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OCTOBER 25, 1990

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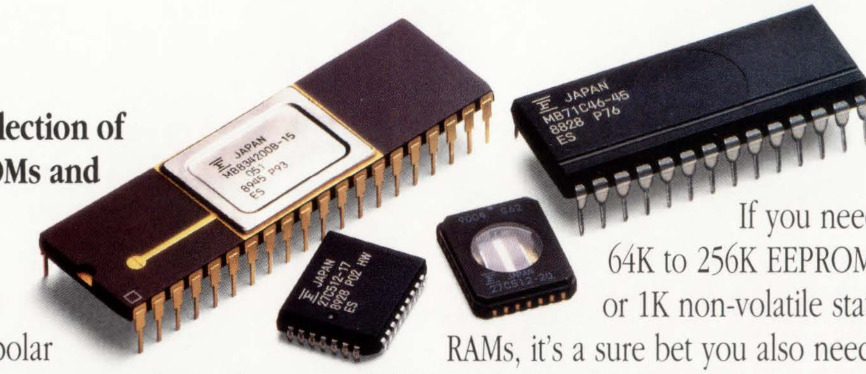

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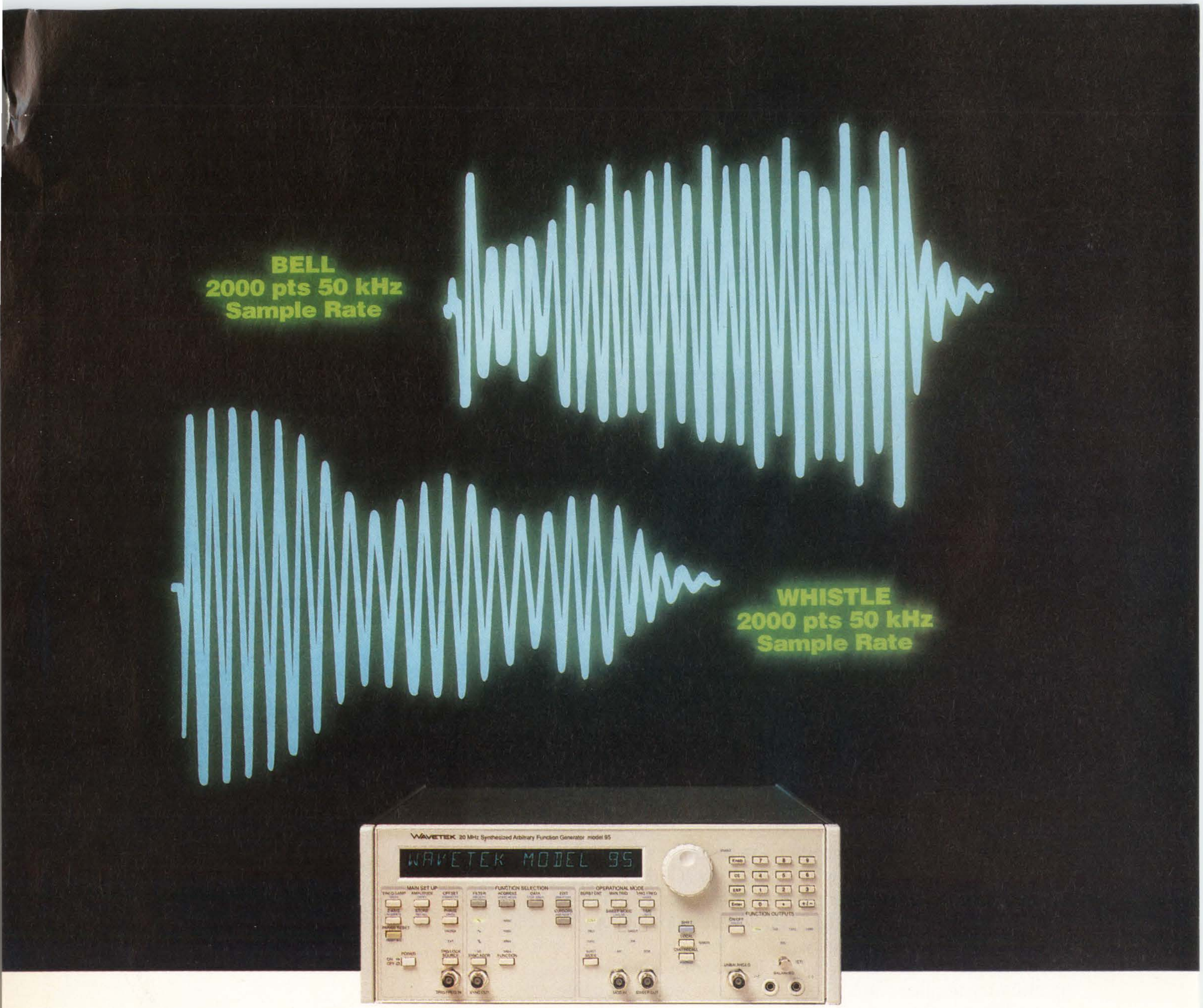

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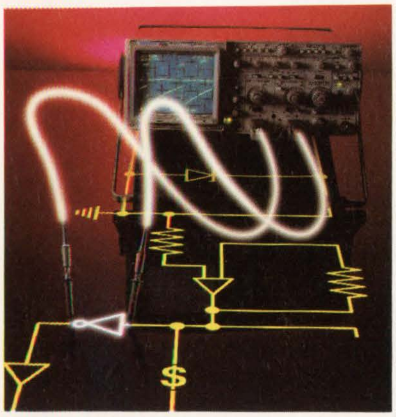
Volume 35, Number 22 — October 25, 1990

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS



On the cover: *When it comes to purchasing digital storage oscilloscopes, you don't have to sacrifice performance for price. But to get the right low-cost DSO for your application, you should carefully consider each instrument's features. See the Special Report on pg 144. (Photo courtesy Tektronix Inc)*

TEST & MEASUREMENT SPECIAL ISSUE

SPECIAL REPORT

DESIGN FEATURES

Continued on page 7

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Continued from page 5

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October 25, 1990

You can now combine the maturity of the PC-based instrumention field *with the convenience of portability to work beyond the confines of the lab (pg 59).*

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TECHNOLOGY UPDATES

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DESIGN IDEAS

EDITORIAL 53

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.

NEW PRODUCTS

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The not-so-serious business of computer games

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

DEPARTMENTS

Finally, a 400 MHz IC Evaluation System.

Before you send those fast ASIC designs off to production, make sure they'll handle the stress of real-world operating conditions.

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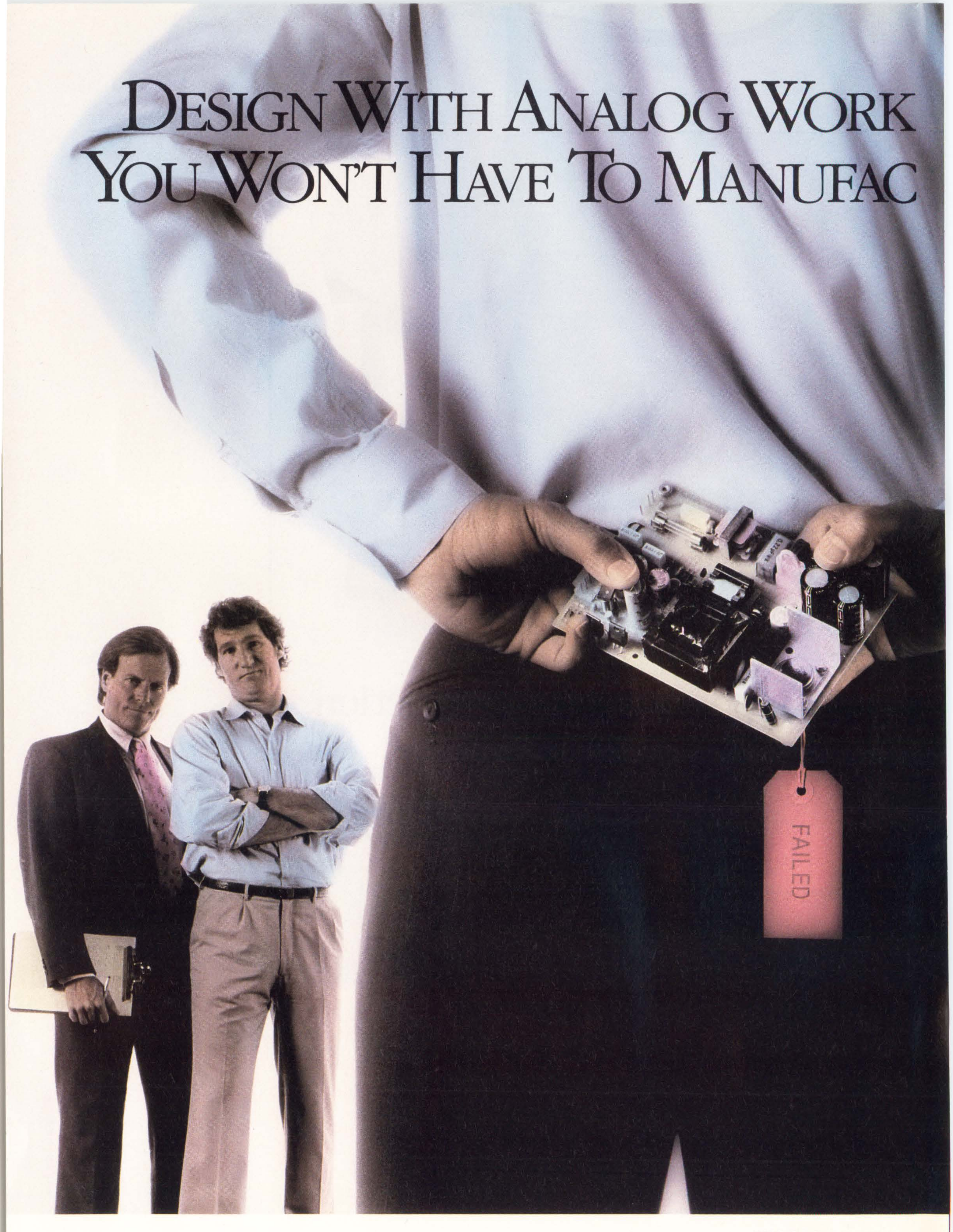
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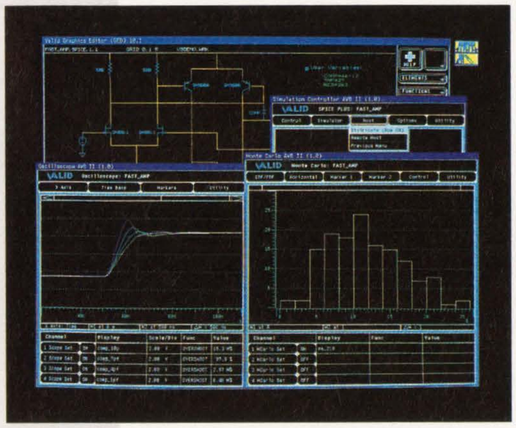

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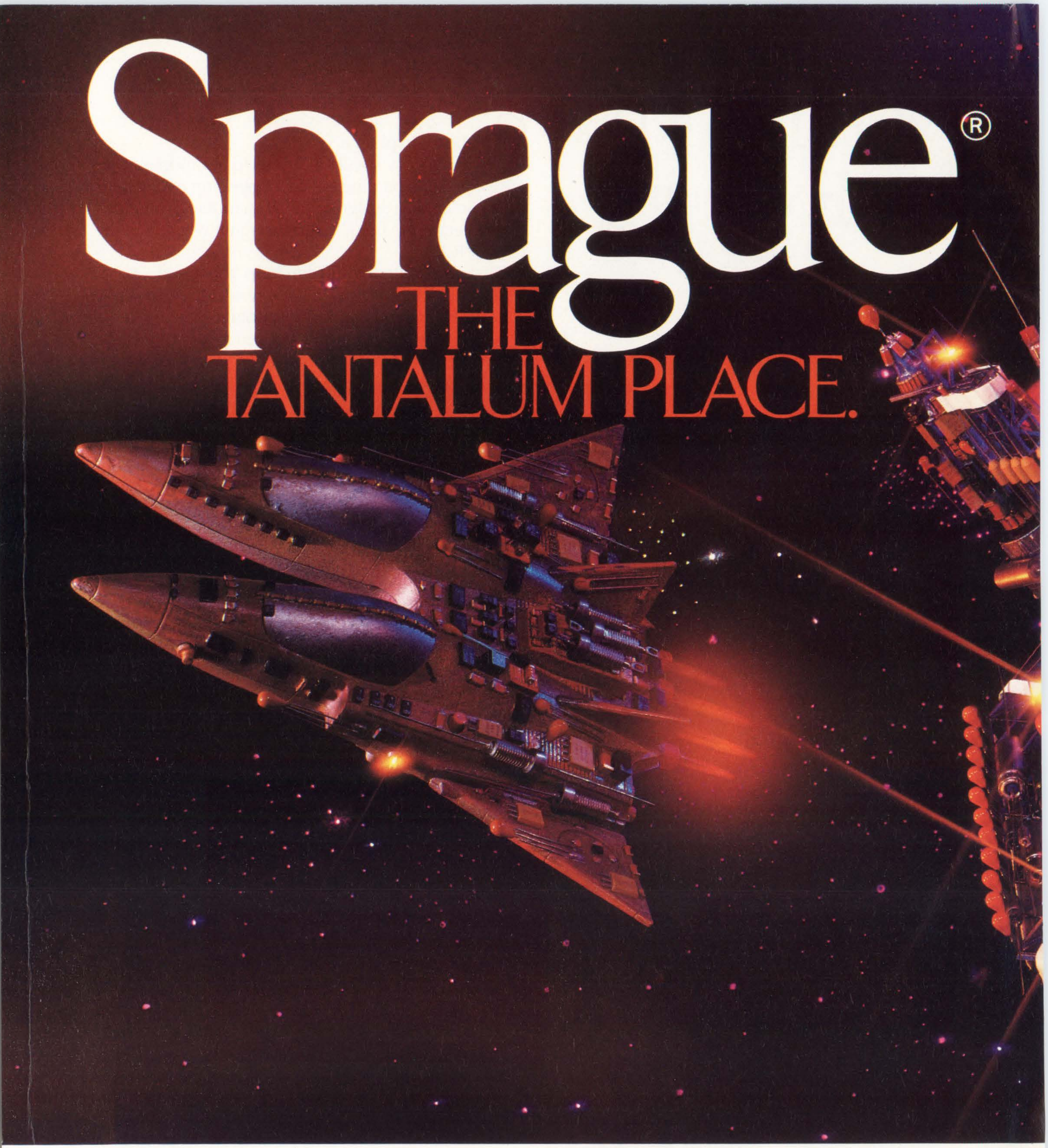

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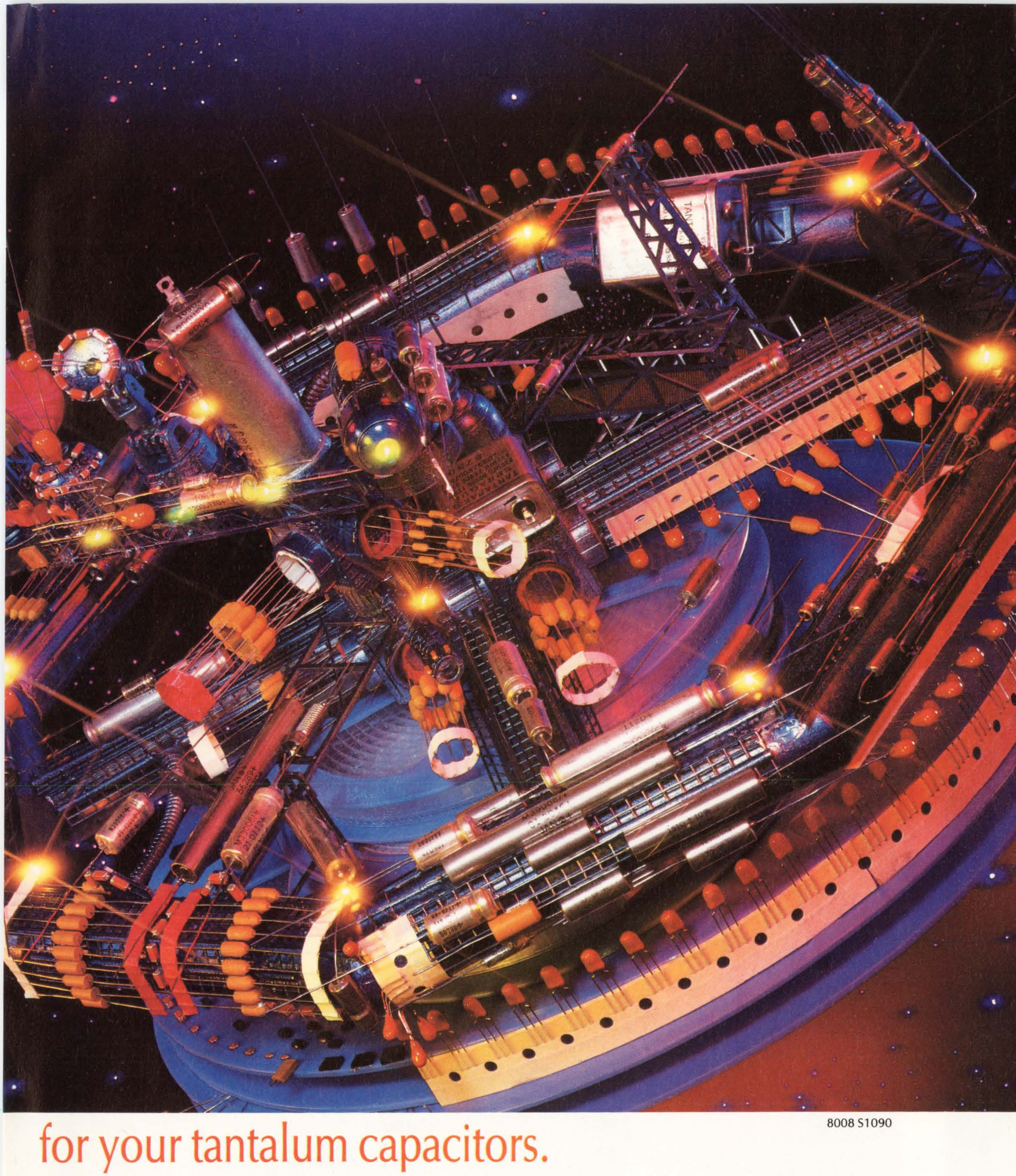

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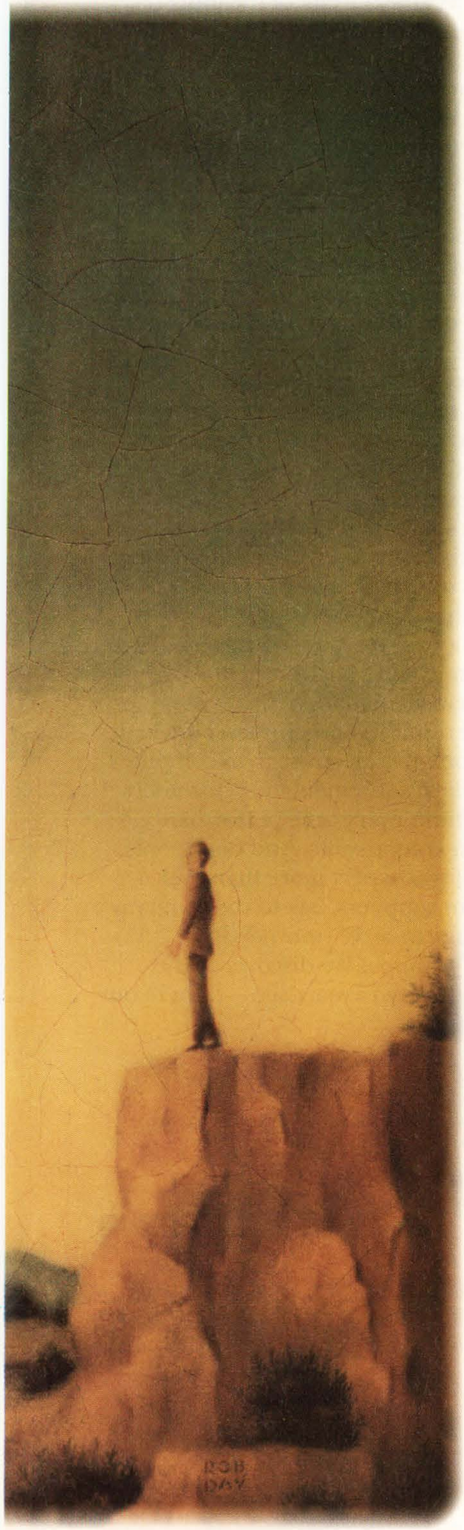

NEWS BREAKS

EDITED BY SUSAN ROSE

600V IGBTs IMPROVE SWITCHING EFFICIENCY BY 50%

International Rectifier (El Segundo, CA, (213) 772-2000) now offers its Ultrafast 600V IGBT (insulated gate bipolar transistor) product line. These power transistors feature a 3V saturation voltage spec, and offer a 50% improvement in switching efficiency over existing IGBTs. IGBTs have a voltage-sensitive gate input (such as MOSFETs have) to what is essentially a bipolar transistor. This family of products offers continuous collector current specs ranging from 13A (IRGBC20U) to 55A (IRGPC50U) at $4.65 to $22.09 (1000). The family also includes 23 and 40A parts. Data sheets list an E_{TS} spec, which defines total switching energy loss at a specific current. The IRGBC20U E_{TS} is 0.5 mJ and the IRGPC50U E_{TS} is 2.8 mJ at half rated current.—Maury Wright

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 IIsi 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-in^2 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

NEWS BREAKS

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 mAhr, respectively. Two more family members, the ⅘Af and D cells, match the highest capacities available for those two sizes: 1000 and 5000 mAhr, 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) 437-5129) 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 Obsipo, 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 V53 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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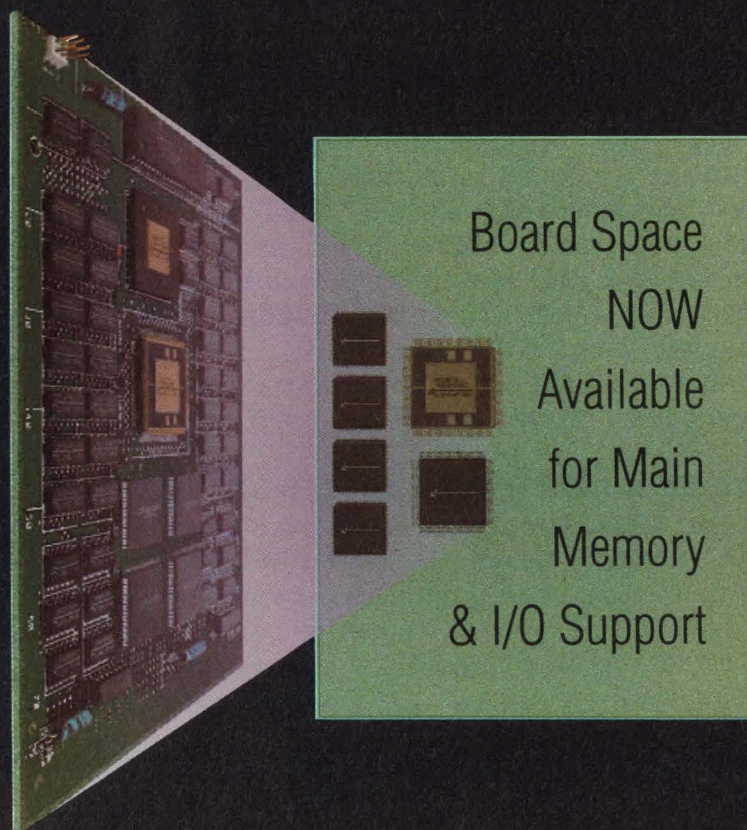

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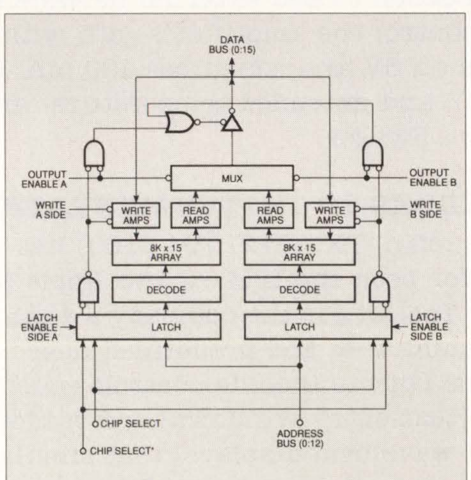

BiCameral SCRAM Logic Diagram

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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 fall-back 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

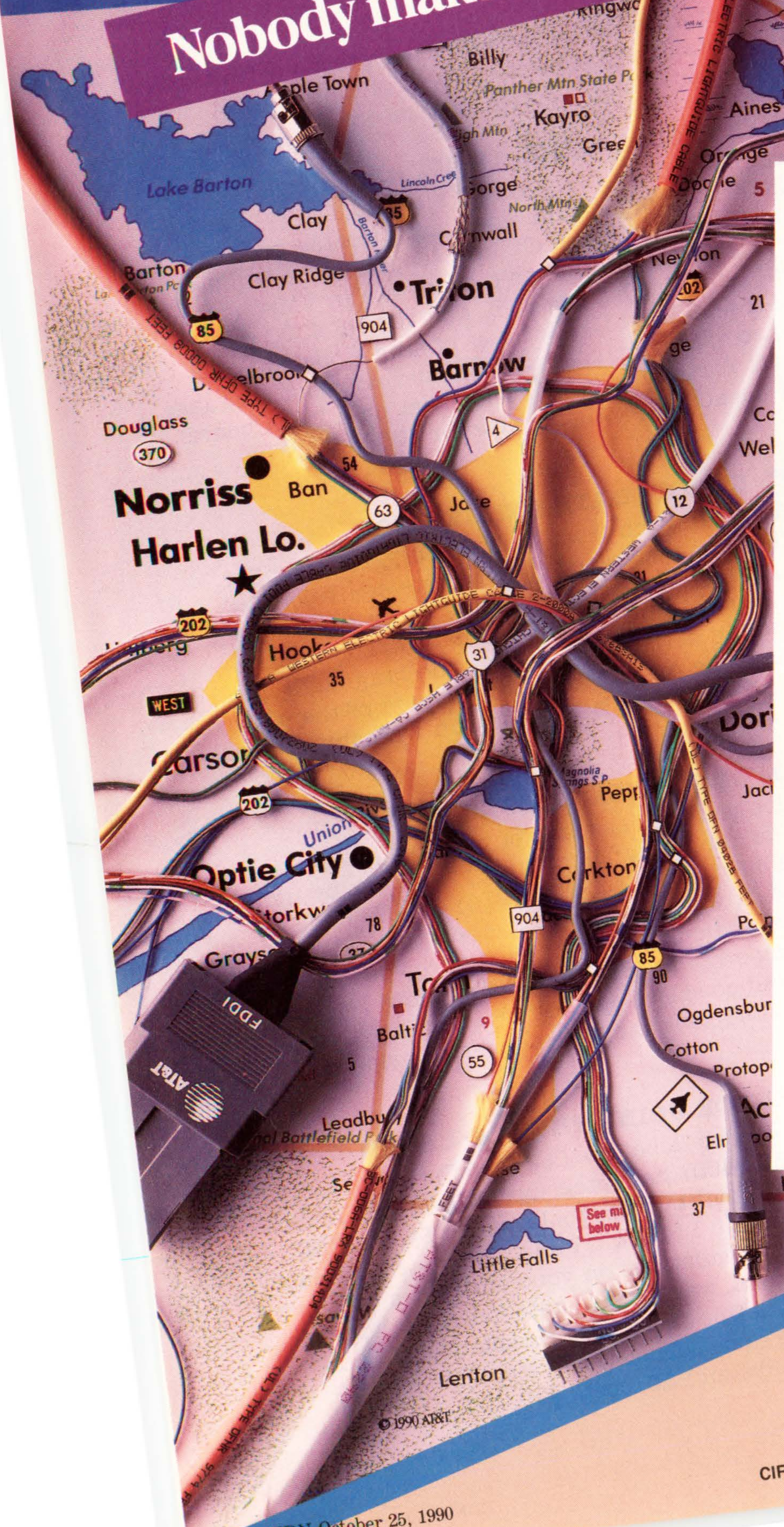
TWO NEW VERSIONS ADDED TO INSTRUMENTATION SOFTWARE

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

AT&T.

Nobody makes more connections.



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AT&T Network Systems

CIRCLE NO. 213

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 × 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

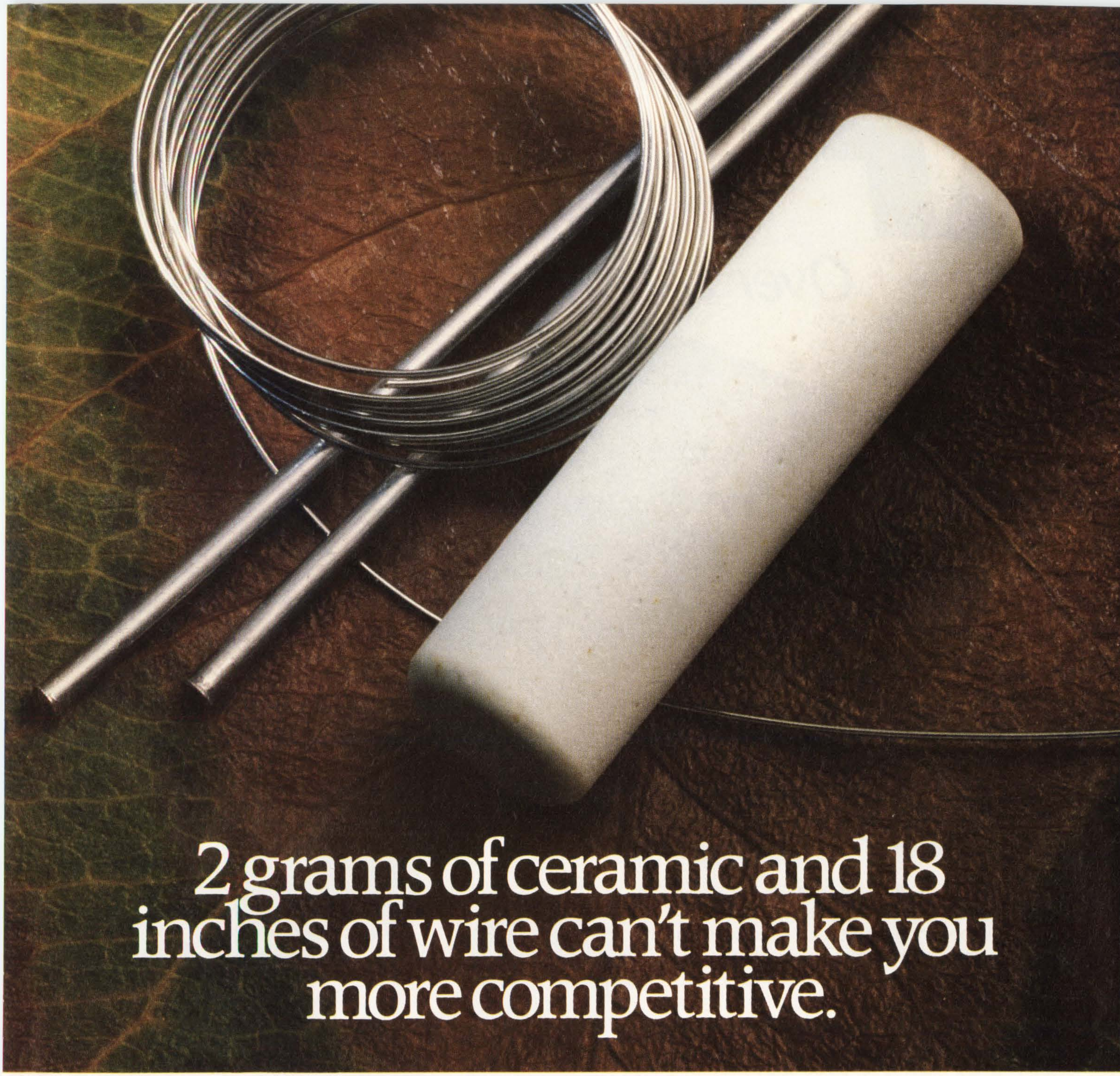
Claiming a 20% improvement in gate utilization from its updated FPGA compiler, Plus Logic (San Jose, CA, (408) 293-7587) has upgraded claimed gate equivalencies for its existing FPGAs. The software package responsible for this progress, Plustran 2.0, compiles schematics generated by several third-party 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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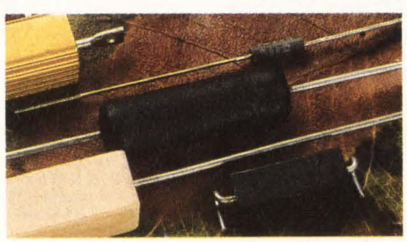

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CIRCLE NO. 214

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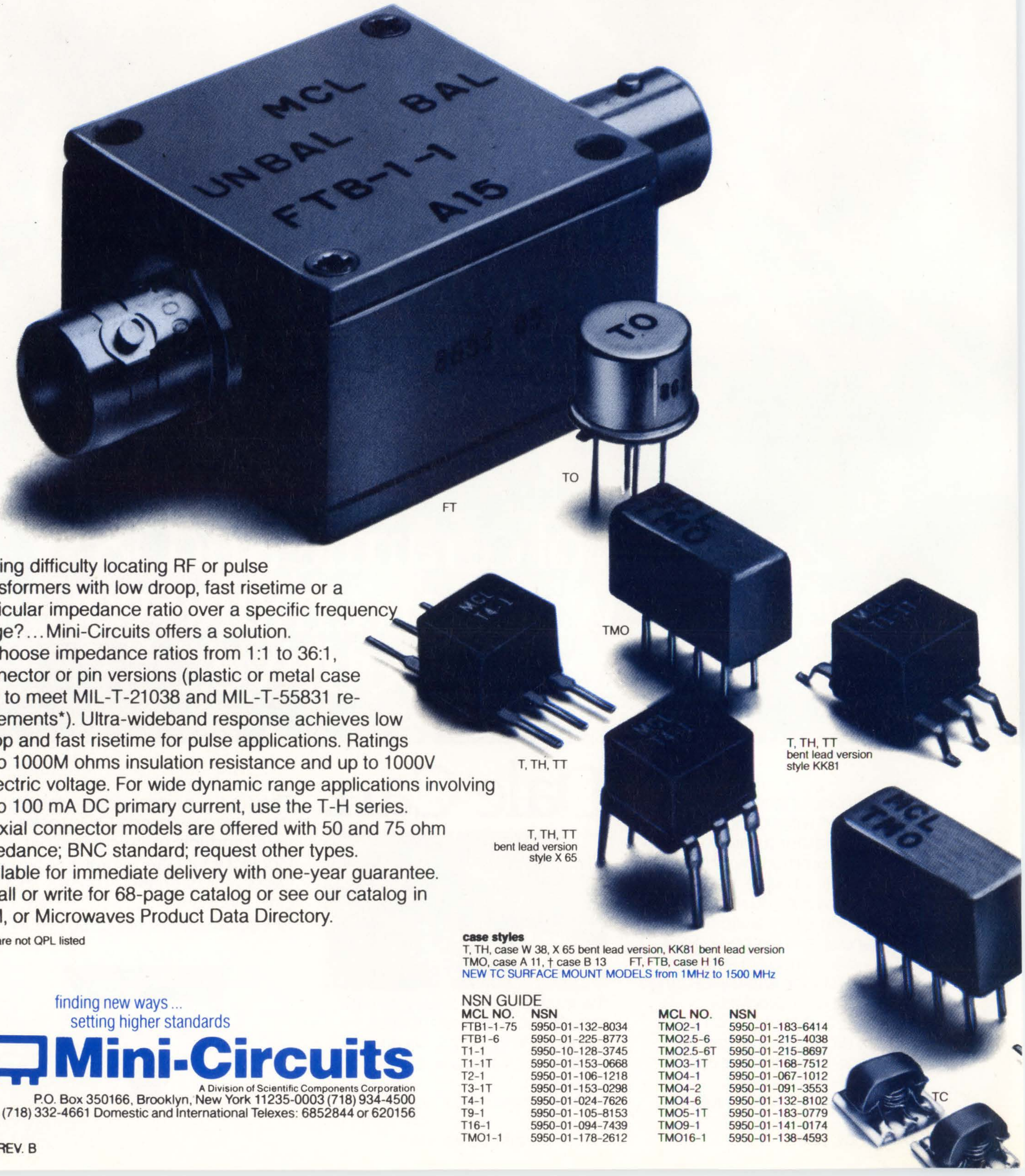

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*units are not QPL listed

case styles
T, TH, case W 38, X 65 bent lead version, KK81 bent lead version
TMO, case A 11, † case B 13 FT, FTB, case H 16
NEW TC SURFACE MOUNT MODELS from 1MHz to 1500 MHz

NSN GUIDE

MCL NO.	NSN	MCL NO.	NSN
FTB1-1-75	5950-01-132-8034	TMO2-1	5950-01-183-6414
FTB1-6	5950-01-225-8773	TMO2.5-6	5950-01-215-4038
T1-1	5950-10-128-3745	TMO2.5-6T	5950-01-215-8697
T1-1T	5950-01-153-0668	TMO3-1T	5950-01-168-7512
T2-1	5950-01-106-1218	TMO4-1	5950-01-067-1012
T3-1T	5950-01-153-0298	TMO4-2	5950-01-091-3553
T4-1	5950-01-024-7626	TMO4-6	5950-01-132-8102
T9-1	5950-01-105-8153	TMO5-1T	5950-01-183-0779
T16-1	5950-01-094-7439	TMO9-1	5950-01-141-0174
TMO1-1	5950-01-178-2612	TMO16-1	5950-01-138-4593

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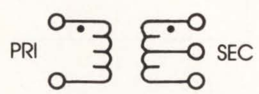
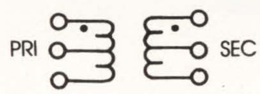
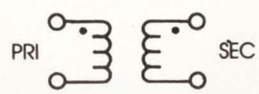
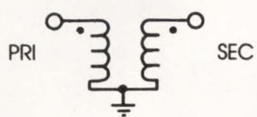
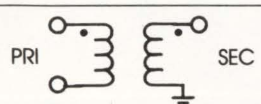
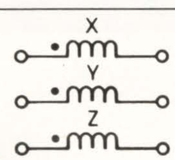
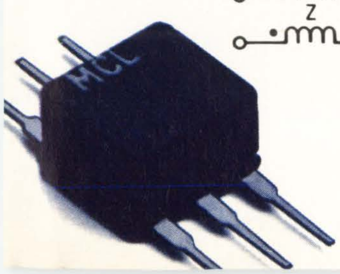
C72-1 REV. B

FORMERS

3KHz-800MHz *from* $\$3^{25}$

case style number see opposite page		MODEL NO.	Ω RATIO	FREQUENCY MHz	INSERTION LOSS 3dB MHz	2dB MHz	1dB MHz	PRICE $ Qty. (1-9)
A* 	T	T1-1T	1	.05-200	.05-200	.08-150	.2-80	4.45
		T1-6T	1	.003-300	.003-300	.01-150	.02-50	6.95
		T2-1T	2	.07-200	.07-200	.1-100	.5-50	4.95
		T2.5-6T	2.5	.01-100	.01-100	.02-50	.50-20	4.95
		T3-1T	3	.05-250	.05-200	.1-200	.5-70	4.95
		T4-1	4	.2-350	.2-350	.35-300	2-100	3.25
		T4-6T	4	.02-250	.02-250	.05-150	0.1-100	4.45
		T5-1T	5	.3-300	.3-300	.6-200	.5-100	4.95
		T8-1T	8	.03-140	.03-140	.10-90	1-60	7.95
		T13-1T	13	.3-120	.3-120	.7-80	5-20	4.95
		T16-6T	16	.03-75	.03-75	.06-30	.1-20	5.65
	TH	T4-1H	4	10-350	10-350	15-300	25-200	5.95
	TMO	TMO1-1T	1	05-200	.05-200	.08-150	.2-80	7.95
		TMO2-1T	2	.07-200	.07-200	.1-100	.5-50	8.45
		†TMO2.5-6T	2.5	.01-100	.01-100	.02-50	.05-20	8.45
		†TMO3-1T	3	.05-250	.05-250	.1-200	.5-70	7.95
		TMO4-1	4	.2-350	.2-350	.35-300	2-100	6.25
		TMO5-1T	5	.3-300	.3-300	.6-200	5-100	8.45
		TMO13-1T	13	.3-120	.3-120	.7-80	5-20	8.45
B* 	TT	TT1-6	1	.004-500	.004-500	.02-200	.1-50	6.95
		TT1.5-1	1.5	.075-500	.075-500	.2-100	1-50	5.95
		TT2.5-6	2.5	.01-50	.01-50	.025-25	.05-10	6.45
		TT4-1	3	.05-200	.2-50	.2-50	1-30	5.95
		TT4-1A	4	0.1-300	0.1-300	0.2-250	0.3-180	6.95
		TT25-1	25	.02-30	.02-30	.05-20	.1-10	9.95
	TTMO	TTMO25-1	25	.02-30	.02-30	.05-20	.1-10	11.95
		TTMO1-1	1	.005-100	.005-100	.01-75	.05-40	11.45
		TTMO4-1A	4	0.1-300	0.1-300	0.2-250	0.3-180	13.95
C 	T	T1-1	1	.15-400	.15-400	.35-200	2-50	3.25
		T1.18-3	1.18	0.01-250	0.01-250	0.02-200	0.03-50	5.65
		T1-6	1	.01-150	.01-150	.02-100	.05-50	5.65
		T1.5-1	1.5	.1-300	.1-300	.2-150	.5-80	4.45
		T1.5-6	1.5	.02-100	.02-100	.05-50	0.1-25	5.65
		T2.5-6	2.5	.01-100	.01-100	.02-50	.05-20	4.45
		T4-6	4	.02-200	.02-200	.05-150	.1-100	4.45
		T9-1	9	.15-200	.15-200	.3-150	2-40	3.95
		T16-1	16	.3-120	.3-120	.7-80	5-20	4.45
		T36-1	36	.03-20	.03-20	.05-10	.1-5	6.95
	TO	TO-75	1	10-500	—	10-500	40-250	6.95
	TH	T1-1H	1	8-300	8-300	10-200	25-100	5.95
		T9-1H	9	2-90	2-90	3-75	6-50	6.45
		T16-H	16	7-85	7-85	10-65	15-40	6.45
	TMO	TMO1-02	1	1-800	1-800	2-500	—	9.45
		TMO1-1	1	.15-400	.15-400	.35-200	2-50	6.25
		TMO1.5-1	1.5	.1-300	.1-300	.2-150	.5-8	8.45
		†TMO2.5-6	2.5	.01-100	.01-100	.02-50	.05-20	7.95
		†TMO4-6	4	.02-200	.02-200	.05-150	.1-100	7.95
		TMO6-1	6	.3-200	.3-200	.5-150	5-50	7.95
		TMO9-1	9	.15-200	.15-200	.3-150	2-40	7.95
		TMO16-1	16	.3-120	.3-120	.7-80	5-20	7.95
D 	T	T2-1	2	.050-600	.050-600	.1-400	.5-200	3.95
		T3-1	3	.5-800	.5-800	2-400	—	4.45
		T4-2	4	.2-600	.2-600	.5-500	2-250	3.95
		T8-1	8	.15-250	.15-250	.25-200	2-100	3.95
		T14-1	14	.2-150	.2-150	.5-100	2-50	4.95
	TMO	TMO2-1	2	.050-600	.050-600	.1-400	.5-200	7.95
		TMO3-1	3	.5-800	.5-800	2-400	—	8.45
		TMO4-2	4	.2-600	.2-600	.5-500	2-250	7.95
		TMO8-1	8	.15-250	.15-250	.25-200	2-100	7.95
		TMO14-1	14	.2-150	.2-150	.5-100	2-50	8.45
	FT	FT1.22-1	1.22	.005-100	.005-100	.01-50	.05-25	35.95
		FT1.5-1	1.5	.1-400	.1-400	5-200	1-100	35.95
E 	FTB	FTB-1	1	.2-500	.2-500	.5-300	1-100	36.95
		FTB1-6	1	.01-125	.01-125	.05-50	.1-25	36.95
		■FTB-1-75	1	.5-500	.5-500	5-300	10-100	36.95
F 	T	T-622	1	0.1-200	0.1-200	0.5-100	5-80	3.25
		T626	1	0.01-10	0.01-10	0.2-5	.04-2	3.95



■ Denotes 75 ohm models

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0.1 dB over 1 dB frequency range
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C72-2 REV. B

CIRCLE NO. 215

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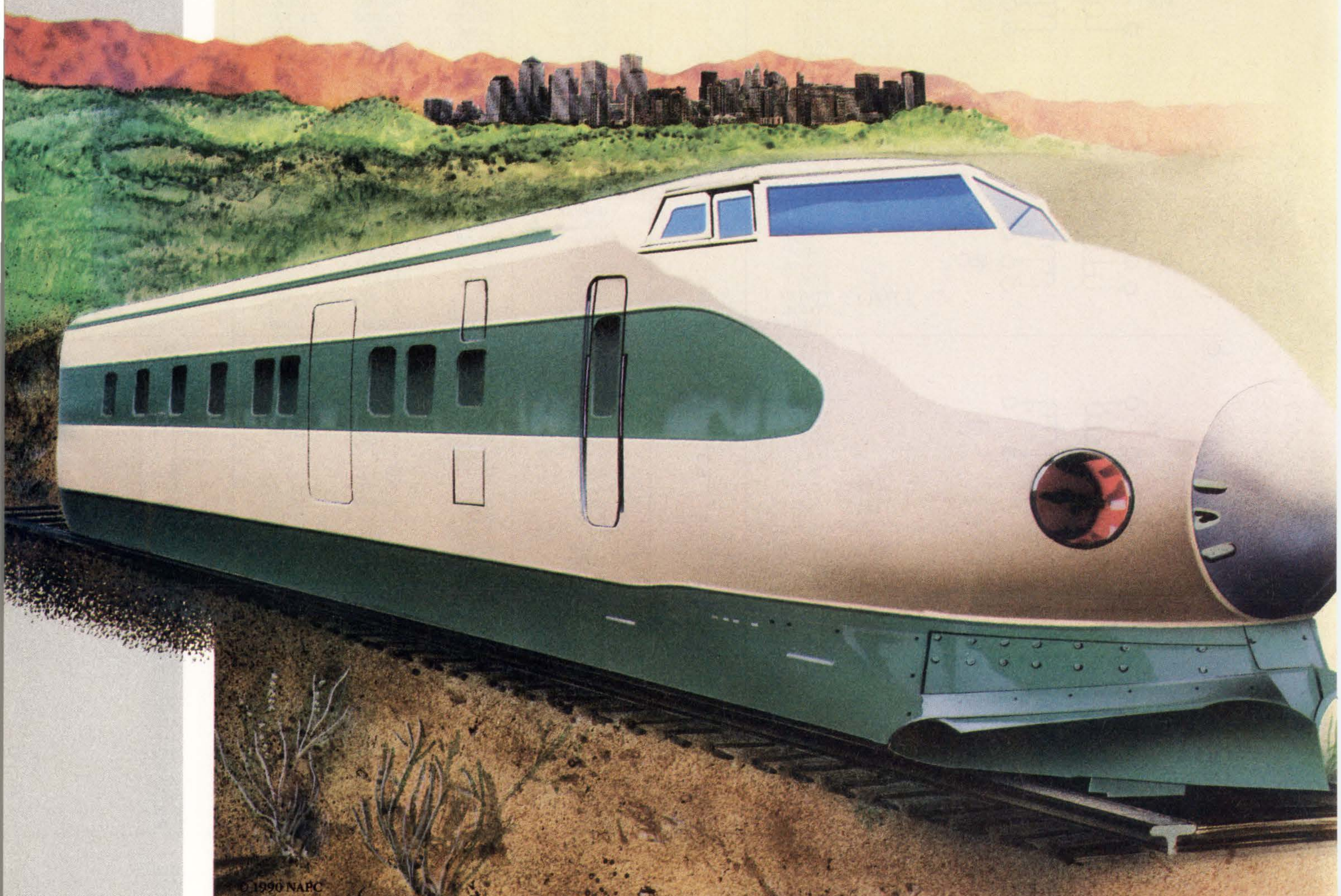

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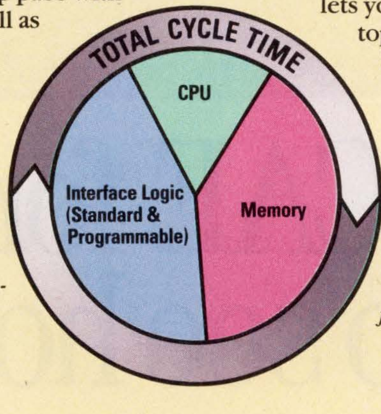

As processor speed increases, and total cycle time decreases, the percentage of time spent performing interface functions becomes more significant.

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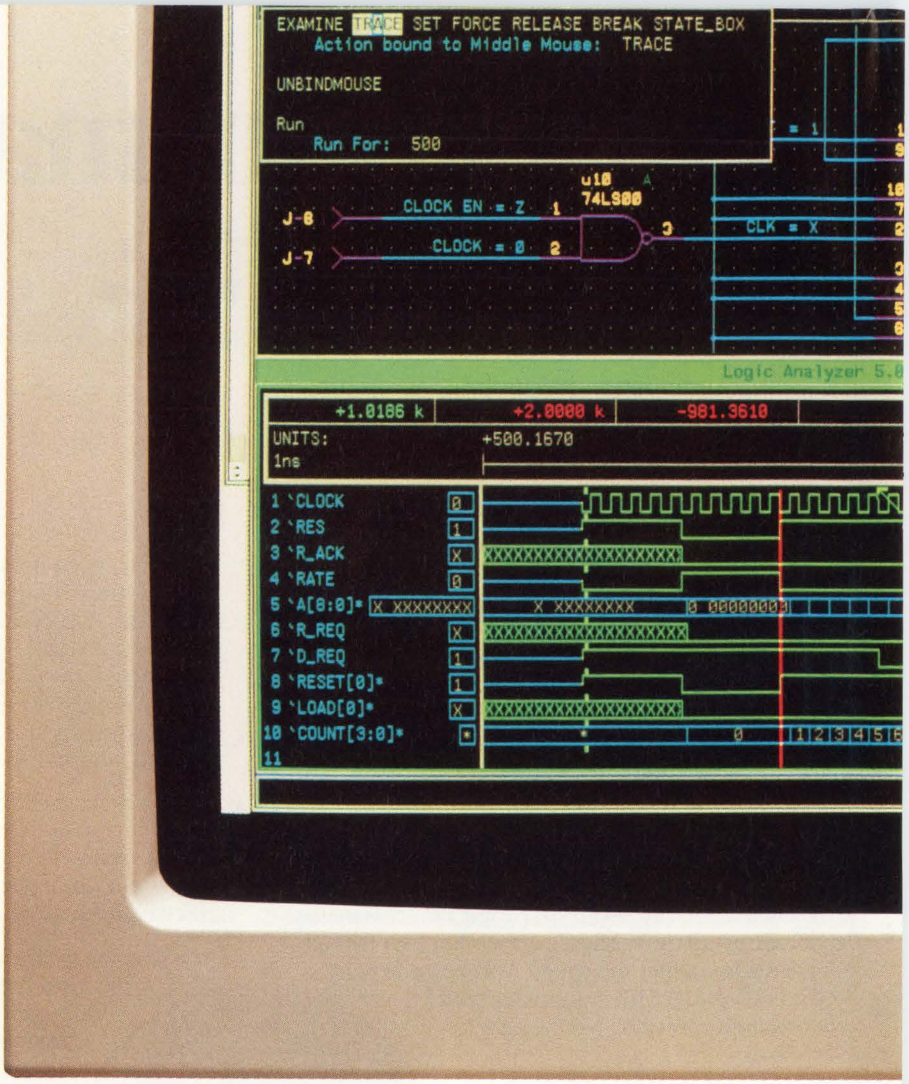
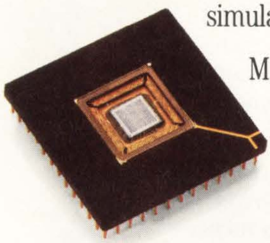


CAE for people to see how their

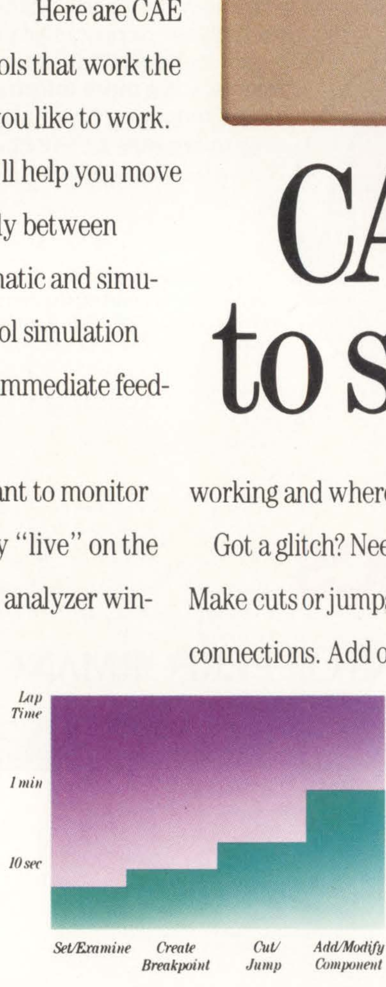
If your CAE tools are telling you too little too late, consider this news from Teradyne. Now you can capture and analyze complex ASIC and VLSI board designs with unprecedented accuracy and ease, using our Vanguard™ schematic entry software and LASAR simulator in Teradyne's MultiSim™ environment.



