, a library manager, a source-level debugger, an Ada profiler, and a global optimizer. Tools include a cross-referencer, a source-dependency lister, a source formatter, and a compilation-order tool. The compiler performs more in-lining and code optimization than other models. It also uses a multithreaded runtime support package that provides deterministic interrupt-handling behavior, which allows you to accurately predict if your application will respond to critical events within a specified period of time. From $12,600 to $102,000, depending on the host configuration and the options you select.

Telesoft, 5859 Cornerstone Ct W, San Diego, CA 92121. Phone (619) 457-2700. FAX (619) 452-1334.

Circle No. 421

Cross-Development Tool Set For R3000 RISC Processors
- Runs on IBM PCs and compatibles
- Includes a floating-point library and a debug monitor
This tool set lets you write, assemble, and debug software for the vendor's R3000 RISC (reduced-instruction-set computer) processors and R3001 microcontrollers. The tool set consists of the IDT7RS357 cross-assembler, the IDT7RS361 PROM monitor, and the IDT7RS355 floating-point library. The cross-assembler runs on any IBM PC or compatible under MS-DOS or SCO Xenix, and it produces object code that you can download to the target system for execution and debugging. The debug PROM monitor resides in the target system and not only provides extensive diagnostic facilities, but also allows source-level debugging from the PC host. The floating-point library provides math routines that you can link to your assembly-language programs, thereby eliminating the need for a math coprocessor. Cross-assembler, $249.50; debug monitor (binary), $995, (source code) $4950; floating-point library, $1295.

Integrated Device Technology Inc, Box 58015, Santa Clara, CA 95052. Phone (408) 727-6116. FAX (408) 988-3029.

Circle No. 420

Memory-Extension System For DOS
- Applications can use available space above 640k bytes
- Accommodates Windows 3.0 device drivers
ExtenDOS is a general-purpose memory-extension system that is compatible with Windows 3.0. It allows application programs to request additional memory space in the region between the 640k-byte top of main memory and the 1024k-byte upper limit. The available memory in that region is managed by DOS, and you don't need a special applications programming interface (API) to access it. Using the vendor's Moveup program, you can run the HIMEM.SYS driver required by Windows in ExtenDOS memory; mouse drivers, network drivers, and other resident programs can also run in the extended memory. ExtenDOS works with all processors of the Intel family. Products featuring ExtenDOS, from $200.

Dakota Research Corp, Box 40, Rapid City, SD 57709. Phone (605) 394-8900.

Circle No. 422

Graphics Application Development Tool
- Works with a variety of DOS extenders
- Library contains more than 200 graphics subroutines
Halo Professional is a developer's tool kit that lets you write large and sophisticated graphics application programs. It works with DOS extenders such as Rational Systems DOS16M and Phar Lap. These ex-

EDN October 25, 1990
tenders allow application programs to use more than 640k bytes of memory. Halo Professional allows you to write application programs that run in protected mode and real mode. It lets you create bit-mapped cursors that improve cursor visibility and look. Your programs can simultaneously display graphics on multiple devices. You can use the tool in conjunction with many popular Basic, C, Pascal, and Fortran compilers. Halo Professional runs on 80286/386-based IBM PCs and compatibles that have a 1.2M-byte floppy-disk drive, a hard-disk drive, and 640k bytes of main memory. It supports dot-matrix, laser, ink-jet, and thermal printers, as well as a variety of display devices, scanners, and pen plotters. $595.

Media Cybernetics Inc, 8484 Georgia Ave, Silver Spring, MD 20910. Phone (301) 495-3305. FAX (301) 495-5964. Circle No. 423

**Spice Model Library Of RF Transistors**

- **Usable with any Spice-compatible simulator**
- **Accounts for all package parasitics**

The RF Device Model Library includes models of 36 foreign and domestic bipolar transistors and JFETs. You can use these models with any Spice-compatible simulator running on any computer. The models use a subcircuit approach that takes into account all package parasitics and matches the published S-parameter magnitude and phase data at all frequencies up to 5 GHz. The package includes several test circuits and schematics that allow you to plot a transistor's S-parameters from Spice simulations. These models are more accurate than those which try to fit device behavior to the standard Gummel-Poon model; the only other accurate models of RF transistors are encrypted, proprietary, and very expensive. The models are available on 5½-in. or 3½-in. diskettes, in IBM PC ASCII format or Macintosh Text format. $99.

Intusoft, Box 6607, San Pedro, CA 90734. Phone (213) 649-9099. FAX (213) 649-4503. Circle No. 424

**C Library Includes Window Management**

- **Allows you to paint windows with shadows**
- **Provides drivers and graphic interface routines for mice**

The Superfunctions C library furnishes C programmers with a variety of complex services for DOS-based computer systems. The expanded-memory interface lets your application sense the presence of expanded memory and use all of the...
The CMOS Compatible Centigrids®

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• Fewer components/connections = greater reliability
• Both latching & non-latching versions available

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CIRCLE NO. 45
features specified by the Lotus/Intel/Microsoft Expanded Memory Standard (LIM EMS) 4.0. The library also supports version 3.2 of the LIM EMS. New window-management functions let you paint windows with shadows, scroll text within the windows, and use many different attributes of color and intensity. In addition to Turbo C 2.0, Turbo C++, Lattice C, Quick C, and Microsoft C 6.0, the library now supports the Watcom C, Zortech C++, and Topspeed C compilers. Superfunctions can now take advantage of the Microsoft C fast-call convention; this strategy lets you pass some parameters by way of the CPU’s registers, instead of pushing them onto and popping them off the stack—a far slower procedure. The mouse interface offers a complete set of functions to interface your applications to Microsoft-compatible mouse drivers, including mouse detection, cursor setup and maintenance, position detection, click detection, and mouse-status detection. $299; upgrade price for purchasers of the earlier version, $45.

Greenleaf Software Inc, 16479 Dallas Pkwy, Suite 570, Dallas, TX 75248. Phone (800) 523-9830. FAX (214) 248-7830. Circle No. 425

Updated Reliability-Prediction Software
- Conforms to the provisions of Notice 1 of MIL-HDBK-217E
- Uses new data to improve reliability prediction

The vendor has revised three reliability-analysis software packages (Reap, Reapmate, and Reap Basic) to conform to the provisions of Notice 1 of the DoD MIL-HDBK-217E. This Notice provides new data that permits more accurate prediction of the failure rates of ICs, optoelectronic components, and semiconductors. The Reap software provides sensitivity tests for temperature, quality, and environment; it also includes an expandable, menu-driven component library. You can link the Reap programs with the vendor’s thermal-analysis software to improve the accuracy of the reliability predictions. The programs run on IBM PCs and compatibles and on engineering workstations that run under VMS and Unix. From $995 for single-user PC versions; from $10,000 for workstation versions. Current users can upgrade to the new version for one-third the cost of each full license.

Systems Effectiveness Associates Inc, 20 Vernon St, Norwood, MA 02062. Phone (617) 762-9252. Circle No. 426

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**CAE & SOFTWARE DEVELOPMENT TOOLS**

**Object-Oriented Software Development System**
- Supports Microsoft Windows release 3.0
- Provides improved memory management

Kappa PC version 1.1 is a high-performance development system for object-oriented application programs that run on IBM PCs and compatibles under Microsoft Windows 3.0. This interactive system incorporates facilities for object-oriented programming, rule-based reasoning, and active graphics. Because of the software's improved memory management, applications with as many as 5000 objects can run in less than 2M bytes of memory. Working with the Windows DDE (dynamic data exchange) feature, Kappa PC can exchange data with other Windows applications such as Excel and Toolbook. The system also includes links to spreadsheets, database applications, and ASCII files that do not support DDE. You can write your applications in ANSI C or in the proprietary Kappa Application Language (KAL). Registered users of version 1.0 can upgrade to version 1.1 for $165. For first-time purchasers, a complete 1.1 development system costs $3500; a runtime license for each application you develop with Kappa costs $450.

**IntelliCorp, 1975 El Camino Real W, Mountain View, CA 94040. Phone (415) 965-5500.**

Circle No. 427

**Digital-Logic Simulator For The Macintosh**
- Simulates multi-input gates and 3-state gates
- Handles J-K, D, and T flip-flops and ideal delay lines

Navlogic is a digital-logic simulator.