LASAR's accurate worst-case timing analysis means you won't be held up by faulty prototypes.

Here are CAE tools that work the way you like to work. They'll help you move quickly between schematic and simulation, and let you control simulation interactively. You'll get immediate feedback at every step.

Click on nodes you want to monitor and watch signal activity "live" on the schematic or in the logic analyzer window. By setting breakpoints, you can freeze the action when results aren't what you expect. In no time, you'll know where your design is working and where it's not.



If you find a problem, fix it and see the results in seconds, because we eliminate compilation for most common design changes.

Got a glitch? Need to invert a signal? Make cuts or jumps on schematic interconnections. Add or delete components. You'll see the effects of design changes instantly because we shortcut compilation for the modifications you make most frequently. This means you can try out "what-ifs" with record speed, reducing design-loop time from tens of minutes to tens of seconds.

Best of all, with CAE tools from Teradyne you can be sure that what

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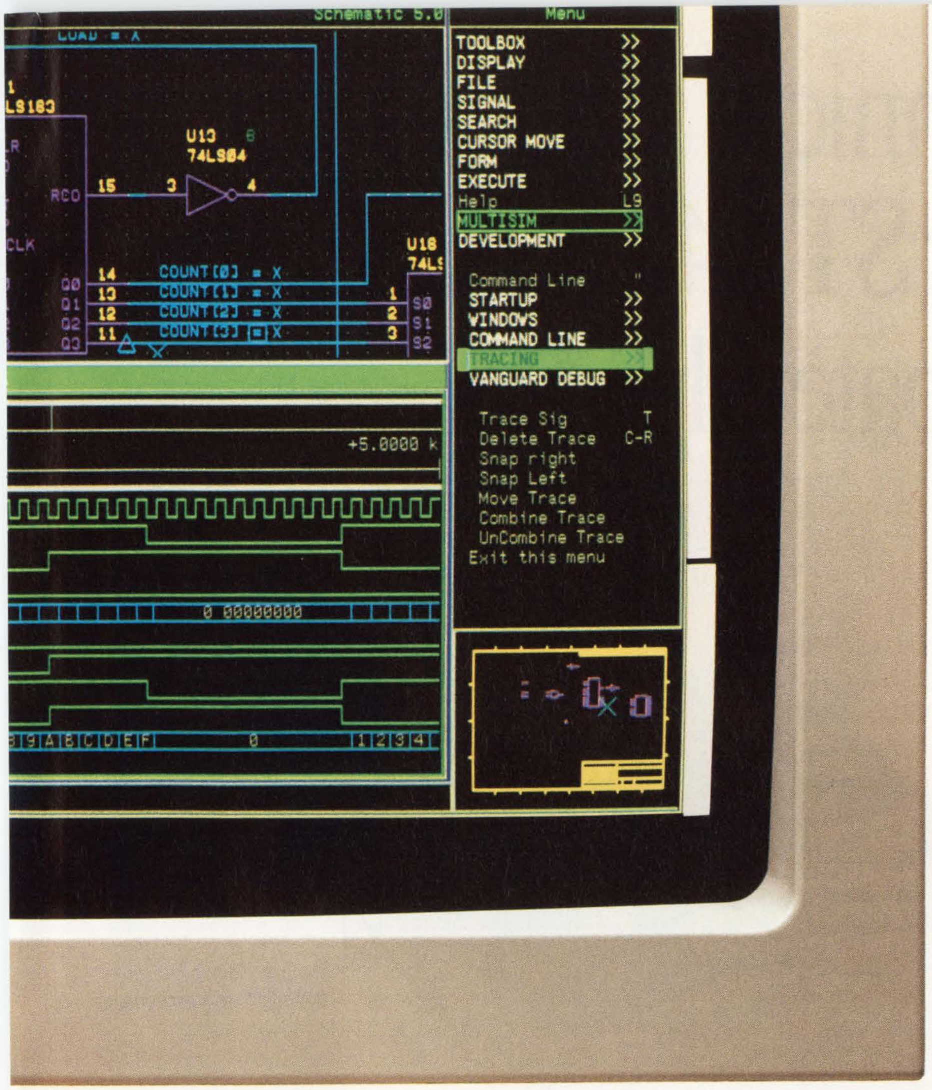
Schematic 5.0
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TRACING
VANGUARD DEBUG
Trace Sig
Delete Trace
Snap right
Snap Left
Move Trace
Combine Trace
UnCombine Trace
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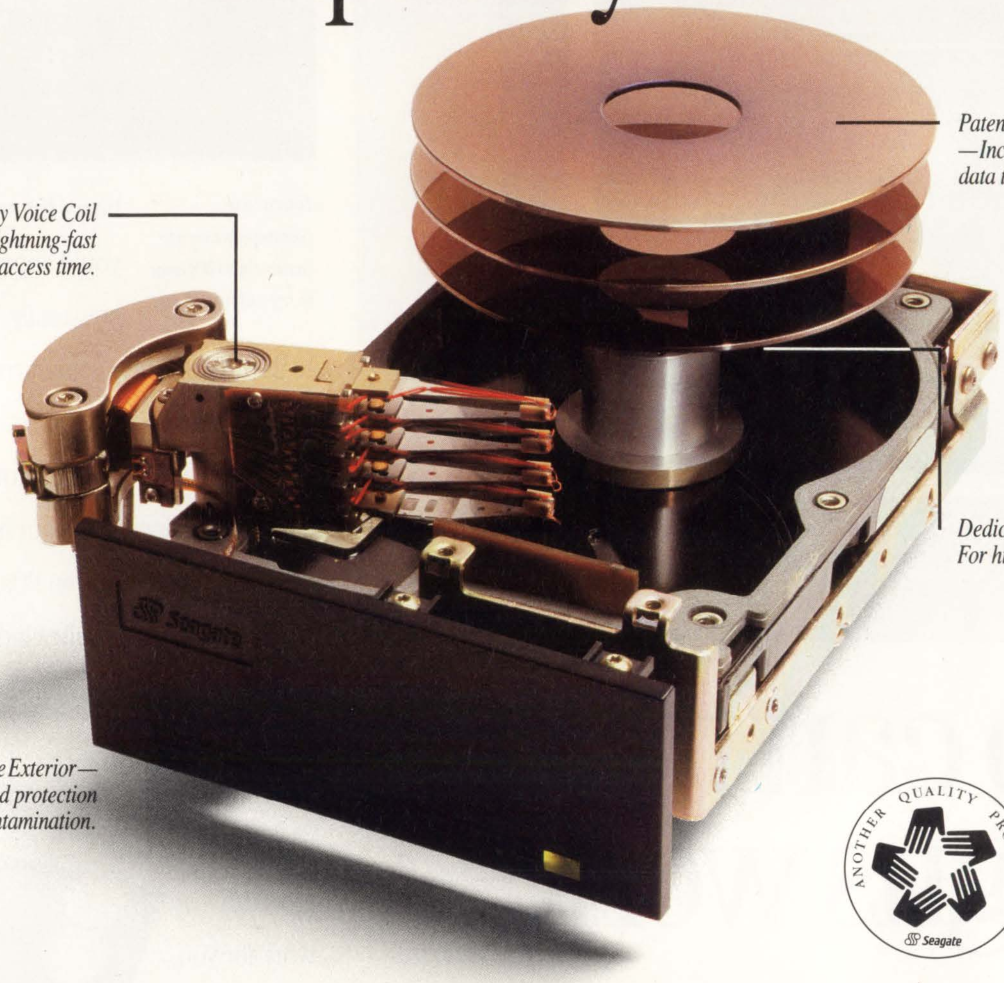
U13
74LS04
COUNT[0] = X
COUNT[1] = X
COUNT[2] = X
COUNT[3] = X
+5.0000 k

The technical advantages of our ST1144 family are patently clear.



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CIRCLE NO. 217

SIGNALS & NOISE

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

---

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Unlike some specialized publications that cover only test and measurement, EDN balances its T&M coverage with that of other topics. By responding to the following questions, you can help ensure that our test and measurement articles will better suit your needs.

What sort of information about test and measurement do you want in EDN? Please rank in order of importance, with 1 being most important:

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___ Hands-on reviews of products
___ Other (Please specify.)________________

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		Oscilloscopes
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		Above 30 MHz
		Arbitrary waveform generators
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		Spectrum analyzers
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		Programmable power sources
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		Data-acquisition systems, chart recorders, data loggers
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		VXIbus-based instruments
		Instrument-control software
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		Automatic test equipment (ATE)
		Other types of instruments and instrumentation software (please list)

____
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If you would welcome a follow-up phone call by an EDN editor, please give your name and phone number. This information will not be shared with anyone else.

Name________________
Daytime phone________________

Send this form or a copy, and any other opinions or questions, by fax to (617) 558-4470 or by mail to EDN Surveys, 275 Washington St, Newton, MA 02158.

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 incapacitation 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 offended by his jingoism. I supported his attacks on the IEEE establishment but was repulsed by his personal attacks on the leadership. I supported his (our) cause but 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.

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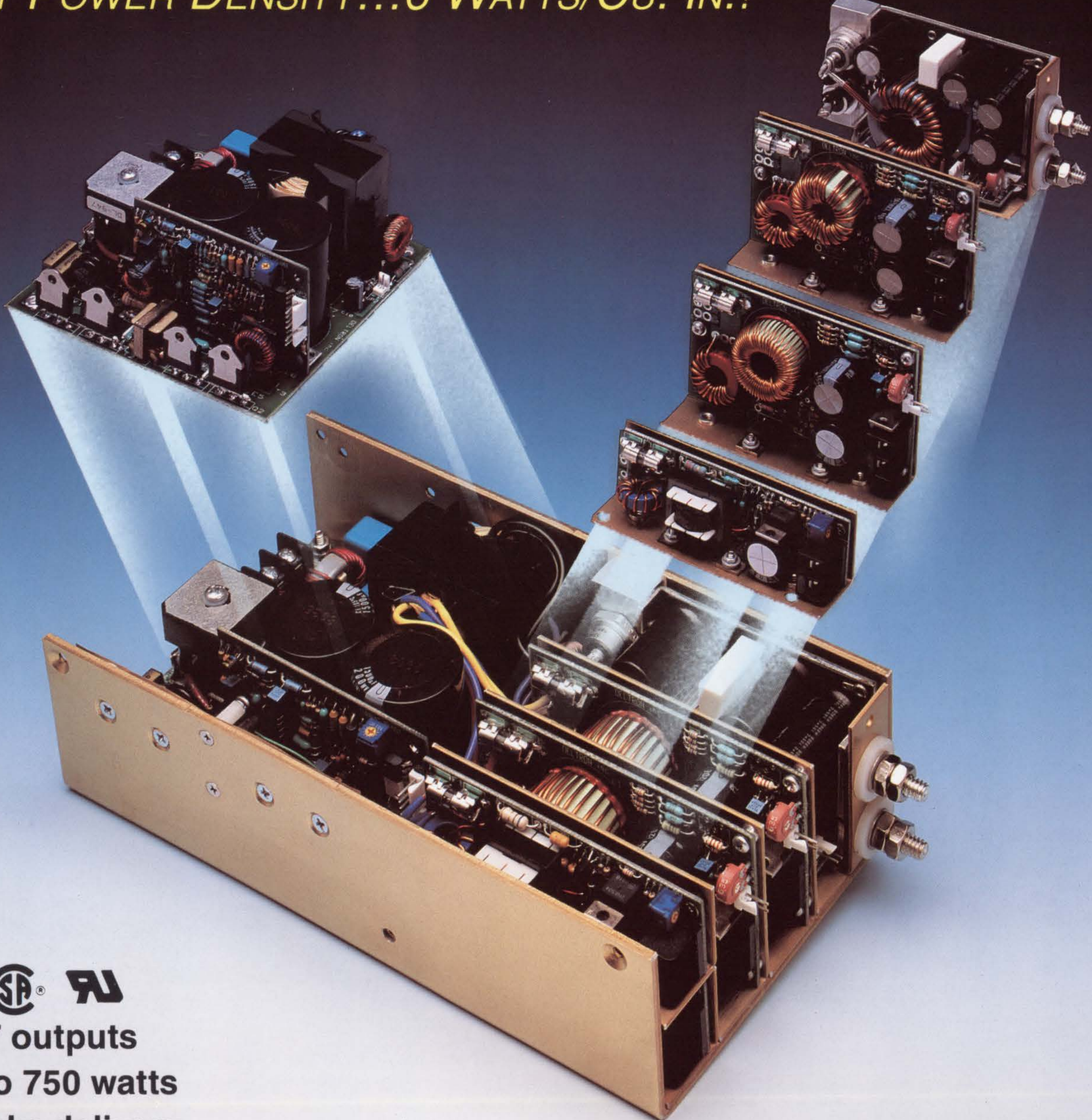
HIGHEST POWER DENSITY...6 WATTS/CU. IN.!



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- 400 to 750 watts
- 2 weeks delivery
- No engineering charge

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POWER PRODUCTS

DESCRIPTION

Moduflex switchers form a comprehensive line of open frame power supplies assembled from standard "off the shelf" modules. These subunits and assembly hardware are pre-approved by safety agencies so that certifications can automatically apply to custom models. Additional advantages include a delivery cycle of two weeks or less and the elimination of engineering costs.

The M Series offers the highest power density available in the industry, delivering 6 watts per cubic inch at an ambient temperature of 50°C. The design features "State of the Art" topology, a meticulous thermal structure and the use of high efficiency circuits and components to attain the desired power density.

The modular system concept reduces manufacturing to simple submodules, capable of high volume production with a superior quality level.

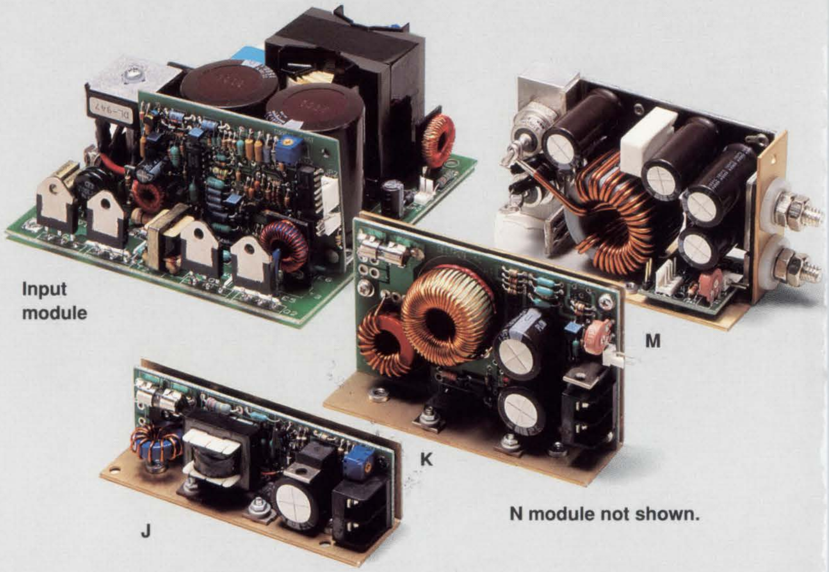
M Series are available in power ratings from 400 to 750 watts with only a slight size increase. This power versatility permits system expansion without the need for extra power supply space.

FEATURES

- No engineering charge.
- 2 week delivery.
- TUV, UL, CSA.
- 6 watts per cubic inch.
- 400-750 watts output.
- 120 kilohertz MOSFET design.
- Current mode control.
- All outputs:
    - *Adjustable*
    - *Fully regulated*
    - *Floating*
    - *Overload and short circuit proof*
    - *Overvoltage protected*
- Standard features include:
    - *System inhibit*
    - *Load proportional DC fan output*
- Options include:
    - *Auto ranger 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.



N module not shown.

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:

MODUFLEX 500W QUAD SWITCHER

M 44 B 2 3 3 6 - YY

- M — Series
- 44 — Configuration
- B — Power Code
- 2 — Output #1 Code
- 3 — Output #2 Code
- 3 — Output #3 Code
- 6 — Output #4 Code
- YY — Sum of Option Codes

M SERIES SELECTION CHARTS

Input Module Power Codes	
A	400W
B	500W
C	600W
D	750W

Output Module Types	
J	1/2 Height
K	Full Height
M	Main
N	Double Main

M Type Main Module Ratings	
Power Rating	Current Multiplier
400W	0.60
500W	0.80
600W	1.00
750W	1.20

Options	
Option Code	Function
01	Power Fail Monitor
02	Auto Ranger
04	Pilot Bias
08	Active Surge Limit
16	UPS/PF Prep
32	Cover
64	Fan Cover

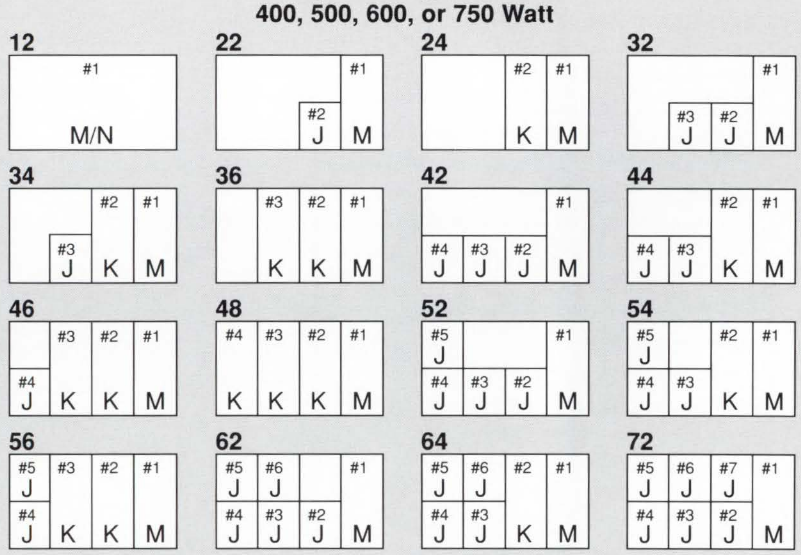
Options 02, 04, 08 mutually exclusive.

Output Modules					
Output		Type			
Code	Voltage	J Amps	K Amps	M Amps	N Amps
0	2 VDC	N/A	20	100	150
1	3.3 VDC	N/A	20	100	150
2	5 VDC	10	20	100	150
3	12 VDC	6	12	42	62
4	15 VDC	5	10	33	50
5	18 VDC	4	8	28	42
6	24 VDC	3	6	21	31
7	28 VDC	2.5	5	18	27
8	36 VDC	2	4	14	21
9	48 VDC	1.5	3	10	16
X	N/T	N/T	N/T	N/T	N/T

N/T Non Tabulated N/A Not Available

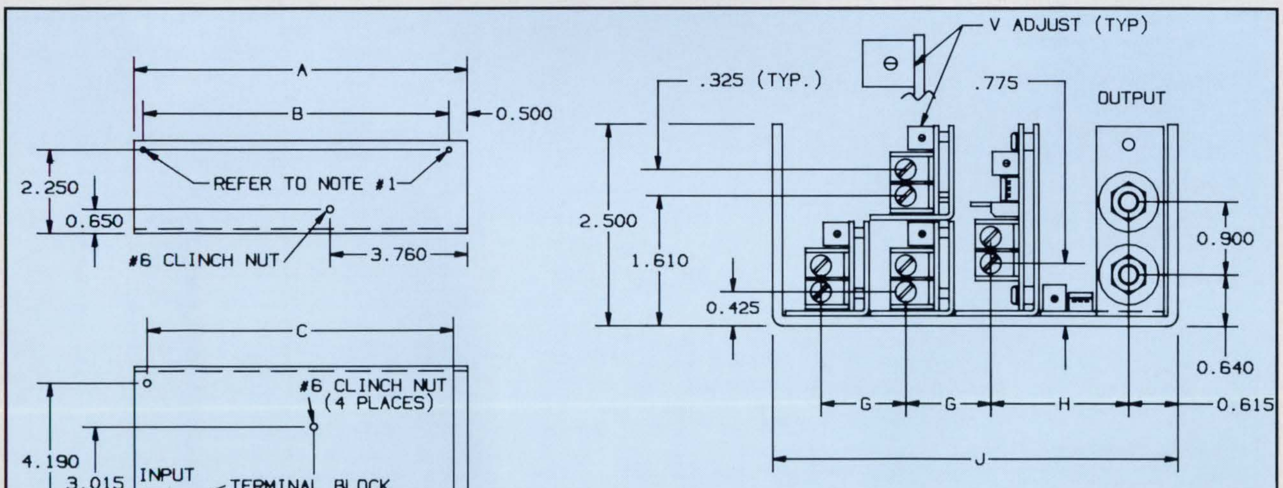
For multiple output modules of a given type, voltages are arranged in ascending order by magnitude in the same sense as the output number sequence. Shaded ratings are standard, others available on special order. Non tabulated intermediate voltages have current ratings equal to straight line interpolation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

Output Configurations
400, 500, 600, or 750 Watt



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.

M SERIES DIMENSIONS



	400/500 W	600/750 W
A	9.000	9.630
B	8.250	8.880
C	8.260	8.890
D	.410	.425
E	3.820	4.450
F	3.930	4.560
G	1.055	1.100
H	1.720	1.760
J	5.050	5.200

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
Units meet UL 1950, CSA 22.2 No. 220, CSA bulletin 1402C, IEC 950, VDE 0804, VDE 0806, VDE 0805 (proposed). Certifications in process.

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
Recovery within 1%.
M and N modules – 200 microseconds.
J and K modules – 500 microseconds.

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.

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Demand Oki 4-Megs and SIMMs

Oki's 4-Meg Product Line-Up

Device	Organization	Access Mode
MSM514100-XXYY	4M x 1	Fast Page
MSM514101-XXYY	4M x 1	Nibble
MSM514102-XXYY	4M x 1	Static Column
MSM514400-XXYY	1M x 4	Fast Page
MSM514402-XXYY	1M x 4	Static Column

Speed Options (XX) Include:
70 = 70ns (tRAC)
80 = 80ns (tRAC) 20ns (tCAC)
8A = 80ns (tRAC) 25ns (tCAC)
10 = 100ns (tRAC) 25ns (tCAC)

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

SIMMs

MSC2341-XXYS8	4M x 8	Fast Page
MSC2340-XXYS9	4M x 9	Fast Page
MSC2350-XXYS12	1M x 36	Fast Page

Speed Options (XX) Include:
70 = 70ns (tRAC)
80 = 80ns (tRAC) 20ns (tCAC)
10 = 100ns (tRAC) 25ns (tCAC)

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CIRCLE NO. 75

New Product Announcement!

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.

The only third generation SCSI device on the market today, it concentrates all the functions of an intelligent SCSI adapter board on a single, smart and extremely fast, chip… for about 15% of the cost.

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.

Those are just a few of the reasons Electronic Design's "Best of the Digital IC's" award went to NCR's 53C700 last year.

And now the NCR 53C710!

For the complete story on the NCR SCSI product line featuring the new 53C710, as well as the upcoming SCSI seminars with the NCR SCSI Development Team, please call:

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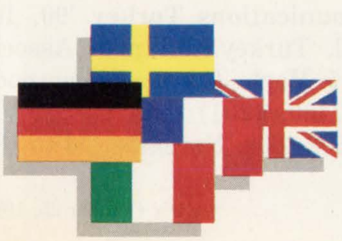
Creating value

CIRCLE NO. 76



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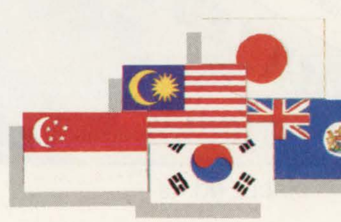

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CALENDAR

Optcon '90, Boston, MA. International Society for Optical Engineering, Box 10, Bellingham, WA 98227. (206) 676-3290. FAX (206) 647-1445. November 4 to 9.

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.

Software Project Management Tools & Techniques (short course), San Francisco, CA. Learning Tree International, Box 45974, Los Angeles, CA 90045. (800) 421-8166; in Canada, (800) 267-1824; in CA, (213) 417-9700. FAX (213) 645-4762. November 6 to 9.

17th Annual Computer Security Conference and National Computer Security Exhibition, Atlanta, GA. Computer Security Institute, 500 Howard St, San Francisco, CA 94105. (415) 397-1881. FAX (415) 995-2487. November 12 to 14.

Wescon/90, Anaheim, CA. Wescon/90, 8110 Airport Blvd, Los Angeles, CA 90045. (213) 215-3967. FAX (213) 641-5117. November 13 to 15.

Figaro+ Hands-On Training (short course), Bethesda, MD. Template Graphics Software Inc, 3510 Dunhill St, San Diego, CA. (619) 457-5359. FAX (619) 452-2547. November 13 to 16.

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.

Communications Turkey '90, Istanbul, Turkey. Kallman Associates, 5 Maple Court, Ridgewood, NJ 07450. (201) 652-7070. FAX (201) 652-3898. November 14 to 18.

MEGA MEMORY.

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MODEL	CONFIG.	SPEED (ns)	PACKAGING	DATA RETENTION
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CXK581000M*	128K x 8	100/120	SOP 525 mil	L, LL
CXK581100TM*	128K x 8	100/120	TSOP	L, LL
CXK581100YM*	128K x 8	100/120	TSOP (reverse)	L, LL
CXK581001P	128K x 8	70/85	DIP 600 mil	L
CXK581001M	128K x 8	70/85	SOP 525 mil	L
CXK581020SP	128K x 8	35/45/55	SDIP 400 mil	
CXK581020J	128K x 8	35/45/55	SOJ 400 mil	

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

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Call us. We've got more breakthroughs on the way. Well over 100 SRAM products spanning the performance spectrum. And the desire to meet—or exceed—your toughest performance spec.

Sony high-density SRAMS are shipping now, complete with competitive pricing. So call (714) 229-4190 today. Or write Sony Corporation Of America, Component Products Company, 10833 Valley View St., Cypress, CA 90630, Attention: Semiconductor sales. FAX (714) 229-4285.

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CALENDAR

Converting, Expanding & Upgrading IBM & PS2 (short course), Indianapolis, IN. Center for Advanced Professional Development, 1820 E Garry St, Suite 110, Santa Ana, CA 92705. (714) 261-0240. November 27 to 28.

Technology 2000, Washington, DC. Technology Utilization Foundation, 41 E 42nd St, New York, NY 10017. (212) 490-3999. November 27 to 28.

Semiconductor Silicon (short course), Davos, Switzerland. Tina Persson, CEI-Europe/Elsevier, Box 910, S-612 01 Finspong, Sweden. 46(0)122-17570. FAX 46(0)122-14347. December 3 to 7.

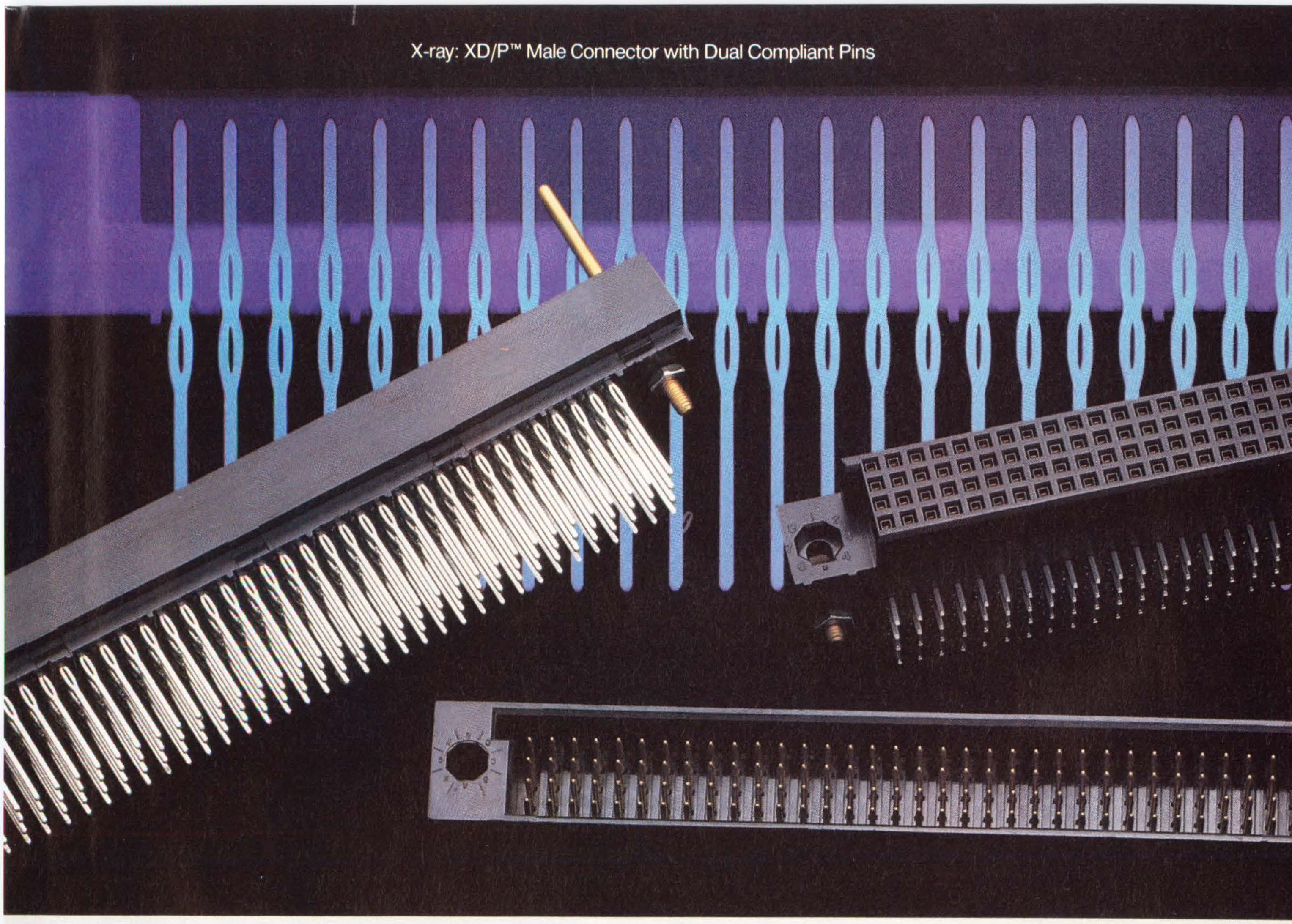
Concurrent Engineering Seminar, San Diego, CA. Logical Solutions Technology Inc, 96 Shereen Pl, Suite 101, Campbell, CA 95008. (408) 374-3650. FAX (408) 374-3657. December 4 to 5.

Fourth International Workshop on Computer-Aided Software Engineering, Irvine, CA. Center for the Study of Data Processing, Washington University, 1 Brookings Dr, Campus Box 1141, St Louis, MO 63130. December 5 to 8.

Applications of Unix Utilities (short course), Seattle, WA. Specialized Systems Consultants Inc, Box 55549, Seattle, WA 98155. (206) 527-3385. FAX (206) 527-2806. January 15.

ATE & Instrumentation West, Anaheim, CA. Miller Freeman Expositions, 1050 Commonwealth Ave, Boston, MA 02215. (800) 223-7126; in MA, (617) 232-3976. January 15 to 17.

Winter 1991 UNIX Technical Conference, Dallas, TX. Usenix Association, 22672 Lambert St, Suite 613, El Toro, CA 92630. (714) 588-8649. FAX (714) 588-9706. January 21 to 25.



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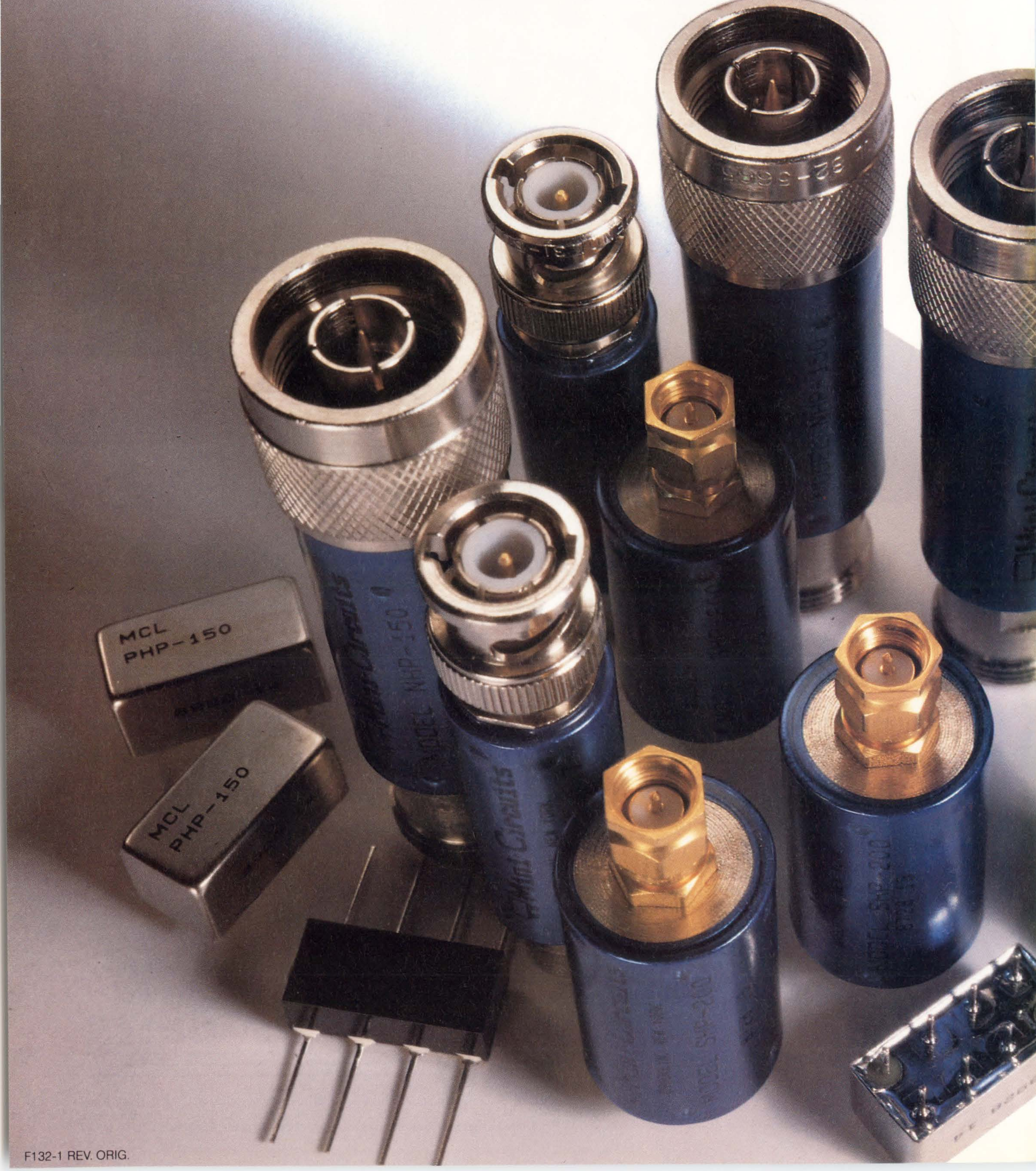
FILTERS



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lowpass, highpass, bandpass, narrowband IF

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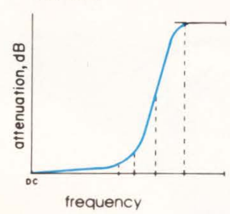
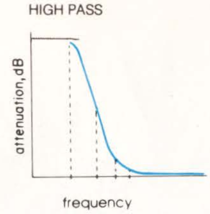
LOW PASS



low pass dc to 1200MHz

MODEL NO.	PASSBAND, MHz (loss <1dB) Min.	fco, MHz (loss 3db) Nom.	STOP BAND, MHz (loss>20dB) Max.	STOP BAND, MHz (loss>40dB) Max.	STOP BAND, MHz (loss>40dB) Min.	VSWR pass-band typ.	VSWR stop-band typ.	PRICE $ Qty. (1-9)
PLP-10.7	DC-11	14	19	24	200	1.7	18	11.45
PLP-21.4	DC-22	24.5	32	41	200	1.7	18	11.45
PLP-30	DC-32	35	47	61	200	1.7	18	11.45
PLP-50	DC-48	55	70	90	200	1.7	18	11.45
PLP-70	DC-60	67	90	117	300	1.7	18	11.45
PLP-100	DC-98	108	146	189	400	1.7	18	11.45
PLP-150	DC-140	155	210	300	600	1.7	18	11.45
PLP-200	DC-190	210	290	390	800	1.7	18	11.45
PLP-250	DC-225	250	320	400	1200	1.7	18	11.45
PLP-300	DC-270	297	410	550	1200	1.7	18	11.45
PLP-450	DC-400	440	580	750	1800	1.7	18	11.45
PLP-550	DC-520	570	750	920	2000	1.7	18	11.45
PLP-600	DC-580	640	840	1120	2000	1.7	18	11.45
PLP-750	DC-700	770	1000	1300	2000	1.7	18	11.45
PLP-800	DC-720	800	1080	1400	2000	1.7	18	11.45
PLP-850	DC-780	850	1100	1400	2000	1.7	18	11.45
PLP-1000	DC-900	990	1340	1750	2000	1.7	18	11.45
PLP-1200	DC-1000	1200	1620	2100	2500	1.7	18	11.45

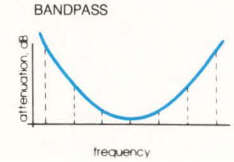
HIGH PASS



high pass dc to 2500MHz

MODEL NO.	PASSBAND, MHz (loss <1dB) Min.	PASSBAND, MHz (loss <1dB) Min.	fco, MHz (loss 3db) Nom.	STOP BAND, MHz (loss>20dB) Min.	STOP BAND, MHz (loss>40dB) Min.	VSWR pass-band typ.	VSWR stop-band typ.	PRICE $ Qty. (1-9)
PHP-50	41	200	37	26	20	1.5	17	14.95
PHP-100	90	400	82	55	40	1.5	17	14.95
PHP-150	133	600	120	95	70	1.8	17	14.95
PHP-175	160	800	140	105	70	1.5	17	14.95
PHP-200	185	800	164	116	90	1.6	17	14.95
PHP-250	225	1200	205	150	100	1.3	17	14.95
PHP-300	290	1200	245	190	145	1.7	17	14.95
PHP-400	395	1600	360	290	210	1.7	17	14.95
PHP-500	500	1600	454	365	280	1.9	17	14.95
PHP-600	600	1600	545	440	350	2.0	17	14.95
PHP-700	700	1800	640	520	400	1.6	17	14.95
PHP-800	780	2000	710	570	445	2.1	17	14.95
PHP-900	910	2100	820	660	520	1.8	17	14.95
PHP-1000	1000	2200	900	720	550	1.9	17	14.95

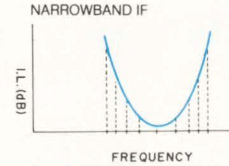
BANDPASS



bandpass 20 to 70MHz

MODEL NO.	CENTER FREQ. MHz F0	PASS BAND, MHz (loss <1dB) Max. F1	PASS BAND, MHz (loss <1dB) Min. F2	STOP BAND, MHz (loss > 10 dB) Min. F3	STOP BAND, MHz (loss > 10 dB) Max. F4	STOP BAND, MHz (loss > 20 dB) Min. F5	STOP BAND, MHz (loss > 20 dB) Max. F6	VSWR 1.3:1 typ. total band MHz	PRICE $ Qty. (1-9)
PIF-21.4	21.4	18	25	4.9	85	1.3	150	DC-220	14.95
PIF-30	30	25	35	7	120	1.9	210	DC-330	14.95
PIF-40	42	35	49	10	168	2.6	300	DC-400	14.95
PIF-50	50	41	58	11.5	200	3.1	350	DC-440	14.95
PIF-60	60	50	70	14	240	3.8	400	DC-500	14.95
PIF-70	70	58	82	16	280	4.4	490	DC-550	14.95

NARROWBAND IF



narrowband IF

MODEL NO.	CENTER FREQ. MHz F0	PASS BAND, MHz I.L. 1.5dB max. F1-F2	STOP BAND, MHz I.L. > 20dB F5	STOP BAND, MHz I.L. > 20dB F6	STOP BAND, MHz I.L. > 35dB F7	STOP BAND, MHz I.L. > 35dB F8-F9	PASS-BAND VSWR Max.	PRICE $ Qty. (1-9)
PBP-10.7	10.7	9.5-11.5	7.5	15	0.6	50-1000	1.7	18.95
PBP-21.4	21.4	19.2-23.6	15.5	29	3.0	80-1000	1.7	18.95
PBP-30	30.0	27.0-33.0	22	40	3.2	99-1000	1.7	18.95
PBP-60	60.0	55.0-67.0	44	79	4.6	190-1000	1.7	18.95
PBP-70	70.0	63.0-77.0	51	94	6	193-1000	1.7	18.95

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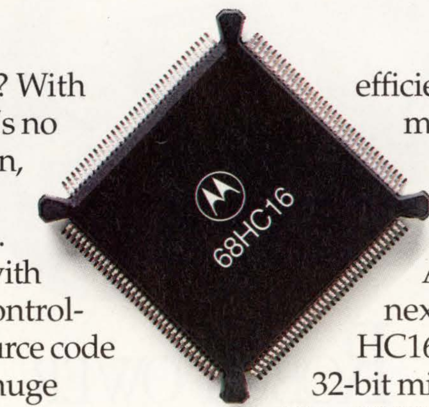

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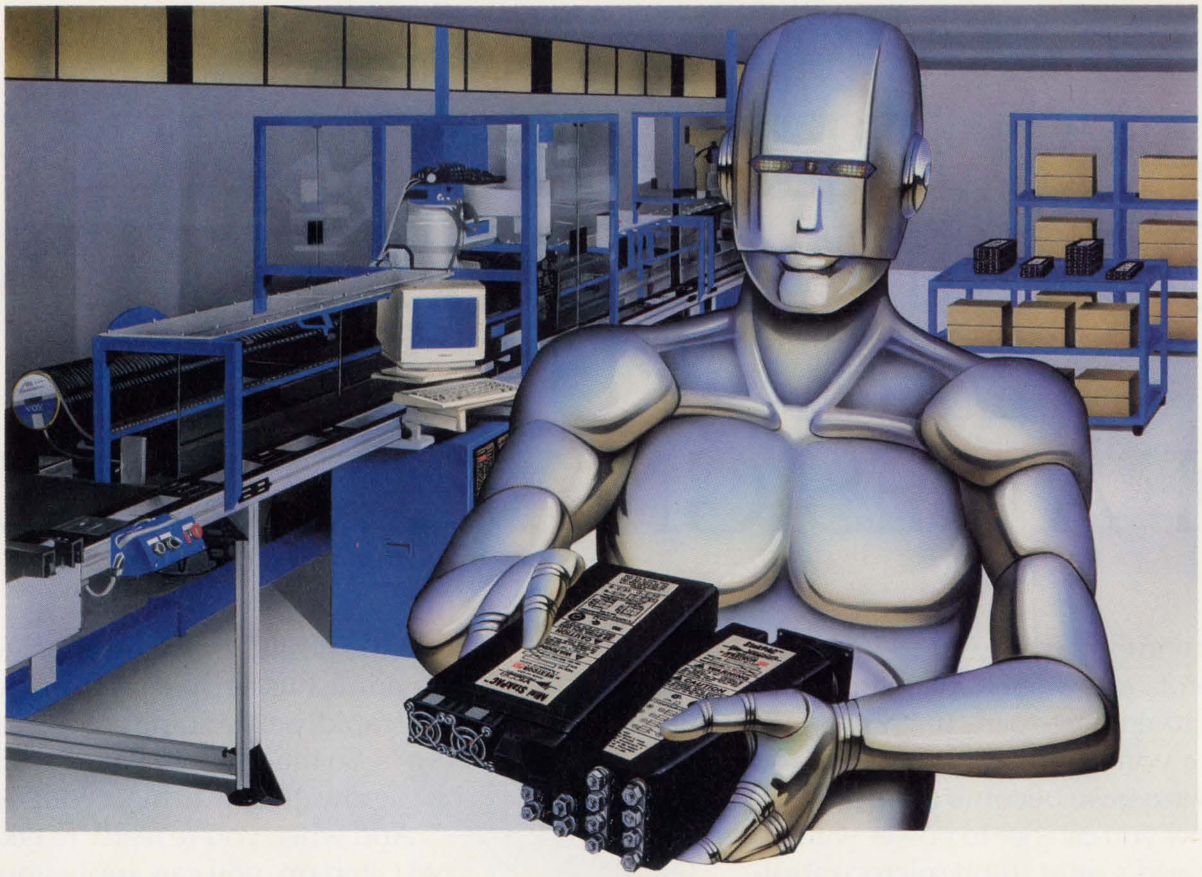

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1200 Watts	**Power**	600 Watts
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Up to 8	**Outputs**	Up to 5
3.2"x5.5"x11.5	**Dimensions**	1.9"x5.5"x12"
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StakPACs are designed and built by Westcor Corporation, Los Gatos, CA, a Vicor subsidiary. StakPACs are sold world-wide through Vicor Corporation, Andover, MA.

STAKPAC STANDARDS 1200 WATT MODELS

Model	Output Voltage (VDC) and Maximum Current (amperes) per Channel				
	#1	#2	#3	#4	#5
Single Output					
SP1-1801	2 @ 240				
SP1-1802	5 @ 240				
SP1-1603	12 @ 100				
SP1-1604	15 @ 80				
SP1-1605	24 @ 50				
SP1-1606	28 @ 42				
SP1-1607	48 @ 25				
Dual Output					
SP2-1801	2 @ 120	5 @ 120			
SP2-1802	5 @ 120	5 @ 120			
SP2-1803	5 @ 120	12 @ 66			
SP2-1804	12 @ 66	12 @ 66			
SP2-1805	15 @ 53	15 @ 53			
Triple Output					
SP3-1801	5 @ 180	12 @ 16	12 @ 16		
SP3-1802	5 @ 150	12 @ 33	12 @ 16		
SP3-1803	5 @ 180	15 @ 13	15 @ 13		
SP3-1804	5 @ 150	15 @ 26	15 @ 13		
Quad Output					
SP4-1801	5 @ 150	12 @ 16	12 @ 16	5 @ 30	
SP4-1802	5 @ 150	15 @ 13	15 @ 13	5 @ 30	
SP4-1803	5 @ 150	12 @ 16	12 @ 16	24 @ 8	
SP4-1804	5 @ 150	15 @ 13	15 @ 13	24 @ 8	
Five Output					
SP5-1801	5 @ 120	12 @ 16	12 @ 16	5 @ 30	24 @ 8
SP5-1802	5 @ 120	15 @ 13	15 @ 13	5 @ 30	24 @ 8
Seven Output					
SP7-1801	5 @ 60	12 @ 16	12 @ 16	24 @ 8	24 @ 8
	#6	#7			
	5.2 @ 28	2 @ 30			

Total output power may not exceed 1200* watts for any model, single or multiple output. Lower power StakPAC models and many other configurations are available.
*Standard models supply 1100 watts; high-powered version 1200 watts. Please contact the factory.

MINI STAKPAC STANDARDS 600 WATT MODELS

Model	Output Voltage (VDC) and Maximum Current (amperes) per Channel				
	#1	#2	#3	#4	#5
Single Output					
ST1-1401	2 @ 120				
ST1-1402	5 @ 120				
ST1-1301	12 @ 50				
ST1-1302	15 @ 40				
ST1-1303	24 @ 25				
ST1-1304	28 @ 21				
ST1-1305	48 @ 13				
Dual Output					
ST2-1401	2 @ 60	5 @ 60			
ST2-1402	5 @ 60	5 @ 60			
ST2-1403	5 @ 60	12 @ 33			
ST2-1404	12 @ 33	12 @ 33			
ST2-1405	15 @ 26	15 @ 26			
Triple Output					
ST3-1401	5 @ 60	12 @ 16	12 @ 16		
ST3-1402	5 @ 60	15 @ 13	15 @ 13		
ST3-1501	5 @ 90	12 @ 8	12 @ 8		
Quad Output					
ST4-1401	5 @ 30	12 @ 16	12 @ 16	5 @ 30	
ST4-1402	5 @ 30	15 @ 13	15 @ 13	5 @ 30	
ST4-1403	5 @ 30	12 @ 16	12 @ 16	24 @ 8	
ST4-1501	5 @ 30	15 @ 13	15 @ 13	24 @ 8	
ST4-1502	5 @ 60	12 @ 16	12 @ 8	5 @ 15	
ST4-1503	5 @ 60	15 @ 13	15 @ 7	5 @ 15	
ST4-1504	5 @ 60	12 @ 16	12 @ 8	24 @ 4	
ST4-1505	5 @ 60	15 @ 13	15 @ 7	24 @ 4	
Five Output					
ST5-1501	5 @ 30	12 @ 16	12 @ 16	5 @ 15	24 @ 4
ST5-1502	5 @ 30	15 @ 13	15 @ 13	5 @ 15	24 @ 4

Total output power may not exceed 600 watts for any model, single or multiple output. Lower power Mini StakPAC models and many other configurations are available. Please contact the factory.

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CIRCLE NO. 94

EDITORIAL

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—or picoprocessor, 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.

Jon Titus
Editor

Jesse H Neal
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1987, 1981 (2), 1978 (2), 1977, 1976, 1975

American Society of
Business Press Editors Award
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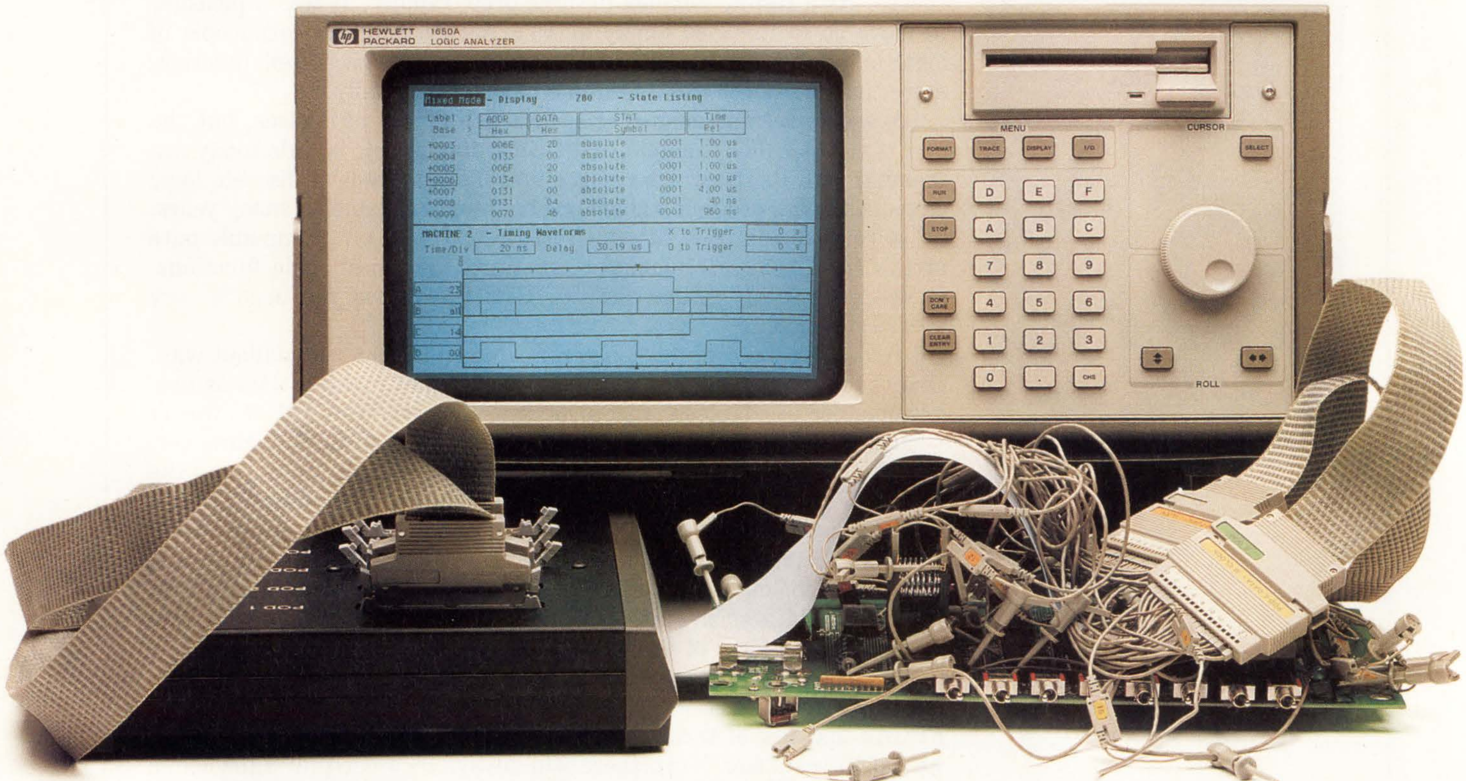

All logic analyzers give you integrated state and timing, sooner or later.

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Connect the probe to your board for state and you're automatically hooked up for timing. Or vice versa.

This means no more dual probing – a pain anytime and the source of loading problems – and no reconfiguration between state and timing. Which makes these analyzers simple to learn and use.

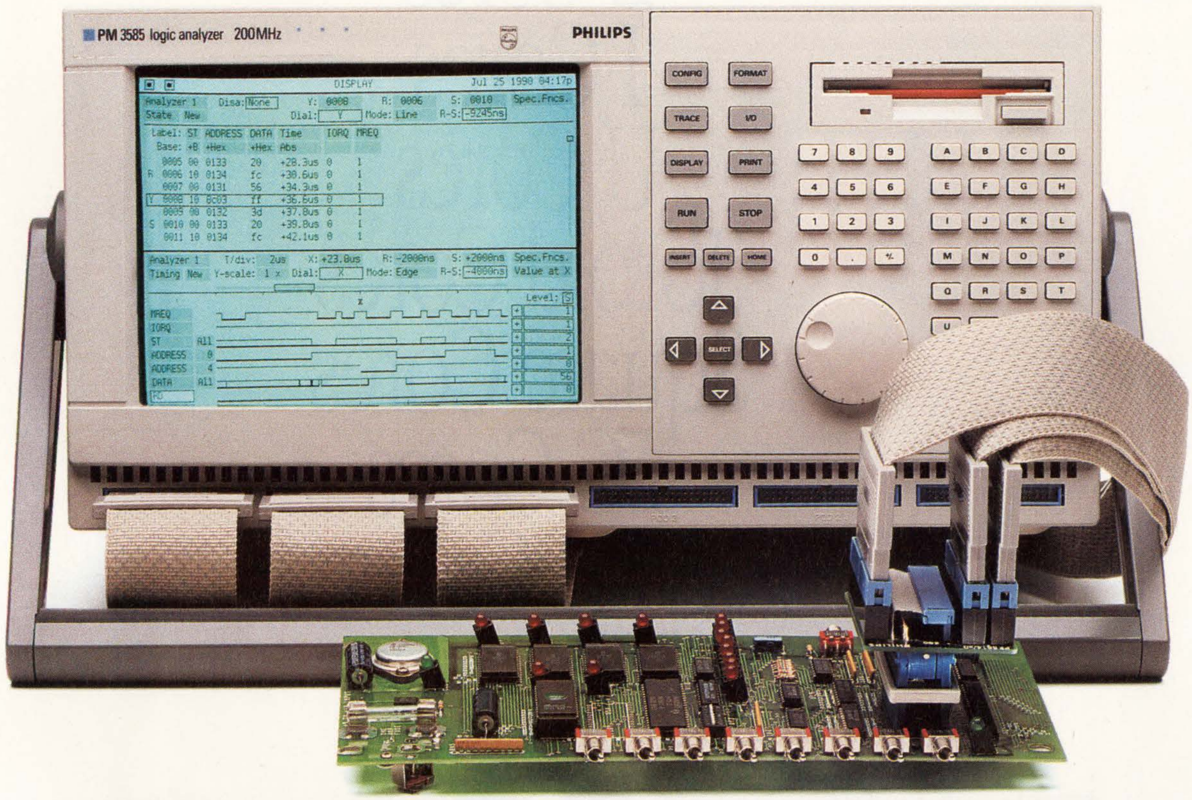
Plus, the pop-up menus and keyboard shortcuts guide you quickly through setup and data analysis. No matter if you use it every day or once a year.

What's more, capturing an elusive bug has never been easier with eight unrestricted trigger levels that let you select from state and

A basic comparison: Record all state and timing data on an 8-bit microprocessor with multiplexed bus, 8-bits for address, 3 control signals and a clock.	HP 1654B	Tek PRISM/MPM	Philips PM 3580/30
Probing: Channels used One connection	48[1] No	48[2] No	20 Yes
Setups	Two	Two+	One
Interfaces to learn	Two	Two+	One
Integrated state & timing triggering	No, only one arming condition	No, only indirect 4-bit Teklink	Yes, 8 levels
State & timing data per pin	No	No	Yes
Price	$6700	$8600	$4250

Footnotes: 1) 8 channels lost to de-multiplexing
2) De-multiplexing requires double probing and only nine high-speed channels on basic unit

PHILIPS



Why not sooner?

timing trigger conditions on each level.

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V33	16 MHz
V60	16 MHz

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CIRCLE NO. 100

Portable PCs tackle instrumentation tasks

Personal computers have already moved beyond the office to enter the laboratory as intelligent instruments. Now, portable PCs are entering the next instrumentation frontier: the real world.

Richard A Quinnell, Regional Editor

TEST & MEASUREMENT

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 expandability, 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**

As rugged as it looks, this metal-cased PC *from Grid Systems has two full-size expansion slots, allowing you to make it into an instrument you can take nearly anywhere.*

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.

Omnilab II is a good name for this multipurpose system *from Orion Instruments. It is a logic analyzer, digital oscilloscope, and waveform generator combined with a PC.*

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 instrumentation 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 1—Portable PCs with standard expansion slots

Company	Model no.	Plug-in slots	RAM memory standard/maximum (M bytes)	Hard-disk capacity standard/optional (M bytes)	Display	Starting price	Battery capacity
Chaplet Systems	LA-30A	1 AT, ½ size 1 XT, ½ size	1/5	20/40	640×400 backlit LCD four levels of gray	$1999	AC powered
Datavue	Snap 1+1	1 XT, ½ size	640k/1.6	20	640×200 backlit LCD	$3695	AC powered
Grid Systems	Gridcase 1535	1 AT 1 XT	1/8	40/100	640×400 backlit LCD	$5525	2.4 Ahr
Micro Express	Lyte-Byte 3400	1 AT, ½ size	1/5	40/100	640×400 gas plasma four levels of gray	$2295	AC powered
Toppcs International	LT3400	1 AT, ½ size	1/5	40/200	640×400 gas plasma four levels of gray	$3000	AC powered 1.5 Ahr optional battery

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

Portable PCs for instrumentation

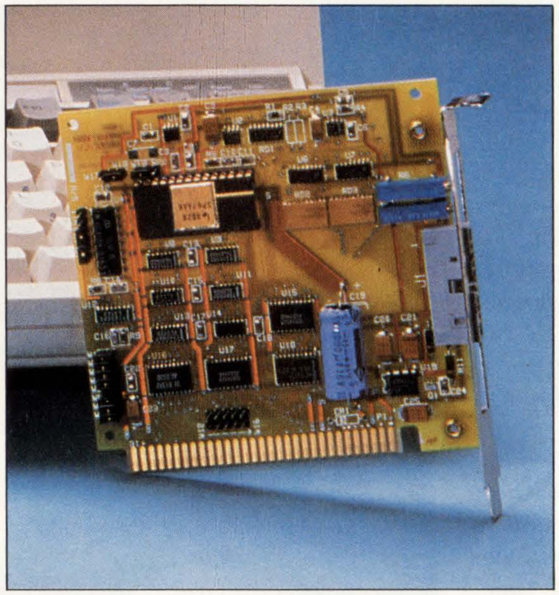
As discouraging as these considerations seem, there are portable PCs that will handle engineering instrumentation applications. Bitwise Designs, for example, offers an entire line of ac-powered portable PCs for engineers, called the VP series. Each member of the series features two full-size AT-bus-compatible 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 640×400-pixel backlit LCD display. It costs $5525.

The Gridcase 1535 accepts two plug-in cards: a full-size AT-bus-compatible card and a full-size XT-bus-compatible card. To power the plug-in cards, the unit's battery will supply 3.5A at 5V, 0.75A at +12V, and 0.5A at −12V. The battery's capacity is 2.4 Ahr.

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.



Designed with portable PCs in mind, *the DT2814 data-acquisition board from Data Translation requires minimal space and power. The board generates its own −12V power because many portable PCs don't.*

Integrated PC systems

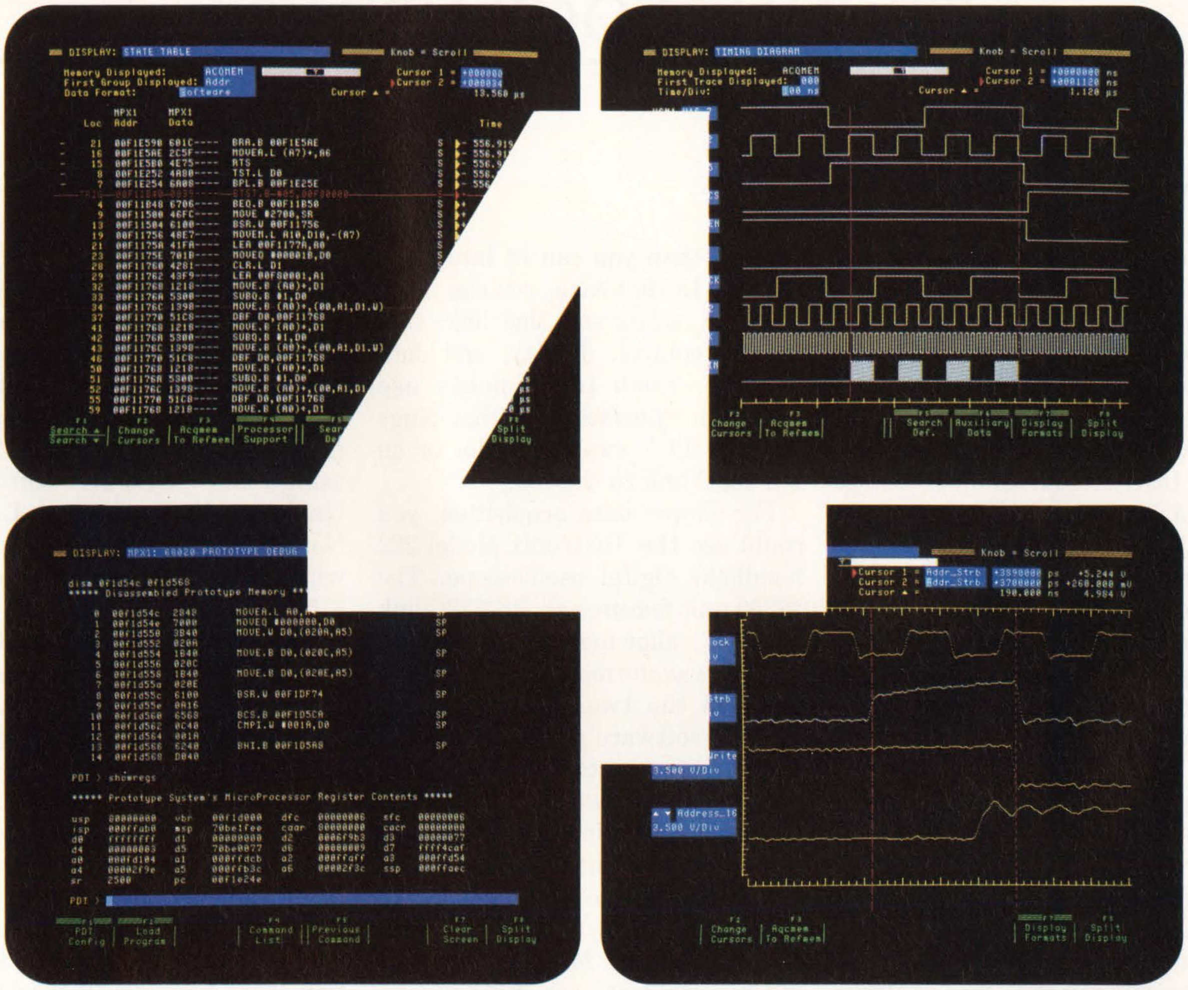
If the business of selecting a portable PC and plug-in device is more of a hassle than a help, you may choose to purchase an integrated system. These systems have the advantage of using plug-in cards that are matched to their computer. The system designers have addressed power and size constraints for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

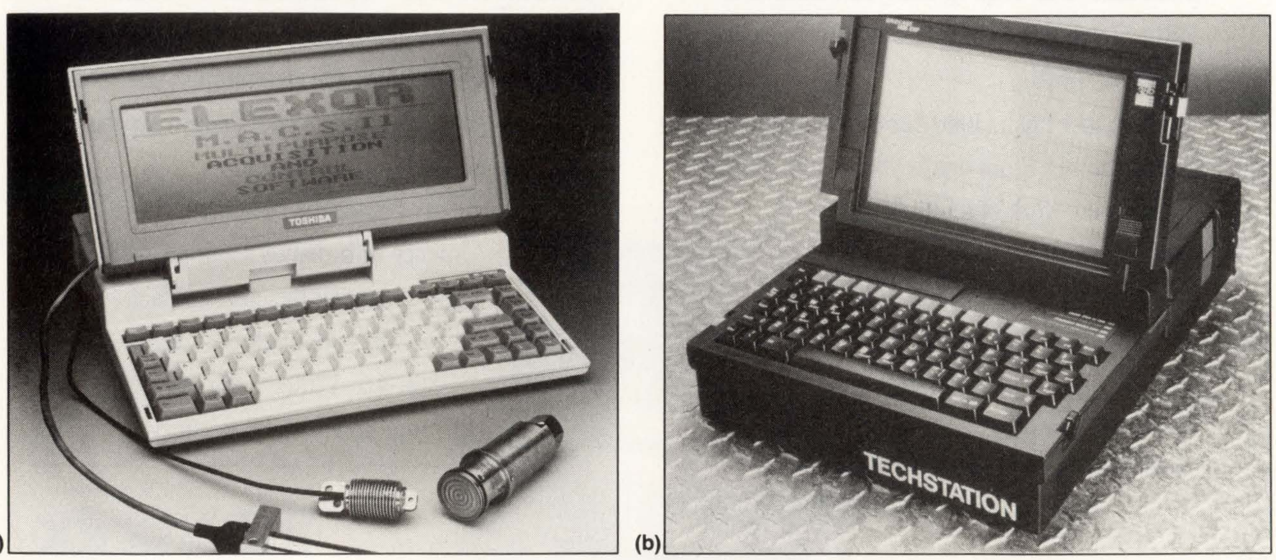
You may need the portability and ease-of-use available with an integrated system, yet require more capability than you can fit into a PC chassis. In that case, you can use a portable instrument that links to a PC for control, display, and data storage. Such instruments use either an interface card that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

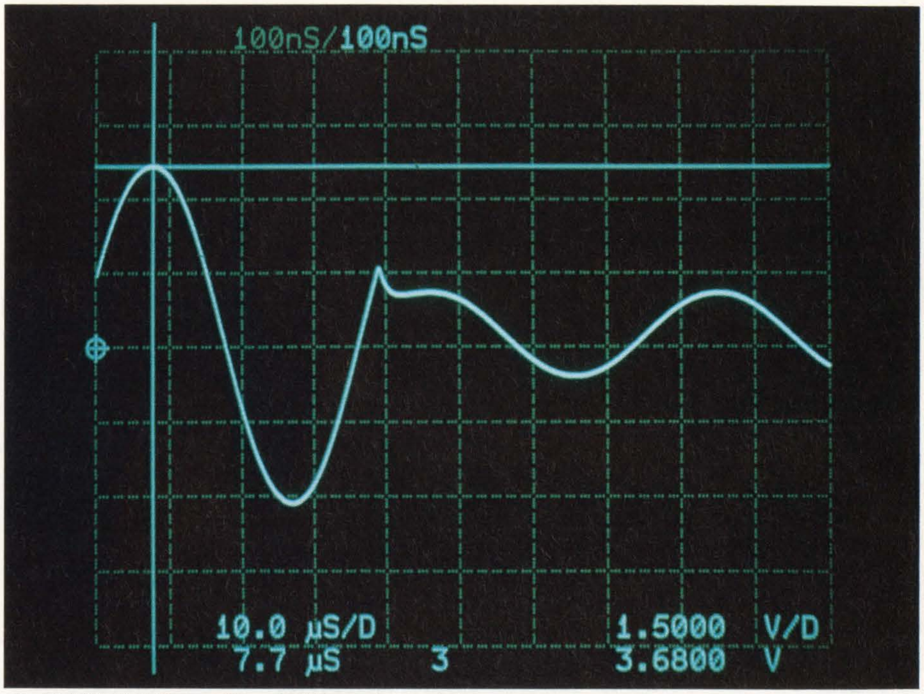
The Model 500P uses a dc/dc converter to power its modules. The unit will also power your portable PC, providing 2.5A at 12V ±2%. You can choose a 9.5 to 18V version



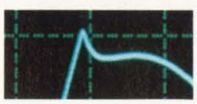
(a) (b)

Add sensor, will travel *should be the motto of these PC-based systems. The TD-4000* ***(a)*** *from Elexor 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?



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



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

Tektronix DSA602:
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.)

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

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INSTRUMENTS OF DISCOVERY

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. **EDN**

Reference

1. Novellino, John, "PC-based instruments grow in number and power," *Electronic Design—Edge*, December 1988, pg 7.

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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Datavue
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Grid Systems Corp
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John Fluke Mfg Co Inc
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(800) 443-5853;
in WA, (206) 346-6100
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Keithley/Metrabyte/DAC
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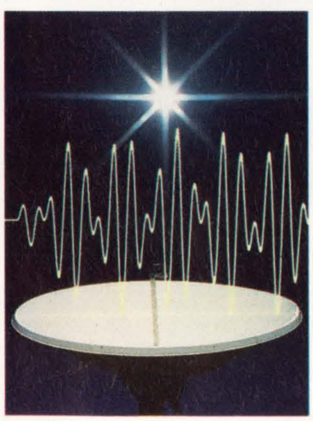

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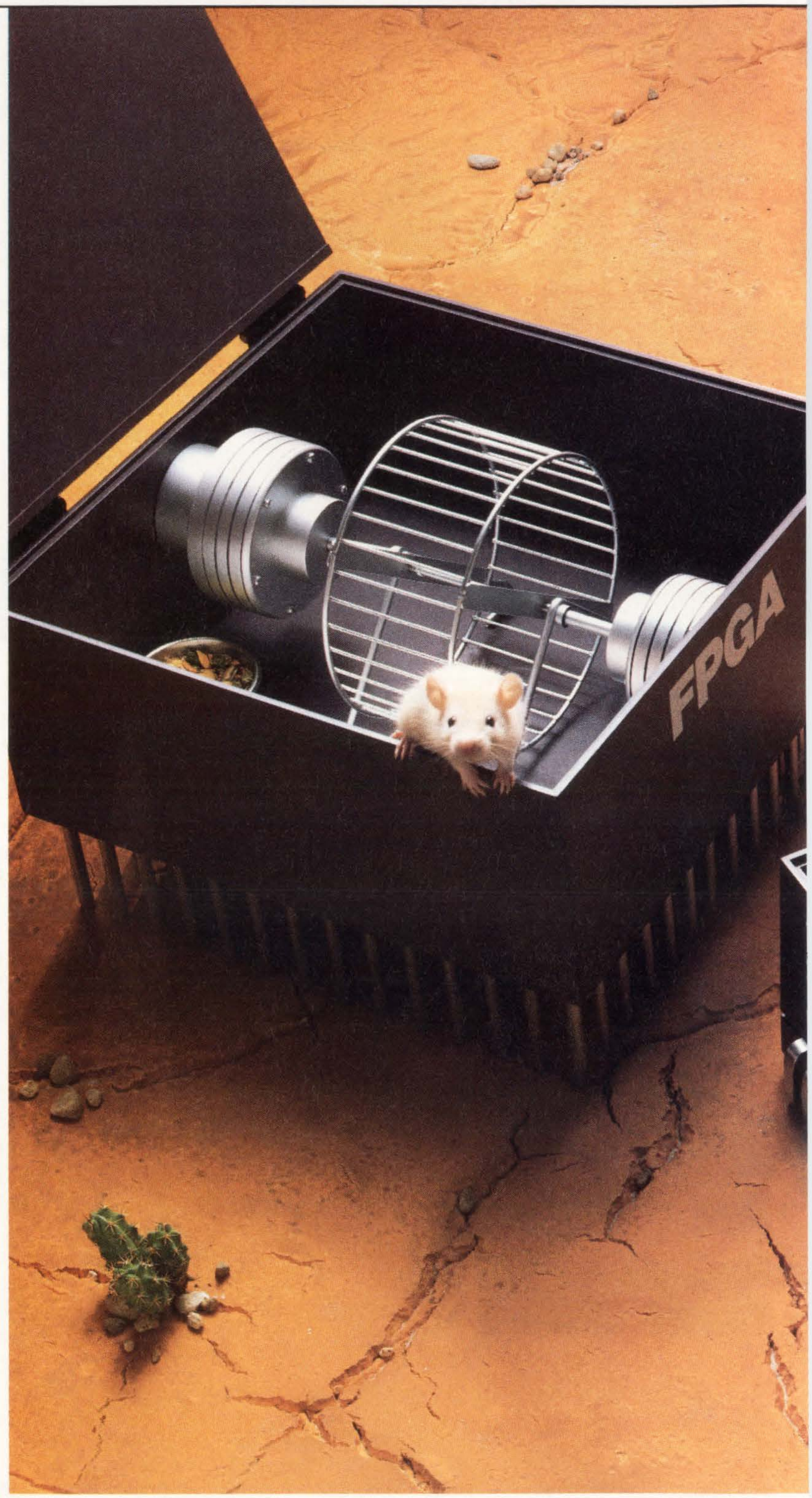

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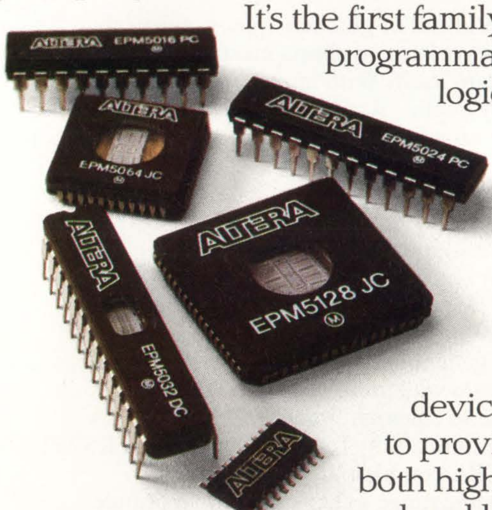

devices to provide both high speed and high logic density where it counts. At the system level.

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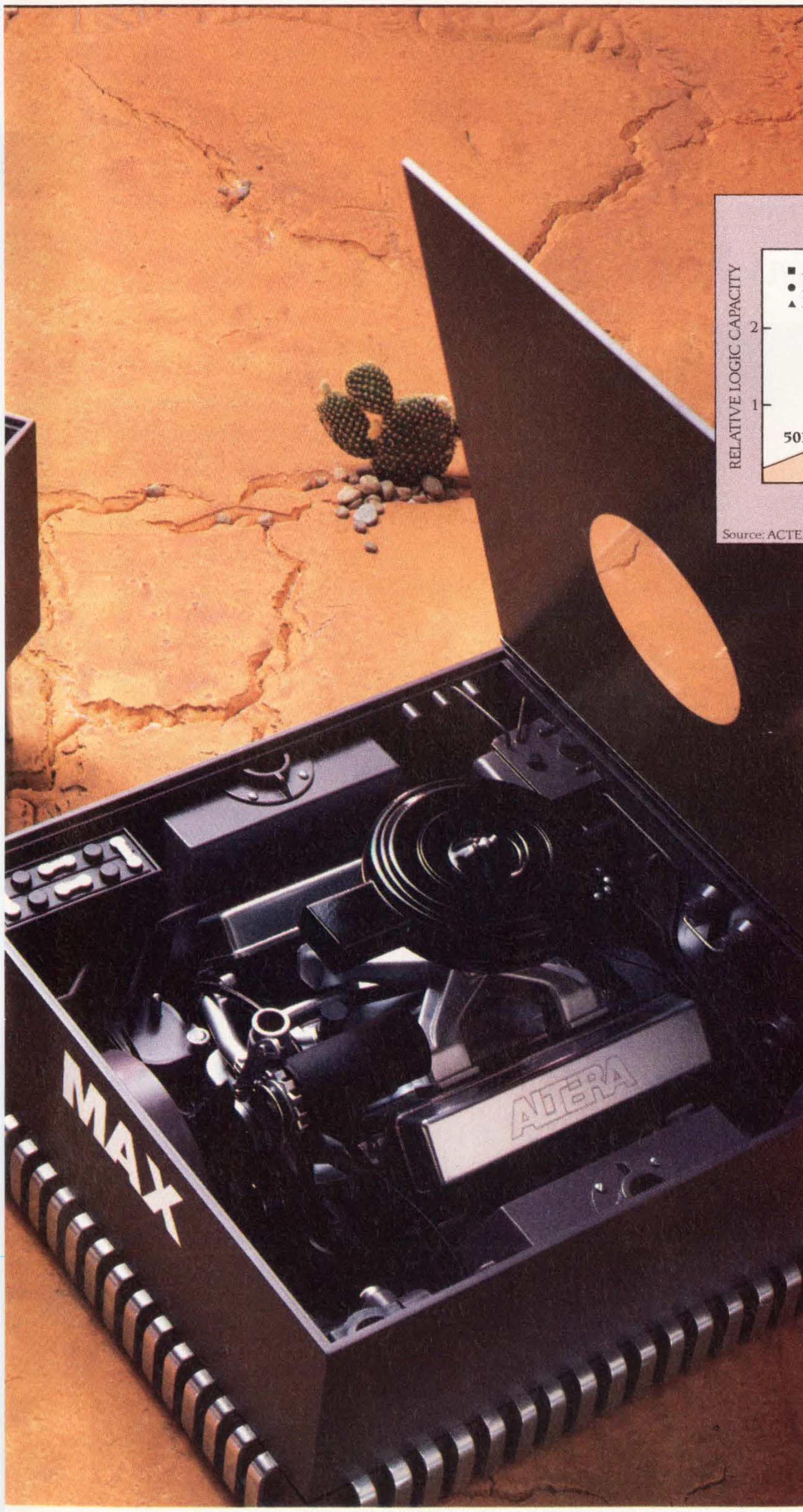
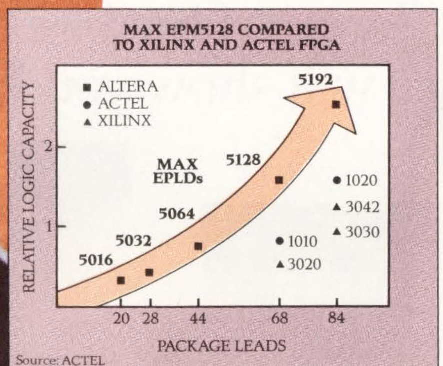


can integrate anything from simple system glue logic right up to complex graphics coprocessors and LAN and memory controllers.



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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.

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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.

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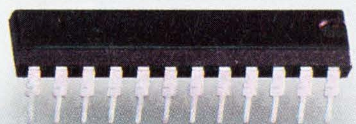
Wider word widths and additional cards on backplanes are requiring higher drive currents to assure incident wave switching.

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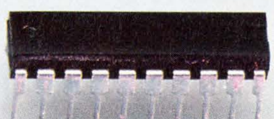
MOS memory array interfaces create the high-capacitive loading environments that can result in overshoot and undershoot conditions. As a result, system reliability suffers. To handle this situation, our BiCMOS memory drivers incorporate a series damping resistor output structure that delivers advanced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



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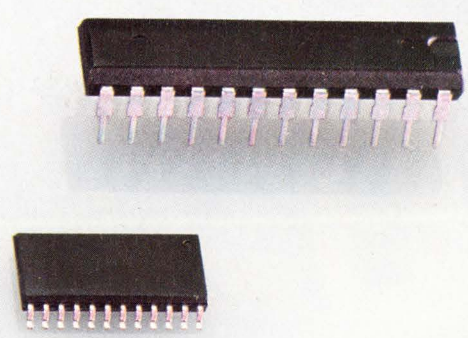

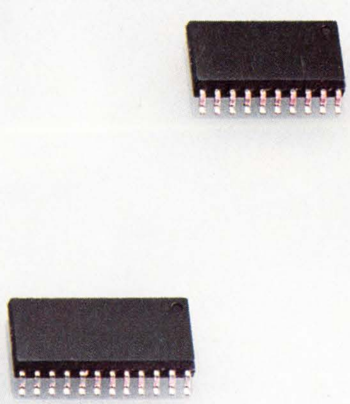

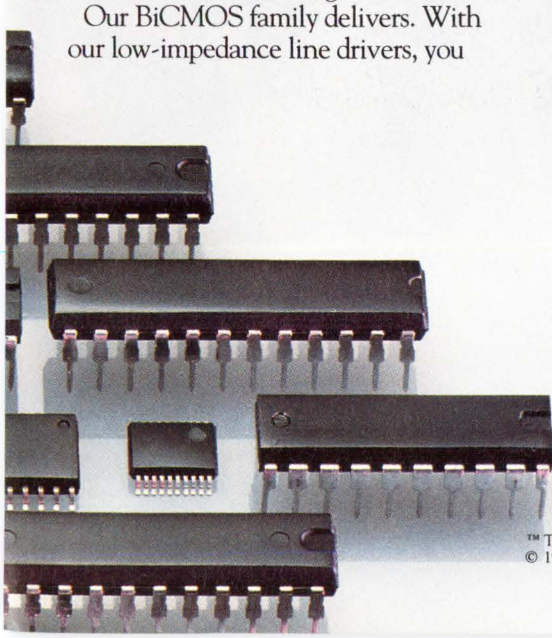

TEXAS INSTRUMENTS

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Eight megabytes of RAM was only $320,000?
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C&C Computers and Communications

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.

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Cross-debuggers are so much better than they used to be that you need to rethink the way you use them. Now, you can thoroughly test—not just debug—each element of your program at every stage of its development.

Charles H Small,
Senior Editor

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.*

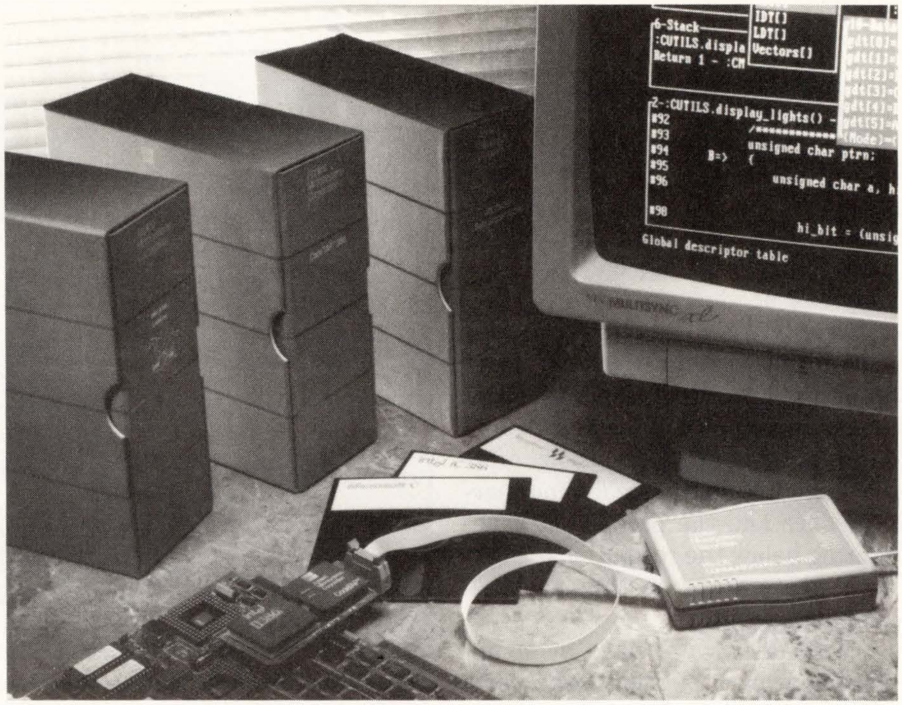
ous entities by their symbolic names. They now automate what used to require considerable operator intervention. The simplest example of such a powerful feature is the "watchpoint."

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.



***Offering a subset of in-circuit-emulator features**, Applied Microsystem's CodeTAP provides a fast, nonintrusive link between a debugger and a target system.*

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.

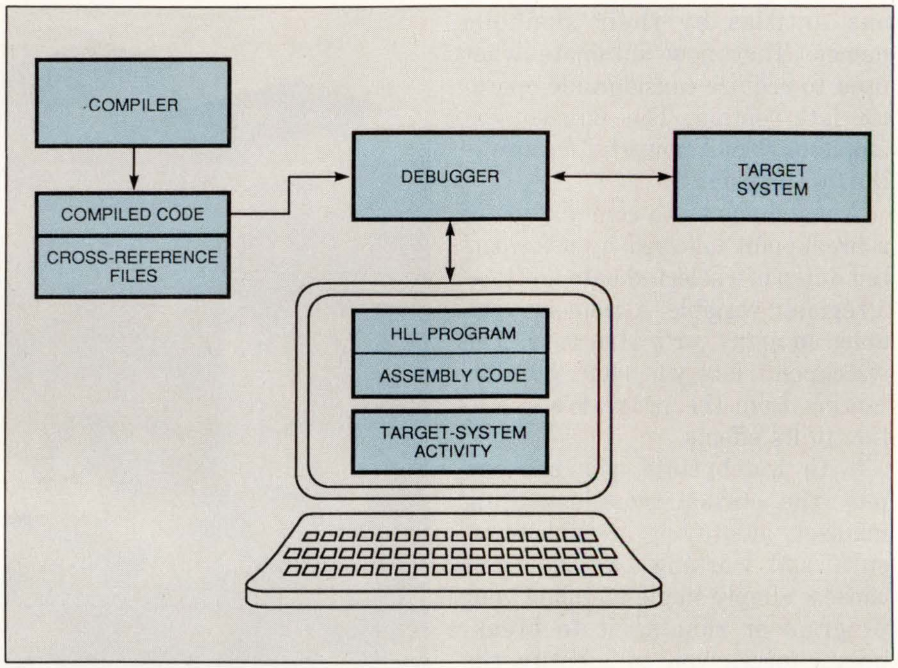


***Fig 1—Debuggers have seen recent** improvements at all three of their interfaces: compiler, human, and target-system.*

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-

Table 1—Target-system/debugger links

Feature	Solves logical problems	Visibility	Debugging	Runtime execution	Diagnostics	Solves runtime problems	Simple breakpoints	Doesn't use memory	Doesn't use I/O	Doesn't require code patch	Electrical transparency	Solves real-time problems	Time stamp	Trace	Overlay memory	Complex breakpoints	Execution transparency	Buffering	Cost
Monitor	•	•	•	•	•														$
Codetap	•	•	•	•		•	•	•	•	•	•								$$
ROM emulators	•	•	•	•	•	•	•		•		•	•	*	*	*	*			$$
In-circuit emulator	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	$$$

* = optional

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ware interrupts) mandate the highest power, least-intrusive hardware link to your target system. **Table** 2 shows Applied Microsystem's estimated breakdown, normalized over 100 bugs, for the time spent debugging these three classes of software problems.

Table 2—Bug breakdown

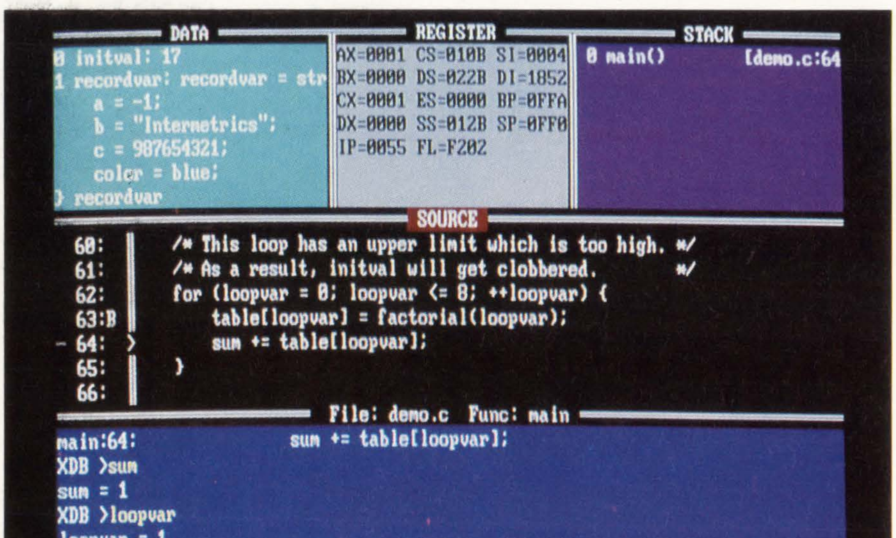
Class of bug	Number of problems	Time spent debugging
Logical	85	20 to 30%
Runtime	10	20 to 40%
Real time	5	40 to 50%

Note: Normalized over 100 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 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.



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.*

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,

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.

Teamed with an IBM PC, *cross-debuggers like Concurrent Science's Soft-Scope allow software engineers to "corner test" each element of their code as they write it.*

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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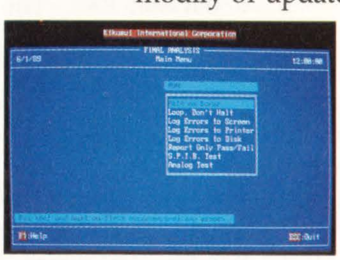

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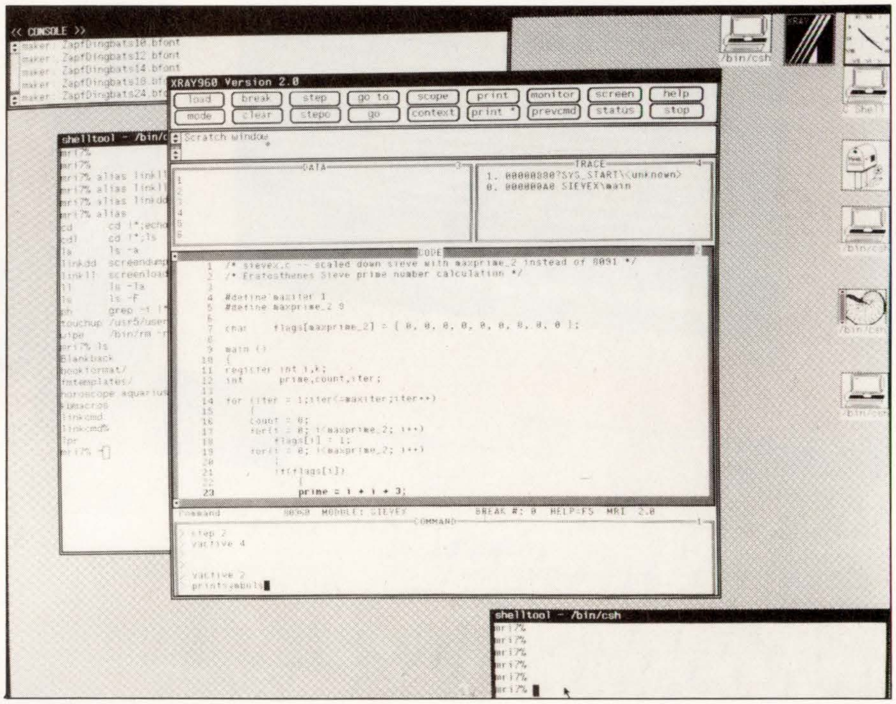
HLL Cross-Debuggers

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.



You can invoke commands *for a windowing debugger, such as Microtec Research's Xray, by using a mouse more quickly than you could with older command-line interfaces.*

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.

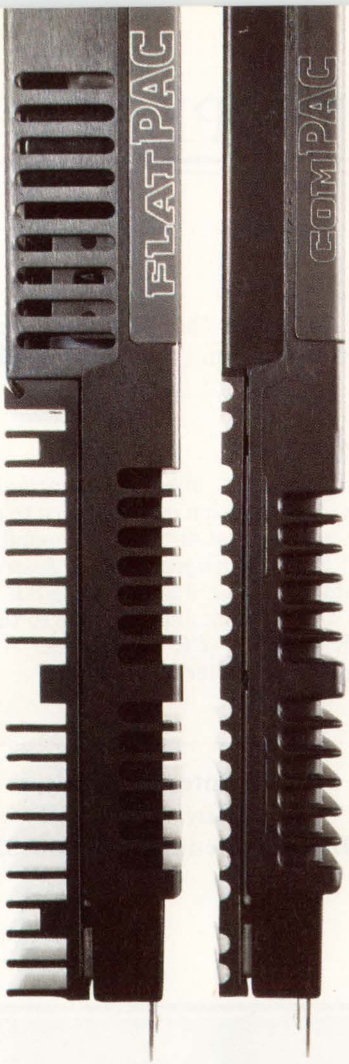
However, the existence of different versions of Intel's OMF should warn you to examine closely any claims that a debugger is "OMF compatible." Take your cue from such past claims as, "Centronics compatible," "RS-232C compatible," or "IBM PC compatible." Emulogic claims that Slice can work with any compiler;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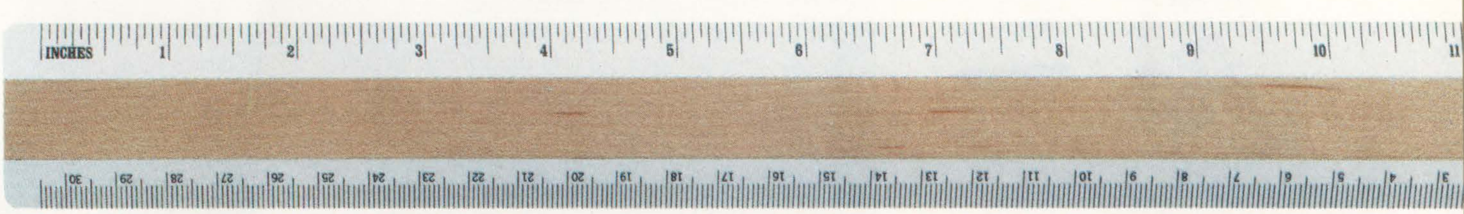

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Providing a comprehensive, correlated list of host computers, compilers, debuggers, links, and target processors is a daunting task that is well beyond the scope of this article. To make matters worse, the situation changes daily. If a combination 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 debugger to make the program you're working on run. EDN

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2. Duntemann, Jeff, "Rising to the WAR on Bugs," *PC Techniques*, August/September 1990, pg 20.

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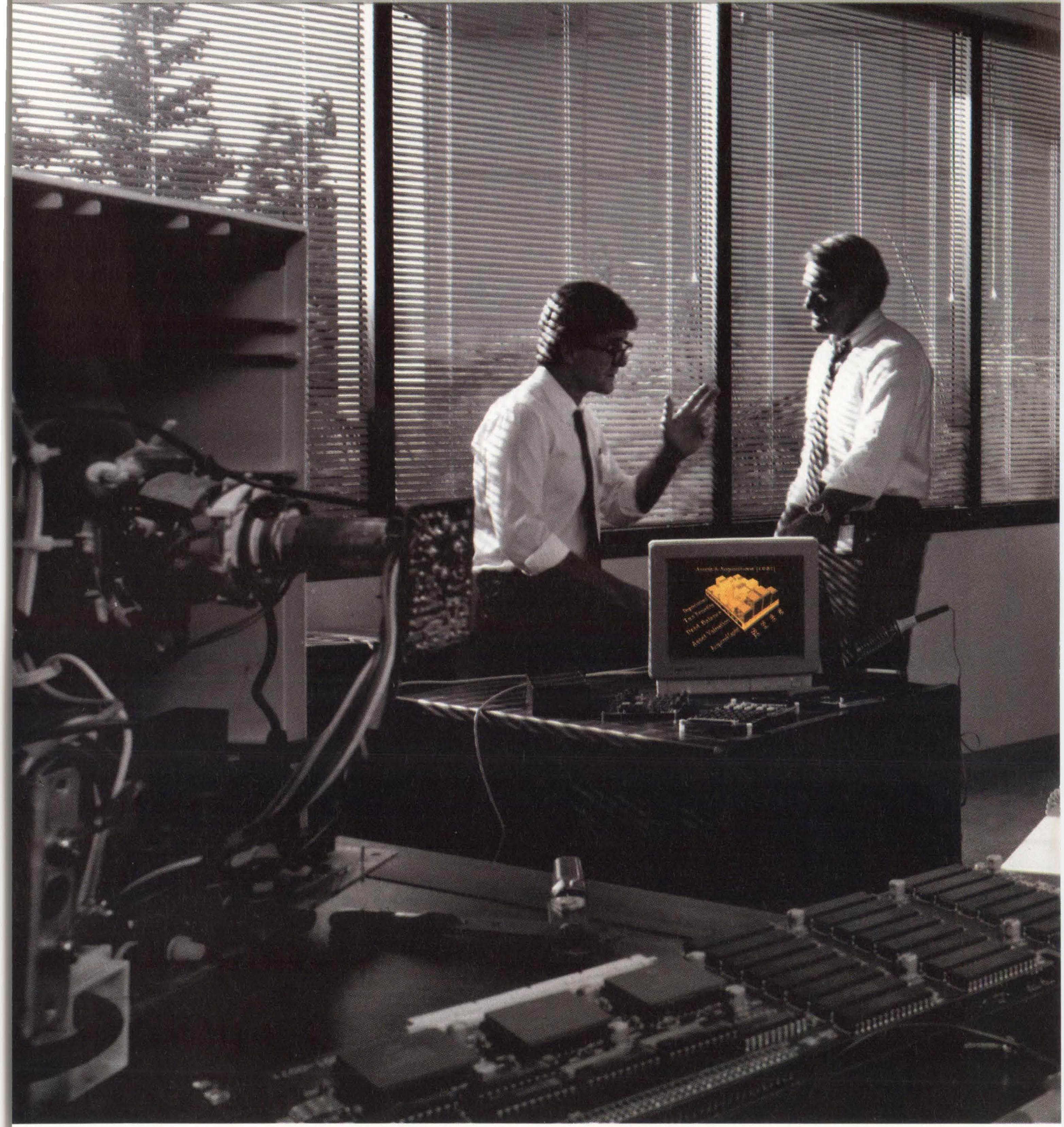

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COLUMN ADDRESS ACCESS TIME (MAX)	30NS	35NS
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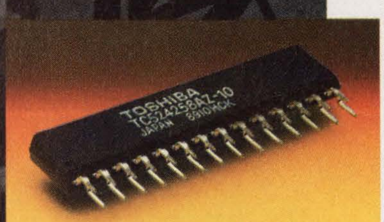

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Micro Linear's family of PWM and Power Factor Control IC's provide highly-integrated solutions for a broad range of switching power supplies.

Product Category	Features
Power Factor Control	High Efficiency Flyback or Boost
PWM Controllers	1 MHz, Additional Fault Protection, Synchronization
Resonant Control	ZVS and ZCS to 3 MHz
Motor Control	BLDC Sensorless Commutation

of the power curve.

capability. Even stability improvements.

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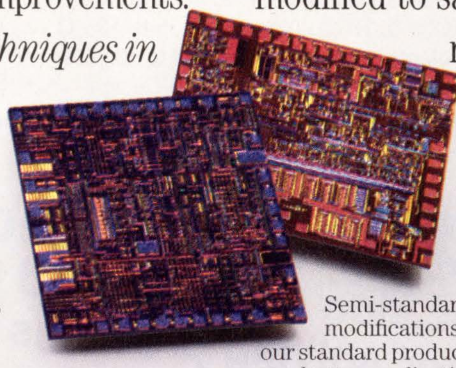
Now you have some unique design options. With our new ML4410 sensorless motor controller, the first controller designed to automatically commutate brushless DC motors without the need for Hall-effect sensors. So you can eliminate the inherent alignment, torque ripple and flutter problems previously encountered with Hall-effect commutation. And design smaller, lower cost, higher reliability motors for any continuous speed application.