**Quality ROM Tools**

Genesis Microsystems has been a producer of quality 8086-family ROM development tools since 1982.

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For more information call Genesis Microsystems Corp. at (707) 542-5000. Or write 146-D Wikup Dr., Santa Rosa, CA 95403.

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for the Macintosh II computer. The program can simulate both standard and 3-state gates; there is no limit on the number of inputs. In addition, the program can simulate J-K, D, and T flip-flops and ideal delay lines. You can specify the variables to be plotted; a separate program performs the plotting. For a large number of time intervals, the program divides the plot into several incremental windows, each having as many as six variables. You can save the incremental windows as Macintosh PICT files, and then print them. $199.

Kask Labs, 1207 E Secretariat Dr, Tempe, AZ 85284. Phone (602) 831-1420. Circle No. 428

Auxiliary Tools For OrCAD CAE Products

• Shell provides master menu for running all OrCAD programs
• Translator converts third-party netlists to OrCAD format

Or-Tools 2.5 is a set of utility programs that complement OrCAD CAE products, making these products easier to use and providing additional functions. Or-Shell lets you select and run any OrCAD program from a single menu; it uses no additional memory because it resides on disk and reloads itself only when the application you have selected completes its operations and returns control to the OS. Netcon is a netlist translator that converts netlists created by EEDesigner, Futurenet, Tango, Case, Telesis, or PADS-PCB into the OrCAD-PCB format. This program also creates the time stamps used by OrCAD SDT and OrCAD PCB. Other tools can make stuff files from a parts list; edit and modify Gerber files; update old schematics; compare and merge SDT libraries; and automate many other time-consuming and tedious tasks. $99.

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- You can connect eight VGA computers to four VGA displays.
- Remote unit located as far as 1000 ft away controls switch.

The SM-8X4-15V VGA video-matrix switch has eight inputs and four outputs. It allows eight IBM VGA-compatible computers to be connected to four VGA display devices. A remote-control unit, called the SM-RMT-8X4, can control the switch from as far as 1000 feet away. The remote-control unit has 32 backlit and touch-activated switches for selecting the VGA source. You can connect each VGA source independently to any or all of the four VGA display devices. The remote-control unit connects to the matrix switch via a 5-pin DIN connector. The matrix switch is housed in a plastic case that measures 8.5 x 11.5 x 12 in. The SM-8X4-15V switch operates from 110 or 220V ac and comes with eight 6-ft cables. $2450. The SM-RMT-8X4 remote-control unit is housed in a plastic case that measures 8 x 2.7 x 5 in. and comes with a 25-ft cable. $525.

**Network Technologies Inc**, 19145 Elizabeth St, Aurora, OH 44202. Phone (800) 742-8324; in OH, (216) 543-1646. FAX (216) 543-5423. Circle No. 430

**80486 Workstation**

- IBM PC, PC/XT, and PC/AT compatible.
- Has 4M bytes of RAM and 40M or 100M bytes of disk storage.

The DRS Model 75 workstation uses a 25-MHz 80486 µP. The system is IBM PC, PC/XT, and PC/AT compatible and runs on the MS-DOS 3.3, MS-DOS 4.01, and OS/2 operating systems. It contains 4M bytes of RAM that's expandable to 16M bytes and either 40M or 100M bytes of storage on a 3½-in. hard-disk drive. An additional 40M or 100M bytes for a hard-disk drive is available as an option. The system has one half-length and two full-length AT expansion slots. It has an RS-232C port and supports the TCP/IP protocol for Ethernet communications. The unit comes with an IBM VGA-compatible card; a monochrome or color VGA display monitor is optional. When equipped with the company's PCPower terminal emulation or PowerWindows software and linked to the com-
pany's Officemedia network, the system can access Unix productivity tools such as electronic mail and document conversion. 40M-byte system, $6900; 100M-byte system, $7500.

International Computers Ltd
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• Uses universal pattern on 0.1-in. grid of pads
• Operates from ±5 V to ±12 V
The EISA Pad-Per-Hole prototyping board for the EISA bus combines easy soldering with flexibility. It uses a universal pattern of holes on 0.1-in. grid spacing with individual pads for each hole. The card operates from ±5 V to ±12 V, and has ground buses, which are easily accessible on the entire board surface. Some board features include 50Ω characteristic impedance levels throughout, copper-plated-through holes, solder-coated hole-and-pad surfaces, FR4 base material, surface-marked pin designations, and nickel/gold-plated contact fingers. The 4-layer board measures 4.5 × 13.125 × 0.062 in. The board comes with mounting hardware, instructions, and layout sheet. $169.05.

Vector Electronic Co, 12460 Gladstone Ave, Sylmar, CA 91342. Phone (818) 365-9661. Circle No. 432

21-In. Color Monitor
• Has resolution from 1024 × 768 to 1600 × 1280 pixels
• Accepts ECL digital- or analog-input signals
The C21LMAX 21-in. color monitor is compatible with the Artist XJS Graphics Controller board from Artist Graphics. The noninterlaced monitor has three display resolutions—1024 × 768, 1280 × 1024, or 1600 × 1200 pixels. Some features include horizontal-scan rates from 48 to 96 kHz; vertical-scan rates from 60 to 80 Hz; 40 fLs of brightness; dot pitch of 0.31 mm; video bandwidth of 200 MHz; and both digital- and analog-input ports. The unit automatically adjusts to horizontal- and vertical-scan rates. User controls include front-panel brightness and contrast controls; side-panel power and degauss controls; and rear-panel height, vertical-position, width, and horizontal-position controls. The unit measures 19 × 19.5 × 19 in. It weighs 60 lbs without tilt-swivel base. $3895.

Image Systems Corp, 11543 K-Tel Dr, Hopkins, MN 55343. Phone (612) 935-1171. FAX (612) 935-1386. Circle No. 433

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E DN October 25, 1990  CIRCLE NO. 224
80386 Portable Computer
• Runs at 33 MHz and has VGA gas-plasma display
• Has 32k-byte cache RAM and 4M bytes of system RAM
The Regal II/33 portable IBM PC-compatible computer uses a 33-MHz 80386 µP. The 20-lb unit has an IBM VGA-compatible gas-plasma display with 640 x 480 pixels and 16 shades of gray. Other features include 4M bytes of RAM, a 40M-byte hard disk, as well as a 1.44M-byte, 3½-in. floppy-disk drive, and an external 1.2M-byte, 5½-in. floppy-disk drive. In addition, you can expand the 4M-byte RAM to 8M bytes, using an expansion card. The unit also includes a 32k-byte cache RAM, that is expandable to 64k bytes, and a detachable keyboard with a full complement of 102 keys. The display driver can run an external 800 x 600 color VGA monitor. The computer has two full-sized expansion slots and measures 16 x 9 x 7.5 in. A 15-month warranty covers parts and labor, and the computer comes with a 30-day money-back guarantee. $3899; model with an EGA display, $3599.

Micro Express, 1801 Carnegie Ave, Santa Ana, CA 92705. Phone (800) 642-7621; in CA, (714) 852-1400. FAX (714) 852-1225.

Circle No. 434

I/O Coprocessor Board
• Utilizes 10-MHz V40 µP in IBM PC expansion slot
• Host communication takes place through 1k-byte RAM
The 6P21 I/O coprocessor board serves as an expansion slot in the IBM PC bus. The 4.2 x 5.5-in. card is a slave processor for I/O and real-time control applications. Host communication takes place through a 1k-byte dual-ported RAM. The board utilizes a 10-MHz V40 µP. When multiple boards co-exist on a single host, each board requires 2k bytes of memory space for communication and one host interrupt line. The board doesn't occupy any host I/O space or host DMA space. The board's BIOS provides DOS emulation, thus allowing the host to download programs through the dual-ported RAM. Because the board runs all DOS function calls,
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**Mesa Electronics**, 1329-D 61st St, Emeryville, CA 94608. Phone (415) 547-0837. FAX (415) 547-4738. Circle No. 435

**DSP Board**
- Utilizes 40-MHz TMS320C25 DSP chip for ISA bus
- ADC samples eight channels at 300 KHz with 12-bit resolution

The Model 250 DSP board for a 16-bit ISA bus utilizes a 40-MHz TMS320C25 DSP chip. It can also accommodate the faster TMS320C25-50, the EPROM-based TMS320E25, and the TMS320C26. The board provides both analog and digital I/O channels. An A/D converter samples eight single-ended channels at a maximum of 300 kHz with 12-bit resolution. The board provides two analog-output channels, as well as a serial interface for the DSP chip. The board can have as much as 64k words of zero wait-state programmable RAM and 128k words of one wait-state data RAM. The data RAM is simultaneously available to the host and DSP chip through the use of an onboard memory controller. The host-to-data RAM transfer speed can be as high as 3M bytes/sec. The board comes with an assembler and a debugger and programs for FFTs, signal and spectrum display, digital filtering, recording and playing back to and from disk, and waveform editing. Model 250, with 40-MHz TMS329C25, 4k words of program RAM, and 32k words of data RAM, $1095.

**Dalanco Spry**, 89 Westland Ave, Rochester, NY 14618. Phone (716) 473-3610. Circle No. 436

**Ink-Jet Printer**
- Provides 300 x 300 dpi for paper sizes to 11 x 17 in.
- Has 64 ink-jet nozzles and prints at 2 pages/minute in draft mode

The EPI-4000 ink-jet printer provides 300 x 300-dpi resolution on paper sizes as large as 11 x 17 in. The printer utilizes 64 ink-jet nozzles arranged in a 16 x 4 staggered pattern. It prints bidirectionally with maximum speed depending on the font and quantity of data. It prints as fast as 2 pages/minute in draft mode. The printer is compatible with software written for the HP LaserJet Series II and Epson FX and LQ models. The print controller uses a 10-MHz 68000 µP and 512k bytes of RAM with an optional 2M-byte memory board. The printer can print on letter, legal, executive, A4, ledger B, #6, and #10 paper sizes, and DL envelopes. It has an automatic feed for single sheets and envelopes, and an optional push tractor is available for continuous paper and labels. $1999.

**Epson America Inc**, 23530 Hawthorne Blvd, Torrance, CA 90505. Phone (213) 539-9140, ext 4438. Circle No. 437
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Hitachi Denshi America Ltd, 150 Crossways Park Dr, Woodbury, NY 11797. Phone (516) 921-7200. Circle No. 438

10M-Sample/Sec Transient Recorder
- Includes eight flash ADCs
- Has 32k bytes of battery-backed RAM for each channel

The 2028 transient recorder houses eight channels in a single module. Each channel includes a 5-MHz-bandwidth S/H amplifier, a 10M-sample/sec flash converter, an 8-bit flash A/D converter, and 32k bytes of high-speed battery-backed RAM. The ADCs maintain dynamic accuracy of 7.2 effective bits to 1 MHz and 6.8 effective bits to 5 MHz. Data for all channels is sampled simultaneously under control of an internal programmable clock or an external source. The internal generator can synchronize additional transient-recorder modules. Battery-backed RAM stores all control settings. You can set the amount of memory needed, and use as little as 256 bytes. A programmable attenuator divides the input by 2, 5, or 10. You can program offsets to ±1/2 of full scale, and you can connect the input for an impedance of either 50Ω or 2.5 kΩ. $4900.


Time-To-Voltage Converter
- Measures pulse widths, periods, and signal-signal delays
- Lets you display measured parameter on a scope

The TVC 501 instantaneous time-interval-to-voltage converter produces an output voltage proportional to an input pulse width, period, or signal-to-signal delay. The unit, which is housed in a modular enclosure from the vendor's TM 500 series, works with any oscilloscope to show you how the measured quantity varies as a function of time. When you set the scope's sensitivity to 100 mV/div, seven ranges cover 1 μsec/div to 1 sec/div. To
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The System 3000 incorporates its own CRT display and keyboard allowing it to be used as a powerful stand-alone programmer. On-screen menus and prompts allow device selection and all system operation functions to be easily executed. The System 3000 also gives you full-screen editing of both memory and logic data including test vectors. Light pen operation and custom Z-packs for life cycle testing and other specialized functions set the System 3000 apart from any other Universal Programmer.

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Tektronix Inc, Box 19638, Portland, OR 97219. Phone (800) 426-2200. Circle No. 440

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- Functionally tests devices with as many as 40 pins
- Library includes most TTL ICs
The BoardMaster 4000 is a static in-circuit tester for digital pc boards. The unit functionally tests and diagnoses faults in ICs with as many as 40 pins soldered to a board. You make connections to the IC under test with a clip on the end of a cable. The tester accommodates both DIP and surface-mount devices. To isolate the IC under test, the tester back-drives the outputs of the surrounding devices. The tester can also check ICs not mounted on boards and can compare a board under test with a known-good board. The unit’s library of device tests includes those for most TTL ICs. You can set logic one and zero levels yourself, however. The tester includes a CRT that displays the menu-driven interface and also has RS-232C and Centronics ports and a 3½-in. floppy-disk drive that reads and writes in a proprietary format. $13,500.

United Electronic Industries, 10 Dexter Ave, Watertown, MA 02172. Phone (617) 924-1155. FAX (617) 924-1441. Circle No. 441

ABI Electronics Ltd, Mason Way, Platts Common Industrial Park, Barnsley, South Yorkshire S74 9TG, UK. Phone (0226) 350145. FAX (0226) 350483. Circle No. 442

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EDN October 25, 1990 267
PC plug-in card that itself accepts plug-on boards, a plug-on in-circuit emulator (ICE) for the AT&T DSP16A, and the tool vendor’s Emu16 software. An optional plug-on board contains an AT&T T7525 linear, 16-bit Codec (coder/decoder), which, among other things, performs A/D and D/A conversion.

The ICE plug-on card connects via a 30-in. ribbon cable to the 84-contact socket on your target system; this system normally accepts the DSP chip in its plastic leaded chip carrier. The ICE supports DSP16A operation with a 33-nsec instruction cycle. The software’s windowed display shows disassembled code, all the DSP’s registers, breakpoint locations, and the contents of internal RAM and external scratchpad RAM. The only performance penalty is the insertion of a single Go-To instruction at the start of your interrupt handler. $2800; Codec plug-on card, $250.

TJ Consultants Inc, Box 198, Lake Hopatcong, NJ 07849. Phone (201) 663-3501. Circle No. 443

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Sunrise Electronics Inc, 524 S Vermont Ave, Glendora, CA 91740. Phone (818) 914-1926. FAX (818) 914-1583. Circle No. 444
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- Supports VME and VME64 buses

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$3550.

Vmetro Inc, 2500 Wilcrest, Suite 550, Houston, TX 77042. Phone (713) 266-6430. FAX (713) 266-6919.
Circle No. 445

Vmetro A/S, Sognsveien 75, N-0855 Oslo 8, Norway. Phone (47-2) 39 46 90. FAX (47-2) 18 39 38.
Circle No. 446

Self-Calibrating D/A Card For Macintosh II
- Has eight 12-bit channels
- Accepts data at 500,000 words/sec

The M2-AO is a self-calibrating, analog-output and digital I/O card for the Macintosh II series. The card has eight 12-bit analog outputs and 16 digital channels, each of which can act as an input or an output. The board has no calibration adjustments; it calibrates itself by comparing its outputs to onboard, factory-calibrated references. Each analog channel has a switch-selectable output range of 0 to 10V, 0 to 5V, ±5V, or 4 to 20 mA. In the voltage mode, the outputs source or sink 15 mA. In the current mode, output voltage compliance is 2.6 to 50V. The vendor includes its QuickLog software as well as a driver for attachment to high-level-language programs. $1195.