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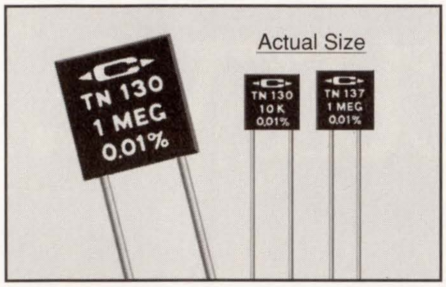
Type TN Lab Grade Low TC Precision Resistors

New

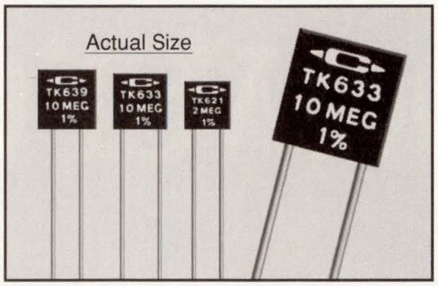


1 K to 1 Meg, Tolerance to ±0.01%
Low TC to 5 ppm/°C, 0°C to 70°C

- **Non-Inductive Design**
- Tolerance of ±0.01%, ±0.025%, ±0.05%, ±0.1%, ±0.25%, ±0.50% or ±1%
- Low TC of 5, 10 or 20 ppm/°C, 0 to 70°C
- Space Efficient Radial-Lead Design

For Type TN data, circle number 121

Type TK Low TC Precision Radial-Lead Film Resistors

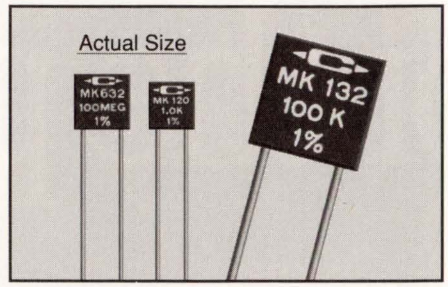


Low TC to 5 ppm/°C, -55°C to 125°C

- **Non-Inductive Design**
- Resistance Range 1 Kohm to 10 Meg
- TC of 5, 10 or 20 ppm/°C, -55 to 125°C
- Tolerance of ±1% (available to ±0.05%)
- Space Efficient Radial-Lead Design

For Type TK data, circle number 122

Type MK Precision Power Radial-Lead Film Resistors



0.50 Watt (CK05), 0.75 Watt (CK06)

- **Non-Inductive Design**
- Resistance Range 1 Ω to 100 Meg
- TC as low as 50 ppm/°C, -15°C to 105°C
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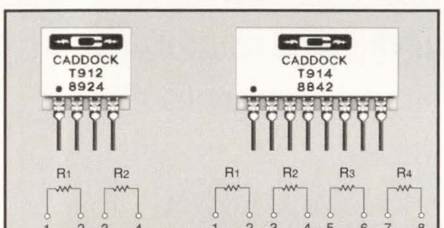

T912 Schematic 1:1, 9:1 or 10:1
T914 Schematic 4 equal value resistors

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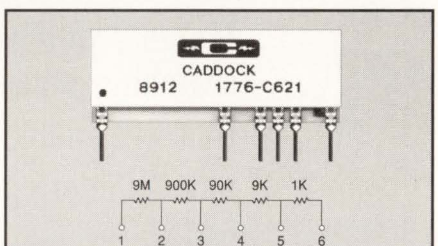
- Custom ratios available, 1:1 to 250:1

For Type T912/T914 data, circle 124

Type 1776 Precision Decade Voltage Dividers



1776-C621 Schematic

Voltage Division 10:1 to 10,000:1

- Ratio Tolerance 0.02%, 0.05%, 0.1%, 0.25% or 0.5%
- Ratio TC of 5, 10, 25 or 50 ppm/°C, from 0°C to 70°C
- Select from 39 Different Models
- Voltage Rating to 1,200 Volts

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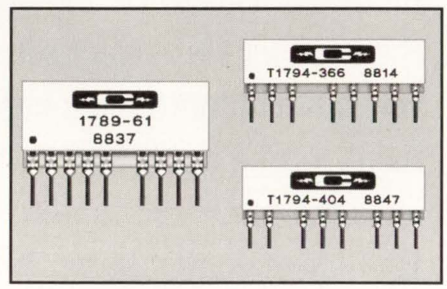

Ratio Tolerance to 0.01%

- Resistance Range 0.5 ohm to 50 Meg
- Abs. Tolerance from ±0.025% to ±1%
- Ratio Tolerance from 0.01% to 1%
- Abs. TC of 15 ppm, 25 ppm, 50 ppm or 80 ppm/°C, from 0°C to 70°C
- Ratio TC of 5 ppm, 10 ppm, 25 ppm or 50 ppm/°C, from 0°C to 70°C

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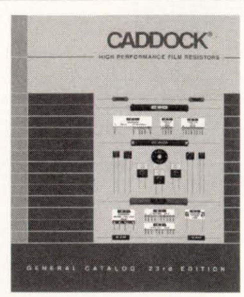


Brawny amps stretch small-signal limits

Op amps that operate at voltages beyond the traditional ±15V supply span, and that supply >100-mA load current, eliminate the need for buffers and boosters.

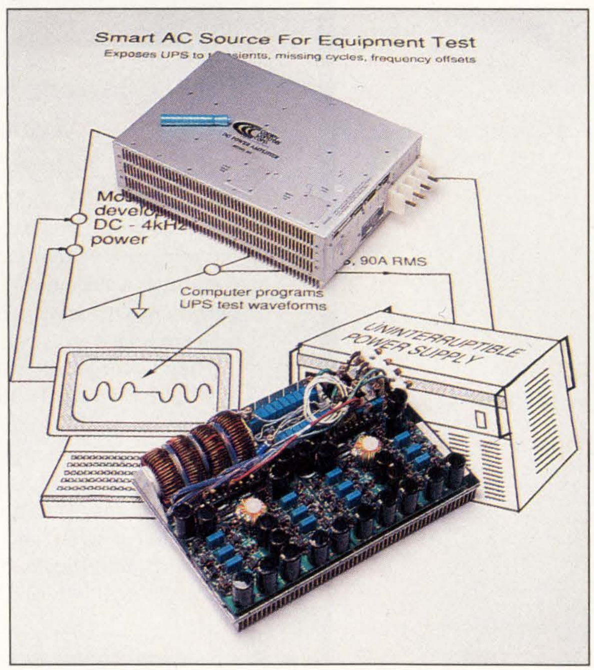
Bill Travis,
Contributing Editor

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 a ±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).



***Pulse-width modulation beats the heat** in Copley Controls' 232 amplifier. Its class-D operation and bridge-configured output stage allow the unit to deliver to a load ±400A peak at ±160V.*

Two new series of monolithic op amps from National Semiconductor push the

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CIRCLE NO. 113

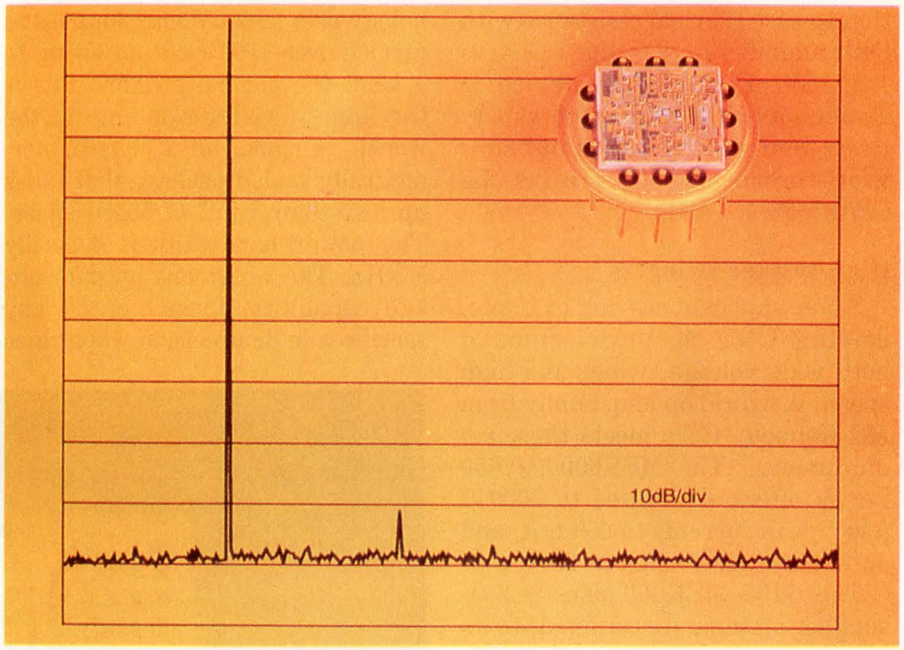
High-voltage/high-current op amps

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 $18.05 (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.



Current-feedback architecture *takes the credit for the high speed of Comlinear's CLC207 op amp. The ±15V device delivers ±150 mA to its load and slews at 2400V/μsec.*

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 junction-to-case thermal resistance with both amplifiers operating is 3.4 vs 1.2°C/W. Finally, the device is slower—its slew rate is 0.5 vs 6V/μsec, and its typical gain-bandwidth product is 600 kHz vs the OPA2541's 1.6 MHz.

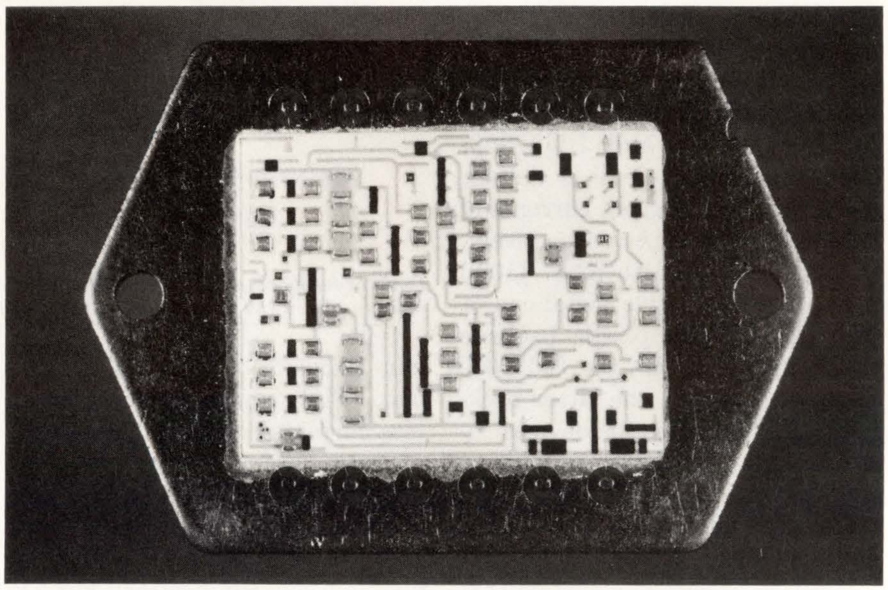
High-voltage swingers

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 ±80V 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 ±35V 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 ±600V 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.

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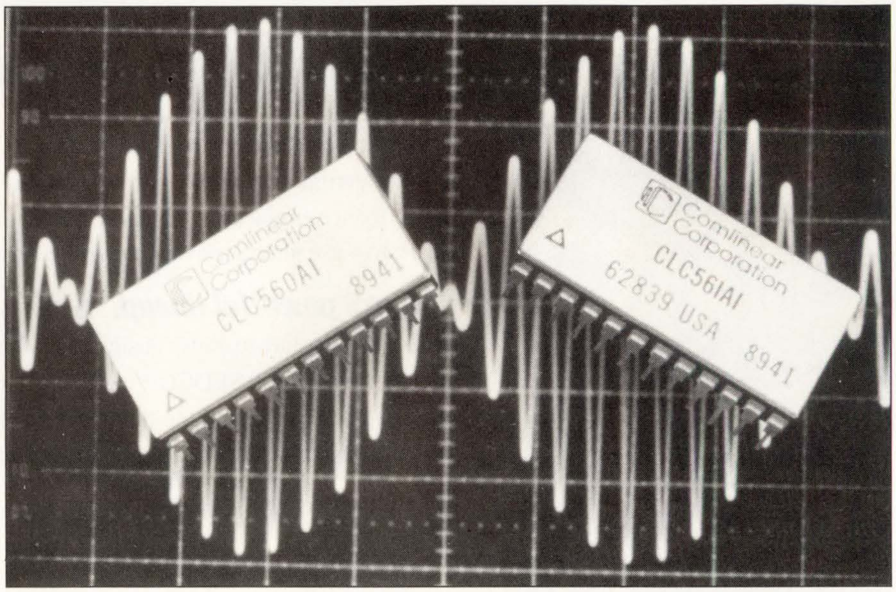
High-voltage/high-current op amps



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. EDN

Reference

1. Travis, Bill, "Current feedback revs up op amps," *EDN*, September 3, 1990, pg 107.

Article Interest Quotient
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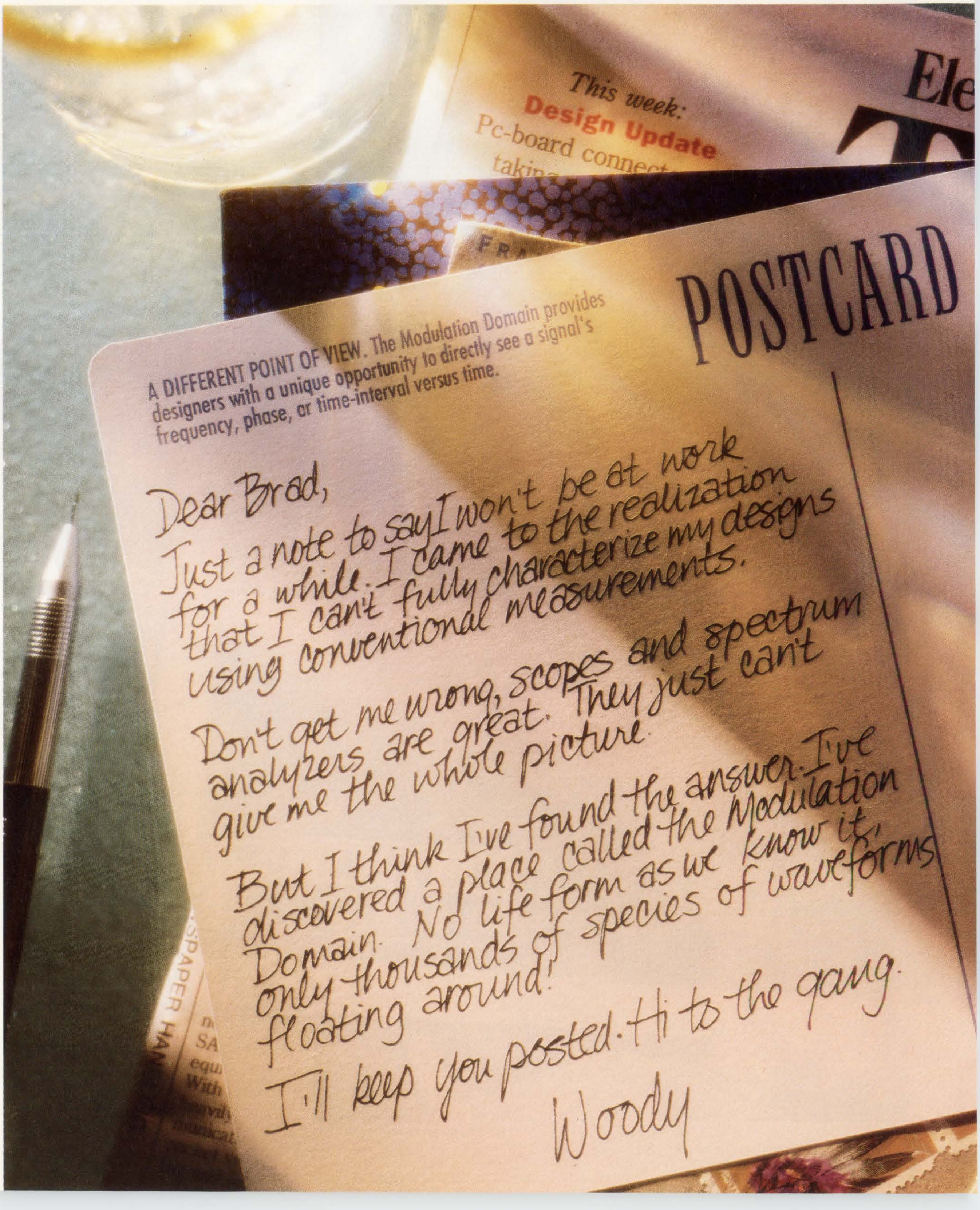
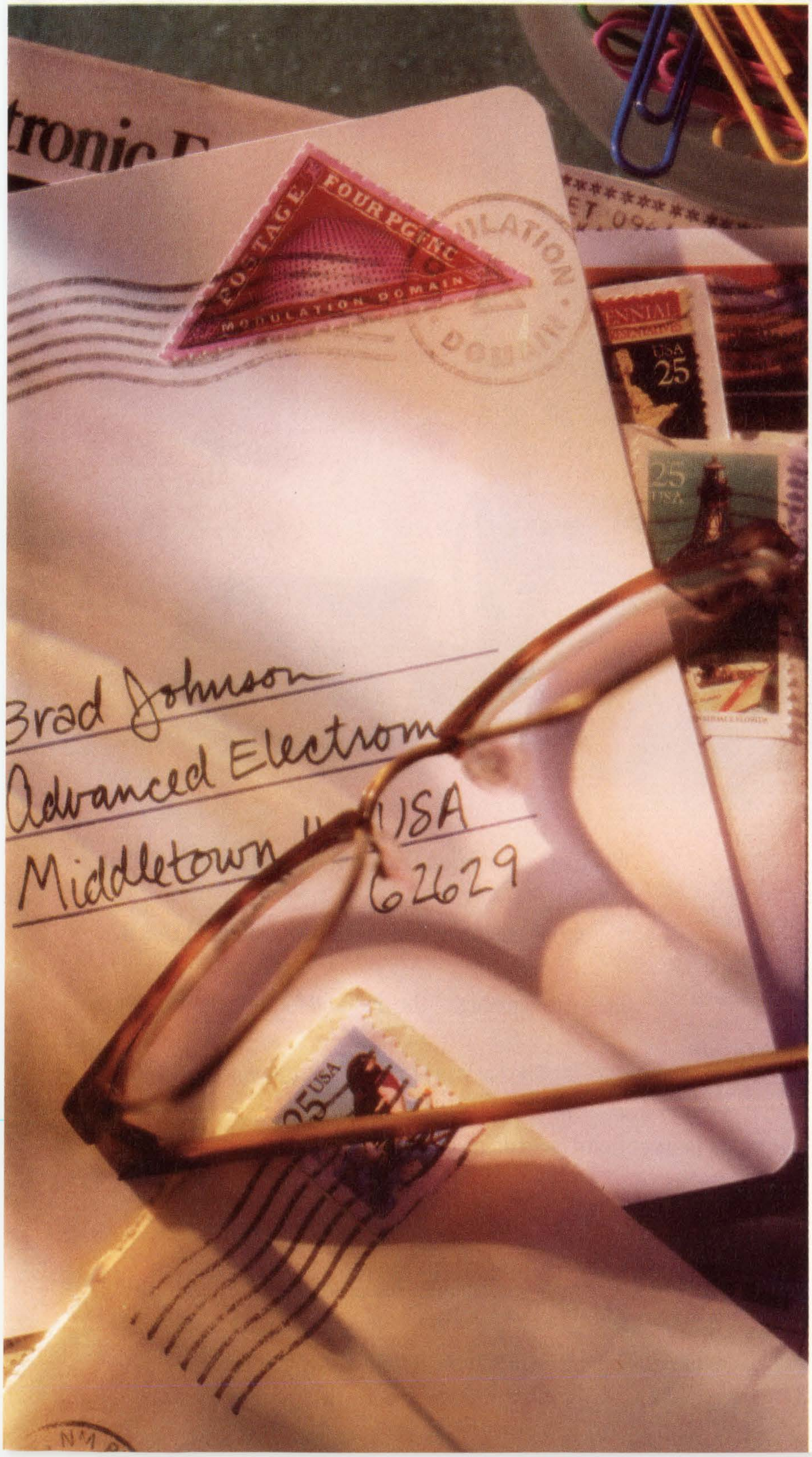
High 500 Medium 501 Low 502

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 to get a better look at his designs.



the Modulation Domain



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.

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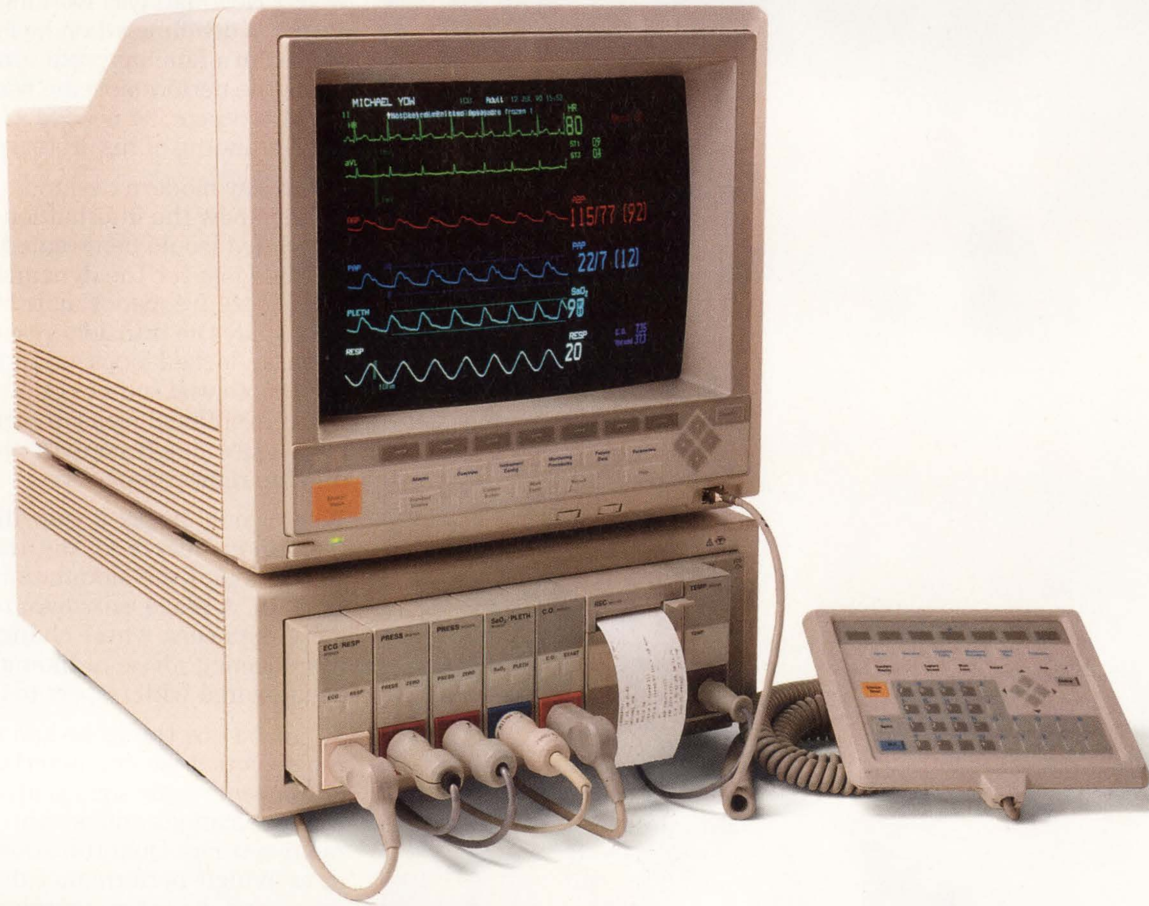

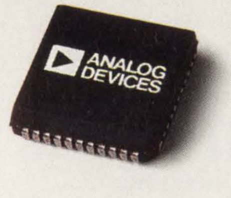

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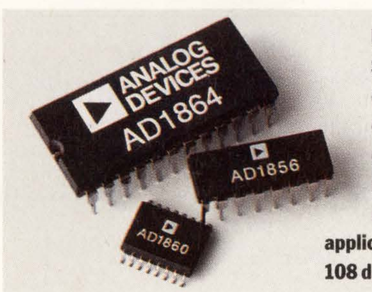

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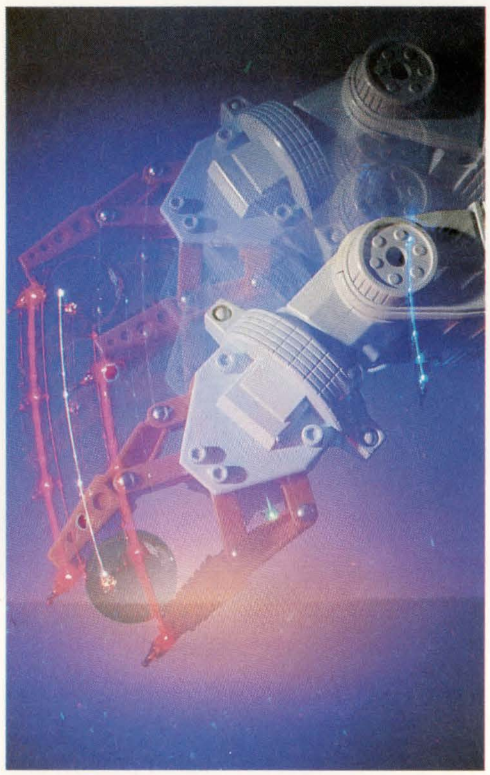

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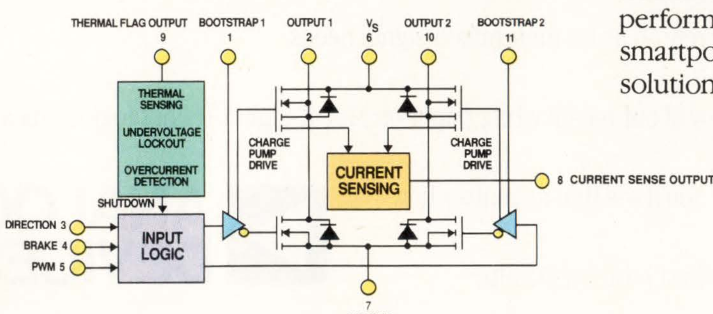

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Not only does the LMD18200 know when to start, it knows when to quit. Specially equipped with a two-stage thermal warning system, it transmits a distress flag to the host system at 145° C, allowing you enough time to take any corrective action.

And if the temperature reaches 170° C, the device automatically shuts down. A fail-safe feature that eliminates damage to your equipment.

What's more, the LMD18200's on-chip defense system provides overcurrent protection, which prevents damage both to the device and the motor in case a shorted load causes the motor to draw excessive current.

PLAY IT SMART.

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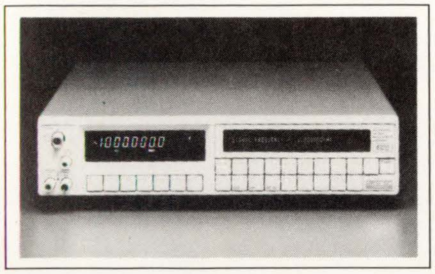
National Semiconductor Corp.
P.O. Box 7643
Mt. Prospect, IL 60056-7643

National Semiconductor

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 11V 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.

Datron Instruments Ltd, Hurricane Way, Norwich NR6 6JB, UK. Phone (603) 404824. FAX (603) 483670. Hall 20, stand A24.

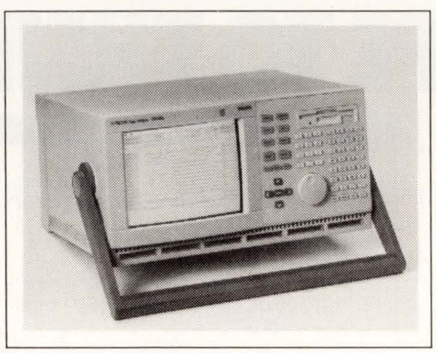
Circle No. 804

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. Hall 25, stand C06.

Circle No. 805



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.

Philips Industrial & Electroacoustic Systems, Box 218, 5600 Eindhoven, The Netherlands. Phone (40) 784959. FAX (40) 788256. Hall 24, stand B4.

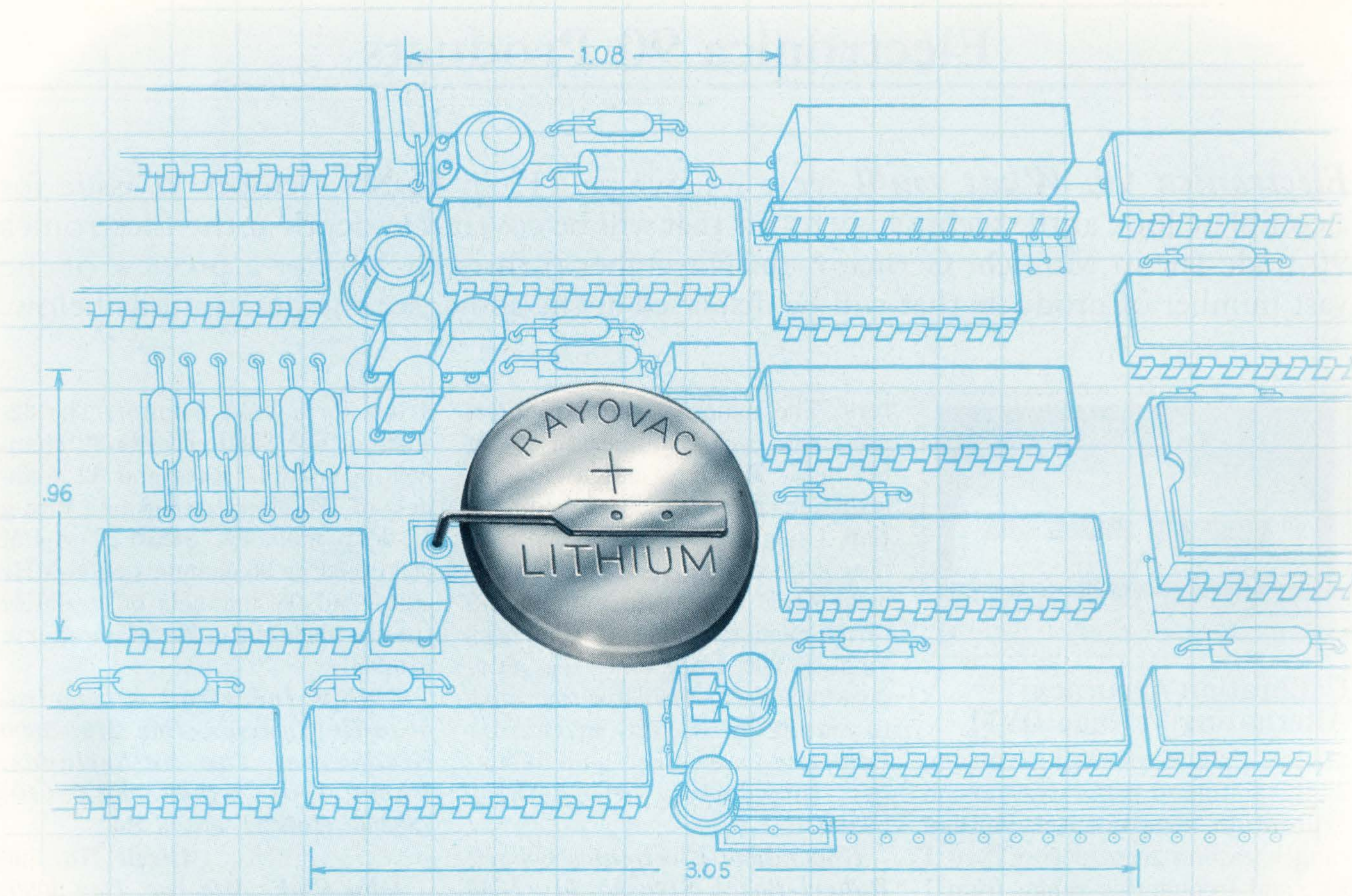
Circle No. 806

John Fluke Mfg Inc, Box 9090, Everett, WA 98206. Phone (206) 347-6100. FAX (206) 356-5116.

Circle No. 807

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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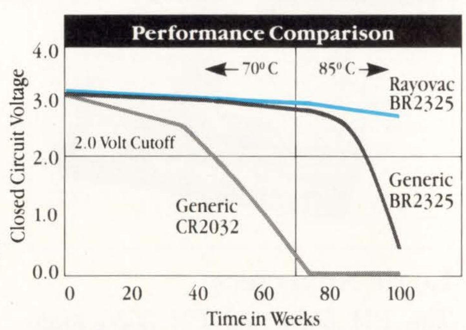

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CIRCLE NO. 85

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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 £6 to £9. Samples of FX802 and FX806 available now; others due second quarter of 1990.

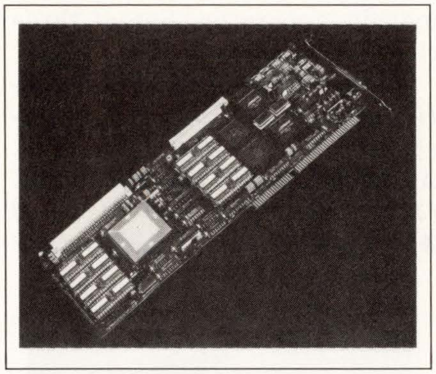
Consumer Microcircuits Ltd, 1 Wheaton Rd, Witham CM8 3TD, UK. Phone (376) 513833. FAX (376) 518247. Hall 25, stand A04.

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.

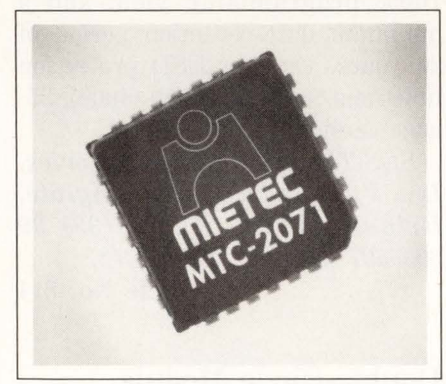
Dual analog inputs feed sigma-delta ADCs, which sample at up to 100 kHz or 400 kHz, with a linearity of 16 or 12 bits, respectively. Processed data passes to twin 16-bit DACs, producing two channels of analog output. Optional in-line fourth-order Butterworth filters al-



low 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.

Loughborough Sound Images Ltd, The Technology Centre, Epinal Way, Loughborough LE11 0QE, UK. Phone (509) 231843. FAX (509) 262433. Hall 18, stand D08.

Circle No. 809

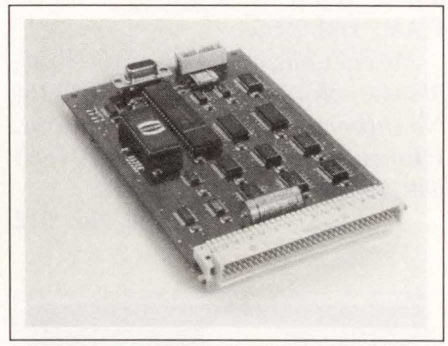


ISDN U Interface Transceiver Chip

The MTC-2071 chip enables full duplex digital data transmission via standard twisted-pair telephone cable (U interface), using 4B/3T line code. The chip employs an internal DSP adaptive filter for echo cancellation and equalization. You can use the chip in ISDN networks on subscriber loops up to 4.2 km and 8.2 km, with 0.4- and 0.6-mm-diameter cable, respectively. Maximum dissipation is 250 mW, and the package is a 28-pin plastic leaded chip carrier. $25.50 (10,000).

Mietec Alcatel, Raketstraat 62, B-1130 Brussels, Belgium. Phone (10) 322 7281811. FAX (10) 322 2427552. Hall 19, stand B07.

Circle No. 810



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).

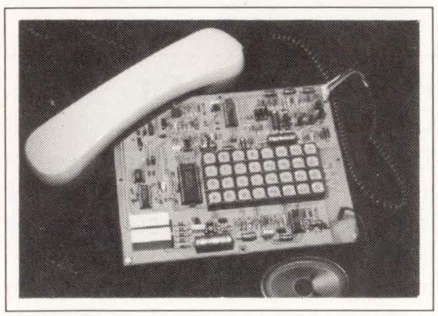
Harting Elektronik GmbH, Postfach 1140, D-4992, Espelkamp, Germany. Phone (5772) 470. FAX (5772) 47461. Hall 2, stand C05.

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-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.

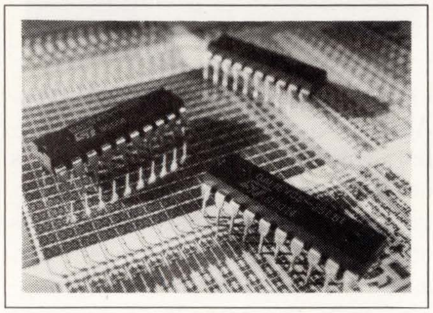
Force Computers GmbH, Prof-Messerschmitt-Strasse 1, D-8014 Neubiberg, Munchen, Germany. Phone (89) 608140. FAX (89) 6097793. Hall 19, stand A11.
Circle No. 812



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 melody generator. Set of three chips, DM 9 (500,000).

Austria Mikro Systeme International GmbH, Schloss Premstätten, A-8141 Unterpremstätten, Austria. Phone (3136) 36660. FAX (3136) 2501 3650. Hall 19, stand A12.
Circle No. 813



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).

SGS-Thomson Microelectronics, Ltd, Via C Olivetti, 20041 Agrate, Brianza, Italy. Phone (39) 39 6035597. Hall 24, stand B12.
Circle No. 814

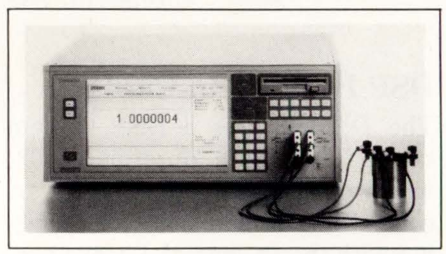
Double-Diode Module

The BYT230PI 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 1×1.5 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

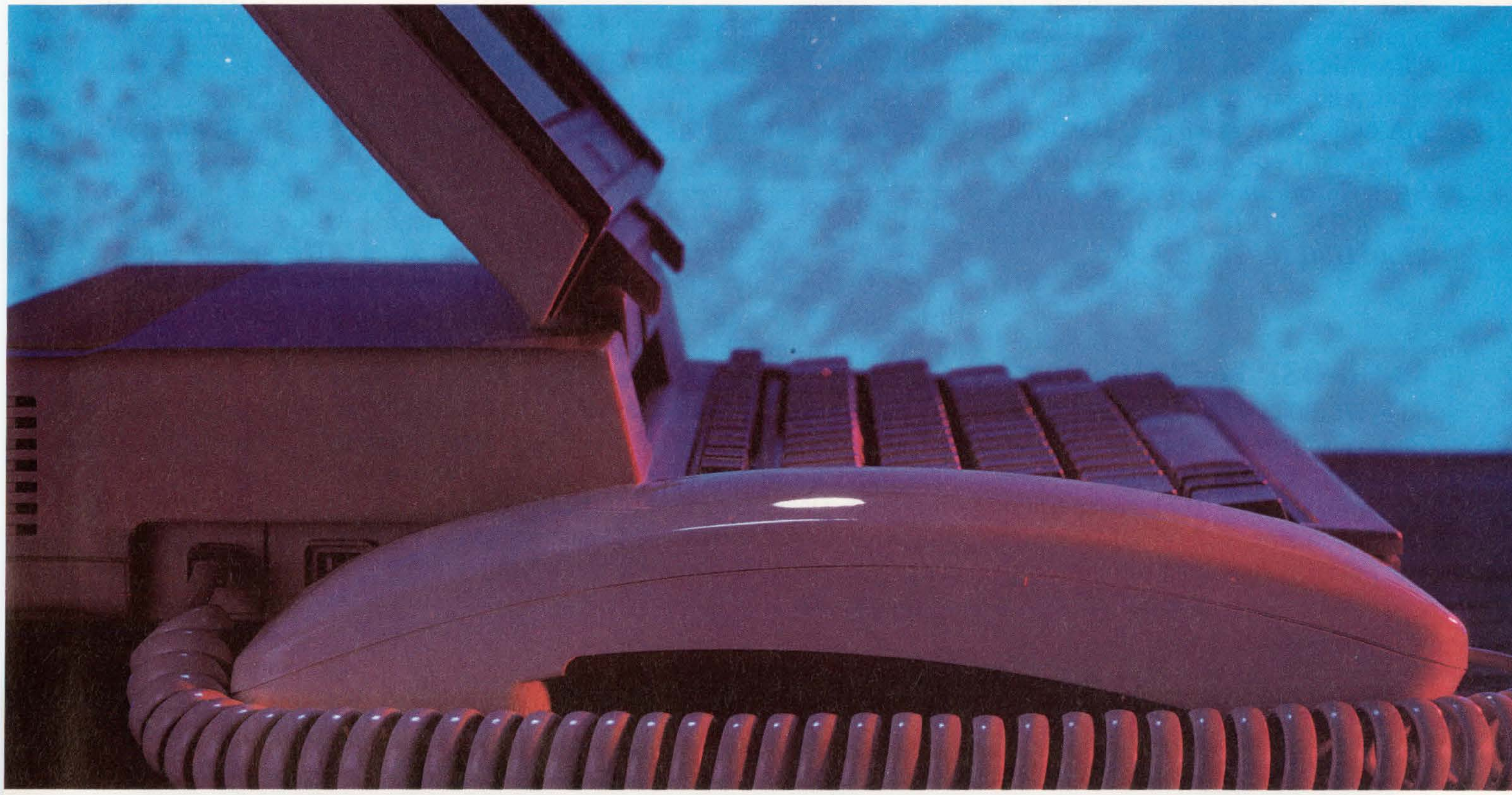
The 8047 AT consists of a 7½-digit multifunction digital voltmeter combined with a 12-MHz IBM PC/AT-compatible computer. The unit has a 210×130-mm black-and-white LCD; you control it by making window selections using cursor keys. DC voltage input ranges from 100 mV to 1 kV. Accuracy at 10V is 9 ppm for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

Prema Prazisionselektronik GmbH, Robert-Koch-Strasse 10, D-6500 Mainz 42, Germany. Phone (6131) 50620. FAX (6131) 506222. Hall 25, stand A10.
Circle No. 816

SIEMENS



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Siemens also offers cost-effective solutions for analog interface, including single and dual channel Digital Signal Processing Codec Filters. Designed with DSP architectures for maximum programmability.

And Siemens invented a unique, all-CMOS monolithic ISDN Echo Cancellation Circuit, the first single chip solution for the standardized U-interface. With the power to double the traffic-handling capability of *any* existing telephone line.

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For details, call (800) 456-9229, or write Siemens Components, Inc. 2191 Laurelwood Road Santa Clara, CA 95054-1514. Ask for literature package M12A003.

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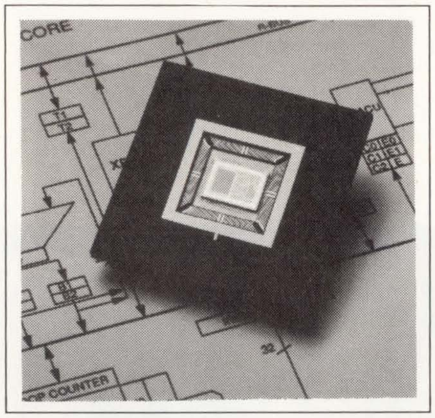
CIRCLE NO. 83

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).

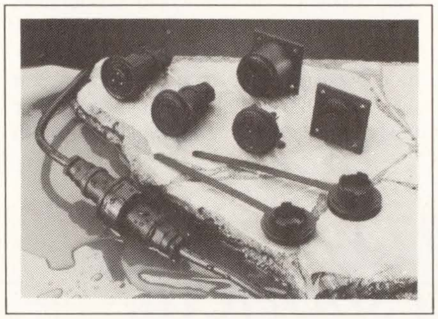
SGS-Thomson Microelectronics, ZI de Rousset-BP2, 13106 Rousset Cedex, France. Phone (4225) 8800. FAX (4229) 0068. Hall 24, stand B12.
Circle No. 818

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 tablet. 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 95.2×40.2×25.0 mm. £144.

Astec High Voltage, Astec House, Genesis Business Park, Albert Dr, Woking GU21 5RW, UK. Phone (483) 756066. FAX (483) 757223. Hall 24, stand B6. **Circle No. 821**

Miniature DC/DC Converter

The NMF series of dc/dc voltage converters produces single outputs of 5, 9, 12, 12.75, or 15V from an

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AT&T

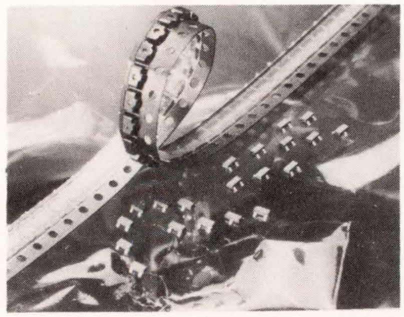
CIRCLE NO. 84

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 × 6.0 × 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, Tanners 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 I_C rating of 1A in a surface-mount



SOT23 package. Both types feature a V_{CESAT} of 0.3V typ at 1A I_C. H_{FE} is a minimum of 40 at the peak I_C rating of 2A, and increases to 100 at 0.5A I_C. At a 25°C ambient temperature and mounted on a 0.6-mm substrate of 80 mm^2, 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

Miniature SAW Filter

The Y6960M SAW filter fits in a 5-pin single-in-line package. It has a 10-MHz bandwidth designed for a 118-MHz center frequency. Insertion loss is 30 dB, with a passband ripple of 0.4 dB. Group delay ripple is typically ±20 nsec, and the filter suppresses any trailing signals at center frequency by 47 dB. DM 8.80 (1000).

Siemens AG, Postfach 801709, D-8000 Munchen 80, Germany. Phone (89) 4144 8083. FAX (89) 4144 8082. Hall 23, stand A4.
Circle No. 824

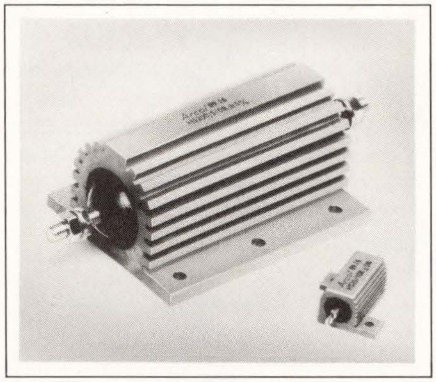
Nickel-Hydride Rechargeable Cell

The VNH range of rechargeable cells comprises three models in sizes C, SC, and AA. For the same size, these nickel-hydride batteries possess 50% greater capacity than Ni-

Cd alternatives. A complete recharge is possible in 1 hour, and continuous charging is possible at 10% of the Ahr capacity rating. The cells discharge at 5 times the Ahr capacity rating and survive 1000 charge/discharge cycles. Samples of the VNH1.0, AA-size, 1.0-Ahr version, DM 5. Available first quarter of 1991.

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 9LG, UK. Phone (872) 77431. FAX (872) 222002. Hall 24, stand B21. **Circle No. 826**

50W AC/DC And DC/DC Power Supply

The M series consists of six power supplies that produce a single, dual, or triple output of 48V dc from an ac or dc voltage input. The input voltage range extends from 7 to 372V dc or 90 to 264V ac at line frequency. All models maintain a 50W power rating and operate at 85% efficiency in ambient temperatures of −40 to +71°C. You can choose a model with variable output from 0 to 110% of nominal. £200 (10).

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

Universal Programmer

The AP-III programs single EPROMs, EEPROMs, bipolar PROMs, microcontrollers, PLDs,

One of the world's biggest battery suppliers is now on the way to Jupiter.

Varta batteries are on board the missile "Galileo" that will enter Jupiter's atmosphere in 1995. During the 6-year mission, two special 70 V lithium batteries ensure the precise data collection functions of a particle sensor. Varta – supplying the energy to take science into new dimensions. In the same reliable way as in trail-blazing electrotechnical and electronic projects all over the world.

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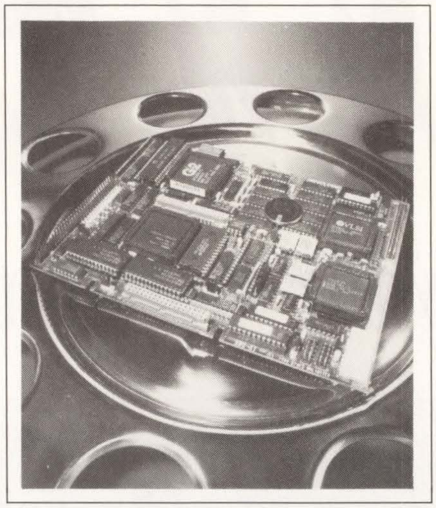
CIRCLE NO. 87

electrically programmable logic devices, and generic array logic devices. You can operate the program from a front-panel keyboard or remotely via a 115k-baud RS-232C link to an IBM PC or compatible. Standard internal RAM capacity is 1M bits, but it is upgradable to 4M bits. Optional extenders allow you to program multiple devices. The programmer includes support software and a lifetime update service for new devices. DM 5498.

Owen Electronic GmbH, Ringstrasse 11, D-6798 Kusel, Germany. Phone (6381) 5085. FAX (6381) 8584. Hall 20, stand A19.
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 5.75×7.75×0.85 in. £550 (10).

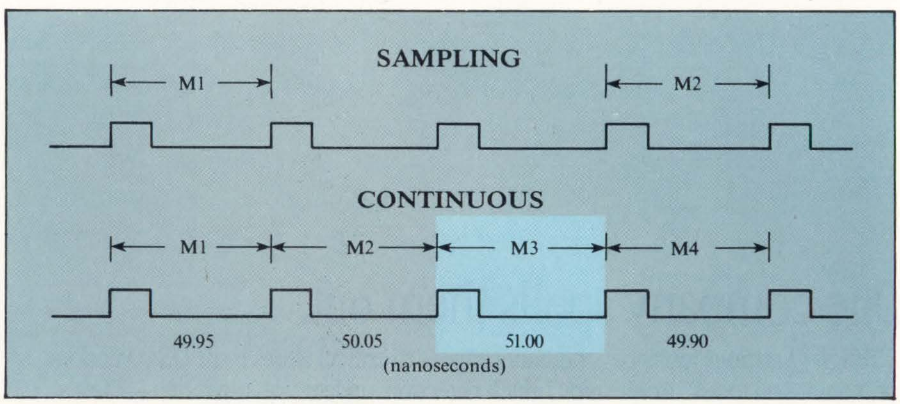
Nevin Developments Ltd, 48 Charlton Rd, Andover, Hampshire SP10 3JL, UK. Phone (264) 332122. FAX (264) 332125. Hall 24, stand B13A. **Circle No. 829**

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 2.91×1.18×0.47 in., and links to your pc board by a pair of

JITTER.

Is it limiting your system performance?



Trying to analyze the adverse effect of jitter and isolate the failure using Random Sampling has been a problem. International Test Instruments (ITI) offers you the solution — Continuous Time Ordered Measurements using the Digital Timing Analyzer (DTA).

The DTA measures and stores up to 524,000 continuous intervals at data rates up to 20 MHz*. It can store these individual measurement values in the order they occurred at resolutions as fine as 50 ps. Interval deviations exceeding the accepted boundaries can be isolated and the events surrounding the interval can be easily analyzed.

Find out how the DTA and its application software** can help you pinpoint the problem area, determine the proper compensation and reduce the jitter that limits your system performance. For a no-obligation demonstration or to receive more information, call:

INTERNATIONAL TEST INSTRUMENTS, INC.

15550-B ROCKFIELD,
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IRVINE, CALIFORNIA 92718.
1-800-2525-ITI
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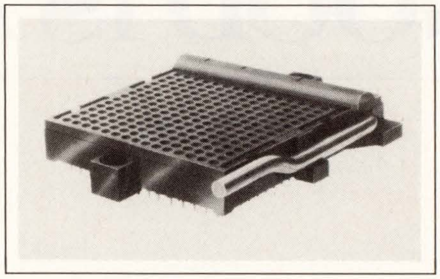
British Telecom and Dupont Technologies Ltd, Whitehouse Rd, Ipswich, Suffolk IP1 5PB, UK. Phone (473) 42250. FAX (473) 240490. Hall 24, stand B17A. **Circle No. 830**

Zero-Insertion-Force PGA Test Socket

The ZIF PGA family includes 10 sockets for test and burn-in of programmable gate arrays. Pin grid sizes range from 12×12 to 21×21. Cam action forces each normally closed contact to open to receive the component. This design prevents dependency on plastic for contact force when the component is in place. To accommodate burn-in temperatures of −65 to +200°C, contacts are made of nickel-boron plated alloy. You can choose a left-



or right-action handle and sockets with or without fixing lugs. 15×15 version, $34.50 (100).

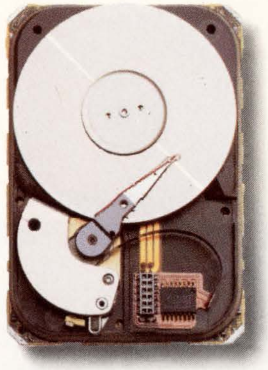
Aries Electronics (Europe), Unit 3 Furtho Court, Towcester Rd, Old Stratford, Milton Keynes MK19 6AQ, UK. Phone (908) 260007. FAX (908) 260008. Hall 16, stand F9. **Circle No. 831**

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**

WITHOUT A MEMORY?