Strawberry Tree Inc, 160 S Wolfe Rd, Sunnyvale, CA 94086. Phone (408) 736-8800. FAX (408) 736-1041.
Circle No. 447
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- Makes 100,000 16-bit conversions/sec
- Has eight differential inputs

The DVX 2503 is an 8-channel data-acquisition board for the VME and VXI buses. It contains a differential amplifier that provides a common-mode rejection of 100 dB at 60 Hz and allows software control of gain. The 16-bit A/D converter makes 400,000 conversions/sec. The board, which in VXI parlance is B size and in VME terms is 6U size, also includes a 1000-word FIFO buffer. The buffer ensures continuous data collection despite gaps in data transfer caused by latencies of the controlling processor and the DMA channel. The unit’s equivalent input noise in a 700-kHz bandwidth is ±50 µV rms. Harmonic distortion is −92 dB at 10 kHz. The board includes a sequencer that can work with multiplexer boards to expand the unit’s capacity to 256 channels. $4500. Delivery, 8 to 10 weeks ARO.

Analogic Corp., 8 Centennial Dr, Peabody, MA 01961. Phone (508) 977-3000. FAX (508) 532-6097. TLX 6817144. Circle No. 448

IEEE-488 Bus Monitor

- Plugs into IBM PC bus
- Monitors IEEE-488 bus to 1 MHz, captures and saves activity

The GPIB-410 full-length card plugs into the IBM PC bus. Using the card, a PC can monitor the lines of an IEEE-488 bus in real time, and capture bus transactions in the PC’s memory or save them on disk. Other capabilities include single stepping through bus operations, triggering on specified events, and emulating source or acceptor devices. You can set the handshake speed as fast as 1 MHz. The PC that houses the bus monitor board can act as the bus controller. The monitor’s program can capture bus data in the background while the bus control program operates in the foreground. The monitor’s program
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<table>
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<tr>
<th>HTBasic</th>
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<th>HP BASIC</th>
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<tr>
<td>YES</td>
<td>IEEE-488 GPIB (HP-IB), RS-232 Instrument Control</td>
<td>YES</td>
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<tr>
<td>YES</td>
<td>Integrated Environment: Mouse, Editor, Debugger, Calculator</td>
<td>YES</td>
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<tr>
<td>YES</td>
<td>Supports 16 Megabytes of Memory (breaks DOS 640K barrier)</td>
<td>YES</td>
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<tr>
<td>YES</td>
<td>Engineering Math: Matrix Math, Complex Numbers</td>
<td>YES</td>
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<tr>
<td>YES</td>
<td>High Level Graphics: Screen, Plotter, Printer</td>
<td>YES</td>
</tr>
<tr>
<td>YES</td>
<td>Structured Programming with Independent Subprograms</td>
<td>YES</td>
</tr>
<tr>
<td>YES</td>
<td>Runs on Industry Standard Personal Computers</td>
<td>NO*</td>
</tr>
<tr>
<td>YES</td>
<td>Industry Standard Graphic Printer Support: Epson, IBM, lasers, etc.</td>
<td>NO</td>
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<td>YES</td>
<td>Industry Standard Network Support: Novell, IBM, Microsoft, NFS, etc.</td>
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<tr>
<td>YES</td>
<td>Industry Standard IEEE-488 Support: National Instruments, IOtech, etc.</td>
<td>NO</td>
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<tr>
<td>YES</td>
<td>Exchange data files with Industry Standard PC applications</td>
<td>NO*</td>
</tr>
<tr>
<td>YES</td>
<td>No-charge Telephone Technical Support</td>
<td>NO</td>
</tr>
<tr>
<td>YES</td>
<td>Instant on-line HELP system</td>
<td>NO</td>
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</tbody>
</table>

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- Saves logged data in as much as 512k bytes of RAM

The SBS-2300H is a data-acquisition and control card with onboard intelligence. It has ten 12-bit analog I/O channels, 48 digital I/O lines, a keypad port, two serial ports, and EPROM and EEPROM programmers. The unit runs automatically when you apply power; a built-in debugger displays variables during program execution. Onboard ROM contains CamBasie, a multitasking language that supports 32 background tasks including nine counters and eight timers. An audio output and two PWM outputs are software programmable. The board operates in a stand-alone mode, consuming 600 mW. It can accommodate 512k bytes of RAM for logging data. A peripheral port lets you add more functions. $595.

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16-Bit A/D Converter

• Self calibrating
• Digitizes at a 50-kHz rate

The MN6400 self-calibrating, 16-bit A/D converter can digitize analog input signals at a 50-kHz rate. Powering the device initiates the calibration feature, which ensures that all performance specifications are met. The device is a complete A/D converter, and it includes an inherent T/H function, an analog input buffer, a reference, a clock, control logic circuitry, and a parallel-data bus driver. Analog input ranges are 0 to 5V, 0 to 10V, ±5V, and ±10V, with digital control over unipolar and bipolar operation. The device, which operates from ±15 and 5V supplies, consumes 750 mW. Packaged in a double-wide, side-brazed DIP, the MN6400 is available in four performance grades and three levels of reliability screening. Prices range from $175.00 to $293.25 (100).

Plessey Semiconductors Corp, 1500 Green Hills Rd, Scotts Valley, CA 95066. Phone (408) 438-2900. FAX (408) 438-7023.

Circle No. 403

Logarithmic Amplifier

• Operates from 100 to 600 MHz
• Has 70-dB voltage gain

Designed for use at radio frequencies in the 100- to 600-MHz range, the SL3522 logarithmic amplifier delivers a dynamic range of 70 dB. The monolithic chip contains seven logging stages and a video summing and buffer amplifier. On-chip decoupling reduces the possibility of instability due to the high gain of the device. Additional features include a differential RF input, limited RF output, and a buffered 2V video output. The IC also has provisions for external adjustment of gain and offset. Specified for operation over the −55 to +125°C military temperature range, the SL3522 comes in a 28-pin miniature ceramic package and costs $925 (100).

Philips Components-Signetics Co, Box 3409, Sunnyvale, CA 94088. Phone (408) 991-2000.

Circle No. 404

Fast Microcontrollers

• Operate at 24 MHz
• Available in two versions

Featuring 24-MHz speed, the 80C51 contains 4k × 8 bits of ROM; the 80C31 does not include any ROM. The devices, which have an internal instruction time of 500 nsec, can perform an 8 × 8 multiply in 2 µsec. The microcontrollers offer two software-selectable, power-saving operating modes. In the idle mode, the CPU is frozen while allowing the RAM, timers, serial port, and interrupt system to operate. In the power-down mode, RAM contents are saved while the oscillator is frozen, allowing all other functions to remain inoperative. The devices have a five-source two-priority interrupt structure, oscillator and clock circuits, a serial I/O port, 32 I/O lines, and two 16-bit counter/timers. Package options include 40-pin DIP, 44-pin PLCC, and 44-pin quad flatpack. In plastic DIP, the SC80C51 costs $3.46; the SC80C31 costs $3.02 (10,000).

Micro Networks, 324 Clark St, Worcester, MA 01606. Phone (508) 552-5400. FAX (508) 853-8296.

Circle No. 402

Fast High-Density ROMs

• Access times are 110 nsec
• Have 4M-bit density

Featuring access times of 110 nsec, the 4M-bit IMP23416 and IMP23408 can feed data into microprocessors without relying on wait states. The 23416 holds 256k 16-bit words of data, which is equivalent to approximately 700 encyclopedia pages. Data are read from the device 16 bits at a time for direct compatibility with 16-bit µPs. The 23408 holds 512k 8-bit bytes of data, which makes it compatible with 8-bit microcontrollers. Both versions operate at 25 mA from a single 5V supply.

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International Microelectronic Products Inc, 70 E Daggett Dr, San Jose, CA 95134. Phone (408) 434-1397. Circle No. 405

4-Bit Microcontrollers
- Operate to 6 MHz
- Contain 12k or 16k bytes of masked ROM

The TMP47CXXXX series of 4-bit microcontrollers contains 12k or 16k bytes of masked ROM and a 768-nibble RAM, and have minimum instruction times of 1.3 µsec at 6 MHz and 244 µsec at 32 kHz. The TMP47C1260 and C1660 also contain an 8-bit A/D converter, a remote-control signal with preprocessing capability, and LED direct-drive capability. The TMP47C1270 and TMP47C1670 contain a 28-bit display controller, 4-LED direct-drive capability, a 14-bit PWM output, and a remote-control signal with preprocessing capability. All four devices are available in 64-pin DIPs and quad flatpacks. Production pricing is less than $5 (50,000). Delivery, 10 weeks ARO.