To hear most people in the computer business talk, you'd think the only valuable part of a system is its microprocessor.

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CIRCLE NO. 89

Looking
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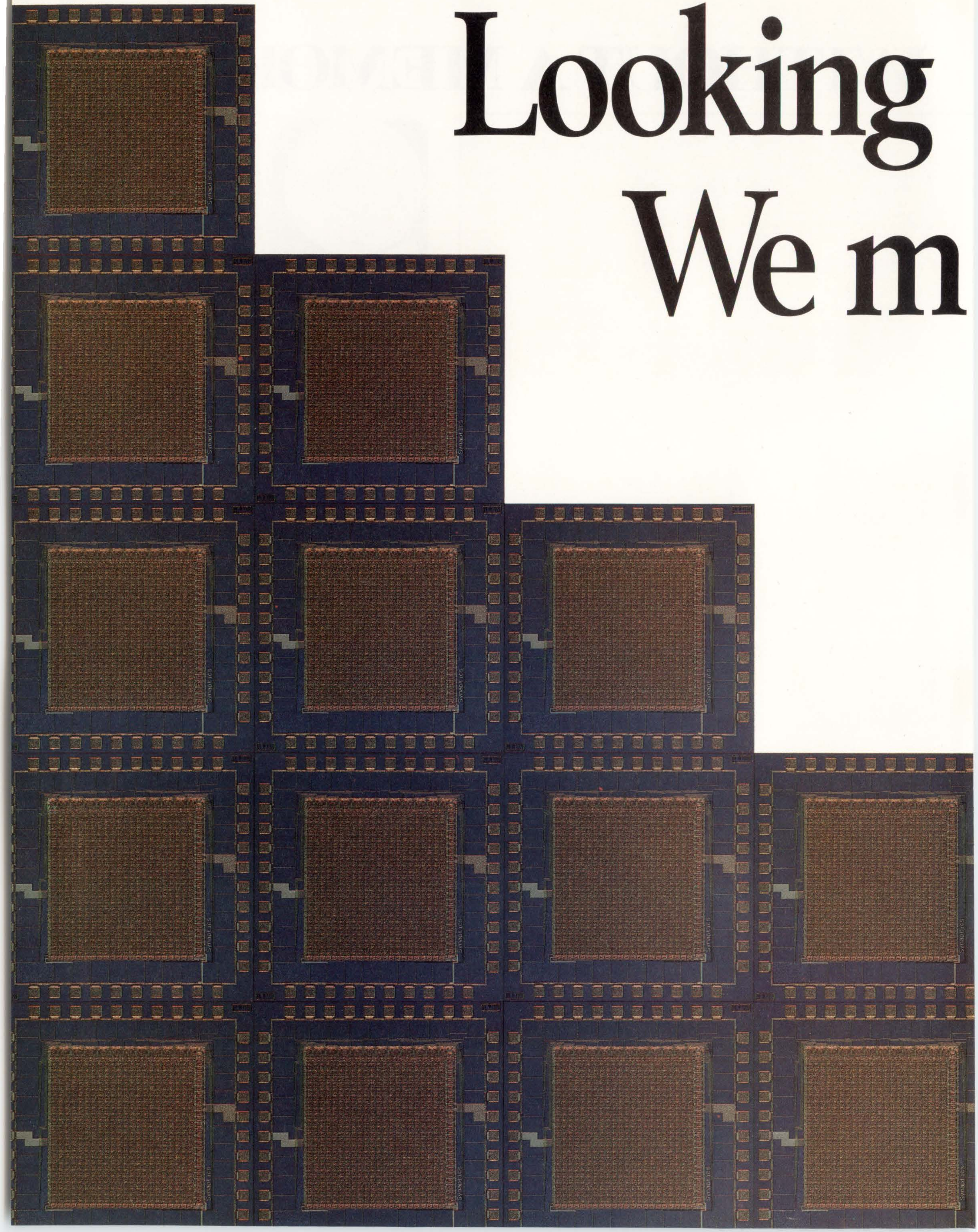

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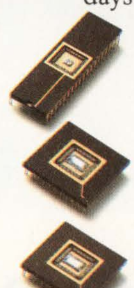

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Getting started is easy as getting design rules and process information in our newly published Foresight User Manual.

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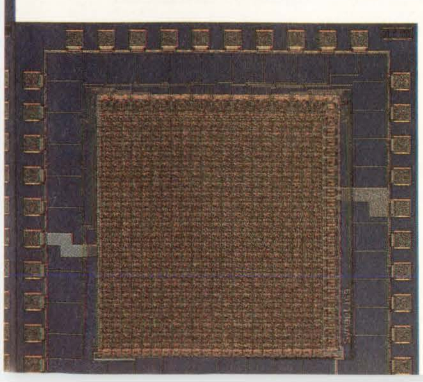

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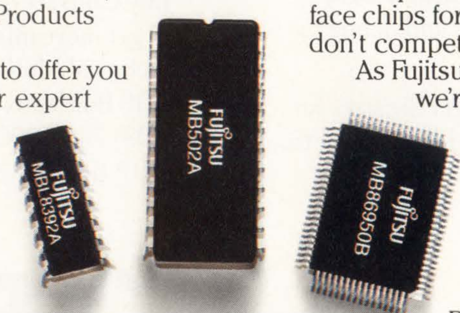

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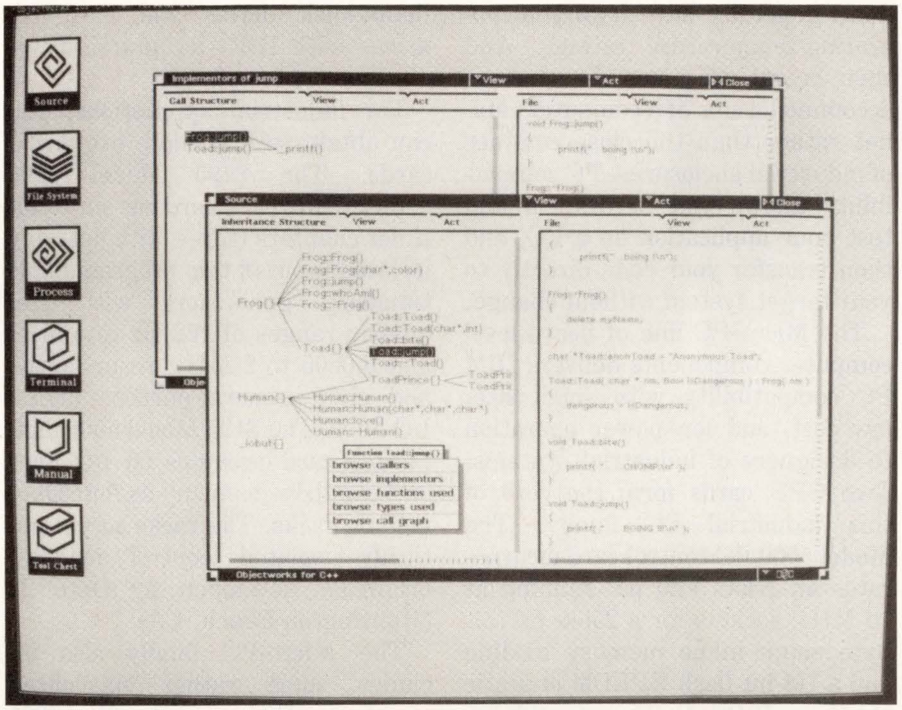
EDN EDITORS' CHOICE

INNOVATION

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.



The inheritance browser draws class inheritance trees *and supports multiple inheritance. This is one of four browsers in Objectworks\C + + that gives you diverse graphical views of your design.*

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, mother boards designed 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.

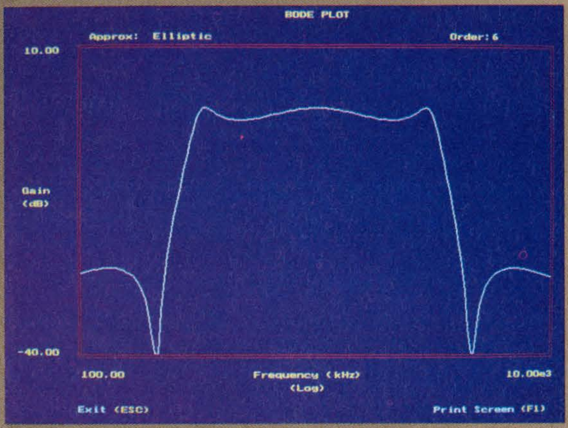
Although it uses the standard 8-bit PC bus, the entire Micro-PC card line uses a proprietary form factor. Micro-PC cards will plug into PCs (using a standard PC end plate) so you can use them during development on a desktop machine, but commodity expansion cards marketed for desktop PCs will not

***The 4-slot card cage and power supply** of the Micro-PC require less space than an IBM PC/AT's power supply.*

PSpice

MicroSim Corporation

The Standard for Circuit Simulation Has Expanded



Advanced Filter Designer Bode Plot

Advanced Filter Designer: *New* Front End Design Tool

The PSpice family of products includes both the Circuit Analysis and Circuit Synthesis packages. The Circuit Analysis package contains our PSpice circuit simulator and its options, and the Circuit Synthesis package contains our filter synthesis products, Advanced Filter Designer and Standard Filter Designer.

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 fransfer 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.

Filter Designer works with our PSpice circuit simulation package. PSpice and its options form an integrated package for the analysis of electronic and electrical circuits.

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CIRCLE NO. 91

UPDATE

fit in a Micro-PC's card cage. Micro-PC cards measure 4.9×4.2 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. Phone (303) 430-1500. FAX (303) 426-8126.

Circle No. 734

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"JN193-12-102590

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×24-bit arrays of program memory and private 32k×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 multiported 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 nonaligned 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.

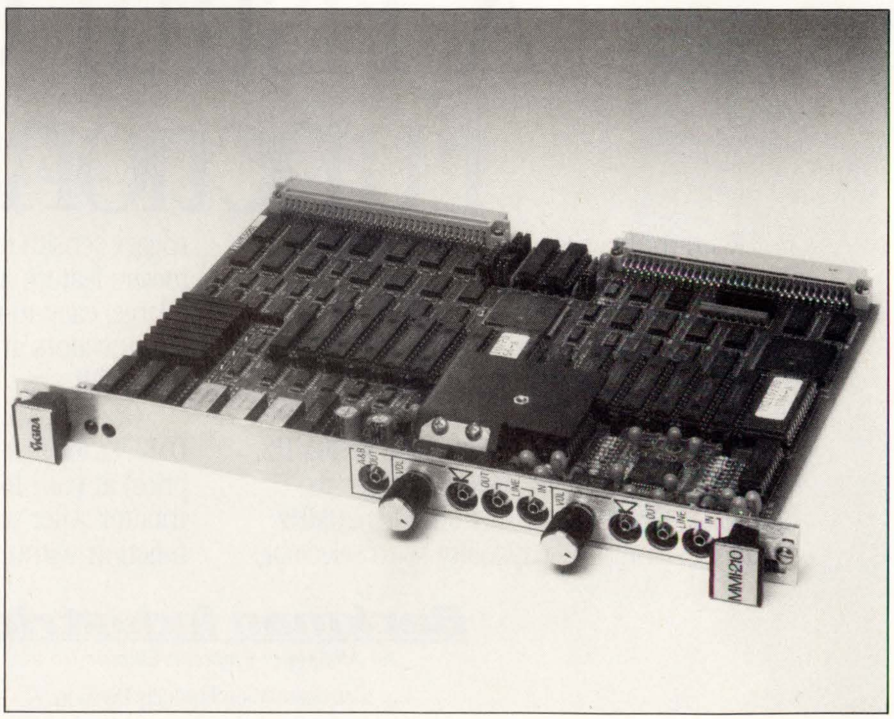
Firmware on the board offers a choice of 4-bit ADPCM (adaptive differential PCM), 16-bit linear PCM, 8-bit µ-law, and 8-bit A-law data encoding and compression. The audio-data capacity the board offers varies according to the sampling rate and encoding scheme you use. For example, the board requires 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***

Vigra Inc, 4901 Morena Blvd, Bldg 502, San Diego, CA 92117. Phone (619) 483-1197. FAX (619) 483-7531.

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.*

VMEbus-compatible CPU and storage modules implement a complete 80486-based system

Two VMEbus modules, collectively measuring 6×9×3.2 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 pc board, five custom gate arrays, and 4M-bit RAM chips enabled the company to fit the complete mother board 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.

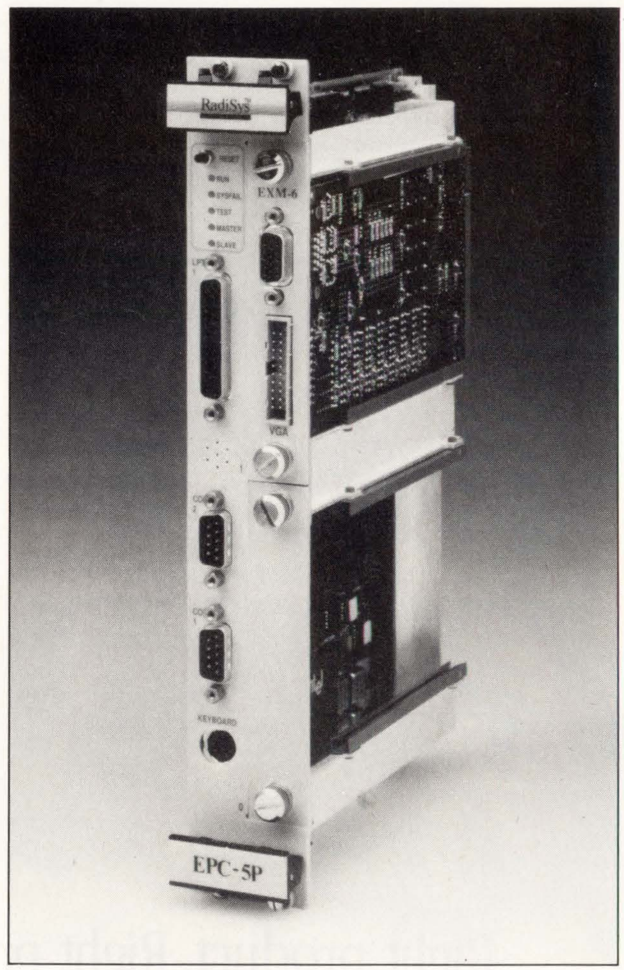
The company also offers its EPConnect software with the EPC-5 system. The software provides system-development and runtime packages that simplify the development of MS-DOS- (including Microsoft Windows), OS/2-, and Unix-based systems.

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

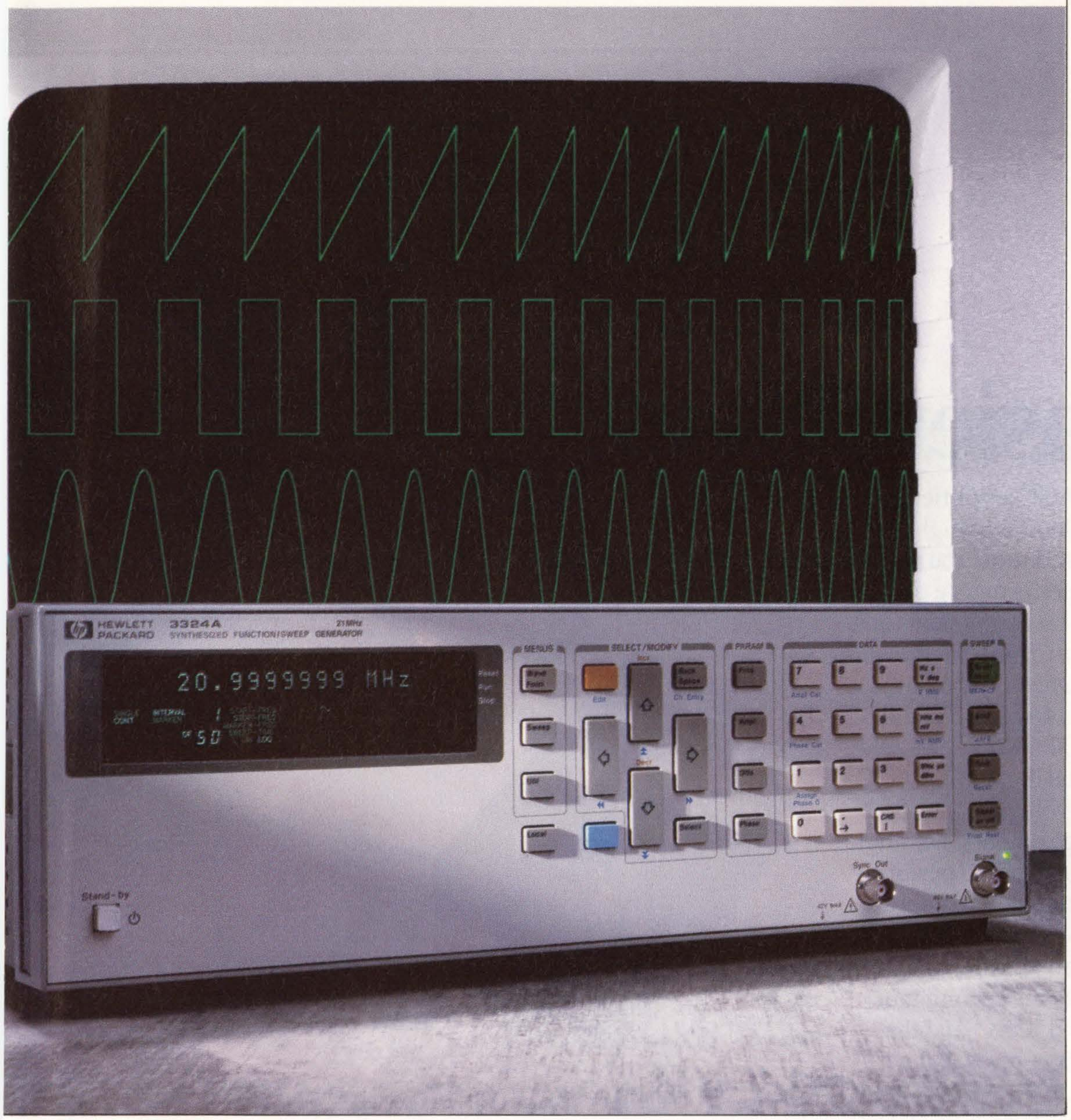
Radisys Corp, 19545 NW Von Neumann Dr, Beaverton, OR 97006. Phone (503) 690-1229. FAX (503) 690-1228.

Circle No. 733



The 6×9×3.2-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.

There is a better way.

HEWLETT PACKARD

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 3.37×2.125-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 DS6400EV CyberCard or a smaller, key-sized 2.375×1.12-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.

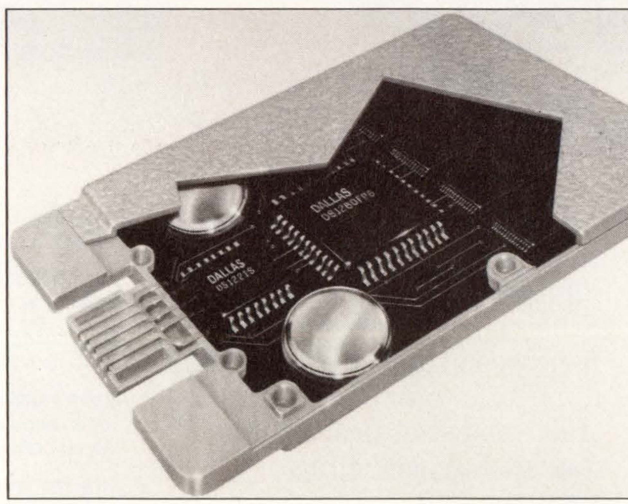
To increase the MTBF, this card has five pins rather than the 68 connectors often used by competing data cards. The reduced pin count was made possible by its serial-transfer scheme and 1M-bps transfer rate. Internal cyclic-redundancy-check circuitry monitors and validates the serial data transmissions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

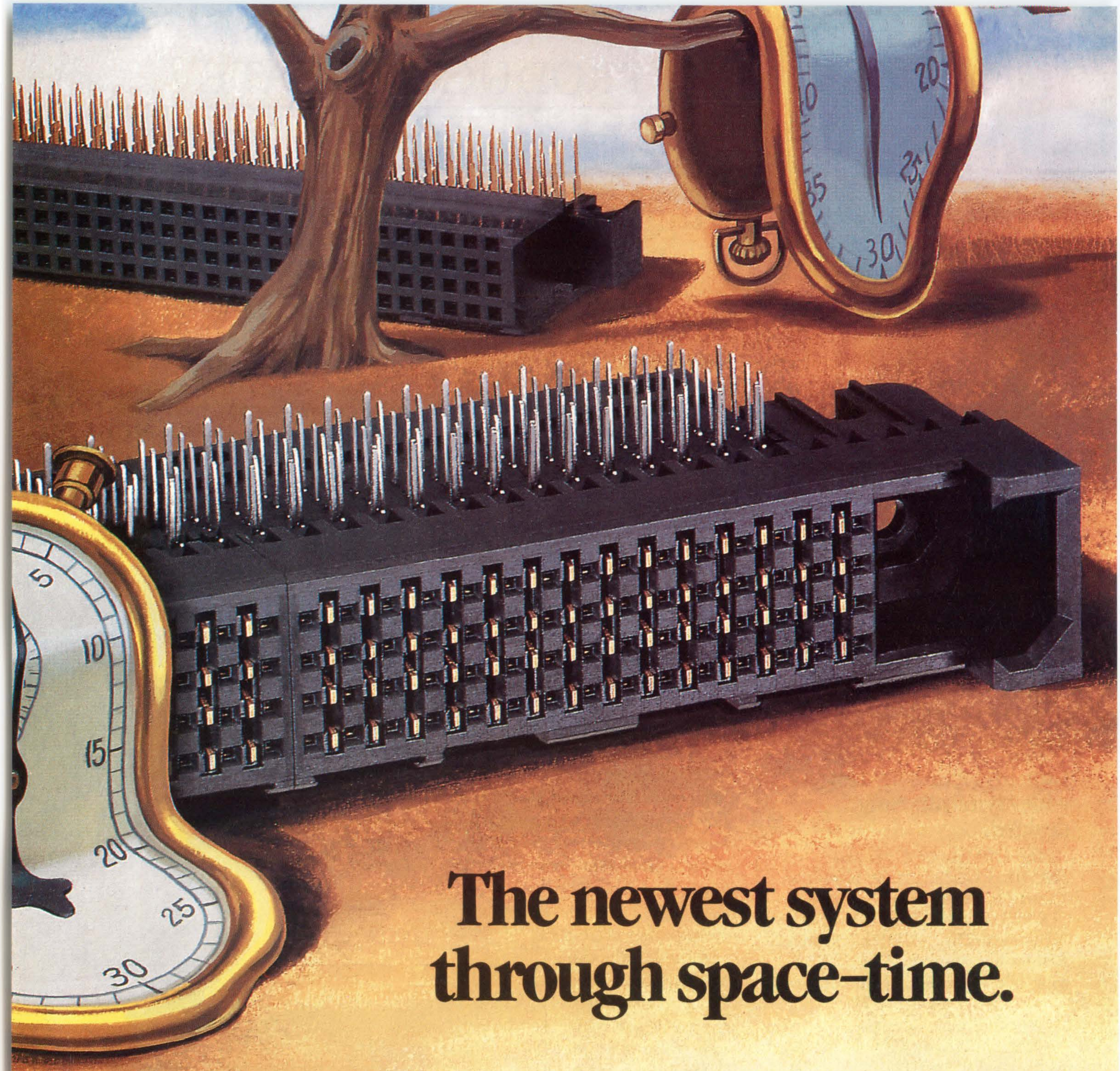
Prices range from \$3.50 for a 64-bit CyberKey to \$250 (100) for a 4M-bit CyberCard EV. Flush-mounted or recessed receptacles for the Cyber series range from \$3.90 to \$4.50 (100).—***J D Mosley***

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

Circle No. 731



Providing 10 years of nonvolatile static-RAM storage for as much as 4M bits of data, *CyberCard withstands harsh environments and provides a connector life of 50,000 insertion/extraction cycles.*

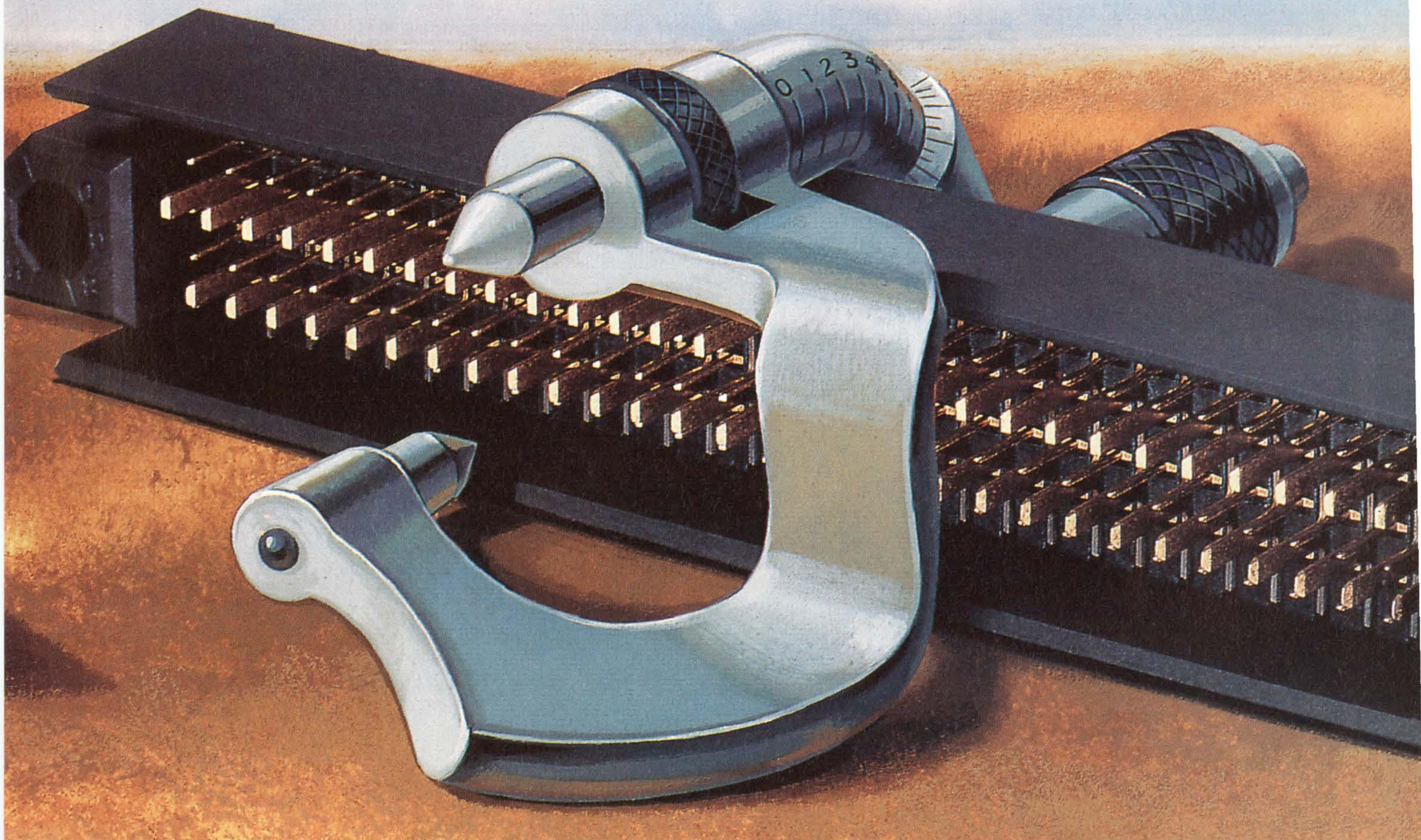


The newest system through space-time.

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.



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 risetimes 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.

For advanced design and manufacturing of complete characterized multilayer backplane systems, contact AMP Packaging Systems, Inc., P.O. Box 9044, Austin, Texas 78766, (512) 244-5100.

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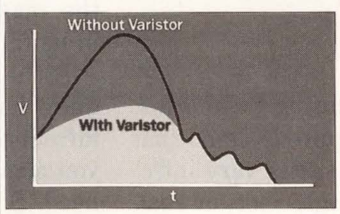

They're widely used for incoming AC protection and clamping circuits. And they're available in a wide range of packaging—axial leaded, radial leaded, leadless surface mount, high-energy modules and connector-pin configurations.

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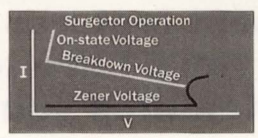

Because Surgector devices respond so quickly and can shunt lots of energy away from the circuit, they're perfect for protecting expensive components from all kinds of transients. Lightning strikes, load changes, switching transients, commutation spikes, line crosses—all the things nature throws your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

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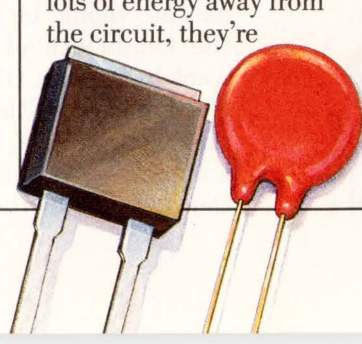


EDN SPECIAL REPORT

LOW-COST DIGITAL STORAGE OSCILLOSCOPES

Low-cost DSOs show steady improvements in bandwidth, sample rate, and measurement features. Products vary widely, so you'll have to shop carefully to get the features you need.

Doug Conner,
Regional Editor

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.

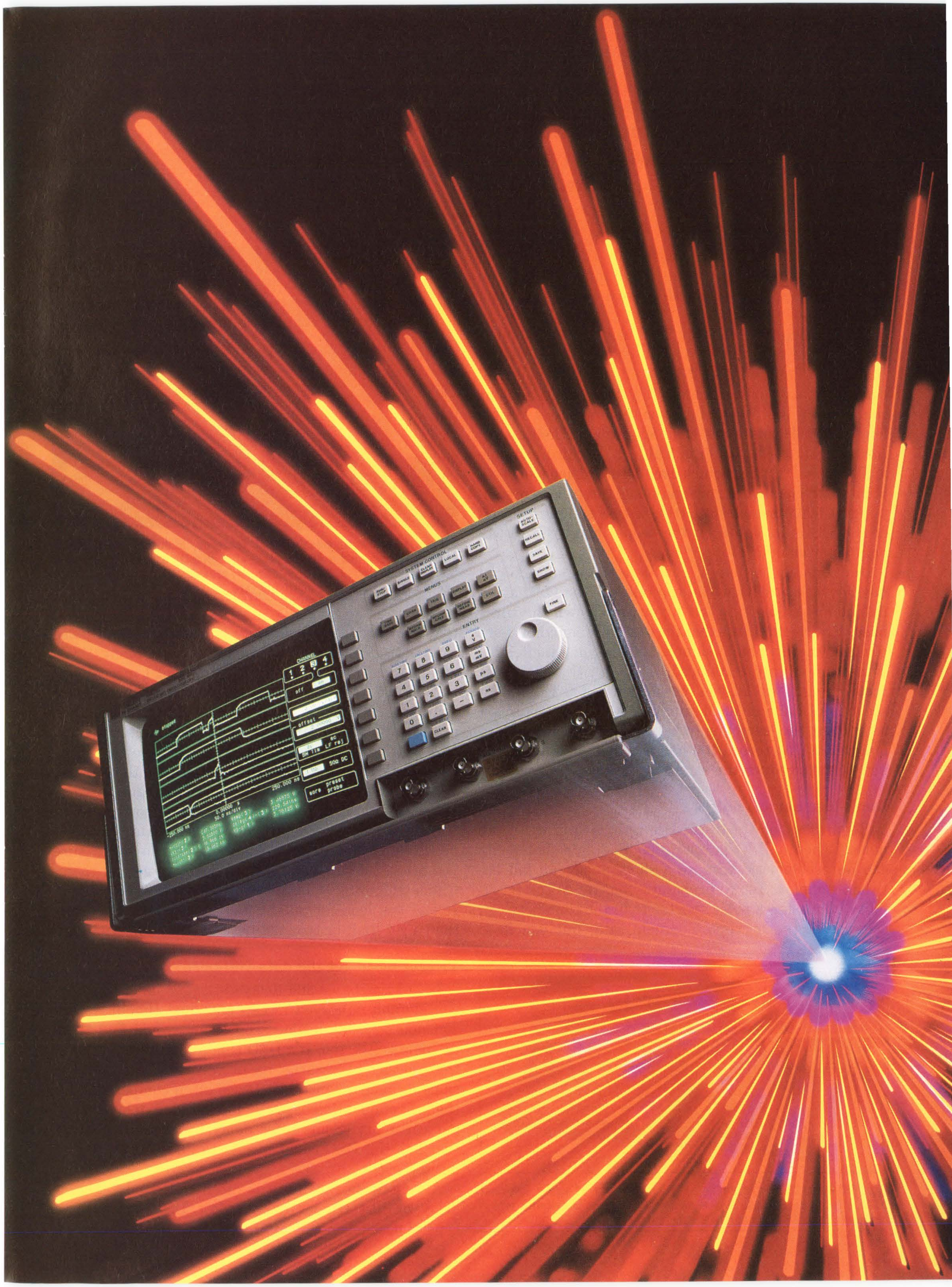
Another important consideration for single-shot acquisitions is the number of digitizers. DSOs with one digitizer can only sample at their maximum rate on one channel. If you need to use two channels, the maximum sample rate divides in half.

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

DSOs that cost less than $8000 and have bandwidths greater than 50 MHz have broken the price/performance barrier. (Photo courtesy Hewlett-Packard Co)

TEST & MEASUREMENT



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.

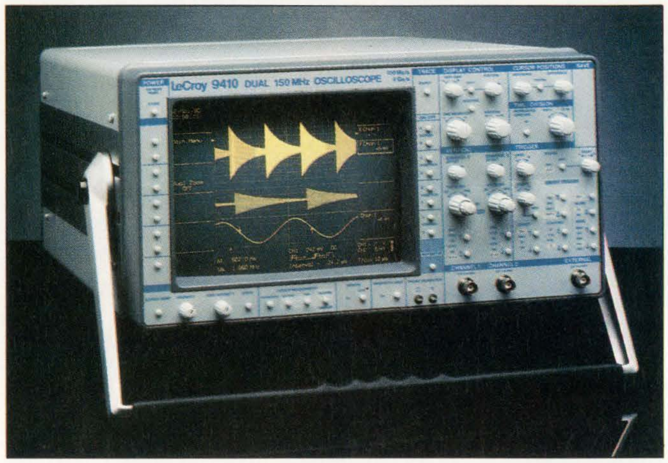
For example, the LeCroy 9410 has two 10,000-point records, one for each of its two channels, no restrictions. The Panasonic VP-5710A offers a 64k-point record length on one channel. If you're using all four channels of the VP-5710A, you're down to a record length of 16k points per channel—still the longest 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

The 100-MHz, 250M-sample/sec PM 3375 is one of seven low-cost DSOs offered by Philips. This model performs nine automatic measurements in addition to cursor measurements.



Extensive automatic-measurement features, a memory-card mass-storage system, and a 4000 × 4000-pixel display are key features of the LeCroy 9410 DSO. The 150-MHz unit provides 2% vertical accuracy and a 150M-sample/sec digitizing rate.

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,

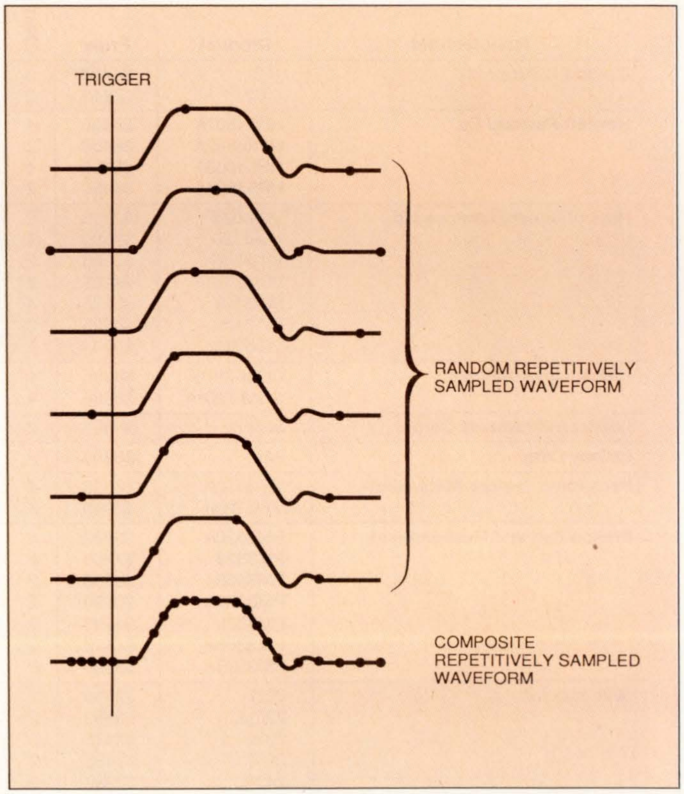


Fig 1—Repetitive sampling builds a composite waveform from data points taken from multiple waveforms. With random repetitive sampling, the form of repetitive sampling typically used by low-cost DSOs, the DSO can acquire data before the trigger because data is continually written into memory.

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

Manufacturer	Product	Price	Channels	Bandwidth (MHz)	Maximum sample rate (M-samples/sec)	Number of channels at maximum sample rate	Repetitive sampling	A/D converter resolution (bits)	Record length (words)	Dual timebases	Averaging	Display data points	Display data points with linear interpolation	Display data points with nonlinear interpolation
Gould Electronics	450	$4450	2	50	100	2	✓	8	501	—	✓	✓	✓	—
	4072	$7245	2	100	400	2	✓	8	1k	✓	✓	✓	✓	✓
Hewlett-Packard Co.	HP54501A	$3465	4	100	10	2	✓	8	501	L	✓	✓	✓	—
	HP54502A	$6450	2	400	400	2	✓	6	501	L	✓	✓	✓	✓
	HP54503A	$5450	4	500	20	2	✓	8	501	L	✓	✓	✓	—
	HP54504A	$6450	2	400	200	2	✓	8	501	L	✓	✓	✓	✓
Hitachi Denshi America Ltd	VC-6024	$2295	2	50	20	1	✓	8	1000 to 2000	—	✓	✓	✓	✓
	VC-6025	$2595	2	50	20	1	✓	8	1000 to 2000	✓	✓	✓	✓	✓
	VC-6045	$3395	2	100	40	1	✓	8	1000 to 4000	✓	✓	✓	✓	✓
	VC-6075	$4195	2	100	50	2	✓	8	1000 to 4000	✓	✓	✓	✓	✓
	VC-6145	$5295	4	100	100	1	✓	8	1000 to 4000	✓	✓	✓	✓	✓
	VC-6175	$4695	2	100	100	1	✓	8	2000 to 4000	✓	✓	✓	✓	✓
	VC-6275	$4995	2	100	200	1	✓	8	2000 to 4000	✓	✓	✓	✓	✓
Kikusui International	COM-7101A	$4495	4	100	50	1	✓	8	1k	✓	—	—	—	✓
	COM-7201A	$6695	4	200	50	1	✓	8	1k	✓	—	—	—	✓
Leader Instruments Corp	3060D	$4495	2	60	40	1	—	8	2k	✓	—	—	✓	✓
LeCroy Corp	9410	$6990	2	150	100	2	✓	8	10,000	✓	✓	✓	✓	—
Panasonic Factory Automation	VP-5710A	$3995	4	100	20	1	✓	8	16k to 64k	✓	✓	✓	✓	✓
	VP-5720A	$5990	2	50	40	1	—	8	8k	✓	✓	✓	✓	✓
Philips Test and Measurement	PM3320A	$6990	2	200	250	2	✓	10	512 to 4k	✓	✓	✓	✓	—
	PM3323	$7750	2	300	500	2	✓	10	512 to 4k	✓	✓	✓	✓	—
	PM3335	$2350	2	60	20	2	—	8	4k to 8k	—	—	✓	✓	—
	PM3350A	$3590	2	60	100	2	—	8	512 to 4k	✓	✓	✓	✓	—
	PM3355	$4490	2	60	250	2	—	8	512 to 4k	✓	✓	✓	✓	—
	PM3365A	$4490	2	100	100	2	✓	8	512 to 4k	✓	✓	✓	✓	—
	PM3375	$5390	2	100	250	2	✓	8	512 to 4k	✓	✓	✓	✓	—
Tektronix Inc	2211	$2695	2	50	20	2	—	8	4k	—	—	✓	—	—
	2221A	$3995	2	100	100	2	—	8	2k to 4k	—	✓	✓	✓	✓
	2224	$4495	2	60	100	2	—	8	2k to 4k	✓	✓	✓	✓	—
	2232	$5495	2	100	100	2	—	8	2k to 4k	✓	✓	✓	✓	✓
	2431L	$7250	2	300	250	2	✓	8	1k	—	✓	✓	✓	✓

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-cost digital storage oscilloscopes

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.

Envelope mode	Infinite-persistence mode	Analog oscilloscope operation	Automatic measurements	Nonvolatile waveform memories	Volatile waveform memories (waveforms)	Nonvolatile front-panel-setup memories (setups)	Autosetup	IEEE-488 interface	RS-232C interface	Weight (lbs)
✓	✓	—	✓	3	3	1	✓	—	✓	14
✓	—	—	O	8	8	4	✓	✓	✓	46
✓	✓	—	✓	4	2	4	✓	✓	—	22
✓	✓	—	✓	4	2	4	✓	✓	—	22
✓	✓	—	✓	4	2	4	✓	✓	—	22
✓	✓	—	✓	4	2	4	✓	✓	—	22
—	—	✓	—	—	2	—	—	—	—	18
—	—	✓	—	2	—	—	—	—	✓	15
—	—	✓	—	2	—	—	—	—	✓	15
✓	—	✓	L	15*	—	—	—	✓	—	24
—	—	✓	L	4	—	—	—	—	✓	20
✓	—	✓	L	15*	—	—	—	✓	—	24
✓	—	✓	✓	15*	—	—	—	✓	—	24
✓	✓	✓	—	4	1	99	—	✓	—	22
✓	✓	✓	—	4	1	99	—	✓	—	22
—	—	✓	—	2	2	—	✓	✓	—	17
✓	✓	—	✓	Note 3	60	8†	✓	✓	✓	33
✓	—	✓	✓	12	—	10	✓	✓	—	22
✓	—	✓	✓	3 to 8	—	10 to 40	✓	✓	—	33
✓	—	—	✓	4	—	251	✓	O	O	40
✓	—	—	✓	4	—	251	✓	O	O	40
—	—	✓	✓	4	—	—	✓	O	O	19
✓	—	✓	✓	8	—	64	✓	O	O	21
✓	—	✓	✓	8	—	64	✓	O	O	21
✓	—	✓	✓	8	—	64	✓	O	O	21
✓	—	✓	✓	8	—	64	✓	O	O	21
—	—	✓	—	2	2	—	—	—	—	17
—	—	✓	—	3	3	—	—	O	—	18
—	—	✓	—	4	4	—	—	O	O	18
—	—	—	—	29	3	—	—	O	O	18
✓	—	—	✓	4	—	50	✓	✓	—	28

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.

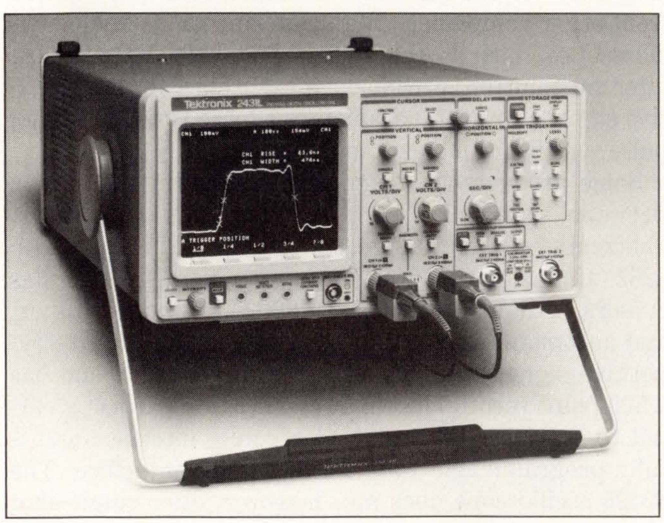
Some products are beginning to blur the distinction between standard analog oscilloscopes and DSOs. Tektronix recently announced the 100-MHz-bandwidth 2252, an analog oscilloscope that is part digital—it has cursors, a digital voltmeter, a 200-MHz counter/timer, and automatic setup. The oscilloscope 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 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.

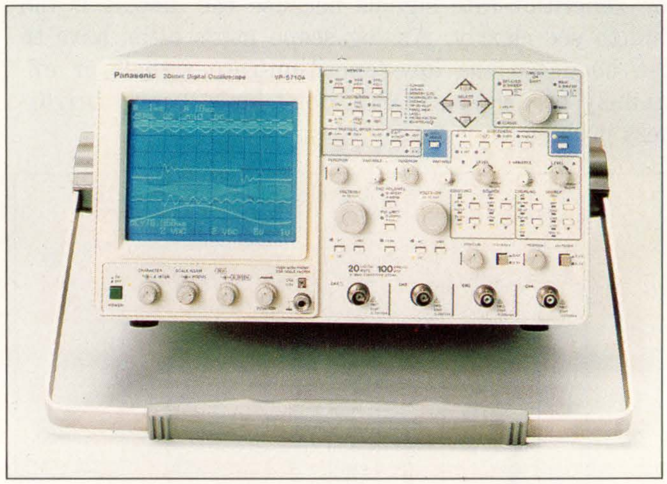
In addition to peak-to-peak voltage and frequency, automatic measurements often include pulse width, period, rise time, and fall time. Some DSOs can average multiple measurements. Others can give you additional measurement statistics such as minimum and maximum value for repetitive measurements.

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.



The 250M-sample/sec, 300-MHz-bandwidth 2431L from Tektronix provides 21 automatic measurements plus cursor measurements.



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-

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

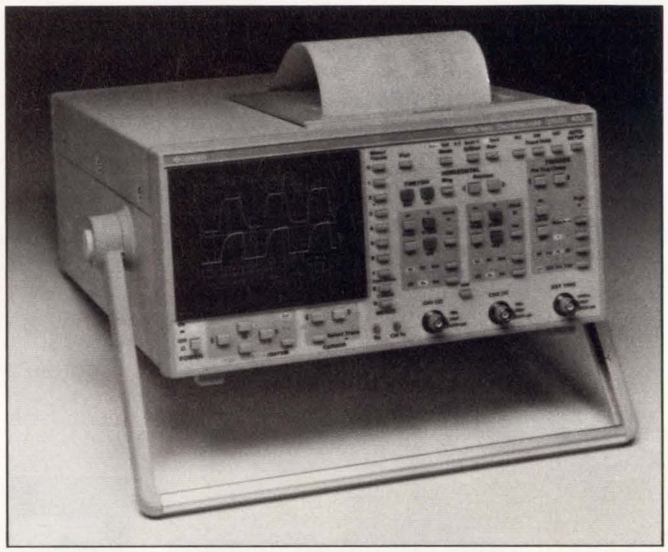
Some DSOs let you see how a waveform changes over time. In envelope mode, the display shows the limits of the waveform over time. At each horizontal time position, the DSO stores the maximum and minimum voltage values and displays them as an envelope.

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.

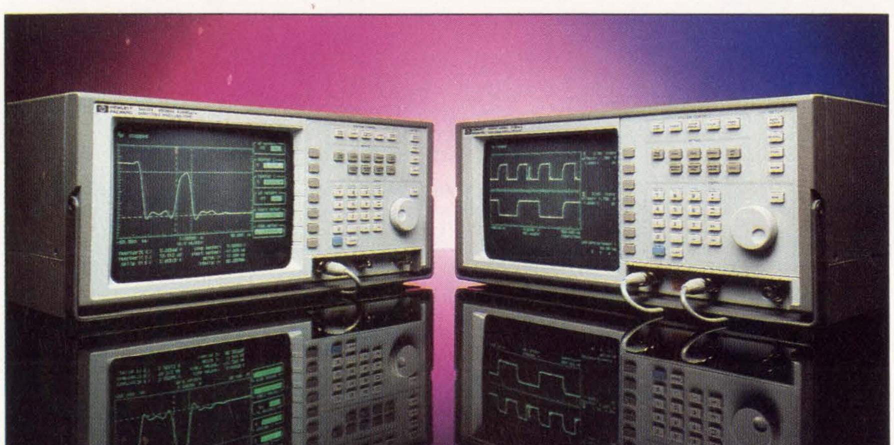


An optional internal plotter is available on some of Gould's DSOs, such as the 450. The 50-MHz, 100M-sample/sec DSO weighs 14 lbs and can operate from ac power or a portable battery pack.

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.

Another alternative to manually adjusting front-



Trading off sampling rate for vertical resolution, both of these DSOs are priced at $6450. Hewlett-Packard's HP 54502A has 6-bit resolution and samples at a maximum rate of 400M samples/sec. The 8-bit HP 54504A samples at a maximum rate of 200M samples/sec. Both DSOs offer a 400-MHz bandwidth for repetitive waveforms.

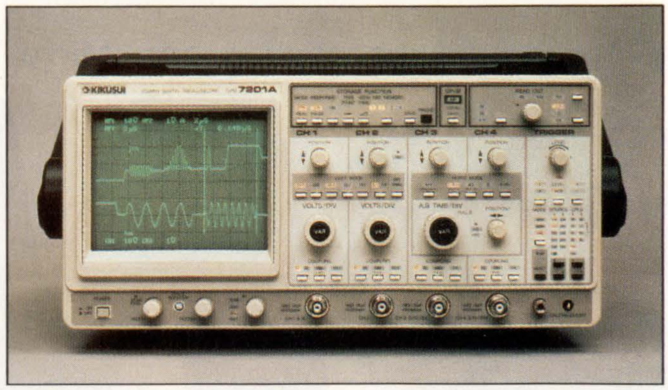
panel settings is using setup memories. You can save setups you use often in setup memories on some DSOs and use them to immediately set specific front-panel configurations.

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. EDN



Both analog and digital operation are available on the 200-MHz 7201A from Kikusui. The 4-channel DSO also includes an IEEE-488 interface.

Reference

1. Conner, Doug, "Cut through the confusion surrounding high-performance DSOs," *EDN*, December 21, 1989, pg 78.

Article Interest Quotient (Circle One)
High 491 Medium 492 Low 493

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.

Gould Electronics
8333 Rockside Rd
Valley View, OH 44125
(216) 328-7000
FAX (216) 328-7400
Circle No. 650

Hewlett-Packard Co
19310 Pruneridge Ave
Cupertino, CA 95014
(800) 752-0900
Circle No. 651

Hitachi Denshi America Ltd
150 Crossways Park Dr
Woodbury, NY 11797
(516) 921-7200
FAX (516) 921-0993
Circle No. 652

Kikusui International
19601 Mariner Ave
Torrance, CA 90503
(213) 371-4462
FAX (213) 542-4943
Circle No. 653

Leader Instruments Corp
380 Oser Ave
Hauppauge, NY 11788
(800) 645-5104;
in NY, (516) 231-6900
FAX (516) 231-5295
Circle No. 654

LeCroy Corp
700 Chestnut Ridge Rd
Chestnut Ridge, NY 10977
(914) 425-2000
FAX (914) 425-8967
Circle No. 655

Panasonic Factory Automation
9401 W Grand Ave
Franklin Park, IL 60131
(708) 452-2410
FAX (708) 452-2575
Circle No. 656

Philips Test and Measurement
Building HKF
5600 MD Eindhoven,
The Netherlands
Phone local office
Circle No. 657

In North America contact:
John Fluke Mfg Co
Box C9090
Everett, WA 98206
(800) 443-5853
FAX (206) 356-5116
Circle No. 658

Tektronix Inc
Box 1700
Beaverton, OR 97075
(800) 835-9433, ext 170
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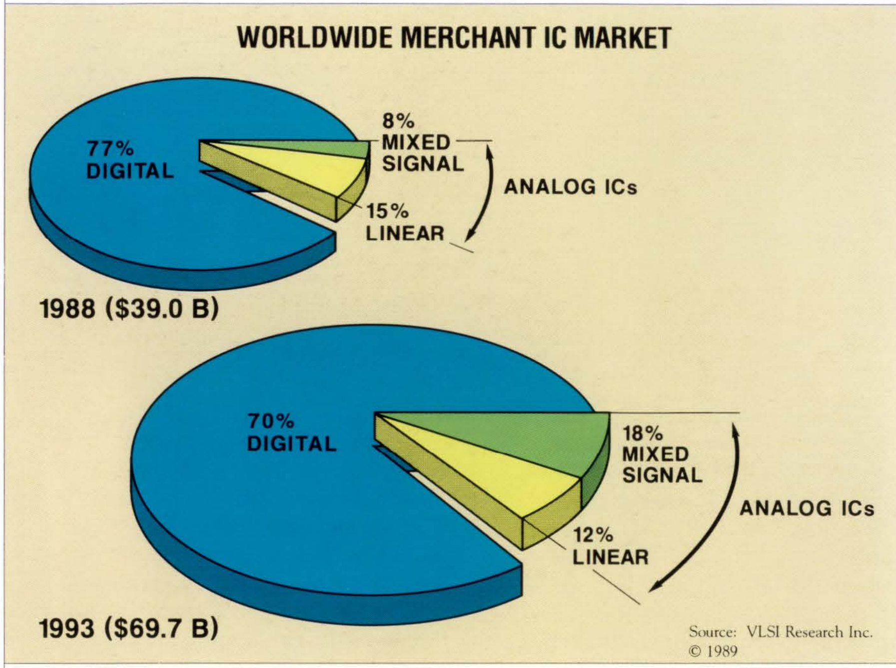

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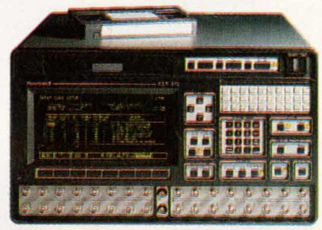

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EDN DESIGNERS' GUIDE TO

bridge circuits
Part 1

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*

TEST & MEASUREMENT

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_C and R_B) 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 dc-bridge signal

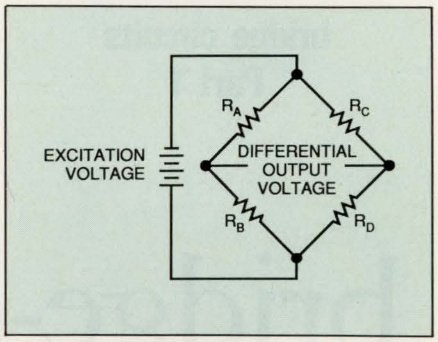


Fig 1—Usually credited to Charles Wheatstone, *the basic resistor bridge is widely used in measurement applications.*

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 LT1021 reference, buffered by IC_{1A} and IC_2, drives the

Table 1—Instrumentation-amplifier performance data

Parameter	LTC1100	LT1101	LT1102	LTC1043 (Using LTC1050 amplifier)
Offset	10 μV	160 μV	500 μV	0.5 μV
Offset drift	100 nV/°C	2 μV/°C	2.5 μV/°C	50 nV/°C
Bias current	50 pA	8 nA	50 pA	10 pA
Noise (0.1 to 10 Hz)	2 μV p-p	0.9 μV	2.8 μV	1.6 μA
Gain	100	10,100	10,100	Resistor programmable
Gain error	0.03%	0.03%	0.05%	Resistor limited, 0.001% possible
Gain drift	4 ppm/°C	4 ppm/°C	5 ppm/°C	Resistor limited, <1 ppm/°C possible
Gain nonlinearity	8 ppm	8 ppm	10 ppm	Resistor limited, 1 ppm possible
CMRR	104 dB	100 dB	100 dB	160 dB
Power supply	Single or dual, 16V max	Single or dual, 44V max	Dual, 44V max	Single, dual 18V max
Supply current	2.2 mA	105 μA	5 mA	2 mA
Slew rate	1.5 V/μsec	0.07 V/μs	25 V/μs	1 mV/ms
Bandwidth	8 kHz	33 kHz	220 kHz	10 Hz

bridge. This potential also supplies the circuit's ratio output, permitting ratiometric operation of a monitoring A/D converter. Instrumentation amplifier IC_3 extracts the bridge's differential output at a gain of 100; IC_{1B} 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 IC_{1B} 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 IC_3, thereby preventing any possible signal infidelity caused by nonlinear IC_3 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. IC_1 biases Q_1 to provide a servo action that forces the bridge's left mid-

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.

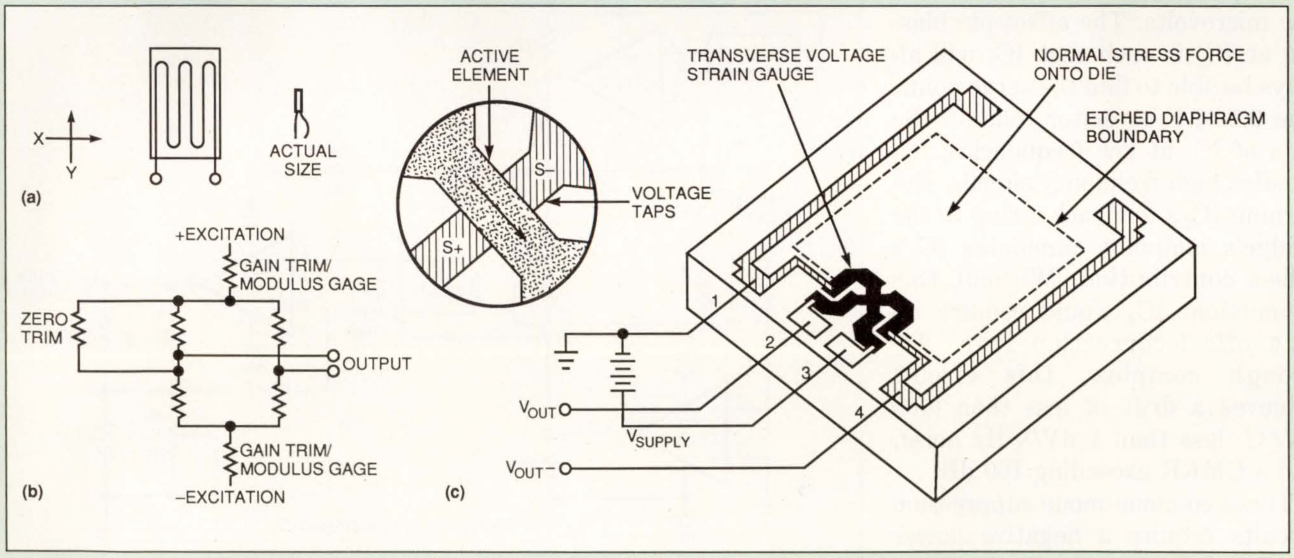


*Fig A—**Modern strain gauges utilize** foil-based designs **(a)**; a simplified schematic shows trimming adjustments to set the zero point and the gain **(b)**. This semiconductor-based device **(c)** uses a piezoresistive effect to provide strain-gauge action.*

point to zero under all operating conditions. The 350Ω resistor ensures that IC_1 will find a stable operating point with 10V of drive delivered to the bridge. This arrangement lets IC_2 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 IC_1 to reduce **Fig 4**'s already small offset error. IC_1 measures the dc error at IC_2's inputs and biases IC_1's offset pins to force the offset to a few microvolts. The offset-pin biasing at IC_2 is such that IC_1 will always be able to find the servo point. The 0.01-μF capacitor rolls off the gain of IC_1 at low frequencies; IC_2 handles high-frequency signals. Returning IC_2's feedback string to the bridge's midpoint eliminates IC_4's offset contribution. Without this connection, IC_4 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/$\sqrt{\text{Hz}}$ 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**

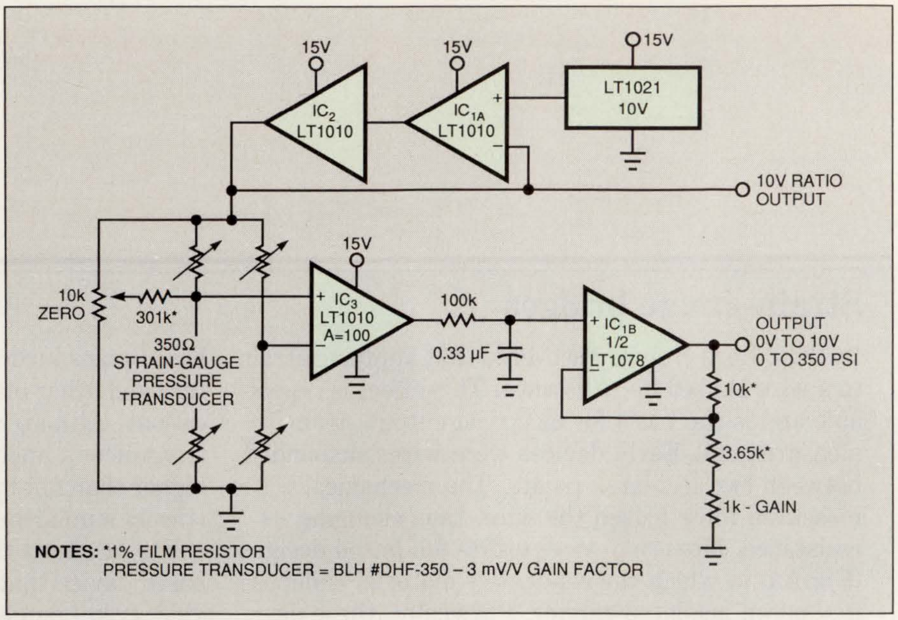


Fig 2—This typical bridge application *uses an instrumentation amplifier, a voltage reference, and buffer amplifiers to provide signal conditioning for a 350Ω transducer.*

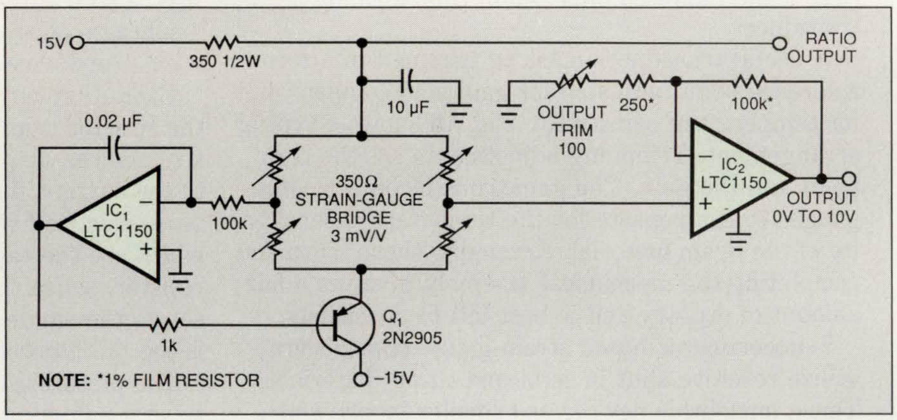


Fig 3—Servo controlling the bridge drive *reduces errors caused by the bridge's common-mode output voltage.*

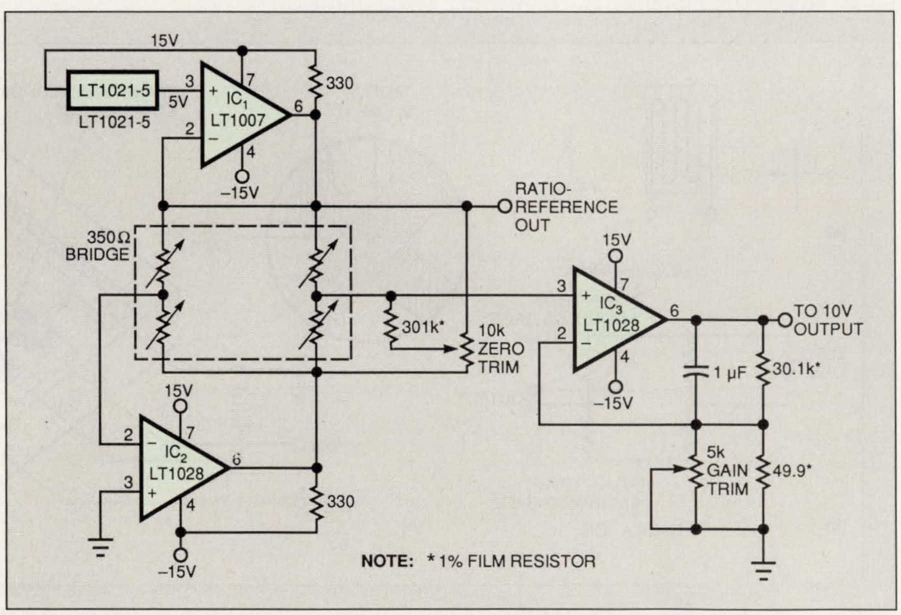
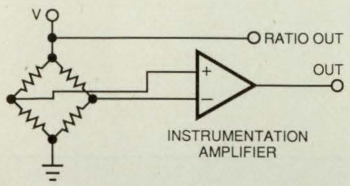
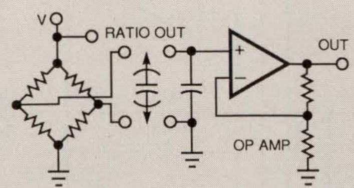
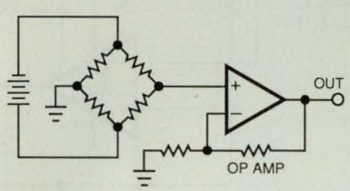
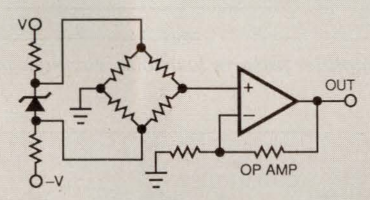
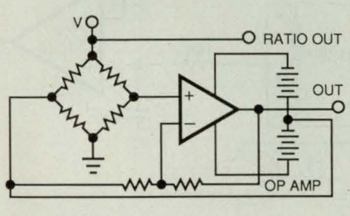
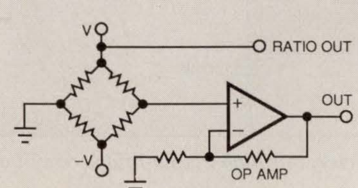
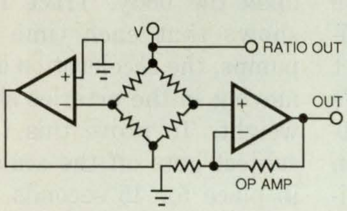


Fig 4—Using low-noise bipolar amplifiers, *this circuit trades dc offset drift for lower noise and is a good candidate for resolving small, slowly varying signals.*

Table 2—Bridge signal-conditioning methods

Configuration	Advantages	Disadvantages
	Best general choice. Simple, straightforward. CMRR typically >110 dB, drift 0.05-2 μV/°C, gain accuracy 0.03%, gain drift 4 ppm/°C, noise 10nV$\sqrt{\text{Hz}}$–1.5 μV for chopper stabilized types. Direct ratiometric output.	CMRR, drift, and gain stability may not be adequate in highest precision applications. May require second stage to trim gain.
	CMRR >120 dB, drift 0.05 μV/°C. Gain accuracy 0.001% possible. Gain drift 1 ppm with appropriate resistors. Noise 10nV$\sqrt{\text{Hz}}$–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.	Multipackage—moderately complex. Limited bandwidth. Requires feedback resistors to set gain.
	CMRR >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$\sqrt{\text{Hz}}$ possible.	Requires floating supply. No direct ratiometric output. Floating supply drift is a gain term. Requires feedback resistors to set gain.
	CMRR >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$\sqrt{\text{Hz}}$ possible.	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.
	CMRR >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$\sqrt{\text{Hz}}$ possible.	Requires precision analog-level shift, usually with isolation amplifier. Requires feedback resistors to set gain.
	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$\sqrt{\text{Hz}}$ possible.	Requires tracking supplies. Assumes high degree of bridge symmetry to achieve best CMRR. Requires feedback resistors to set gain.
	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$\sqrt{\text{Hz}}$ possible.	Practical realization requires two amplifiers plus various discrete components. Negative supply necessary.

Bridge-output amplifiers can extract the bridge's differential output from its common-mode level.

shows one way to achieve this goal. IC_1 biases the LT1054 positive-to-negative converter. The LTC1054's output pulls the bridge's output negative, which causes IC_1's input to balance at 0V. This local loop lets a single-ended amplifier (IC_2) extract the bridge's output signal. The 10-kΩ, 1-μF RC network filters noise, and IC_2'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, IC_1, and IC_2. The LTC1043 switched-capacitor block combines with IC_3 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 IC_3. A second 1-μF capacitor stores the LTC1043 output, maintaining IC_3'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. IC_3'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 IC_3'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

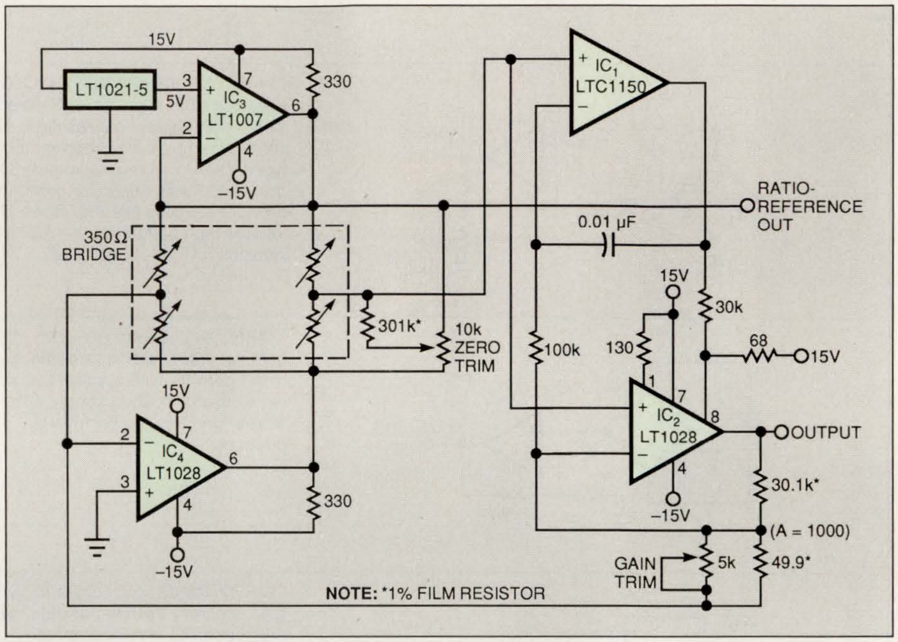


*Fig 5—**This chopper-stabilized bridge amplifier** features low noise, common-mode suppression, and a small offset error.*

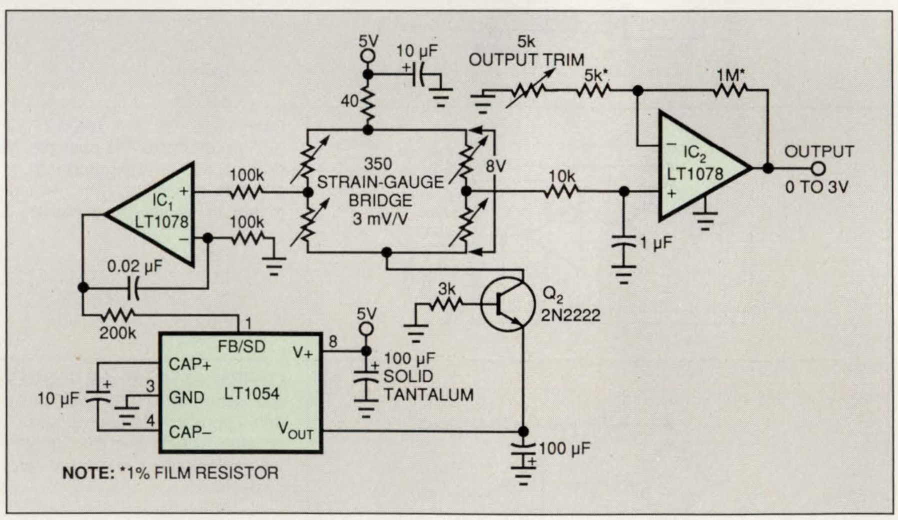


*Fig 6—**Using a positive-to-negative converter,** this high-output bridge circuit operates from a single 5V supply.*

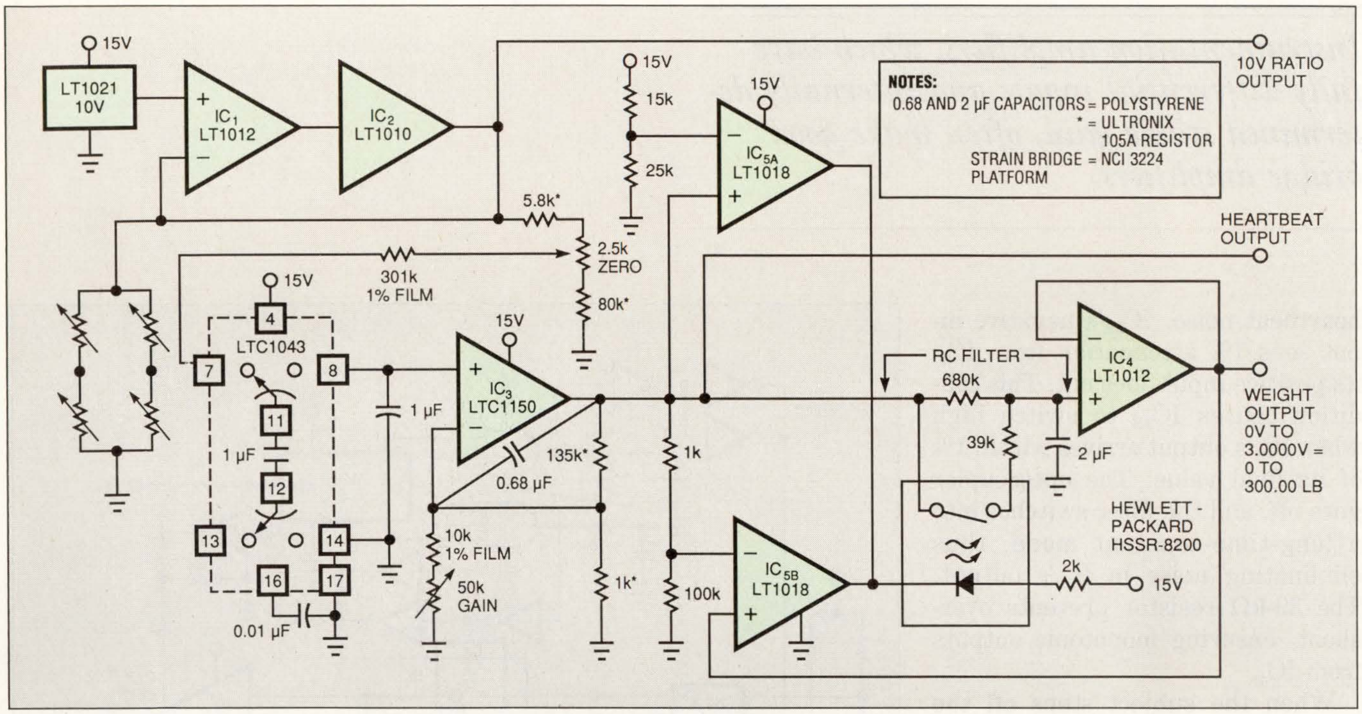


Fig 7—Using switched-capacitor techniques, *this weight-scale circuit can resolve 0.01 lb at 300 lbs full scale.*

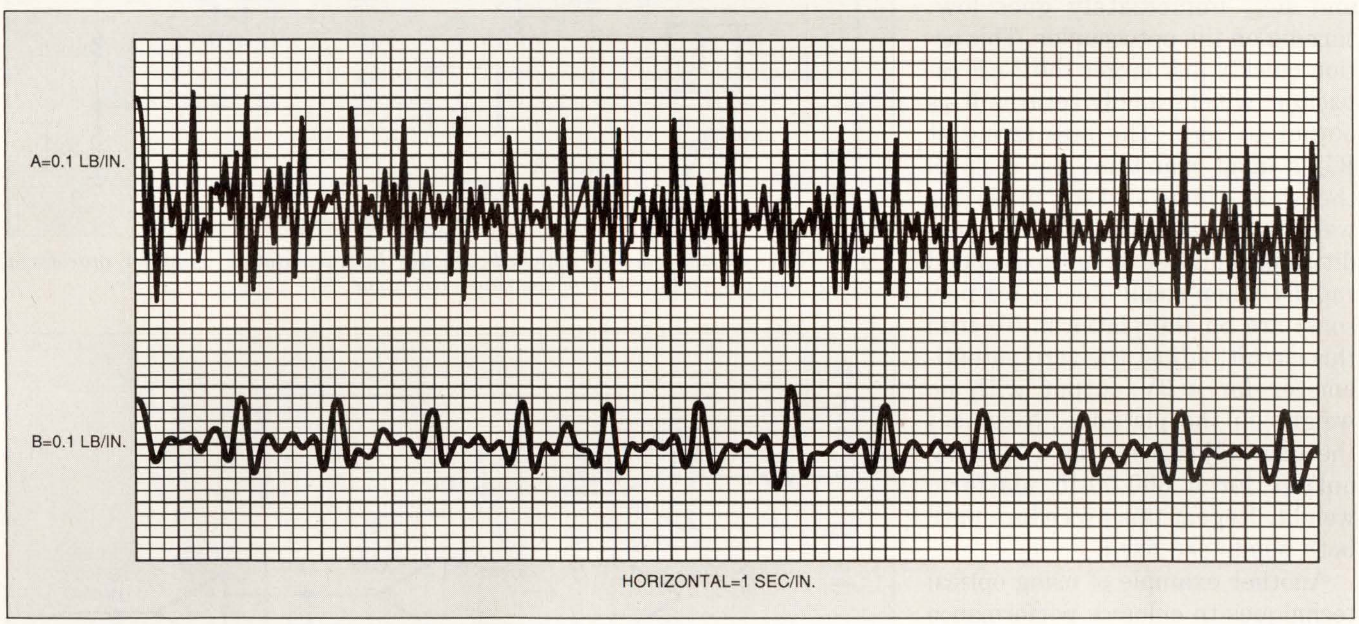


Fig 8—These tracings show the effects of a subject *on the weight-scale platform of* ***Fig 7****. Trace B shows the subject at rest; trace A shows the effects after the subject has exercised.*

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**, IC_4, IC_5, 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, IC_3's output is zero. IC_4's output is also zero, IC_{5B}'s output is indeterminate, and IC_{5A}'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, IC_3's output rises rapidly. IC_{5A} goes high, but IC_{5B} trips low, which keeps the RC filter in its short-time-constant mode. The 2-µF capacitor charges rapidly, and IC_4 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. IC_{5B}'s negative input sees 1% attenuation from IC_3; its positive input does not. This condition causes IC_{5B} to switch high when IC_4'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 IC_4's output. The 39-kΩ resistor prevents overshoot, ensuring monotonic outputs from IC_4.

When the subject steps off the scale, IC_3 quickly returns to zero, and IC_{5A} immediately goes low, turning on the optocoupler. This action quickly discharges the 2-μF capacitor, which rapidly returns IC_4's output to zero. The bias string at IC_{5A}'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 (IC_1). 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 IC_1 sets the offset drift at 0.05 μV/°C. 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, S_1 and S_2,

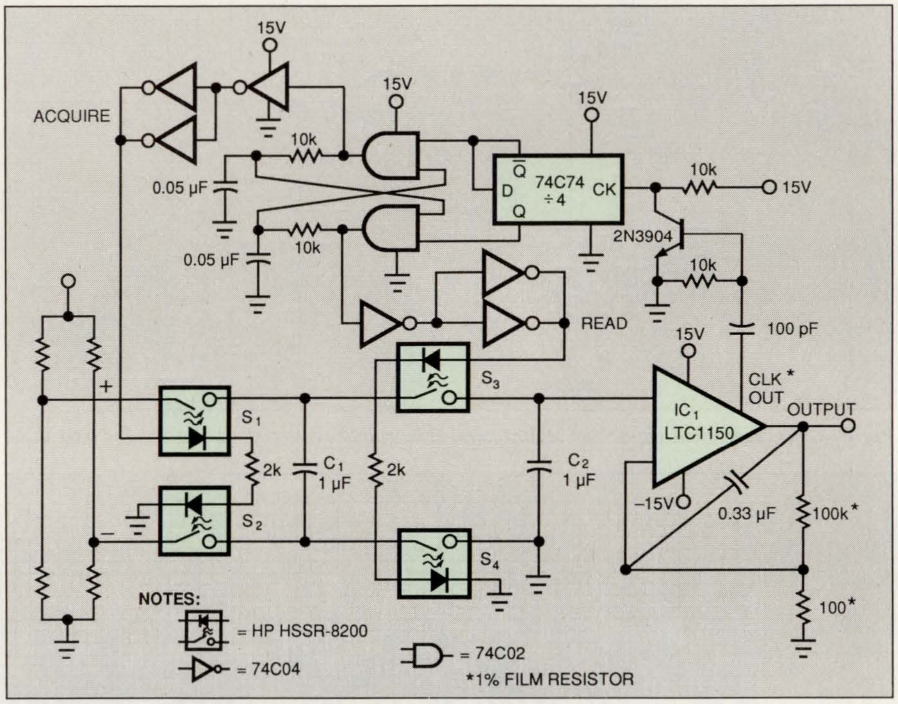


Fig 9—This optically coupled switched-capacitor instrumentation amplifier *provides a floating input and features a 200V common-mode range.*

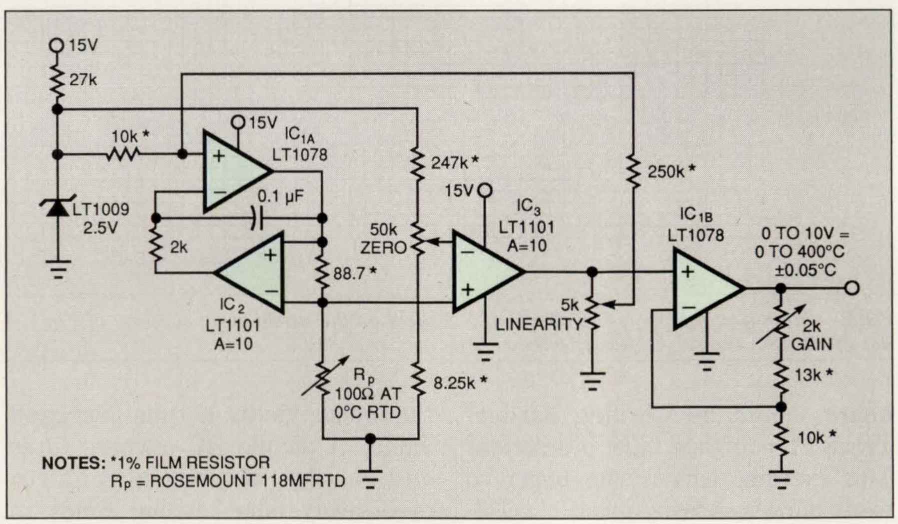


Fig 10—Using platinum RTDs in a bridge configuration, *this circuit can measure temperatures over a range of 0 to 400°C.*

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-µF 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 ±200V. 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.

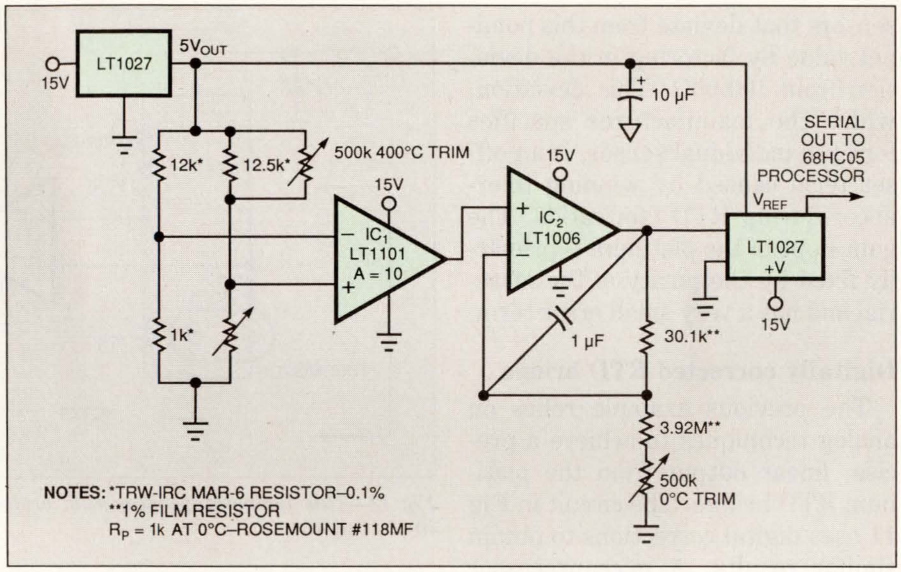


Fig 11—Combined with a microprocessor, *this circuit uses digital correction to achieve a precise, linear output from the platinum RTD bridge.*

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 88.7Ω resistor and the RTD. IC_2 senses voltage differentially across the 88.7Ω resistor and closes a loop back to IC_{1A}. The 2-kΩ, 0.1-µF combination sets the amplifier rolloff for this stable configuration. Because IC_{1A}'s loop forces a fixed voltage across the 88.7Ω 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-kΩ divider. This correction causes the current through R_P to slightly shift with the resistor's operating point, which compensates sensor nonlinearity to within ±0.05°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 (100.00Ω) and adjust the offset trim for a 0.00V output. Next, set the box for a 140°C value (154.26Ω) and adjust the gain trim for a 3.500V output reading. Finally, set the box to 400.00°C (249.0Ω) 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 ±0.05°C. The resistance values in parentheses are for a nominal 100.00Ω (0°C) sensor. You can use

Chopper-stabilized CMOS amplifiers can help eliminate offset drift with time and temperature.

sensors that deviate from this nominal value by factoring in the deviation from 100.00Ω. 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 IC_1 extracts the bridge's differential output. IC_1's output is fed to the LTC1290 12-bit A/D converter via gain-scaling stage IC_2. 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 data. RTD and resistor tolerances mandate zero-and full-scale trims, but no linearity correction is necessary. IC_2's analog output is available for feedback-control applications. Guy M Hoover developed the complete software code for the 68HC05 processor; you can get the code from Linear Technology at no cost.

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 IC_1 provides gain, and IC_2 provides additional trimmed gain to supply a calibrated output. You calibrate the circuit as you would the platinum RTD circuit but with the linearity trim deleted.

In many cases, you'll want to operate a bridge circuit at low power. The most obvious way to minimize power consumption is by restricting the drive to the bridge. However, many bridge-based transducers are low-impedance devices, which complicates the design. Although similar to **Fig 2**, the **Fig 13** circuit re-

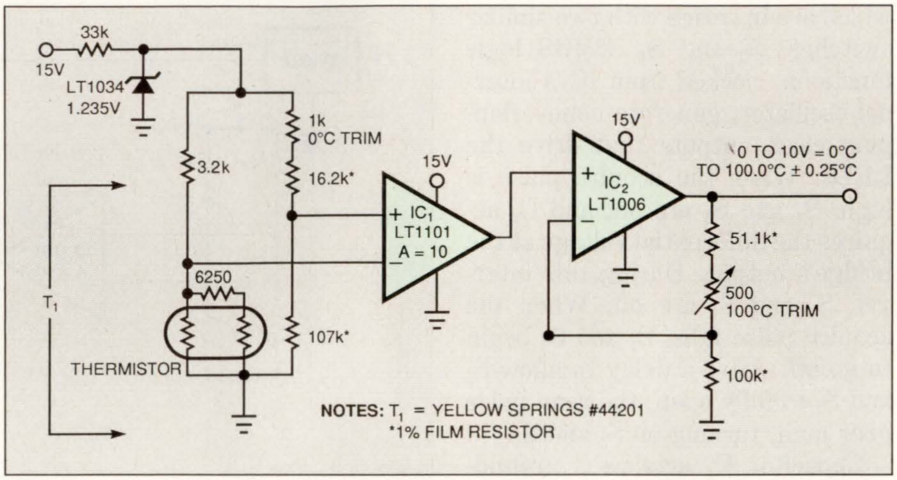


Fig 12—This temperature-measuring bridge *uses a thermistor as a sensor to provide a linear output.*

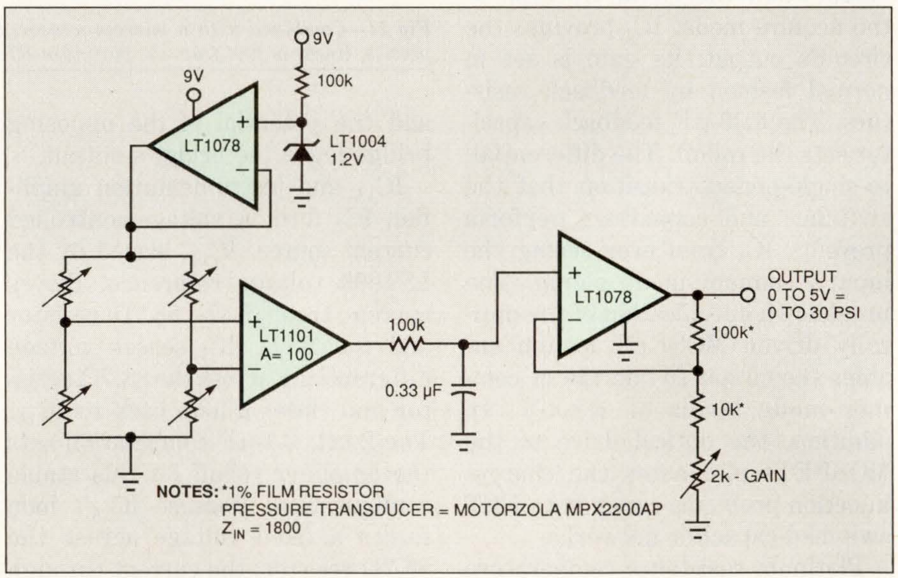


Fig 13—Using a semiconductor-based transducer, *this low-power circuit has a bridge current less than 700 µA.*

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 Q_1's base unbiased, all circuitry is off except the LT1054 plus-to-minus voltage converter, which draws 150 μA of quiescent current. When Q_1's base is pulled low, its collector supplies power to IC_1 and IC_2. IC_1's output then goes high, turning on the LT1054. The LT1054's output (pin 5) heads toward −5V, and Q_2 comes on, which permits the bridge current to flow. To balance its inputs, IC_1 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 IC_1-LT1054 loop's negative output sets the bridge's common-mode voltage to zero, allowing IC_2 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.

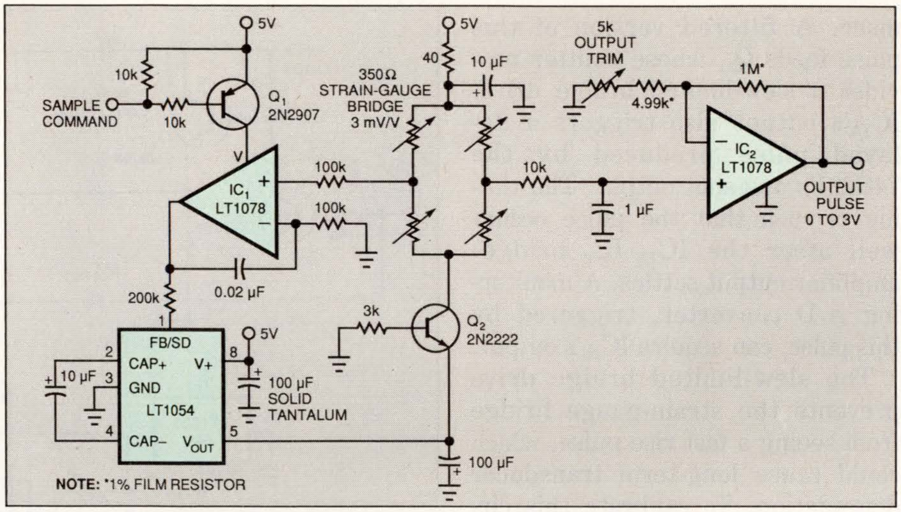


*Fig 14—**Applicable where a continuous output is not required,** this low-power circuit conserves bridge power by turning it off when not needed. Quiescent current is typically 150 μA.*

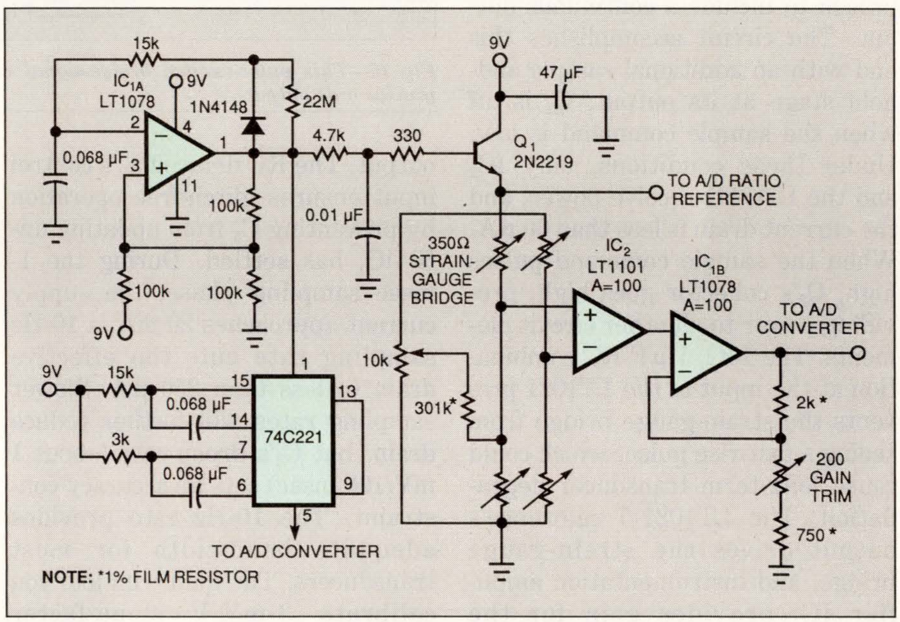


*Fig 15—**This strain-gauge bridge signal conditioner** uses strobed-power techniques to reduce power consumption. At a clock rate of 2 Hz, the circuit's on time is restricted to 250 μsec, which limits the average current drain to about 200 μA.*

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 IC_{1A} 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 Q_1, whose emitter provides a slew-limited bridge drive. IC_{1A}'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 IC_{1B}-IC_2 bridge-amplifier output settles. A monitoring A/D converter, triggered by this pulse, can acquire IC_{1B}'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. Q_2 is off when the sample command is low. Under these conditions, only IC_2 and the LTC201 receive power, and the current drain is less than 60 μA. When the sample command pulses high, Q_2'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 IC_1 provides gain for the bridge's output signal. Simultaneously, S_1's switch-control input ramps toward Q_2's collector. At approximately half Q_2's collector voltage, S_1 turns on, and C_1 stores IC_1's output.

When the sample command drops low, Q_2's collector falls, the bridge and its associated circuitry shut down, and S_1 goes off. C_1's stored value appears at gain-scaled IC_2's output. The RC delay at S_1's control input ensures glitch-free operation by preventing C_1 from updating until IC_1 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 C_1'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 IC_2's output is accurate enough for 12-bit systems.

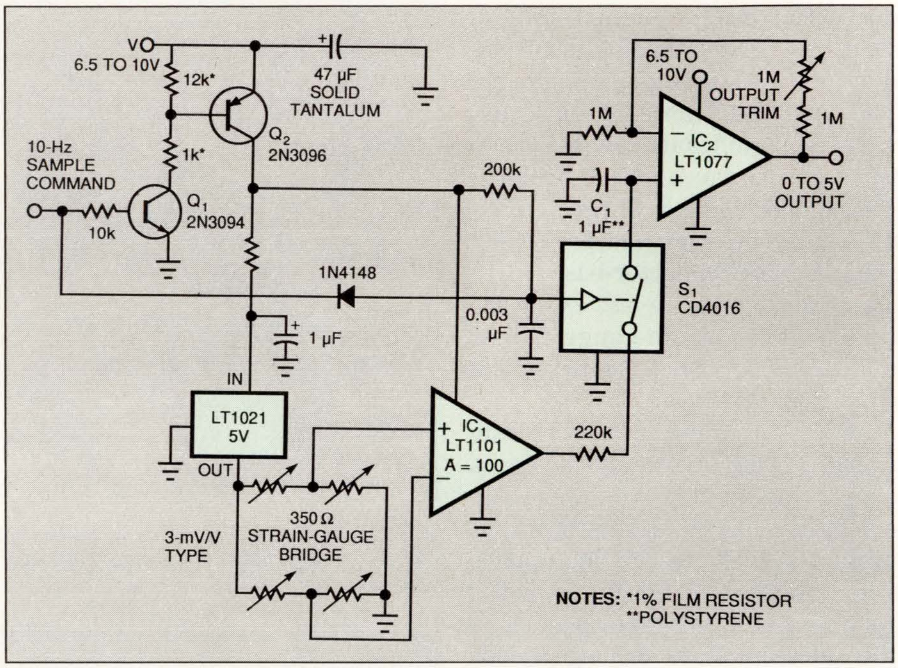


***Fig 16—This pulse-excited bridge-signal conditioner** uses a sample-and-hold circuit to provide a dc output.*

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× 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 IC_{1A}'s output is high, Q_6 turns on, and IC_2's negative input is pulled above ground.

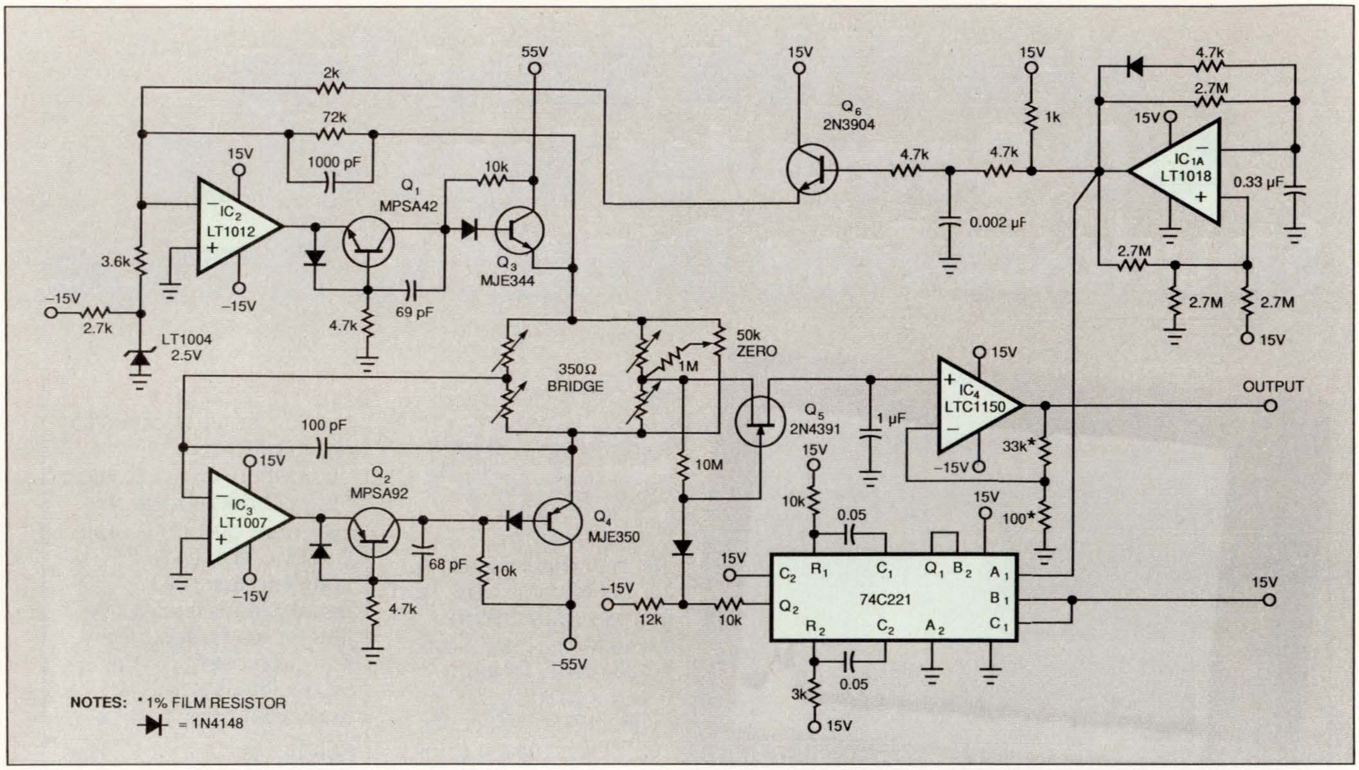


Fig 17—A special case of sampled drive, *this circuit puts 100V across a 10V, 350Ω strain-gauge bridge for short periods of time. The circuit is intended for applications requiring high-resolution outputs from a bridge transducer.*

IC_2's output goes negative, which turns on Q_1. Q_1's collector then goes low, robbing Q_3's base drive and cutting it off. Simultaneously, IC_3 enforces its loop by biasing Q_2 into conduction, which turns on Q_4. Under these conditions, the voltage across the bridge is essentially zero.

When IC_{1A}'s output is low, RC-filter-driven Q_6 responds by cutting off slowly. Now, only the current through the 3.6-kΩ resistor affects IC_2's negative input. The input begins to head negative, causing IC_2's output to rise. Q_1 comes out of saturation, and Q_3's emitter voltage rises. Initially, this action is rapid, but feedback to IC_2's negative input closes a control loop, and a 1000-pF capacitor restricts the rise time. The 72-kΩ resistor sets IC_2's gain at 20 with respect to the LT1004 2.5V reference, and Q_3's emitter servo controls to 50V.

IC_3 responds to the bridge's biasing by moving its output in the negative direction. Q_2 tends toward cutoff, increasing Q_4's conduction. IC_3 biases its loop to maintain the bridge midpoint at zero. To bias its loop, IC_3 must produce a complementary output to IC_2's loop. IC_3's loop rolloff is considerably faster than IC_2's, ensuring that it will faithfully track IC_2's loop action. Similarly, IC_3's loop is slaved to IC_2's loop output and produces no other outputs. Under these conditions, the bridge sees 100V for the 1-msec duration of the clock pulse.

IC_{1A}'s clock output also triggers the 74C221 one-shot circuit. This circuit delivers a delayed pulse to Q_5, which turns on and charges the 1-µF capacitor to the bridge's output voltage. With IC_3 forcing the bridge's left-side midpoint to zero, Q_5, the 1-µF capacitor, and IC_4 see a single-ended, low-voltage signal. The complementary, controlled rise times of the control loops prevent high-transient common-mode voltages.