Toshiba America Electronic Components Inc, 9775 Toledo Way, Irvine, CA 92718. Phone (714) 455-2000, or contact regional office. Circle No. 406

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- Replace bipolar devices
- Offer faster response times

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CIRCLE NO. 150
Pamphlet On Keyboards
A brochure discusses RT-101 Right Touch keyboards for IBM PC, PC/AT, and PS/2 systems. The 8-pg publication provides functional diagrams, engineering data, specifications, features, and 4-color photos of each model.

NMB Technologies Inc, 9730 Independence Ave, Chatsworth, CA 91311. Circle No. 396

Brochure On Real-Time And Storage Scopes
A 10-pg brochure describes and illustrates five models of the Hitachi series of real-time and storage oscilloscopes. The fully illustrated pamphlet covers functions and benefits as well as specifications of the series.

RAG Electronics Inc, 21418 Parthenia St, Canoga Park, CA 91304. Circle No. 397

Volume Advocates Loyalty To DOS
The 410-pg book, Staying With DOS, targets PC users who need better performance from DOS but may not want to invest the time and expense to get a new operating system. Fourteen chapters cover the features of new operating systems and how DOS can be manipulated to provide more memory and speed, better graphics features, multitasking, and networking. Checklists help users assess needs, and Appendix A presents buying information. $22.95.

Ventana Press, Box 2468, Chapel Hill, NC 27515.

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Folder Spotlights Circuit Analyzer
A 4-color, 4-pg brochure presents the Dynalab 1024 circuit analyzer. The illustrated publication discusses complex circuit testing with detailed error reporting, optimized test performance, and software for an accurate test program. It also lists performance features and specifications.

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When you're called upon to computerize data-acquisition systems, Computer-Based Data Acquisition Systems: Design Techniques can help guide you through the design process. The volume contains analytical techniques for creating a functional design. Included in this second edition are sections on measurement error, error as a fundamental design criterion, sampled data systems, error models and budgets, sampling fundamentals, and functional design. $49.95; members, $40.

Instrument Society of America, Box 12277, Research Triangle Park, NC 27709. Circle No. 399

Catalog Lists RF And Microwave Components
This catalog of RF and microwave components incorporates information about Ultramin miniature filters and commercial-grade and tunable filters. Also included are programmable, fixed, and step attenuators; detectors; matching pads; and dc blocks. Other listings cover formulas, graphs, packaging outlines, and environmental capabilities.

Wavetek RF Products Inc, 5808 Churchman Bypass, Indianapolis, IN 46203. Circle No. 400

Source Book Of IBM PC-Compatible Products
The fourth annual edition of the Industrial Computer Source-Book/Supplement covers industrial computer systems and data-acquisition, industrial-control, and communications products for the IBM PC, PC/XT, PC/AT, and compatible computers. The supplement lists more than 500 products in its 96 pages. It has been expanded to include 20-, 15-, and 10-slot rack and tabletop chassis; 20-, 15-, and 10-slot chassis with a built-in keyboard drawer; and 20-, 15-, and 10-slot floor-mount units. Other additions include 386SX and 386 CPU cards, 19-in. rack accessories, and A/D and communications boards.

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BOOK REVIEW

It's back, and it's better than ever


Occasionally a book is published that is immediately embraced by both the professional and academic communities. A book that can successfully assimilate voluminous amounts of often cryptic information and present it to the reader in an easily digestible form. High-Performance Computer Architecture by Harold S Stone is such a book. Now it's back, and it's even better.

The second edition of this highly acclaimed text has seven chapters: Introduction, Memory-System Design, Pipeline Design Techniques, Characteristics of Numerical Applications, Vector Computers, Multiprocessors, and Multiprocessor Algorithms. Each chapter stands on its own; you need not read the first chapter to understand the second, and so on. High-Performance Computer Architecture includes 132 illustrations, a bibliography with 146 entries, and a combination index/glossary. Throughout the book, Stone includes pseudocode and equations to clarify the topics. And starting with Chapter 2, you can find numerous exercises at the end of each chapter.

The first chapter sets the tone of the book with a discussion of the factors that today's computer architect must consider to produce designs that work well and compete in the market. Some of these factors include algorithms, cost/performance, intended workload, architectural assists, and parallel architecture. Computer architects must evaluate their designs thoroughly. Stone declares, "The key to learning about computer architecture is learning how to evaluate architecture in the context of the technology available." He believes that "...methodology, not conclusions, ... needs to be taught."

This philosophy is supported in the text. At the end of the first chapter, Stone expands on the original definition of computer architecture, "to include the design of a computer system from its instruction set and structure down to functional modules," provided by Amdahl et al in the IBM Journal of Research and Development. Stone covers implementation issues in the text that expand the scope of this narrow definition.

Chapter 2, Memory-System Design, covers both cache and virtual memory. This is one of the more thorough discussions of cache-memory design I've seen. As established in the first chapter, Stone's emphasis is on design methodology and the analysis of the design. The primary difference between the first and the second edition in this chapter is Stone's extended treatment of cache-analysis and cache-performance modeling.

In the section on cache analysis, Stone elaborates on the problems associated with utilizing instruction trace-driven cache-evaluation techniques. He presents the cache initialization-transient phenomenon and a variety of techniques for dealing with the initialization transient. Stone has also introduced new material to this section that further illustrates the problem of attempting to evaluate cache performance with short instruction traces.

The cache-modeling section is new to this edition. In it, Stone introduces a model developed by Dominique Thiebaut in "On the Fractal Dimension of Computer Programs and its Application to the Prediction of the Cache Miss Ratio." In Thiebaut's model, the performance of a fully associative cache can be predicted after only a 1-pass analysis of the program trace has been performed to extract the parameters necessary for entry into the model.

The next chapter, Pipeline Design Techniques, discusses the principles of pipeline design and includes coverage of reduced-instruction-set computers (RISCs). Stone ventures deeper into RISC in this edition by discussing it in terms of pipelining. He contrasts and compares RISC to complex-instruction-set computers (CISCs), illustrating how the goals of a RISC-type architecture can be realized by synergistically combining complex instructions with proper pipeline techniques.

Stone presents the remaining four chapters with equal finesse. The professional or student seeking a text on advanced topics in high-performance computer architecture will do well to select this one. Unlike some textbooks I've seen, Stone's book lends itself very nicely to being used as a stand-alone reference. The material it covers is logically presented, well written, and well explained.—Richard W Miller

Richard Miller received a BS in computer science from Chaminade University (Honolulu, HI). He is a Macintosh consultant.

WHAT'S COMING IN EDN

EDN Magazine's November 8, 1990, issue will feature a staff-written Special Report on DSP development software. We'll conclude the designer's guide to bridge circuits and continue the real-time programming series with Part 5. In addition to the regular issue, you'll receive our special Wescon show guide. And look for our semiannual product showcase in the December issues.
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Designers of computer games are expert programmers, successful managers, and still kids at heart.

Jay Fraser, Associate Editor

In the early 1980s Richard Ditton worked for IBM at the John F Kennedy Space Center in Florida designing launch-system software for the space shuttle program. On one especially hot and humid summer’s day he decided to wear his tennis shoes to work. His supervisor suggested he take them off and put on regular shoes. Ditton ignored the suggestion. This lack of response would eventually lead to a new career for him.

“They kept giving me head-reshaping sessions, trying to get my tennis shoes off me,” says Ditton. “That went on for three months. It took them quite a while, but they finally told me not to come back unless I took my tennis shoes off.” He never went back.

Ditton and his wife Elaine moved to Chicago, where he went to work for a toy manufacturer doing what he had always wanted to do—designing computer games. A short time later Elaine joined the same firm as a games designer. In 1985 they quit and formed their own company, Incredible Technologies Inc. In the last five years the Dittons have published dozens of home and arcade games, and last year their company earned $4 million.