IC_4, 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 IC_1 goes high, the control loops remove the bridge's drive, returning the circuit to quiescence. The 1-µF capacitor maintains IC_4's output at dc. IC_{1A}'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 $\Delta V \backslash \Delta T$-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. EDN

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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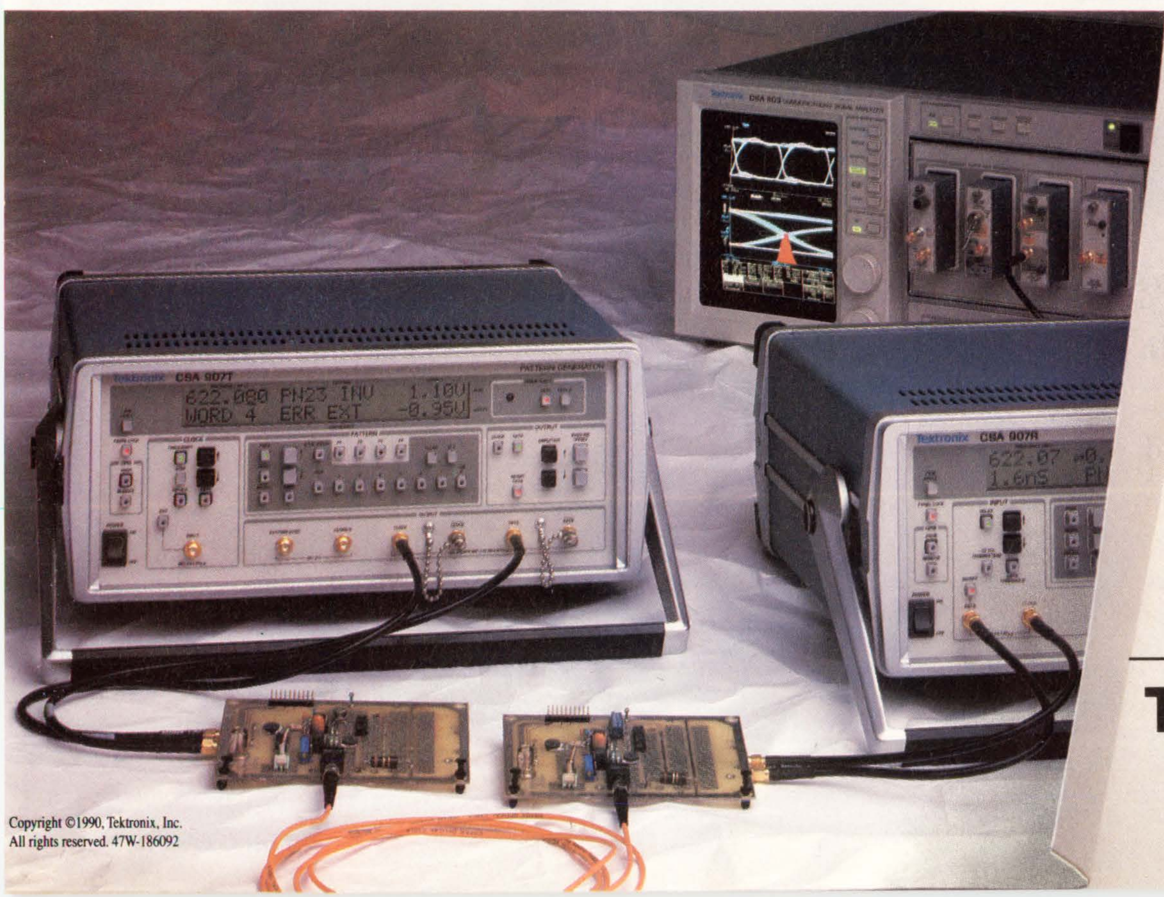

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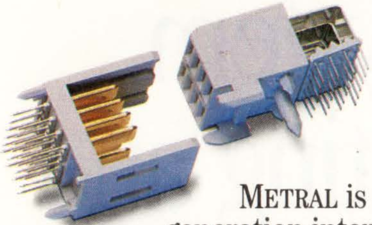

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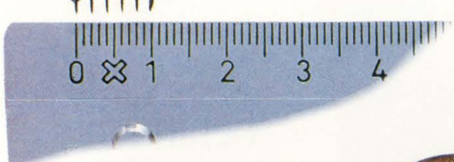

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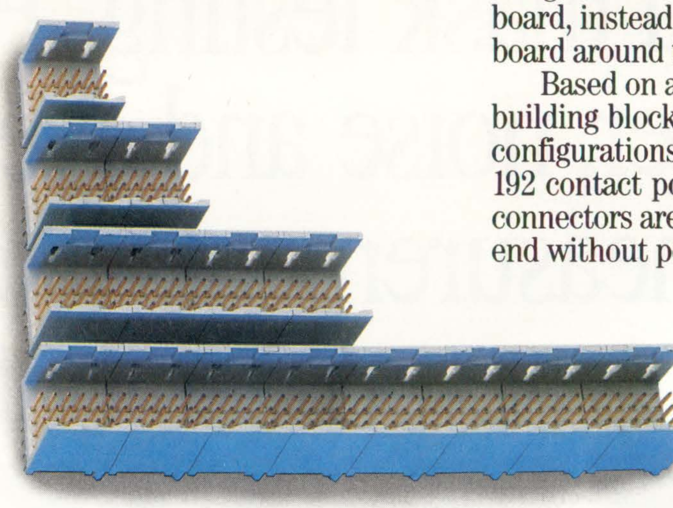

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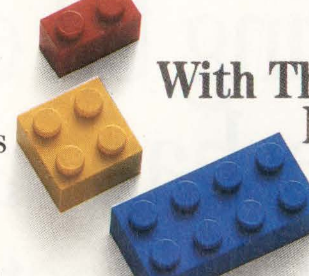

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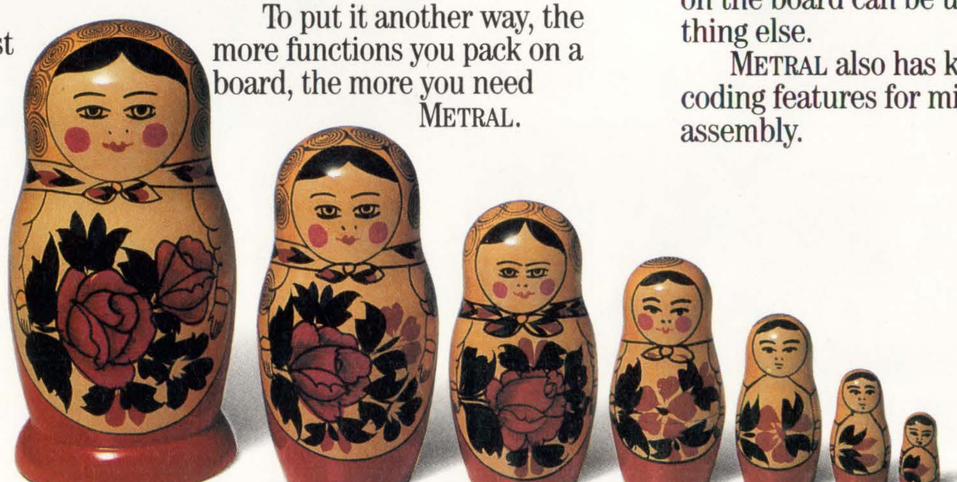

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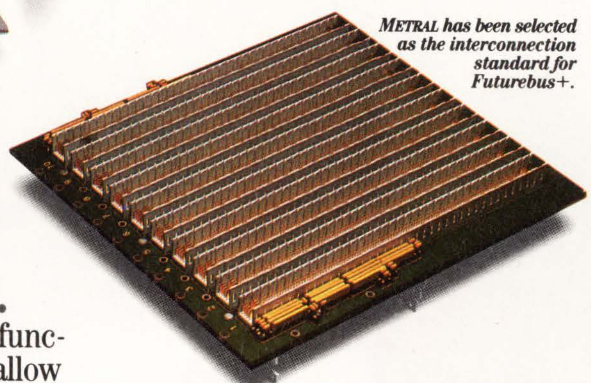
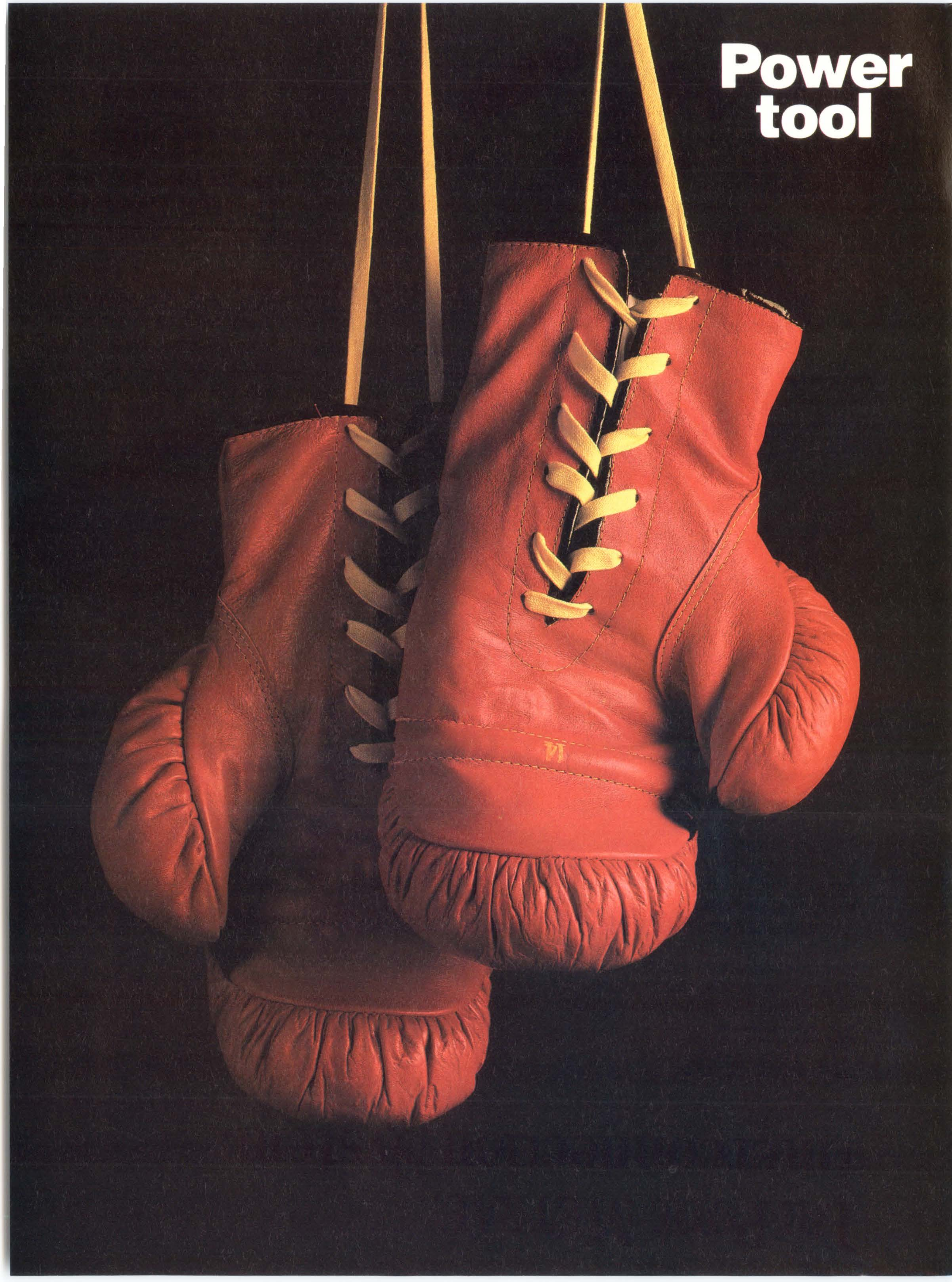


METRAL has been selected as the interconnection standard for Futurebus+.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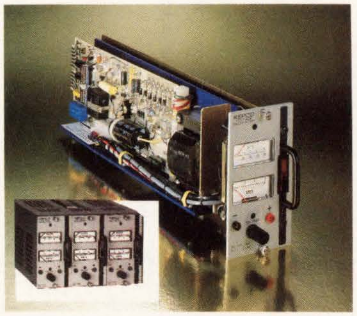

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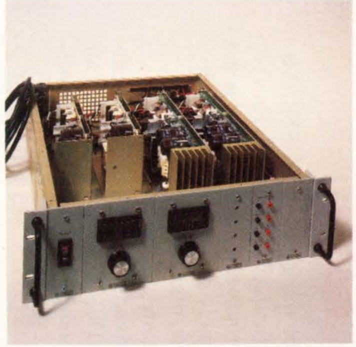

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TEST & MEASUREMENT

Boost instrument-amp CMR with common-mode-driven supplies

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 IC_3 and ratio-matched resistors R_1 through R_4. If the resistor ratio R_2/R_1 exactly matches R_4/R_3, the difference amplifier will boost differential signals by a gain of R_2/R_1 while rejecting common-mode signals. Resistor mismatch will almost certainly limit the difference amplifier's CMR if IC_3 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.

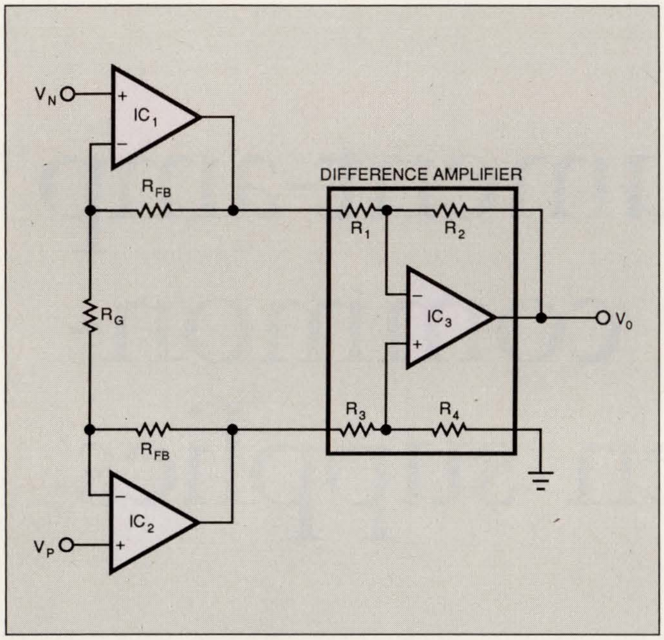


Fig 1—A 3-op-amp instrumentation amplifier *boosts differential signals by a gain of R_2/R_1, if R_2/R_1 matches R_4/R_3.*

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 (IC_1 and IC_2 of **Fig 1**) and three resistors. The gain of this stage is $1+2\cdot R_{FB}/R_G$, and the instrumentation amplifier's overall gain is $(1+2\cdot R_{FB}/R_G)\cdot R_2/R_1$.

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

$$V = V_P \cdot \sin(2\pi f t),$$

$$dV/dt = 2\pi f \cdot V_P \cdot \cos(2\pi f t).$$

$$\text{At } t = 0,$$

$$dV/dt = 2\pi f V_P, \text{ therefore the}$$

$$\text{slew-rate limit} = 2\pi f_{MAX} V_P,$$

where

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

$$V_P = \text{peak common-mode voltage},$$

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

and f_{MAX} = maximum common-mode frequency at amplitude V_P 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

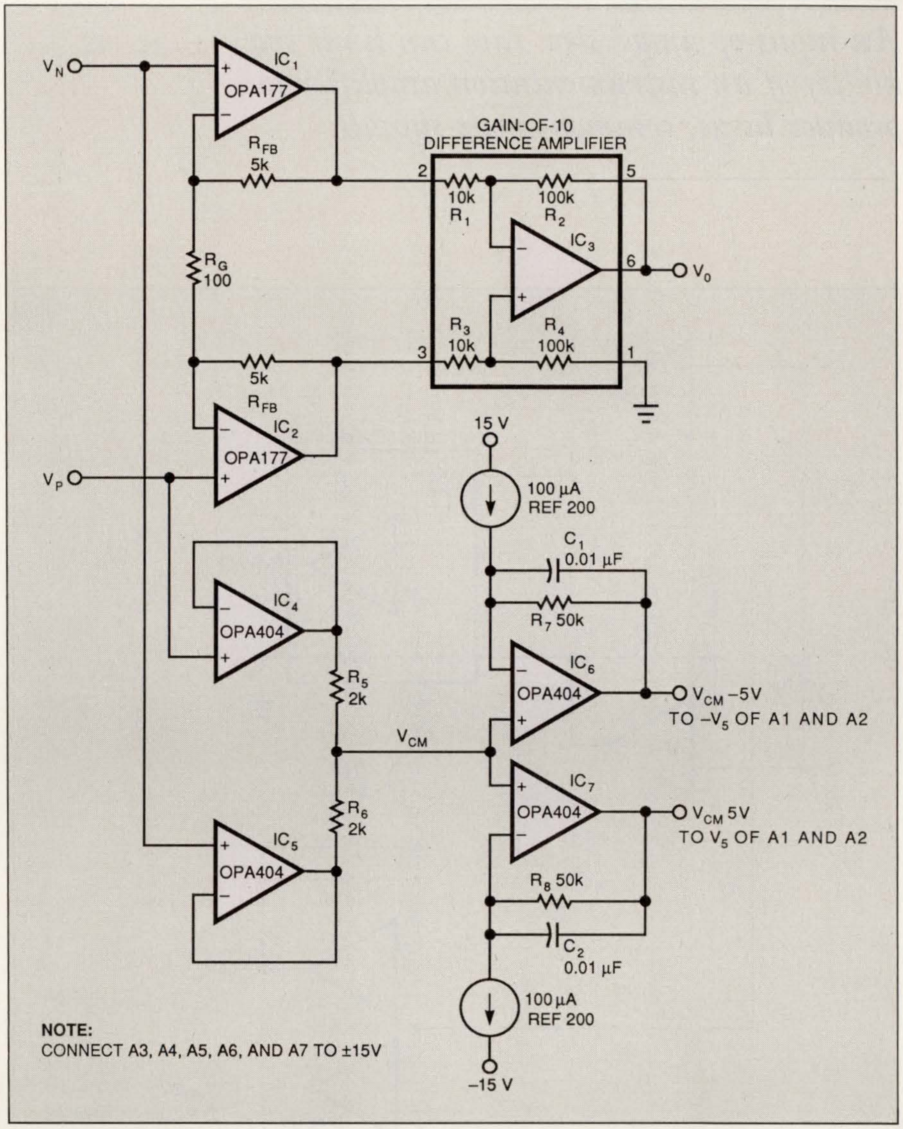


Fig 2—A common-mode voltage buffer *connected to a resistor divider network drives the subregulated supplies that power the enhanced instrumentation amplifier.*

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-µA current source. Since no current flows in the op-amp input, 100 µA flows through the 50-kΩ 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.

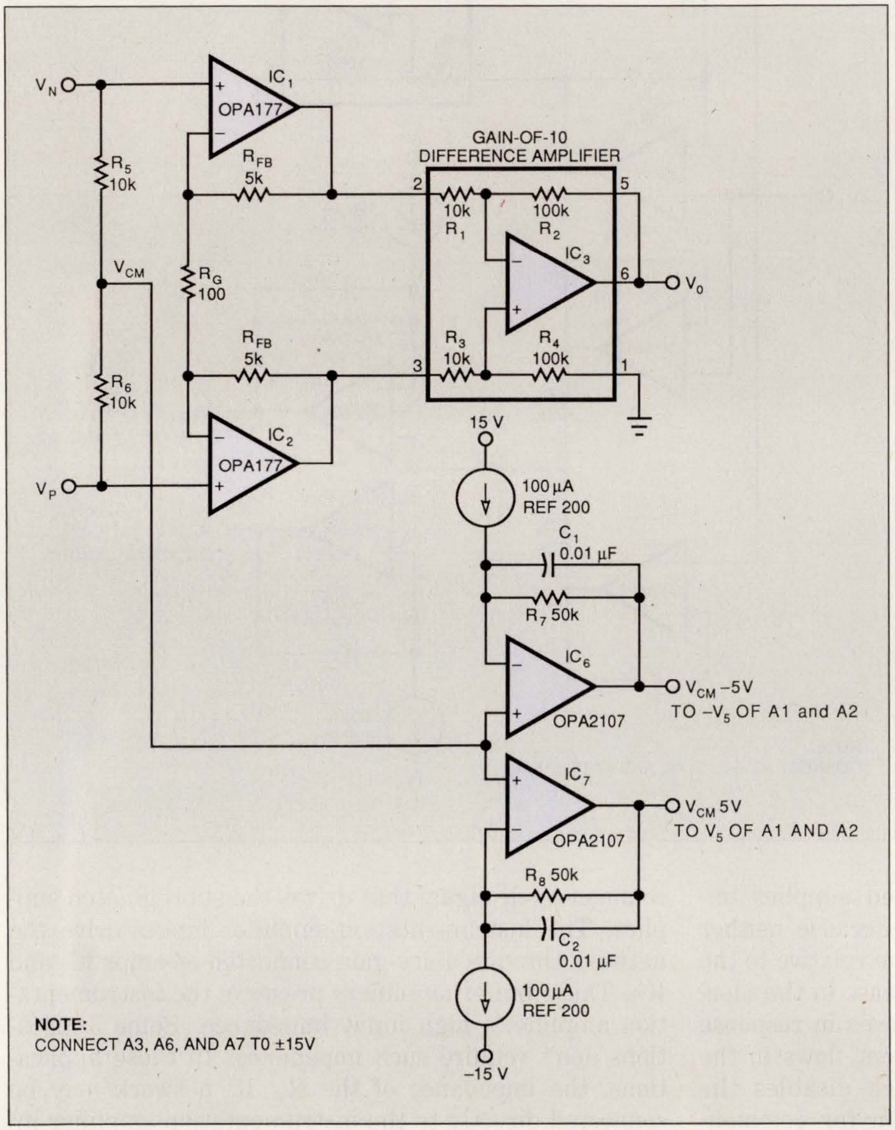


Fig 3—If you don't need high input impedance, *removing the common-mode voltage buffers will still provide better common-mode rejection than standard instrumentation amplifiers and do it at a lower cost.*

negative subregulators' outputs to the power supplies of the input op amps (IC_1 and IC_2). All other op amps are connected to ±15V power supplies.

The subregulated-supply voltage limits the common-mode input range of the enhanced instrumentation amplifier. The outputs of the subregulator amplifiers (IC_6 and IC_7) 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

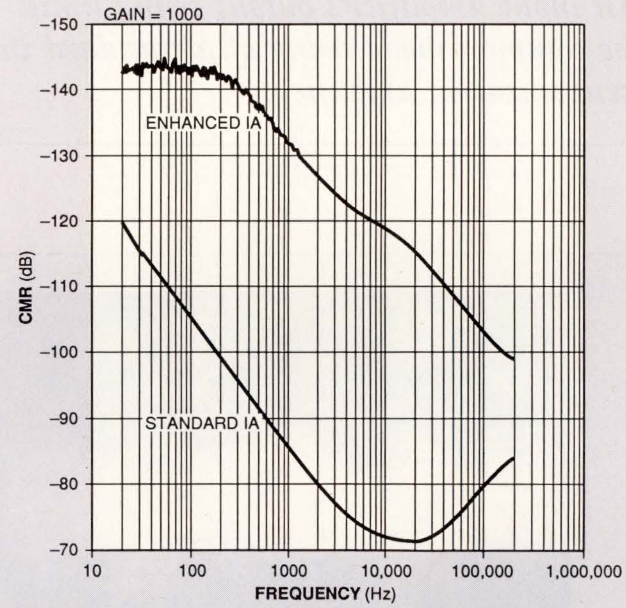


Fig 4—With a gain of 1000V/V, *an enhanced instrumentation amplifier offers common-mode rejection of better than 120 dB at frequencies below 8 kHz.*

input amplifier must deliver 7V common mode plus 5V differential mode in order to bring it up to its 12V-swing limit.

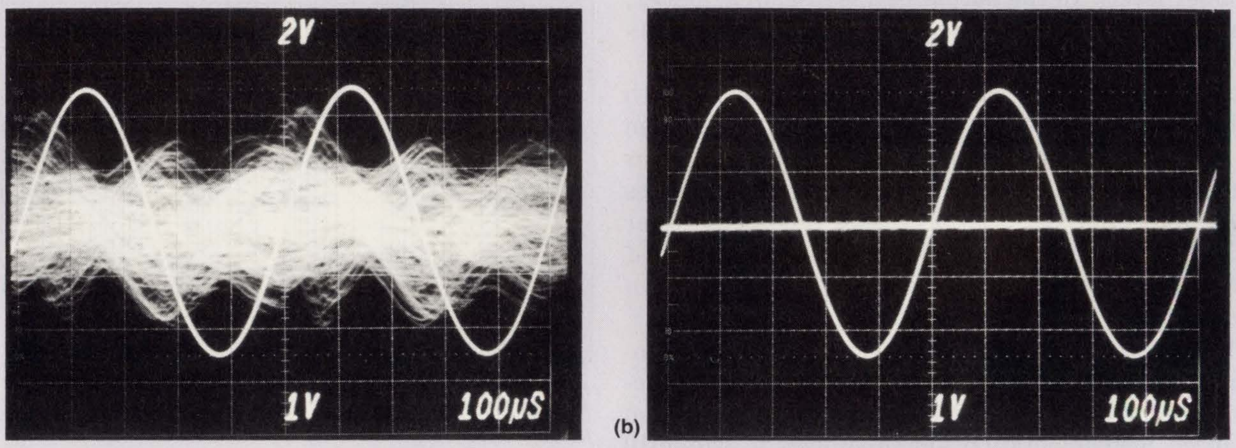
The enhanced instrumentation amplifier also has a ±7V common-mode input limit. Its subregulators are set at ±5V from the input common-mode signal. With a 7V common-mode input, a subregulator's output will be at its 12V-swing limit.

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_S 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_{OS} and 0.1-μV/°C max V_{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

An input amplifier's output swing limits the common-mode swing of a standard instrumentation amplifier.



(a) (b)

***Fig 5—These scope photos show a dramatic difference in common-mode response** between standard **(a)** and enhanced instrumentation **(b)** amplifiers with chopper-stabilized op amps. In both photos, the sine wave is the common-mode input—a 2-kHz, 5V p-p signal; the other trace is the instrumentation-amp output with a differential gain of 1000. Without common-mode drive **(a)**, noise limits the usable CMR to 56 dB with the common-mode input shown. With common-mode drive to the input op-amp power supplies **(b)**, noise performance improves so much that the CMR appears essentially infinite under these test conditions. (The CMR actually measures about 82 dB.)*

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 IC_1 and IC_2. When V_{OS}/dT is critical, chopper-stabilized op amps may be the best choice because they offer 5-μV maximum V_{OS} over temperature. With a $\pm 2.5V$, 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.

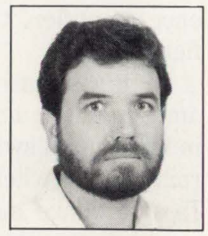
How fast are your amplifiers?

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 IC_4 to IC_7 is much higher than the speed of IC_1 and IC_2.

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 IC_6, IC_7, and IC_3 (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 R_1 to R_4, you may need a potentiometer to adjust CMR. The resulting instrumentation amplifier will provide outstanding performance on power supplies up to $\pm 45V$. EDN

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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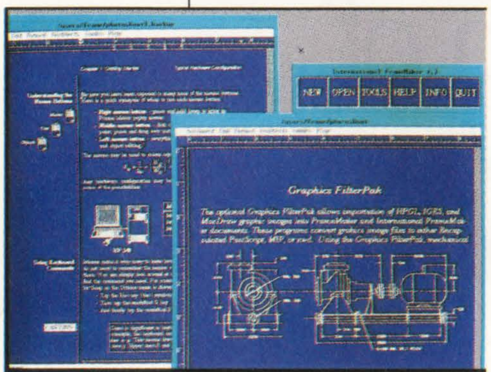

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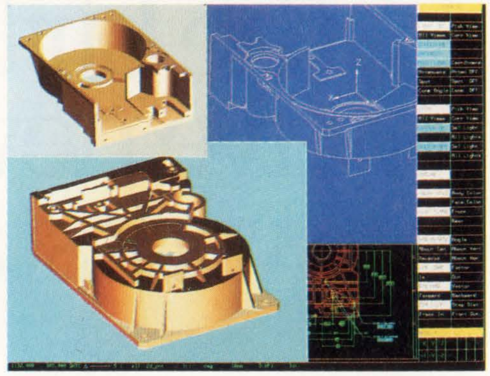

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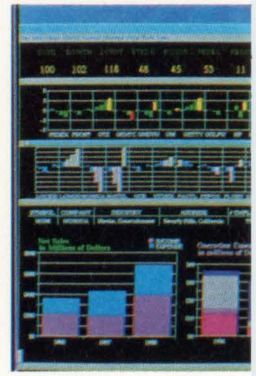

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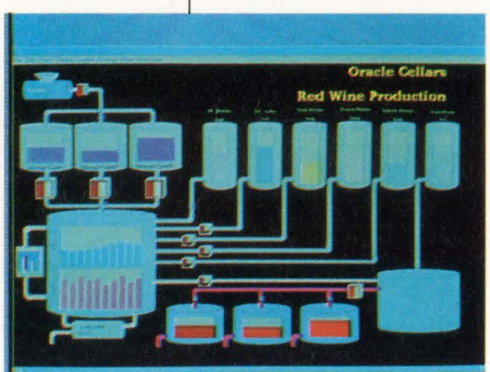

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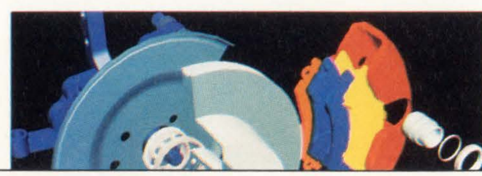

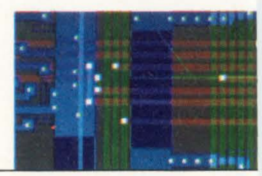

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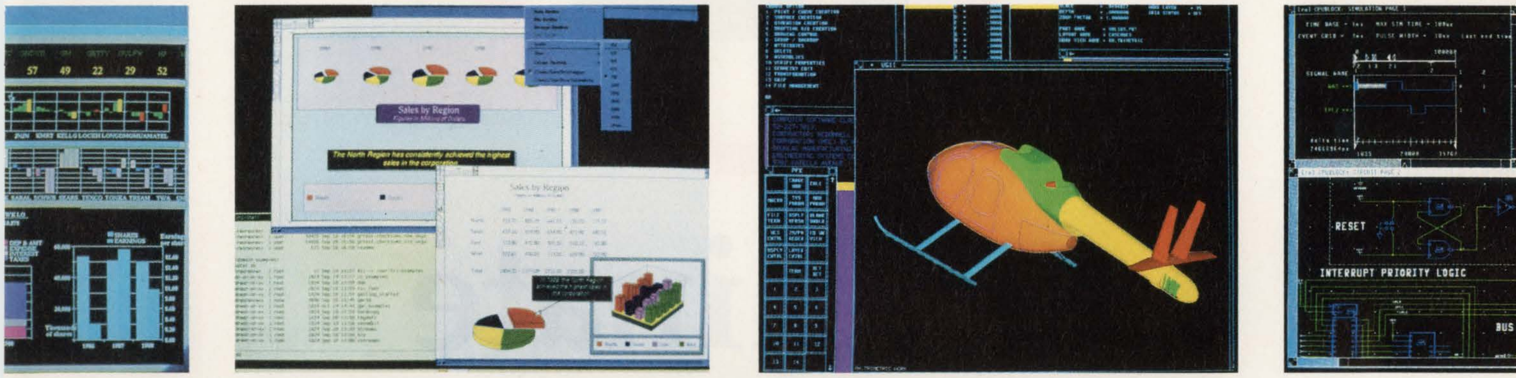

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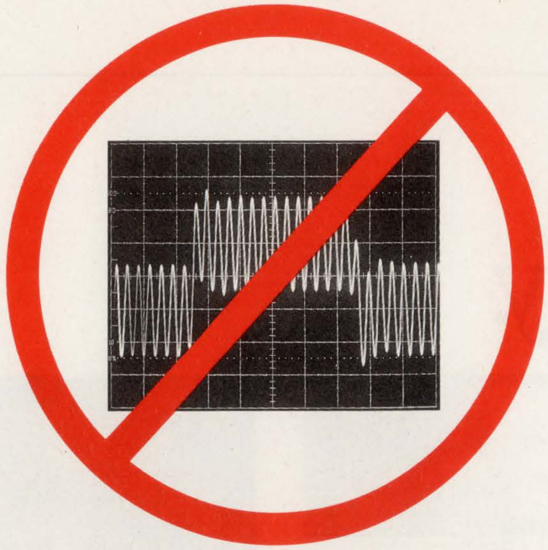
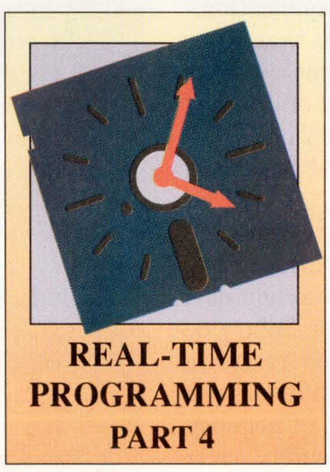


Understanding the complexity of tasking in real time

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.

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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.

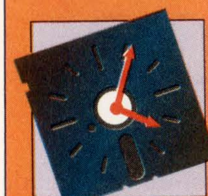
Separating main functions into different tasks is especially important because changes in specifications inevitably become necessary. Ideally, the alterations generated by a single change in the functional specifications should not extend beyond a single task.

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.



Tasking is the central issue that you must consider in the design of a real-time application.

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.

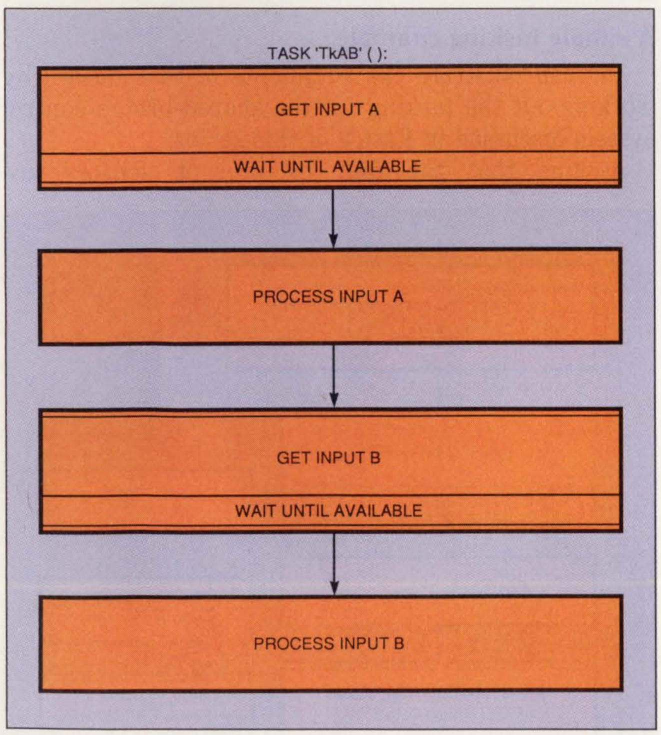


Fig 2—Always try to keep the processor busy with productive work. In this example of serial processing of real-time inputs, the processor can't get input B until it has finished with A. If there is no other task to keep the processor busy until A comes in, then the processor will be idle. If the processing of B doesn't depend on A, the scheme shown here is wasteful.

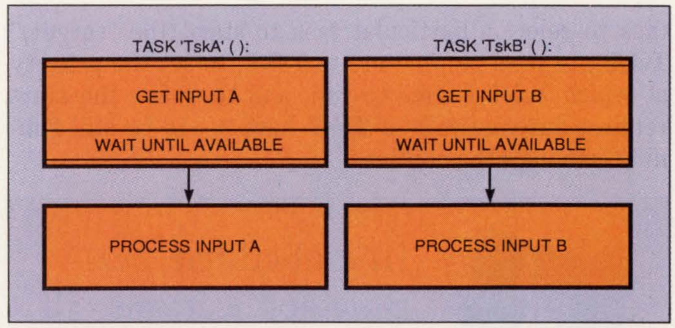


Fig 3—Parallel processing of real-time inputs improves on Fig 2's serial approach. In this example, in which the processing of B doesn't depend on A, the processor can get B without waiting for A.

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

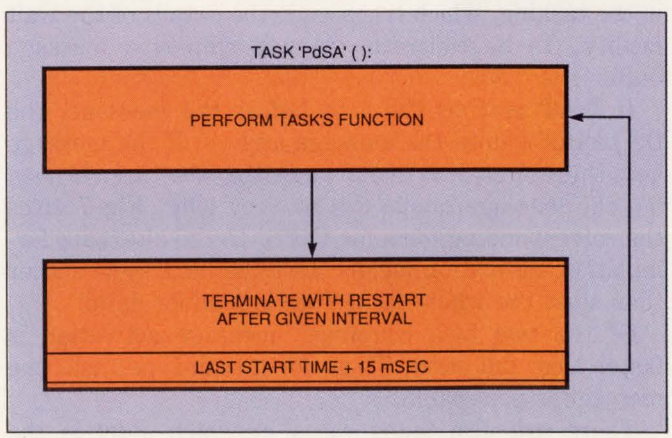
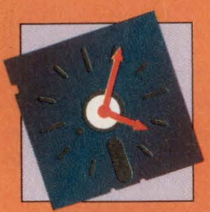


Fig 4—Periodic self-activation is one way a task can become active. When the task completes its function, it issues a call to the operating system to terminate itself and to restart itself after a given interval, in this case 15 msec.

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

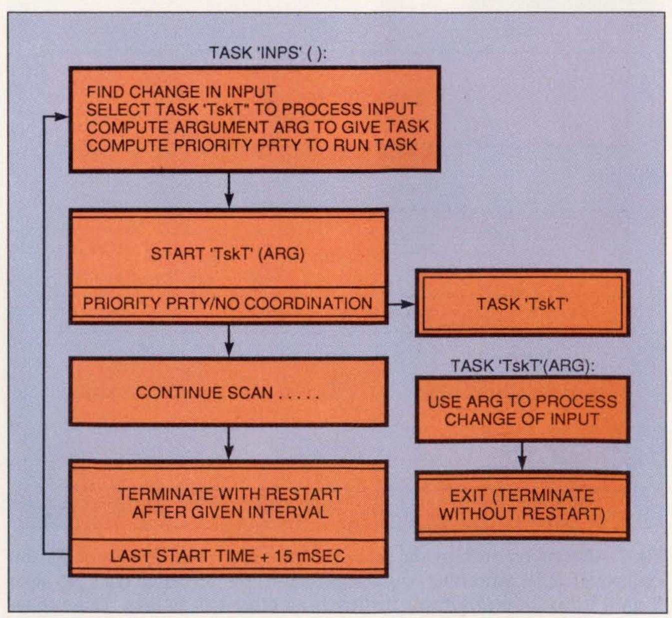


Fig 5—This typical input-scanning task is periodic. It runs every 15 msec, and it starts another task to process any change-of-input information.

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.

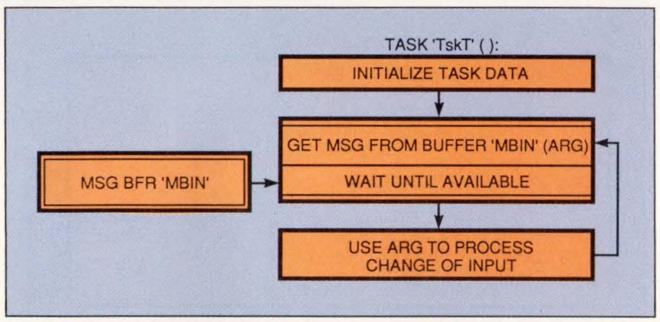


Fig 6—A cyclic task never terminates. In this example, it simply waits for input—in this case a message in a buffer—from another task. Use of this cyclic task contrasts with the approach taken in Fig 5, in which an input-processing task gets restarted with each new input.

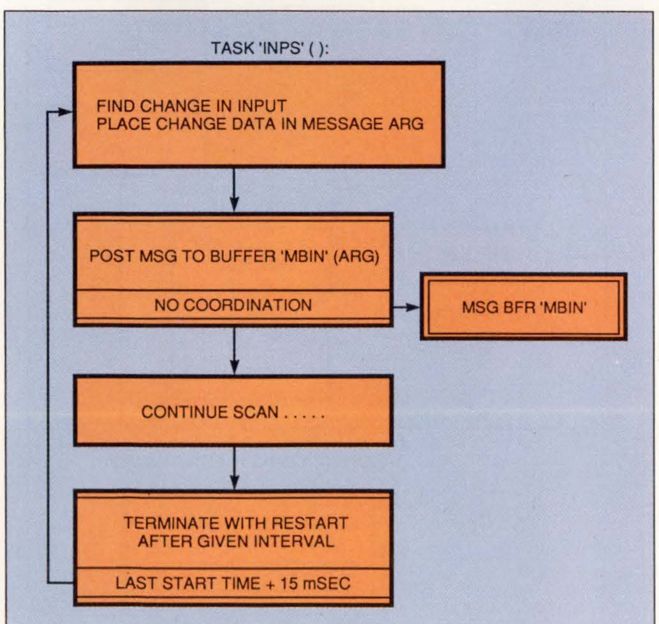


Fig 7—This message-based formulation of an input task passes a message regarding changed inputs to the processing task of Fig 6.

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

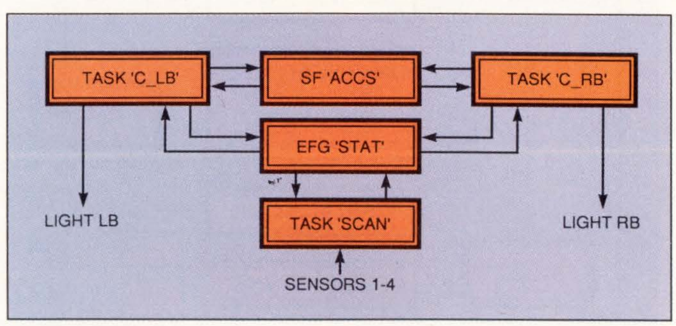


Fig 8—Tasking and coordination are at the heart of controller applications. This example shows tasks that control left-bound and right-bound traffic on a 1-lane bridge. Event-flag group 'STAT' keeps a tally of cars. Semaphore 'ACCS'—which only one task at a time can "own"—grants task access to the bridge.

(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.)

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

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**).

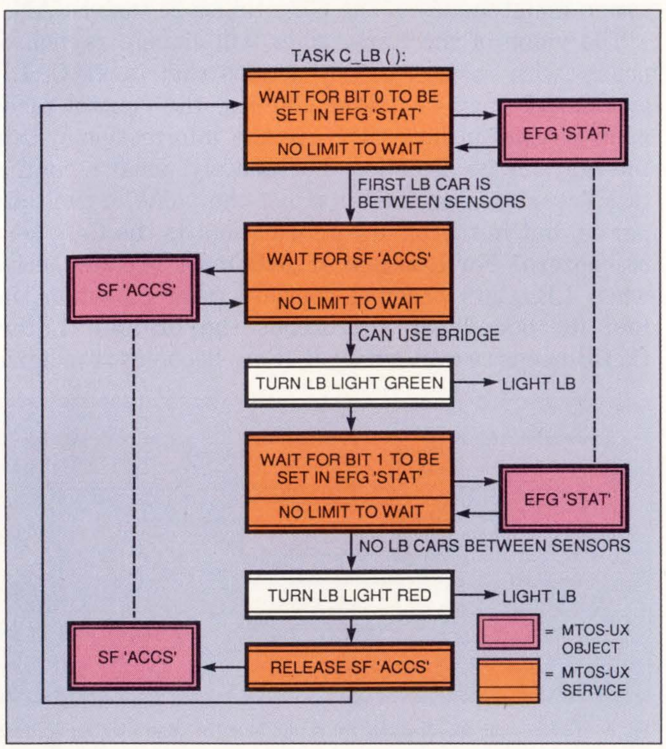


Fig 9—This implementation model shows details of a task that controls left-bound traffic on a 1-lane bridge. The details are hidden in Fig 8, which shows only overall tasking and coordination.

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-

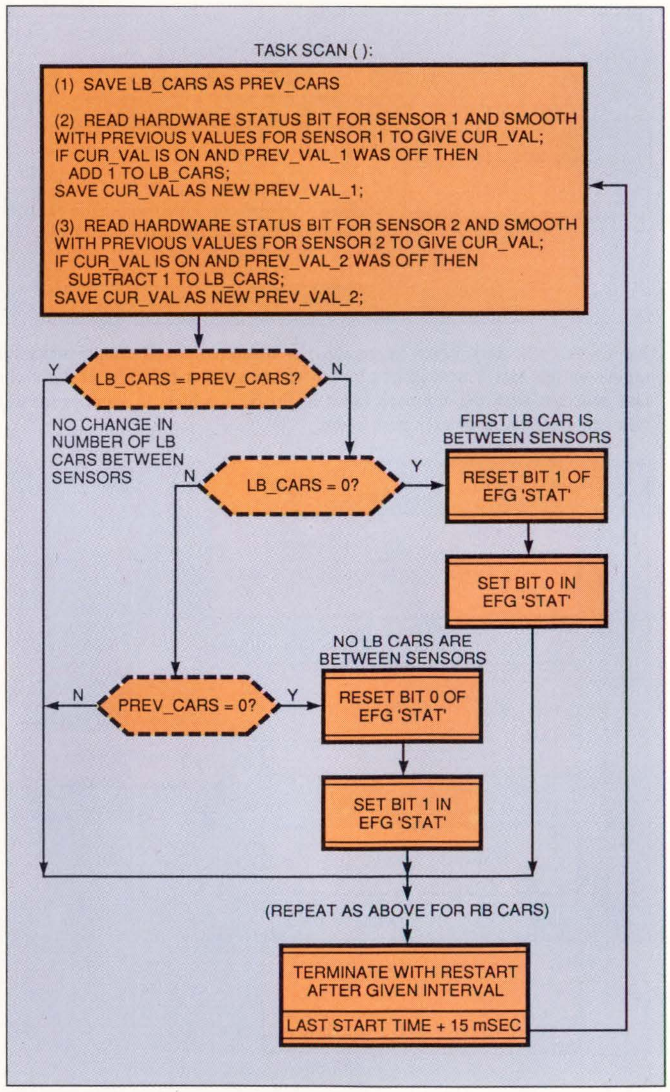


Fig 10—Details of the scanning task that appears only as a block in Fig 8, are shown in this implementation model.

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. EDN

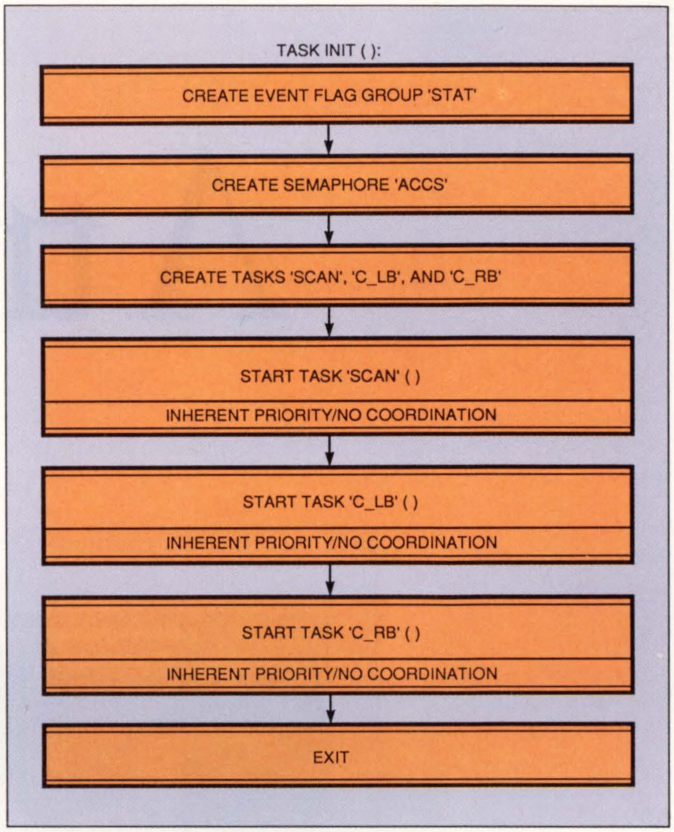


Fig 11—The initialization task creates all the elements of Fig 8's overall tasking and coordination and then terminates itself.

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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.

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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 X11perf 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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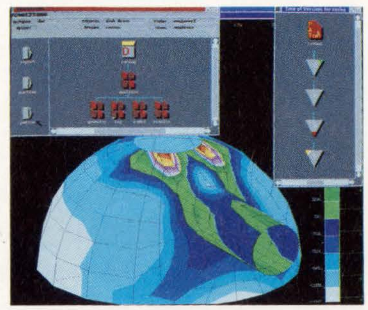

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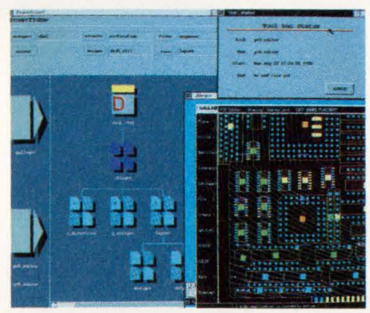

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CIRCLE NO. 74

DESIGN IDEAS

EDITED BY CHARLES H SMALL & ANNE WATSON SWAGER

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 $V_XV_Y/10$. 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—$+V_{REF}$ at TP_1, for example—the integrator ramps until its output reaches −11V. Then, TP_1 changes state and the integrator begins ramping toward +11V. 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 TP_2 to the signal at V_Y. The duty cycle, T_1+T_2, at the output of this second commutating amplifier is as follows:

$$T_1=2RC(11-V_Y)/10, \text{ and}$$

$$T_2=2RC(11+V_Y)/10.$$

During T_1, the voltage at TP_4 equals $-1.1V_X$. During the remaining period, T_2, the pulse height will equal $+1.1V_X$. V_{OUT} is the average, obtained by lowpass filtering, of this T_1 and T_2 combined waveform and equals

$$V_O=\frac{-1.1\ V_XT_1+1.1V_XT_2}{T_1+T_2}=\frac{V_XV_Y}{10}.$$

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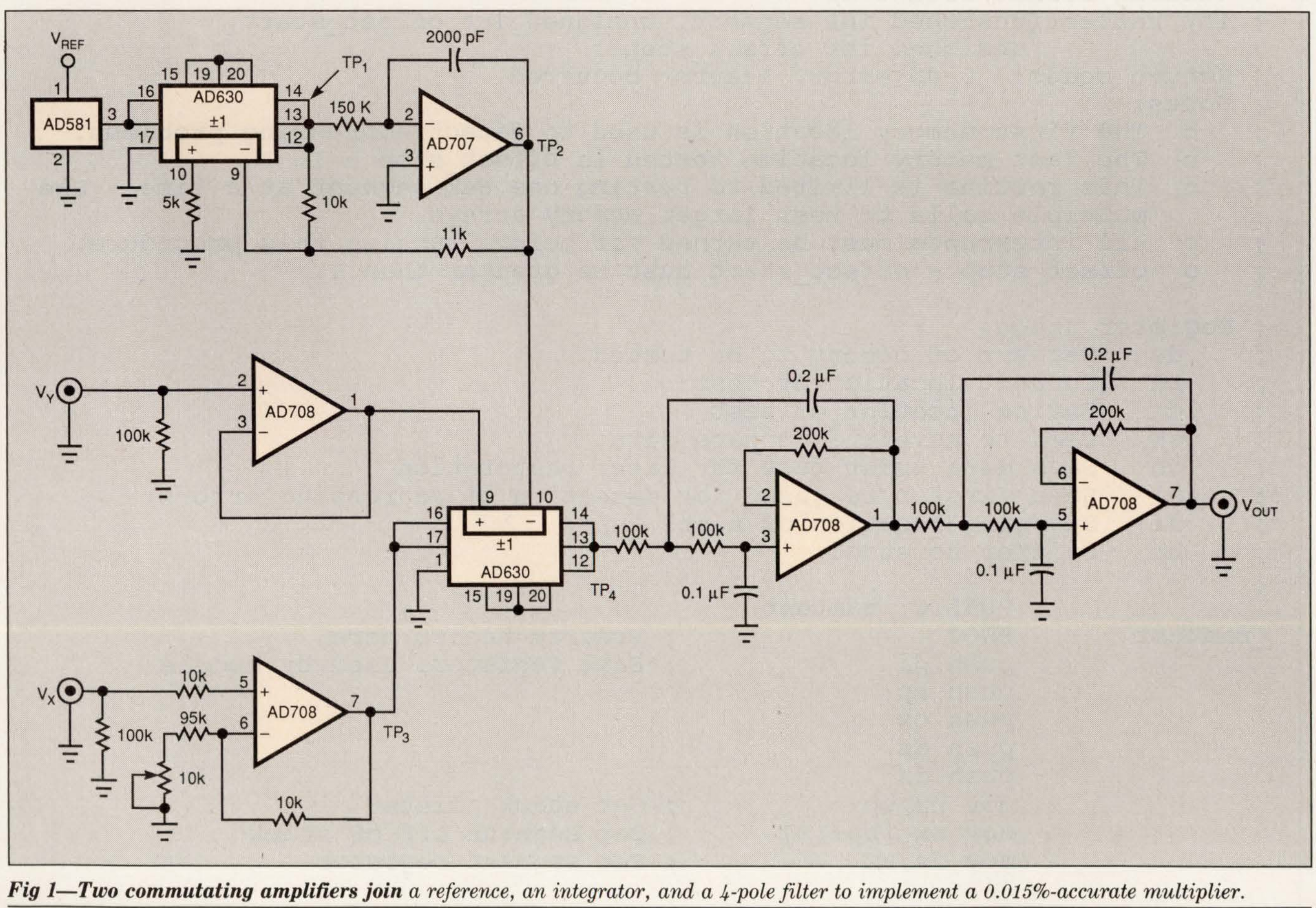

*Fig 1—**Two commutating amplifiers join** a reference, an integrator, and a 4-pole filter to implement a 0.015%-accurate multiplier.*

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.