After leaving the University of California at Berkeley, Paul Grace worked as a programmer for a local bank. He quickly grew tired of it. Electronic Arts, an entertainment-software publisher, was located in nearby San Mateo. Grace had always been interested in computer games, so one day he simply drove down to the company to see if there were any positions available. Even though he had to take a substantial cut in pay, he went to work for Electronic Arts as a software tester. Today he is an associate.
producer specializing in military simulations. He selects and supervises teams that develop new home-computer games.

While attending a conference in Las Vegas, NV, Sid Meier and his friend Bill Stealey, both of whom then worked for General Instruments Corp, passed some time by playing an aerial combat game in an arcade. Stealey, a former jet pilot, complained about the poor quality of the game. Meier, who programmed minicomputers, said he could design a better game in one week flat. Stealey replied that if Meier designed it, he’d sell it.

It took Meier two months to design the game, but Stealey kept his word and the game became a best seller. In 1982 Meier and Stealey left General Instruments and founded their own company, MicroProse Software Inc. Since then Meier has created 10 computer games and more than 2 million copies of them have been sold worldwide.

These people share more than a distaste for conventional jobs. All their lives they have been fascinated by games. When they were children they played simple board games. Today they play sophisticated computer strategy games. Their work is simply an extension of their lifelong love. As Elaine Ditton says, “Programming is a game. Almost more of a game than the games we actually design.”

Computer games are big business. Dozens of companies put out hundreds of titles that sell millions of copies. The price of a single game can be as much as $100. The Software Publishers Association estimates that in North America last year sales of entertainment software (not including arcade games and Nintendo-style cartridge games) exceeded $288 million.

The origin of modern computer games can be traced to the Massachusetts Institute of Technology (Cambridge, MA). In 1962, a young programmer there named Steve Russell designed a game he called “Spacewar!” to run on a DEC PDP-1 that sometimes sat idle in his lab. Although primitive by today’s standards, “Spacewar!” used joysticks and fire buttons to enable players to blast each other’s spaceships to bits.

Russell let people make copies of his game free, and it soon spread to college campuses across the country. At the University of Utah, an engineering student named Nolan Bushnell came up with the idea of a coin-operated video game that could be put in arcades and barrooms just like pinball machines. In 1972 he and a partner put up $250 each and founded Atari to produce a game Bushnell had invented called “Pong.” The game was a smash, and Bushnell and his partner became multimillionaires.

The success of “Pong” lured thousands of programmers to try their hands at creating computer games. Attempting to cash in quickly on the growing boom, companies rushed out games that were poorly designed and too much alike. Arcades and stores were soon crowded with low-quality products, and customers grew disenchanted. In 1983 the computer-games market suffered an
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Sid Meier, whose computer games have sold more than 2 million copies worldwide.

enormous crash. Atari alone lost more than $500 million that year.

The market for home games revived more quickly than the arcade-game market because of improvements in computer hardware. New, more powerful microcomputers were introduced with greatly enhanced graphics, color, and sound capabilities. The new games designed for them were much more sophisticated and complex than the games of the 1970s.

More detailed simulations were devised that gave the player a better feel of piloting an airplane or driving a Grand Prix race car. Sound effects were also upgraded. For example, in sports games players could now hear the crack of the bat or the crunch of a tackle. Network games were introduced that enabled dozens of people to play against each other. Adventure games became more cinematic, with large casts of characters and intricate plots.

Sales of computer games began to pick up in the mid-1980s, but the day of the individual programmer who could create a game all by himself and get rich overnight was gone forever.

“No one person can program and do the art and the sound to the level that the customer expects now,” says Richard Ditton. “How many free-lance, full-length motion pictures are there today? In the early days of motion pictures there were a lot. All you needed was a camera. Throw some actors in front of it, and you could make a movie. If you wanted to make a motion picture now, you’d have to have a director, producer, sound people, lighting people, and many others.”

Elaine Ditton adds, “We started out small, with just the two of us. Then there were three of us. But in the last five years we’ve grown to 50 people because that’s what it takes to get a couple of games out there a year and be competitive.”

Incredible Technologies, Electronic Arts, and MicroProse have somewhat different methods for developing a game, but every game starts with an idea, and there’s no shortage of them. Entertainment-software companies receive thousands of proposals for games every year. Some are just brief letters. Some are elaborate programs on floppy disks. Most are unusable. Unsolicited proposals tend to be too specialized, or to repeat a game that’s already available, or to be just plain bizarre. People have suggested games based on train wrecks or all-out nuclear war.

“There are lots of ideas, good and bad, floating around,” says Sid Meier, “but it’s the execution of the idea that really differentiates a good product from a mediocre product. We don’t get ideas that make us say, ‘This is it! We’ve got to do this one because it’s such an incredible idea. Stop the presses and start this project!’ ”

Nevertheless, lightning does strike. Occasionally a proposal will be accepted by a publisher and developed into a game.

“A man in St. Louis named John Ratcliff came up with an algorithm for displaying a contour map at a fairly high frame rate on a PC and sent it to us,” says Paul Grace. “He had no contacts or anything. He just said, ‘Here’s this contour-mapping program I wrote. What do you think?’"
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“It was too slow for a flight simulator, but I thought that a nuclear-submarine game would be fun. There was a book out at that time about submarine warfare that was really enjoyable reading, and I wanted to do something like that. I got in touch with Ratcliff and told him what we wanted to do. He said that sounded great, so we brought him out and began working on it.”

There’s no secret to doing the programming for a computer game. It’s simply a matter of grinding out the work. John Ratcliff wrote approximately 120,000 lines of code for his submarine game, which took him, working on it in his spare time, about 20 months to write. The game was named ‘688 Attack Sub,’ and it has been a steady seller since its introduction.

The Software Publishers Association estimates that in North America last year sales of entertainment software exceeded $288 million.

Developing a game is also a process of trial and error, as Richard Ditton explains. “I look pretty comatose when I’m working on an idea. I have my feet up on my desk and I’m usually staring at the ceiling. People wonder if I’m asleep most of the day. What I’m doing is taking the idea and formulating it into a program. When I have it all worked out, I turn around and start typing away at the keyboard, implementing it. Then I play it and see that it’s really bad and throw out major chunks of it. Then I start staring at the ceiling again.”

Sid Meier also starts out with a prototype program and proceeds from there. “It’s sort of a process of evolving toward the final product—adding more graphics, adding sound, refining the game play, adding more screens, options, difficulty levels. Sometimes all the elements advance in parallel. Sometimes you need to branch off and work on one in isolation until it’s finished, then go back to the others.”

Paul Grace stresses the importance of teamwork in creating entertainment software. “In ‘688 Attack Sub,’ while we were putting in the hypertext interface we were building screens. As the graphic artist would complete a screen we would code it, make sure the interface fit the screen properly, then continue on to the next screen. The graphic artist is involved from the time we get the go-ahead to start work on the project.”

After the software is written and debugged, perhaps the most important phase of the development takes place. The game is adjusted and refined and polished until it has just the right feel. “Once you program something it’s not done,” says Elaine Ditton. “It has to be tweaked. A good arcade game or a good home game has a feel to it that can only be obtained by playing it over and over and making it exactly as you like it. That’s something that comes from more than just technical knowledge.”

Paul Grace calls the process play-balancing. “After we’re done, we start play-balancing the game. We have our testers play it, to make sure you can win the things you’re supposed to win, and that the things that are supposed to be hard to win are very hard. That’s play-balancing. That’s crafting. That’s what makes a good game a great game.”

“We used to have a joke around here that you know when to stop when the computer’s full,” says Sid Meier. “In those days we were working on Commodore 64s and Ataris and other machines like that with limited amounts of memory. These days you get to a point of diminishing returns and that’s when you stop. You get a feeling from playing the game that it’s done.”

**Preview of coming attractions**

The people who create computer games are very optimistic about the future of their industry, partially because significant improvements in hardware are just around the corner. CD-ROM drives and CDI (compact-disk interac-
At last, a LeCroy you won’t have to beg for.

Now you can get LeCroy Digital Oscilloscope performance for the price of an ordinary oscilloscope. At just $6,990, the new Model 9410 offers you unrivaled measurement capabilities. Waveforms are digitized with high signal fidelity into 10K acquisition memories and presented on the sharpest display of any oscilloscope (the above picture speaks for itself). One can zoom in on fine details, expand signals, and use the 9410’s digital cursors to get the ultimate in precision.

The Model 9410 doesn't stop there. It also includes LeCroy’s SMART trigger that detects buried glitches, timing violations, and logic states (you'll be prepared for the most elusive signals). Internal signal processing calculates time, voltage and frequency parameters in fractions of a second. And all the data can be transferred directly to printers, plotters or PC’s using the 9410’s high-speed GPIB or RS-232.

Price being equal, wouldn't you rather have a LeCroy?
**PROFESSIONAL ISSUES**

Significant improvements in hardware are just around the corner—CD-ROM drives and CD I (compact-disk interactive) will soon be widely available.

“One of the appeals of this industry is that we know hardware is going to keep improving,” says Sid Meier. “The technology of movies does advance, but it’s not going to be twice as good five years from now as it is today. The technology of making music or making television is not going to take the kind of major steps that we think are going to be taken in our industry over the next few years.”

The business of computer games has other appeals as well. “You get a lot of satisfaction when you see people playing your games, having a good time enjoying what you’ve created,” says Richard Ditton.

“The amount of creativity and freedom you have is a real satisfaction of doing this kind of work,” says Sid Meier. “You have an idea, you create it, you mold it, you watch it grow, you finish it, and you produce it. There’s a lot of satisfaction in seeing a project through from beginning to end. It’s not like doing something you don’t want to do. It’s only partly a job.”
Our reputation precedes us! From 5 subsidiaries and 35 distributors in more than 40 countries worldwide, thousands of customers purchased more in 1989 than ever before. And they were able to choose new products from an ever-expanding array of plotters, penless plotters, digitizers, recorders and supplies.

The Graphtec reputation is one of building products that work well and last a long time. We earned that reputation the hard way, by delivering over 40 years of the best innovation, support, and after-sales service in the industry.

To see what we mean, look no further than our MC5500 Digital Multicorder, the world’s smallest 12-channel pen recorder. This powerful instrument combines compact size and 12 recording channels with a wide array of intelligent functions and accessories.

Features include a bright digital display, 32 Kbyte memory card (256 Kbyte optional), 5 different printed logging/report modes, auto bias recording, zone recording, and even a GP-IB interface for control by a host computer.

Technology that matches the reputation... Graphtec.
In A World That's Shrinking Fast, Our Ideas Keep Getting Bigger.

Motorola Corporate Software Research and Development is performing research in compiler technology, optimization methods and development tools. This research covers the full range of Motorola MPUs, from microcontrollers to high performance RISC processors, parallel architectures and DSP. Within the next few years we will have laid the foundation for the design and development of the most advanced optimizing compilers available. There are excellent opportunities related to compiler research available for outstanding people.

We are designing compilers and compiler generation tools, implementing these on state-of-the-art UNIX platforms, and conducting research into improved methods of developing software for embedded systems. We work closely with university and consortium researchers on the latest techniques in optimization and code generation. You will interact with Motorola internal development groups who are developing embedded systems or other projects related to your research. You may also work directly with the designers of new microprocessors to influence future architectures from a systems perspective.

COMPILER RESEARCH & DEVELOPMENT OPPORTUNITIES

R & D ENGINEERS

We require an MS or PhD in Computer Science, Electrical Engineering or a related discipline and 5 years experience developing software, with a major portion being in the development of compilers or related tools. We are especially looking for experience with optimization techniques and code generation. Good written and verbal skills required. Must be able to work closely and effectively with other team members.

PRINCIPAL INVESTIGATORS

We require an MS or PhD in Computer Science with 5-15 years experience in the development of compilers. Significant experience with compiler generation tools and optimization techniques for high-performance systems necessary. Principal investigators will lead small dedicated research teams and interact with chip designers, system architects and external research organizations to define and prototype the next generation of compiler architectures. Good written and verbal skills required. Must have experience leading advanced software development groups and demonstrated leadership in compiler technology.

We offer a competitive salary, a comprehensive benefits package and excellent opportunities for professional growth. For immediate consideration, please send your resume to: Motorola, Inc., Corporate Staffing, Dept. TG9028, 1303 E. Algonquin Road, Schaumburg, IL 60196.

Call today for information on Recruitment Advertising:

East Coast: Janet O. Penn (201) 228-8610
West Coast: Nancy Olbers (603) 436-7565
National: Roberta Renard (201) 228-8602
In just six years, Dell has jumped to the top of the PC industry. Our high performance systems are hot and direct our growth-oriented philosophy. At Dell, the work is significant and requires technical superior individuals with strong initiative.

PERFORMANCE ANALYST
In this senior-level position, you will model, measure and analyze the performance of personal computer hardware and software architectures. To succeed, you must have a BS/MS in EE, CS or Math, plus experience in computer performance analysis, measurement and/or modeling. Broad knowledge of computer architectures is essential.

BIOS ENGINEER
Responsible for the development and integration of BIOS code for 80X86-based personal computer systems. Position requires a BS degree in an appropriate science with 2-4 years of firmware development experience in a PC, or PC-based system environment.

NETWORK VALIDATION ENGINEER
Design, develop and implement cost effective method for testing and trouble shooting. Design test fixtures and equipment test procedures for new products. LAN expertise knowledge of IEEE, ISD/DSI, connectivity expertise, 80286, 80386, 80486, Assembly language, C, DOS, OS 2/400. Indepth understanding of network operating systems and drivers as they apply to PC/AT/architectures.

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Responsible for the design of high performance, 80X86-based motherboards for desktop and portable personal computer systems. Position requires a BSEE and 3-5 years of applicable logic design experience working with advanced bus and computer architectures.

BUS INTERFACE ADAPTER BOARD DESIGN ENGINEER
Responsible for the design of logic for EISA and ISA bus interface adapter boards for personal computer systems. Position requires a BSEE and 3-5 years of applicable computer system and bus adapter board design experience, especially with SCSI, graphics, networking, DMA and bus master techniques.

SYSTEMS ENGINEER
Responsible for resolving hardware and firmware design changes in our 80286, 80386, and 80486 product families. Resolving compatibility issues for third party users both hardware and software. 2 plus years applicable experience in the design of complex systems in microprocessor based systems with knowledge of 80286, 80386 and 80486. Based in Austin, Texas the opportunities are challenging, the cost of living is low and the quality of life is high. If you are ready to imagine where we will be six years from now and you want to help direct that growth, mail or fax your cover letter and resume today: 512/343-3330, Dell Computer Corporation, Professional Employment, Department EDN102590, 9505 Arboretum Boulevard, Austin, Texas 78759.

Dell is an Equal Opportunity Employer. M/F/V/H.
One Company’s Vision Can Give Your Career A New View

GE Aerospace Military & Data Systems Operations states its mission simply. Be the premier contractor for sophisticated command, control, and information systems. We’re making our vision a reality through results-proven professionals like you.

Combine your expertise with our resources and you’ll discover how we reach solutions that no one else can — on time, on budget and right on target. At the same time, you’ll enjoy a level of involvement in national programs that few companies can match. You’ll work in an environment that’s constantly retooling for the future. And you’ll thrive with the opportunities for professional development and advancement that GE offers, including an in-house, accredited Master’s degree program.

We continually seek experienced, degreed systems and software professionals for opportunities in Valley Forge, PA, a thriving suburb of Philadelphia, and metropolitan Washington, DC.

**Systems Engineers & Analysts**
- **Command & Control**
  - C2 operations conceptualization and development
  - Top-level systems design and requirements definition
  - Segment design

**Resource Management**
- Operations research
- Man-machine interfaces
- Software lifecycle

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- Image understanding
- Object-oriented technology
- Sun, Symbolics and VAX environments
- ART, CLIP, KEE, Lisp and C++ languages

**Data Systems Engineers**
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- Network security
- Accreditation of trusted systems
- DoD 5020.28 criteria

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- Software development for vast information processing systems and applications
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**Computer Security Specialists**
- Development of trusted systems, software, databases, operating systems or communications
- 2+ years in a computer security role, ideally in an IBM mainframe environment

**Communications Systems Engineers**
- Systems architecture, requirements analysis and definition, and the design and development of RF analog or digital communications systems
- 3+ years experience with satellite or ground systems

**Telephony Engineer**
- Design, installation and integration of telecommunications systems
- 3+ years experience with digital transmission of data-voice-video, voice-data encryption, digital coding

**Wang VS Systems Analysts**
- Applications and utilities support to Wang VS users
- Hands-on knowledge of Wang VS system utilities, VS procedure language, 20/20 spreadsheet design and development
- 3+ years Wang analytical support experience

**Wang VS Systems Administrators**
- User support and overall resource management for information centers with multiple Wang VS systems
- LAN/WAN operations experience
- BSCS or 3 years experience in systems administration

**Application Programmers**
- Software development for strategic business systems
- 3+ years experience with IBM and Macintosh, DB2 and IDMS

**Systems Programmers**
- Applications development and maintenance, installation of systems products
- Hands-on experience with large mainframe and system internals plus MVS/XA, CICS, VTAM, VM, SMP/E, ACF2, TMS, JES2, ASM2, VMP/HPO

**Relational Database Specialists**
- Transform user requirements into relational models
- Hands-on experience with DB2, IDMS/ADSO, Adabas/Natural, M204, Oracle, Ingres, and Sybase

U.S. citizenship and military or civilian experience in a sensitive classified environment is preferred for most positions.

The vision to make new ideas happen is a hallmark of M&DSO. Now make it the mark of your career. If you are interested in Valley Forge, please send your resume to: GE Aerospace Military & Data Systems Operations, Dept. BJ25, P.O. Box 8048, Philadelphia, PA 19101. Washington candidates should send resumes to: Dept. BJ25, 8080 Grainger Court, Springfield, VA 22153. An equal opportunity employer.
Nestled in a shady forest, Compaq’s beautiful 1,000-acre campus inspires freedom, innovation and personal satisfaction.

When all the elements fall into place, and the right people are free to perform at their absolute best, the result is always successful.

At Compaq, our common sense approach to business has helped make us a world leader in advanced personal computers. But it's our commitment to people, our relentless dedication to building a quality work environment, that's the heart of our success. At Compaq, our people find an environment where they're encouraged to put their greatest abilities to the test—pushing the limits of technology, and finding practical solutions to the needs of today's PC user. An environment that encourages teamwork, yet recognizes individual achievement, where every voice is heard, and where the quality of the product is simply a reflection of the quality of the individual.

Why do the best call Compaq home? Because Compaq brings out the best in its people. Currently, we're looking for talented professionals who welcome challenge and want to play a part in the next generation of high-performance PCs. If you'd like a chance to do your best work, now's your best opportunity.

**Product Engineers**

Take design concepts and develop them into outstanding Compaq products in this high-volume manufacturing position. You will be responsible for monitoring, evaluating and recommending solutions for current and future personal business computers and peripherals, as well as coordinating engineering projects and issues with other areas of Compaq.

Positions are available for Product Engineers with experience in one or more of the following areas:

- Knowledge of disk interface systems (ESDI) or mass storage systems.
- 386/486 based PC architecture or related experience.
- Experience with telecommunications products.
- Mechanical product engineering.

**Statistical Process Control**

Put your expertise to the test supporting the training, administration and implementation of SPC techniques to be used in the manufacturing process. The ability to recommend equipment and tools needed for all SPC applications to ensure the systems are providing critical information for continued process improvement is required.

Qualify with a BS in Engineering or Mathematics and a minimum of three years' experience in a fast-paced manufacturing environment with at least two years' experience in the development and implementation of statistical process control. Familiarity with SMT and/or Thru-hole, PCA manufacturing and quality techniques are preferred. Excellent oral/written communication skills and presentation skills are required.

**Test Engineers**

Develop and design in-house tests and test equipment to use for performing hardware and software tests on PC related products.

Qualify with a BSEE and a minimum of two years' related test development experience. Knowledge of communications related boards is a plus.

**Reliability Engineer**

Start with the ability to perform specific new research and tests in quality areas directly related to electrostatic discharge.

Qualify with a BSEE, an additional degree in ME or MS preferred, and experience in electrostatic discharge technology and RF.

**Diagnostic Systems Engineers**

An exciting opportunity exists for an engineer to develop user diagnostics and software utilities that will be used as aides for innovative new products in the PC and peripheral markets.

We also have openings for engineers to develop and maintain manufacturing diagnostics that provide immediate solutions for system performance problems. A BSEE, BSCS and knowledge of microprocessors is required.

**Component Reliability Engineer**

Develop component test programs to perform engineering evaluations of state-of-the-art VLSI or memory testers. Knowledge of PCs would be a plus. Qualify with a BSEE and a minimum of three years' related test experience.

**Systems Test Engineers**

Qualify with a BSEE, an additional degree in ME or MS preferred, and experience in electrostatic discharge technology and RF.

**Statistical Process Control**

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EDN October 25, 1990
PRODUCT MANAGER
Night Vision Goggles

SRL, a medium sized applied R&D company located on a 30 acre research campus near Dayton, Ohio, has an immediate opening for a Product Manager to lead a night vision goggle development program. Responsibilities include defining the hardware requirements and coordinating the production and product support activities. Requires a BSME or equivalent and 5 years of project management experience in an optical assembly environment. We provide an attractive salary and benefit package along with a challenging technical work environment. Reply in confidence to SRL, Dept. 46.

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EOE/MFHV

If You’re Looking For a Job, You’ve Come to The Right Place.

EDN CAREER OPPORTUNITIES

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Seagate has every reason to be confident as the ’90’s begin.

Our passionate work ethic inspires confidence. By minimizing restrictions and red tape, you’re empowered to do your very best work. And it’s permitted the company to move forward and innovate like never before. With memory storage technology for everything from laptops to minicomputers and mainframes. From 20 Mbytes to 2.5 Gbytes. And it’s a commitment that’s backed by generous R&D spending.

Today, there’s an excitement at Seagate that shows in the work. And in our people. That’s why we’re confident you’ll be interested in one of the following immediate opportunities.

DESIGN ENGINEER - HEADS & MEDIA
BSEE plus three years’ experience in rigid disc, magnetics, and/or analog design. Responsible for the evaluation, qualification, and specification of heads and media for rigid disc applications.

HEADS MEDIA TECHNOLOGY MANAGER
BSEE or related field plus five years accumulated experience in the development, application, and/or integration of magnetic recording heads and media in disc drives. Experience as a project engineer or lead engineer preferred.

ELECTRICAL ENGINEER - PWA DESIGN, MANUFACTURING
BSEE and a minimum three years of directly related design experience.
• Analog LSI Design Engineer
• Read/Write Engineer
• Microprocessor Systems Engineer
• FCC Compatibility Design and Test Engineer
• Brushless DC Motor Control Circuit Design Engineer

MECHANICAL DESIGN ENGINEER
BSME plus three years related experience. Structural and vibration analysis, and machine design.

RELIABILITY ENGINEER
BSEE or a related degree and a minimum of three years of disc drive test and component level failure analysis experience.

APPLICATION ENGINEER
BSEE/EET and a minimum three years of experience. Provide technical expertise for application of rigid disc products to OEM customers, sales, and technical support organizations. Requires disc drive or other electronic applications and digital circuits experience.

Seagate offers excellent salaries, comprehensive benefits, exciting work in a highly professional work place, and the quality yet affordable lifestyle of Oklahoma City.

To arrange an interview, please send your resume in confidence to Seagate, P.O. Box 12313, Oklahoma City, OK 73157, Attn: Professional Staffing, Dept. EDN-10.25. We’re an equal opportunity employer.
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<td><strong>Oper. Temp. (°C)</strong></td>
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<td>-55 to +100</td>
<td>-55 to +100</td>
<td>-55 to +100</td>
</tr>
<tr>
<td><strong>Stor. Temp. (°C)</strong></td>
<td>-55 to +100</td>
<td>-55 to +100</td>
<td>-55 to +100</td>
<td>-55 to +100</td>
</tr>
<tr>
<td><strong>Price (10-24) (1-9)</strong></td>
<td>$39.95</td>
<td>$59.95</td>
<td>$59.95</td>
<td>$109.95</td>
</tr>
</tbody>
</table>

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