*(Ed Note: To download **Listing 1** directly, use the EDN Bulletin Board System.)*

(EDN BBS /DI_SIG #897) **EDN**

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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                 ; Program begins here
               push di              ; Save registers used by module
               push bp
               push cx
               push ds
               push dx
               mov bp,sp            ; Get stack pointer
               mov ax,[bp+12]       ; Get segment off of stack
               mov ds,ax            ; Set segment register
```

Listing 1—RAM Test Program *(continued)*

```
                mov ax,[bp+14]          ; Get starting offset
                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 IC_3 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 IC_3's D_0 through D_6 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 D_0 through D_6 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 IC_3, which includes an uncommitted amplifier for setting the output level.

Fig 2's scope photo illustrates the effect of filtering

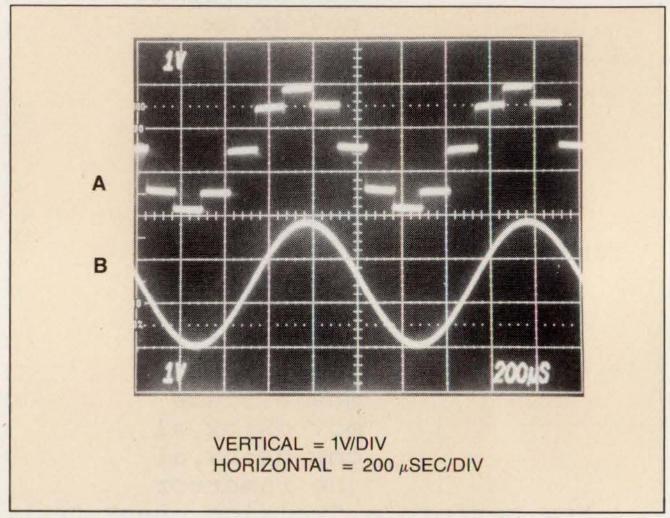

Fig 1—The output of Fig 1's multiplexer *(trace A) emerges from the lowpass, continuous-time filter as a clean sine wave (trace B).*

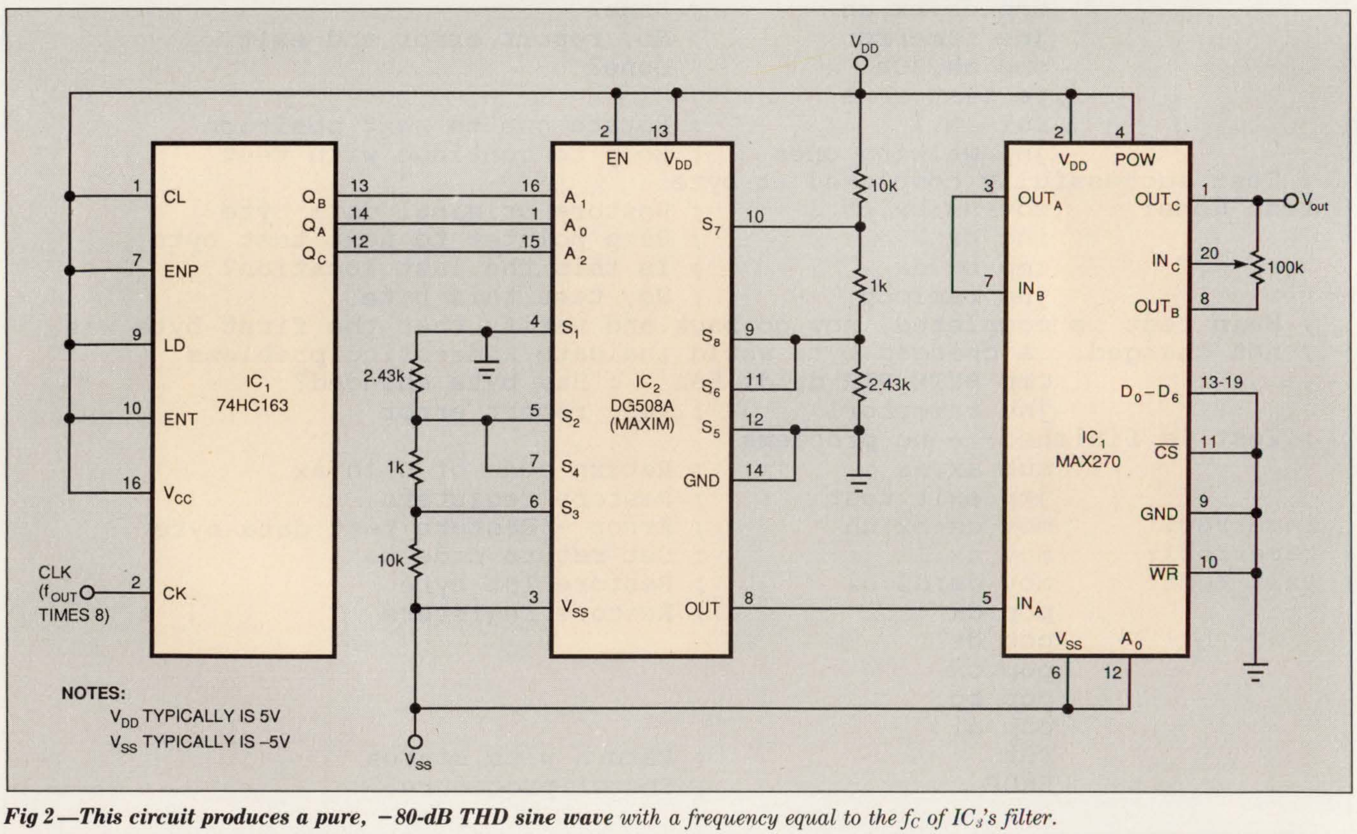

Fig 2—This circuit produces a pure, −80-dB THD sine wave *with a frequency equal to the f_C of IC_3's filter.*

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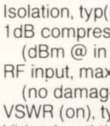
1dB compression, typ (dBm @ in port)	20	20	24
RF input, max dBm (no damage)	22	22	26
VSWR (on), typ		1.4	
Video breakthrough to RF, typ (mV p-p)		30	
Rise/Fall time, typ (nsec)		3.0	



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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 /DI_SIG #898)**

To Vote For This Design, Circle No. 748

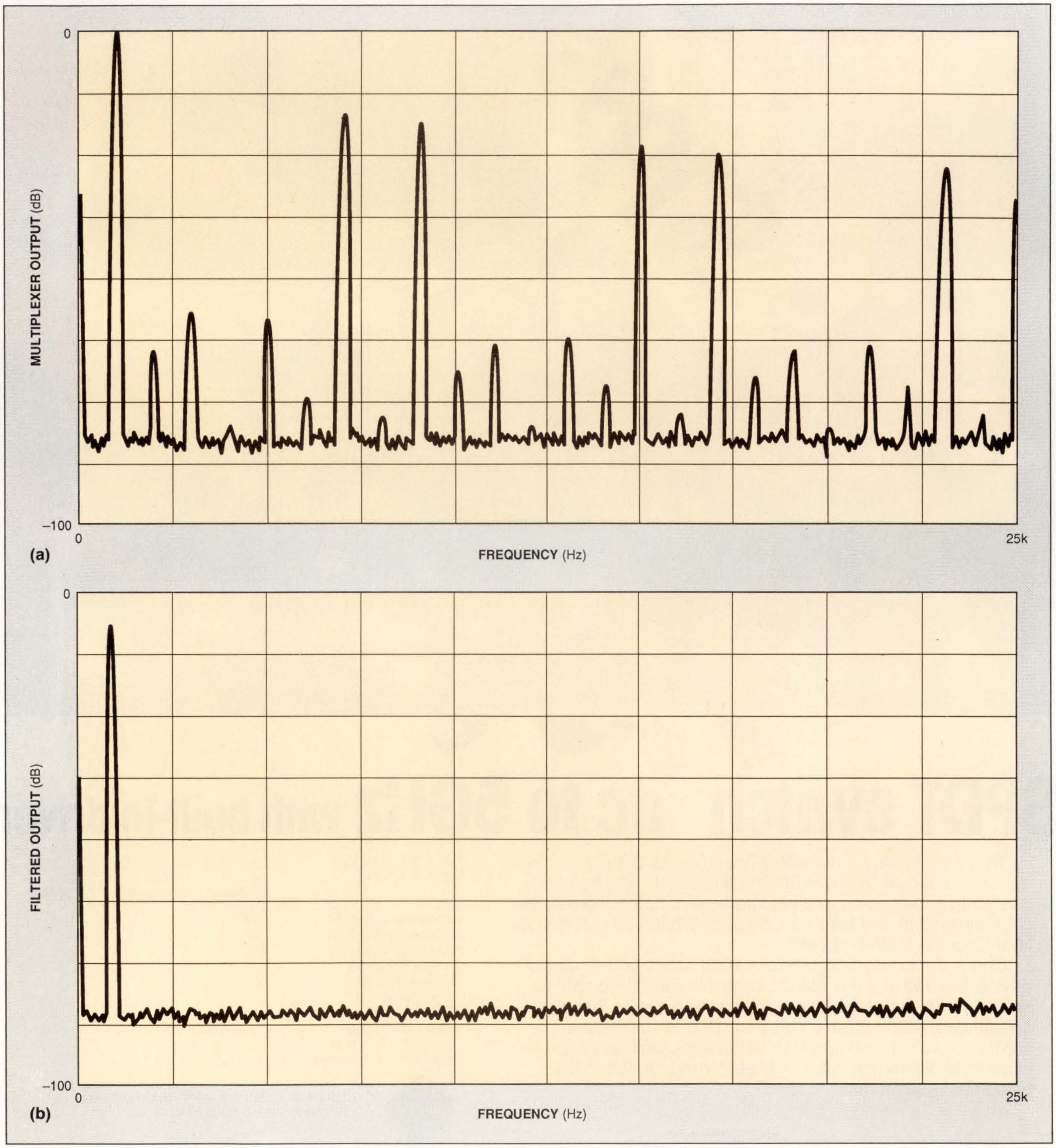

Fig 3—The circuit's approximation process generates *large harmonics in the multiplexer's output spectrum* ***(a)****, which the filter attenuates to below the spectrum analyzer's noise floor* ***(b)****.*

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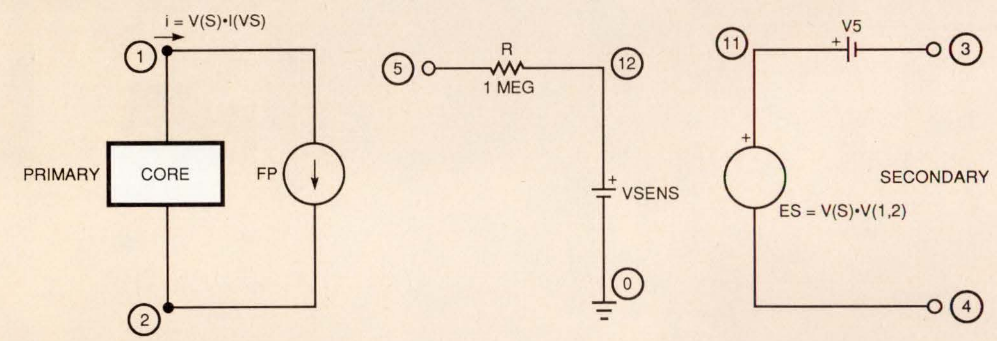
Models exhibit saturation and hysteresis

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)

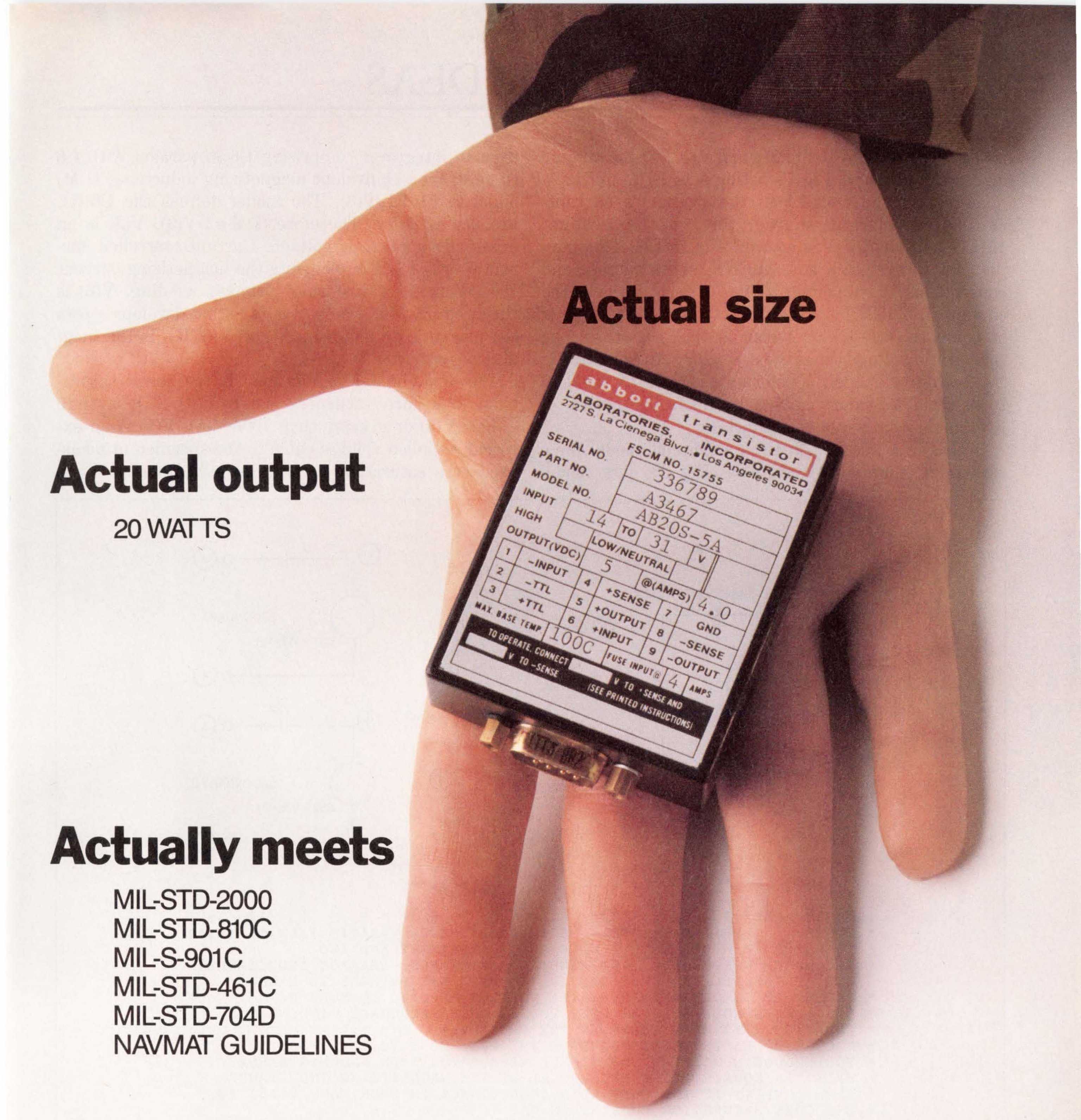


(a)

```
.SUBCKT XFMR2 1    2    3    4    5     6    7    8
* NODES:      PRI+ PRI- SEC1+ SEC1- V=RATIO V=1/LM V=GLOSS V=ILSAT
* TRANSFORMER MODEL WITH 2 WINDINGS (ADD WINDING RESISTANCE
* LEAKAGE INDUCTANCE, ETC. EXTERNALLY AS REQUIRED.)
* THE TURNS RATIO FROM THE PRIMARY TO THE SECONDARY IS SET BY THE
* VOLTAGE APPLIED TO NODE 5 (E. G., WHEN NODE 5 IS AT FOUR VOLTS,
* THE SECONDARY WILL HAVE FOUR TIMES AS MANY TURNS AS THE PRIMARY.
* A CORE MODEL IS CONNECTED FROM THE PRI+ NODE TO PRI- NODE
* TO INCLUDE NONLINEAR INDUCTANCE WITH SATURATION AND HYSTERESIS.
* V(6) IS EQUAL TO THE RECIPROCAL OF THE MAGNETIZING INDUCTANCE
* (1/H), V(7) IS THE CORE LOSS CONDUCTANCE (MHOS), AND V(8) IS
* EQUAL TO THE CORE SATURATION CURRENT (MA).
FP   1   2   POLY(2) VS VSENS 0.0 0.0 0.0 0.0 1MEG
R 5 12 1MEG
VSENS 12 0
VS    11  3
ES    11  4   POLY(2) 1   2  5   0   0.0 0.0 0.0 0.0 1.0
* REFERENCE TO THE NONLINEAR CORE SUBCIRCUIT MODEL
XCORE 1 2 6 7 8 CORE
.ENDS XFMR2
```

(b)

***Fig 1—The voltage at node 5** controls the turns ratio of this 2-winding transformer equivalent circuit **(a)** and Spice model **(b)**.*



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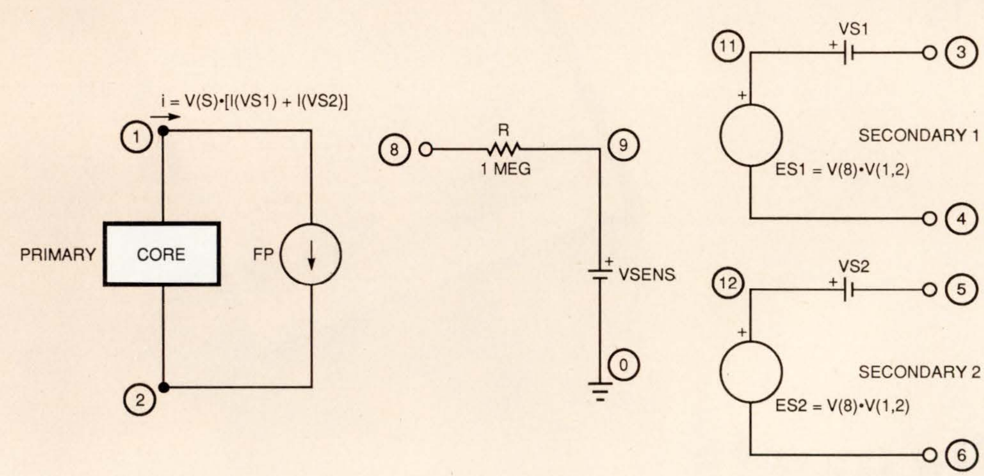
is the turns ratio by definition and V(1,2) is the voltage across the primary. **Fig 1**'s listing sets P4 to unity.

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



(a)

```
.SUBCKT XFMR3 1    2    3    4    5    6    8      13  14  15
* NODES:      PRI+ PRI- SEC1+ SEC1- SEC2+ SEC2- V=RATIO 1/LM GL ILSAT
* TRANSFORMER MODEL WITH 3 WINDINGS - A PRIMARY AND TWO
* SECONDARY WINDINGS.  (ADD WINDING RESISTANCE, LEAKAGE INDUCTANCE,
* ETC. EXTERNALLY.)  THE TURNS RATIO FROM THE PRIMARY TO EACH
* SECONDARY IS DETERMINED BY THE VOLTAGE APPLIED TO NODE 8.
* E.G., WHEN NODE 8 IS AT FOUR VOLTS, EACH SECONDARY WINDING HAS
* FOUR TIMES AS MANY TURNS AS THE PRIMARY.)
* A CORE MODEL IS CONNECTED FROM THE PRI+ NODE TO PRI- NODE
* TO INCLUDE NONLINEAR INDUCTANCE WITH SATURATION AND HYSTERESIS.
* V(13) IS EQUAL TO THE RECIPROCAL OF THE MAGNETIZING INDUCTANCE
* (1/H), V(14) IS THE CORE LOSS CONDUCTANCE IN MHOS, AND V(15) IS
* THE CORE SATURATION CURRENT IN MA.
FP 1 2 POLY(3) VS1 VS2 VSENS 0.0 0.0 0.0 0.0 0.0 0.0 1MEG 0.0 1MEG
R 8 9 1MEG
VSENS 9 0
VS1  11  3
VS2  12  5
ES1  11  4  POLY(2)  1  2  8  0   0.0 0.0 0.0 0.0 1.0
ES2  12  6  POLY(2)  1  2  8  0   0.0 0.0 0.0 0.0 1.0
* REFERENCE TO THE NONLINEAR CORE SUBCIRCUIT MODEL
XCORE 1 2 13 14 15 CORE
.ENDS XFMR3
```

(b)

***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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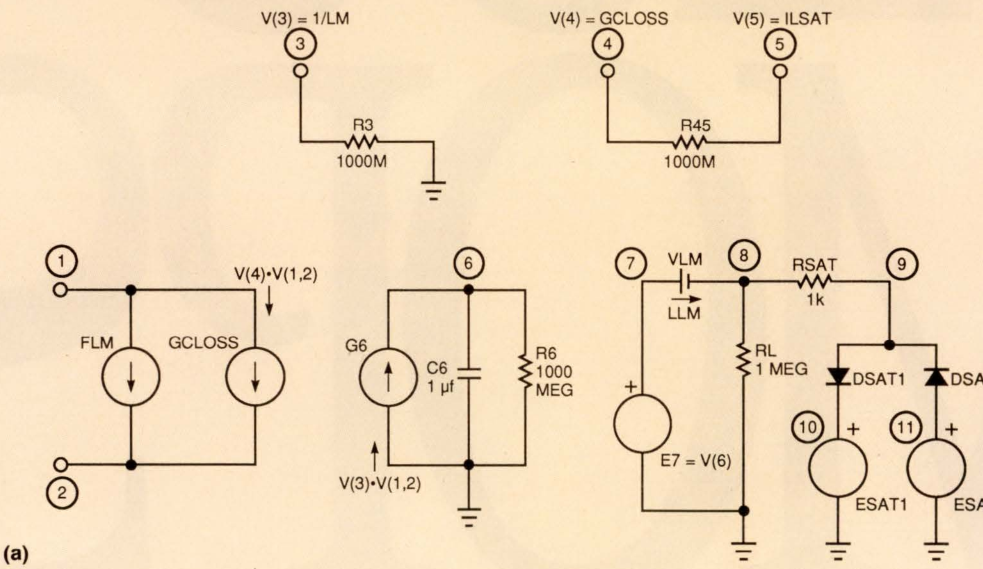
the core saturates, the magnetizing inductance reduces to approximately LM/1000. The transconductance source GCLOSS models the core-loss conductance. This source's current I(GCLOSS) equals V(1,2)·V(4). Because the voltage at nodes 1 and 2 is the same, GCLOSS equals V(4), also an externally dc voltage. 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 mrads/sec. 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.

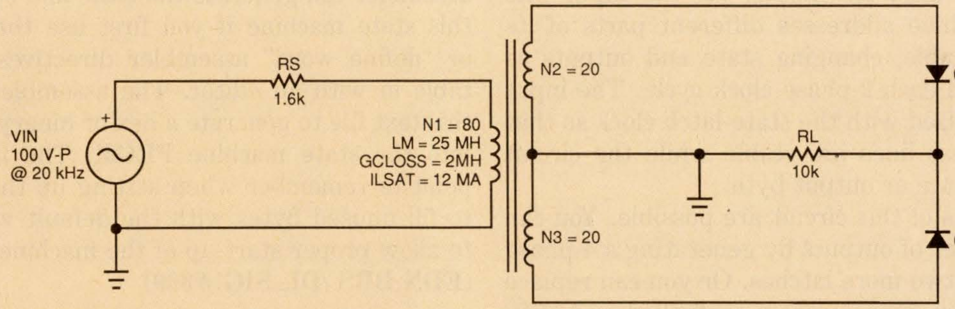
An example of the use of these model is a full-wave rectifier circuit **(Fig 4)**. **(EDN BBS /DI_SIG #901)**

To Vote For This Design, Circle No. 749




```
.SUBCKT CORE 1      2      3      4        5
* NODES:     PRI+   PRI-  V=1/LM V=GCLOSS V=ILSAT
R3 3 0 1000MEG
R45 4 5 1000MEG
FLM 1 2 VLM 1.0
* I(GCLOSS) = V(4)*V(1,2)
GCLOSS 1 2 POLY(2) 1 2 4 0  0 0 0 0 1.0
* I(G6) = V(3)*V(1,2)
G6 0 6 POLY(2) 1 2 3 0  0 0 0 0 1.0
C6 6 0 1UF
R6 6 0 1000MEG
E7 7 0 6 0 1.0
VLM 7 8
RL 8 0 1MEG
* SATURATION CONTROL CIRCUIT
RSAT 8 9 1K
DSAT1 9 10 DIODE
DSAT2 11 9 DIODE
ESAT1 10 0 5 0  1000
ESAT2 11 0 5 0 -1000
.MODEL DIODE D
.ENDS CORE
```
(b)

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.*



(a)

```
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)

* INCLUDE CORE AND THREE-WINDING TRANSFORMER MODELS HERE
```

(b)

Fig 4—Nonlinear core and transformer models are useful *for modelling this full-wave rectifier circuit* ***(a)*** *and Spice code* ***(b)***.

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, S_0, to select either state or output data for latching. Address bits S_1

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 /DI_SIG #899) EDN

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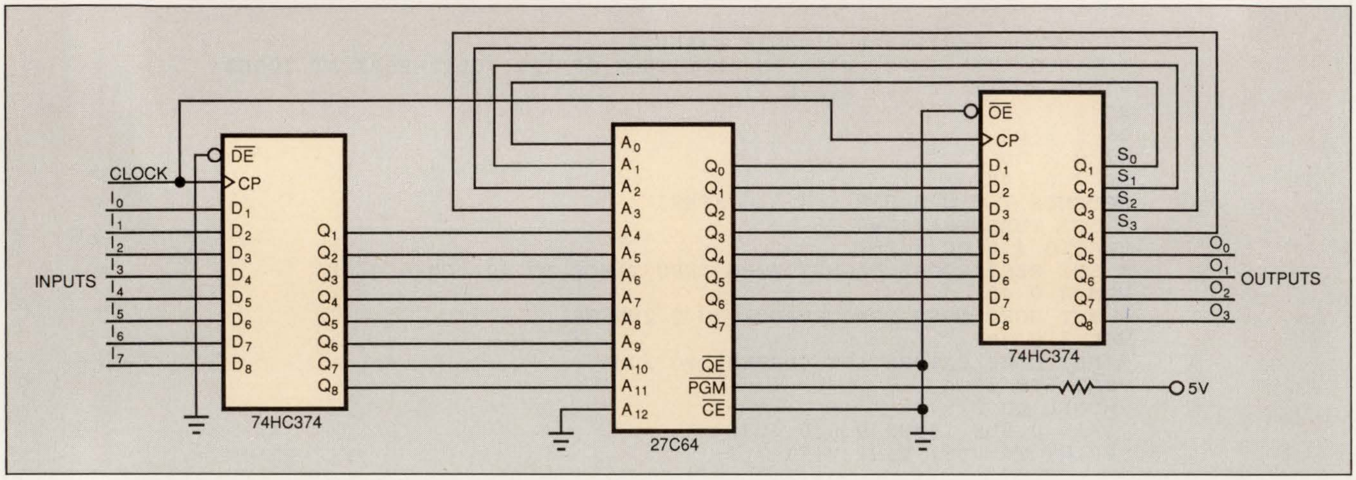

Fig 1—This simple state machine *is limited to 8 bits for both output and state-feedback lines.*

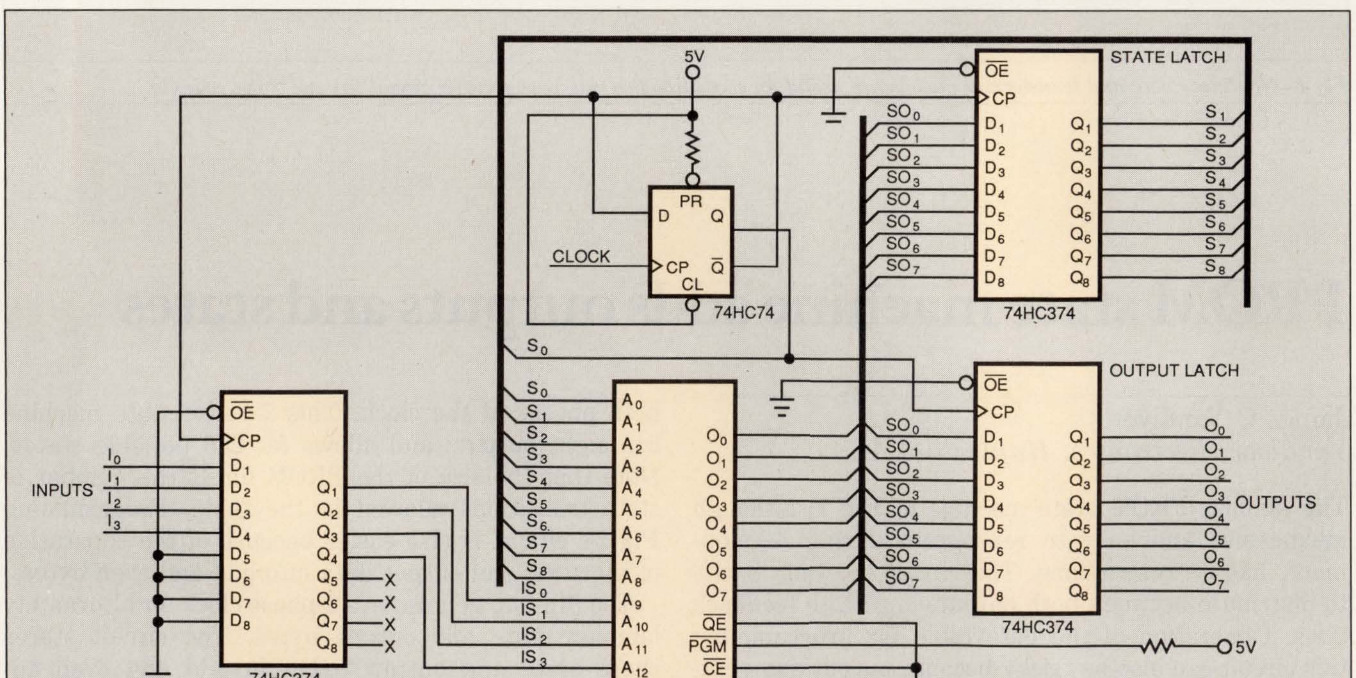

Fig 2—By adding a latch and a flip flop, *this 2-phase state machine uses both clock edges to make better use of the PROM address space.*

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 /DI_SIG #881)**

To Vote For This Design, Circle No. 803

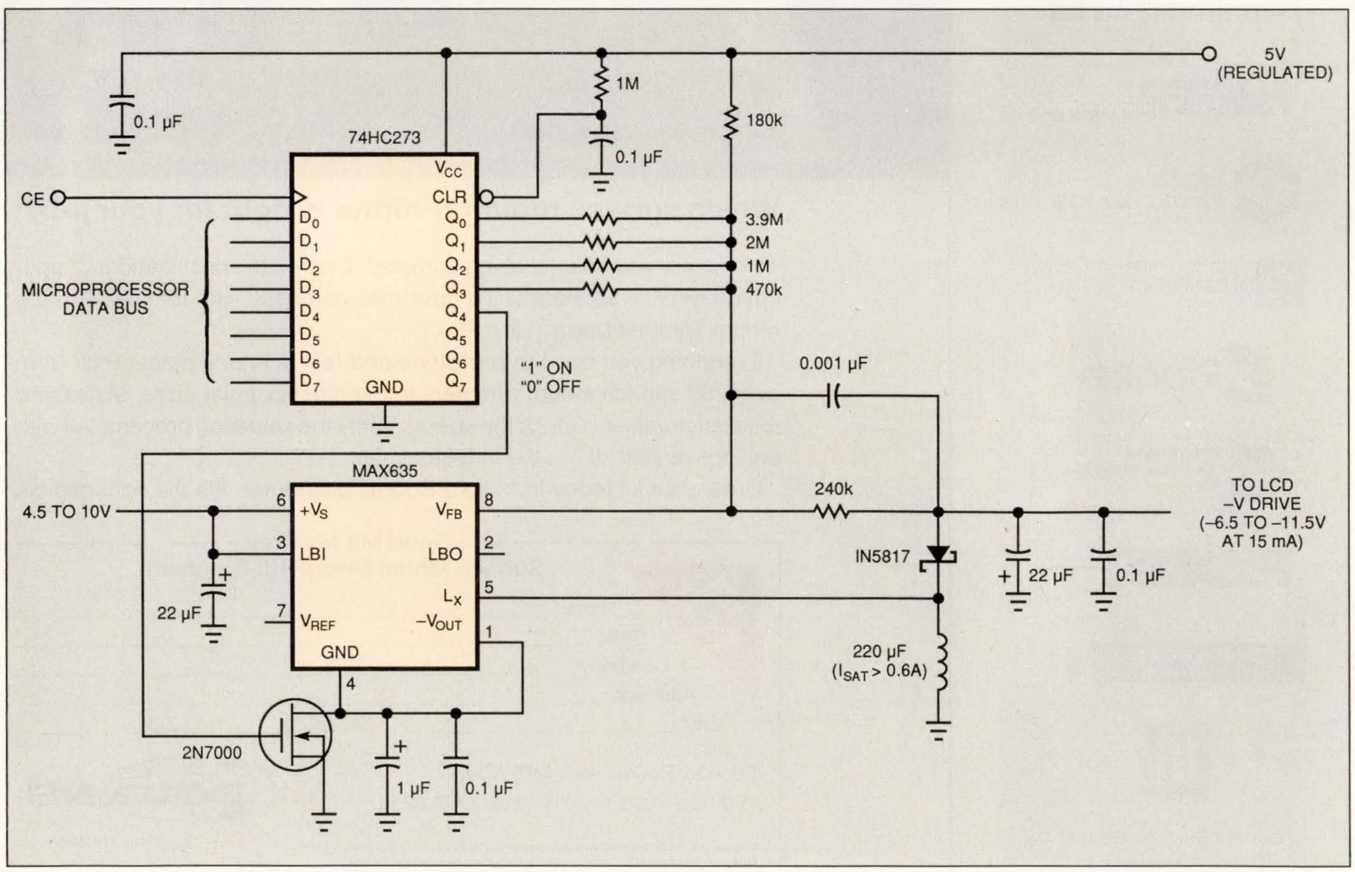

Fig 1—Using a resistor-ladder DAC and a voltage regulator IC, *this circuit uses the system's positive battery supply to generate a digitally variable negative voltage.*

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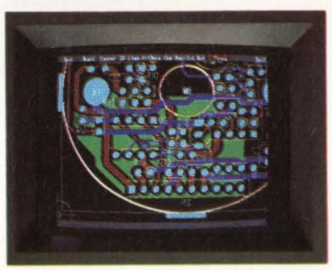

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CIRCLE NO. 132

FEEDBACK AND AMPLIFICATION

EDN's bulletin board is on line

EDN's computer bulletin board system, (617) 558-4241 (2400,8,N,1), has a Design Idea Special Interest Group. Where applicable, you'll find computerized material that you can download, such as program listings, circuit diagrams, and pc-board layouts, posted on the bulletin board. We also want to hear from you. Please use our bulletin board to ask questions, make comments, and propose alternative solutions.

To use the BBS, first call up and log onto the system. To get to the Design Idea Special Interest Group, first select "s", the SIGs option. Next select the "s" new-SIG option and ask for a list of SIGs by entering a "?". Enter the "/DI_SIG" name. Then select the "r" read-bulletin and "s" scan-bulletin options. You should now be able to scan the titles of available Design Ideas (DIs), optionally read an attached explanatory message, and optionally download an attached file. Note that the BBS assigns its own number to each message. You will find our DI number, along with a portion of the DI's headline, when you scan the list of bulletins. You can optionally use our DI number, or any portion of a DI's headline, to search for a particular Idea. To leave the DI editors a message, first get to the /DI_SIG, and then select the "w" write-message option. If you plan to submit a software design idea, please put it on our BBS or send us an ASCII version of your program on disk. We'll load it on the bulletin board for other readers to download.

Charles H Small and Anne Watson Swager
Design Idea Editors

Errata

I apologize for two errors in my Design Idea "Passive network is totally resistive" in the August 2, 1990, issue of EDN. On pg 135, the equation for L should be as follows:

$$L = R/\Omega_0 = R/2\pi F_0.$$

The equation for C should be as follows:

$$C = 1/\Omega_0 R = 1/2\pi F_0 R.$$

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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.

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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 Q_1, Q_2, and C. And in the circuit diagram I sent you, the resistor from the collector of the first transistors is not connected to V_C. 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 U_{REG} to our style, V_C (control voltage). Perhaps you are confusing V_C with V_{CC}. 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

```
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 = 0xff << start_bit;
  stop_mask = 0xff >> (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) = 0xff;
     *(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, Q_1. Now, you need only the op amp as an additional external element to get almost the same linearizing effect **(Fig 1).**

Rainer Lackmann
Frauhofer Institut
Finkenstrasse 61 41 Duisburg
West Germany

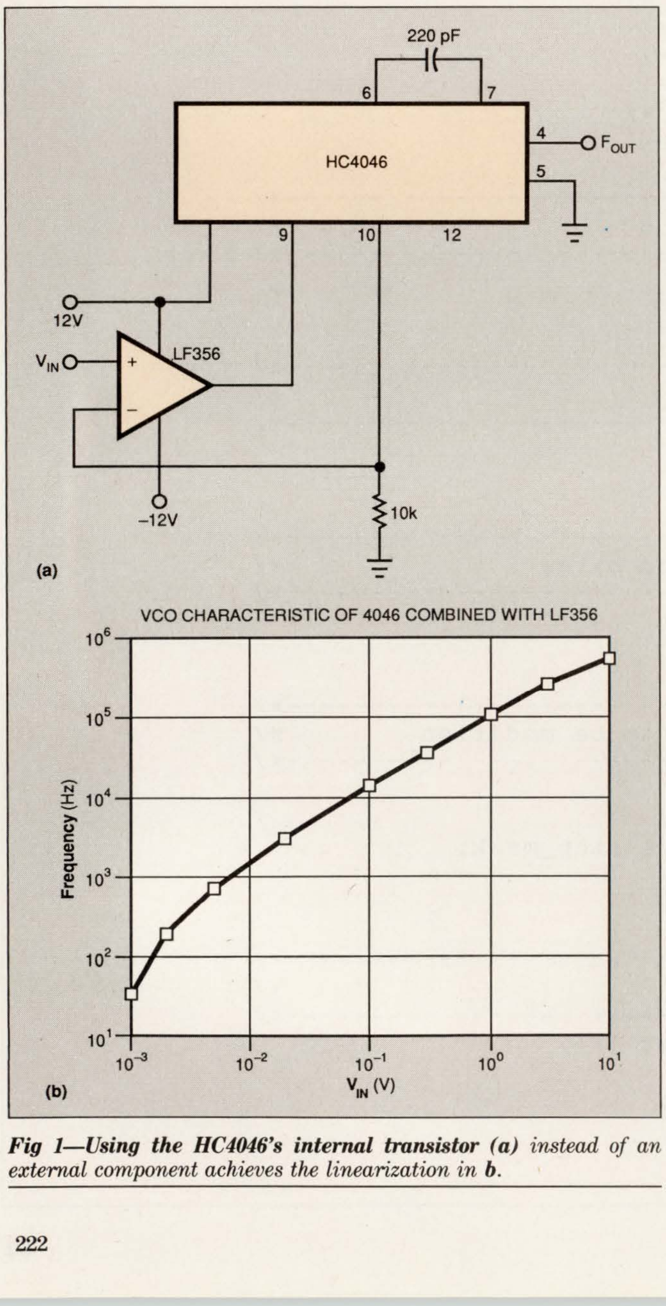

***Fig 1—Using the HC4046's internal transistor (a)** instead of an external component achieves the linearization in **b**.*

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 R_2 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 July 19, 1990, issue is entitled "MOSFET and oscillator compose relay," submitted by Andy Fewster of Siliconix Ltd (Newbury, UK).

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).

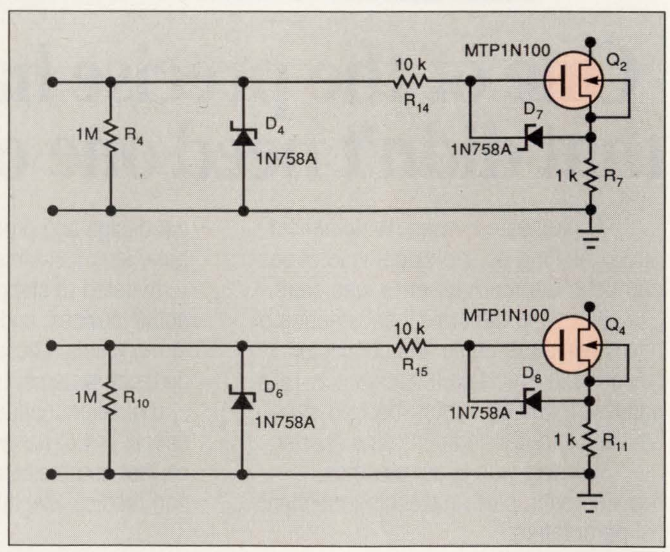
FEEDBACK AND AMPLIFICATION

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 Q_2 and Q_4 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 D_4 and D_6, respectively. In addition, Scott Ellington should have been identified as co-author.

Don Michalski
Associate Director
Scott Ellington
Senior Design Engineer
Space Astronomy Laboratory
University of Wisconsin
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.)



EDN

LINEAR TECHNOLOGY

DESIGN NOTES

Number 40 in a series from Linear Technology Corporation *October, 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 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.

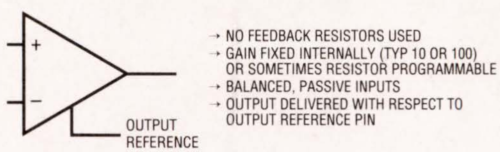


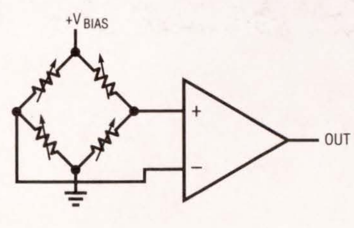
Figure 1. Conceptual Instrumentation Amplifier

PARAMETER	CHOPPER STABILIZED LTC1100	MICROPOWER LT1101	HIGH SPEED LT1102
Offset	10μV	160μV	500μV
Offset Drift	100nV/°C	2μV/°C	2.5μV/°C
Bias Current	50pA	8nA	50pA
Noise (0.1Hz-10Hz)	2μVp-p	0.9μV	2.8μV
Gain	100	10,100	10,100
Gain Error	0.03%	0.03%	0.05%
Gain Drift	4ppm/°C	4ppm/°C	5ppm/°C
Gain Non-Linearity	8ppm	8ppm	10ppm
CMRR	104dB	100dB	100dB
Power Supply	Single or Dual, 16V Max	Single or Dual, 44V Max	Dual, 44V Max
Supply Current	2.2mA	105μA	5mA
Slew Rate	1.5V/μs	0.07V/μs	25V/μs
Bandwidth	8kHz	33kHz	220kHz

Figure 2. Comparison of The New IC Instrumentation Amplifiers

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



BRIDGE TRANSDUCER	AMPLIFIER	V_{BIAS}	COMMENTS
350Ω Strain Gage (BLH #DHF – 350)	LTC1100	10V	Highest Accuracy, 30mA Supply Current
1800Ω Semiconductor (Motorola MPX2200AP)	LT1101	1.2V	Lower Accuracy & Cost. < 800μA Supply Current

Figure 3. Characteristics of Some Bridge Transducer - Amplifier Combinations

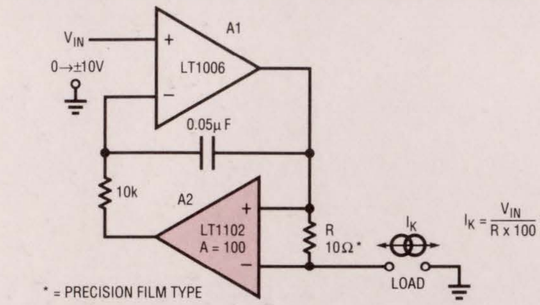


Figure 4. Voltage Programmable Current Source is Simple and Precise

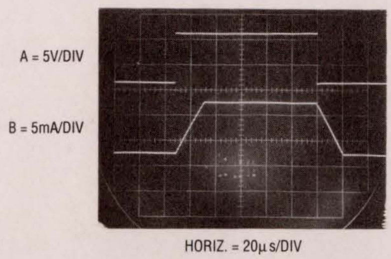


Figure 5. Dynamic Response of the Current Source

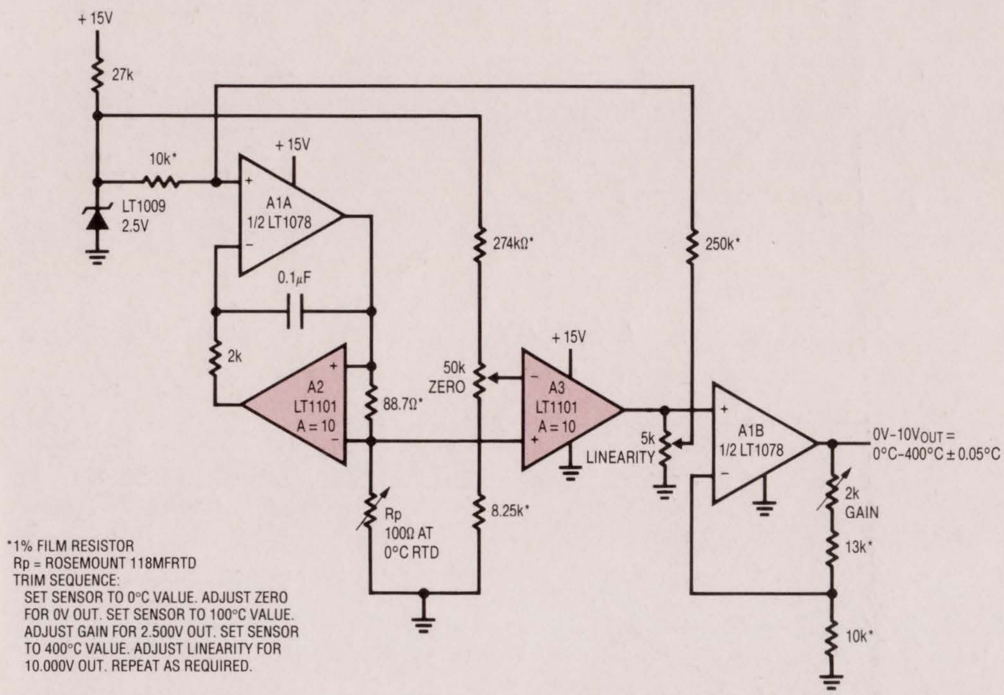


Figure 6. Linearized Platinum RTD Bridge. Feedback to Bridge from A3 Linearizes the Circuit

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 bridges 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."

For literature on our Instrumentation Amplifiers,
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call (408) 432-1900, Ext. 456

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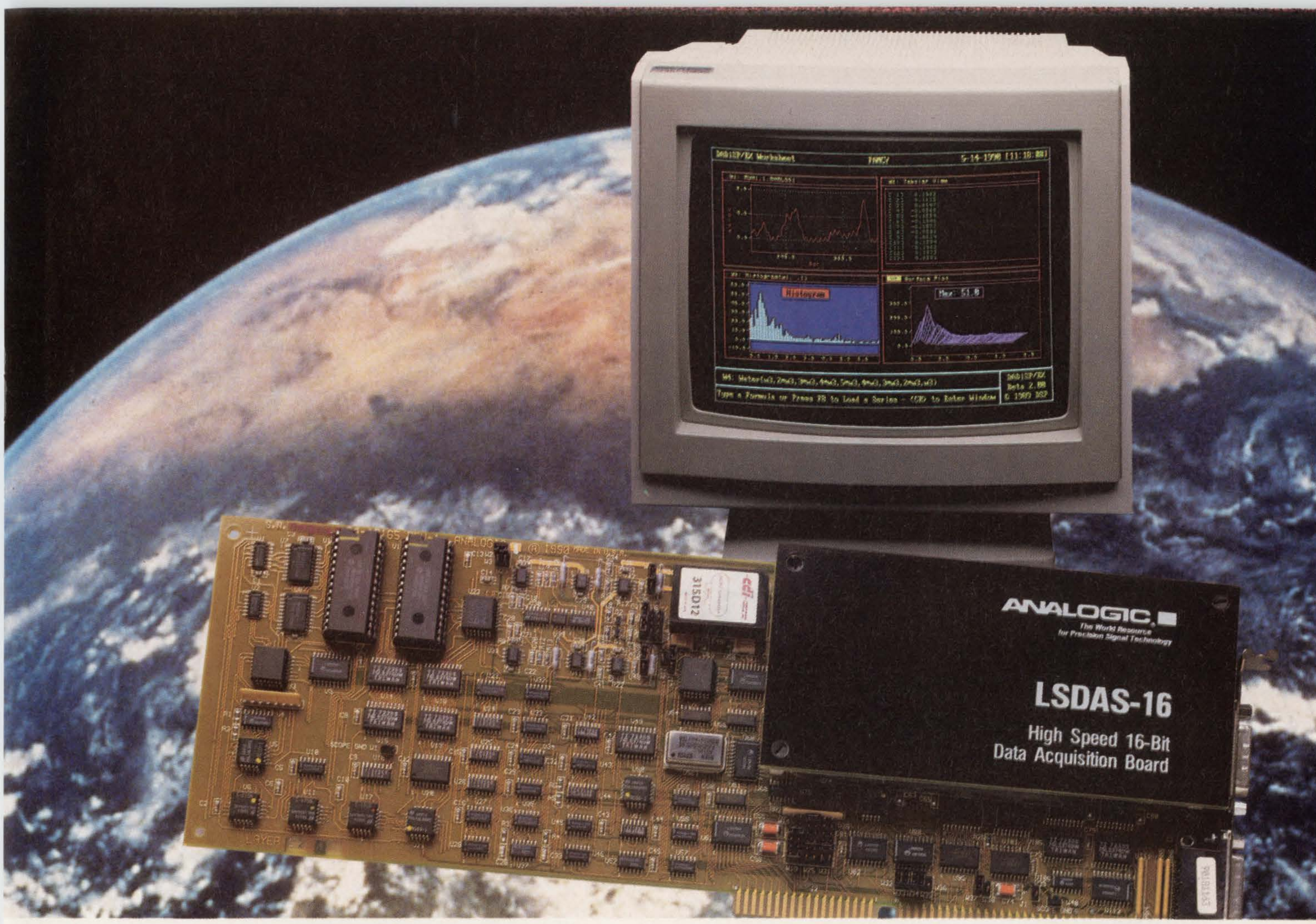
BA/GP 1090 180K



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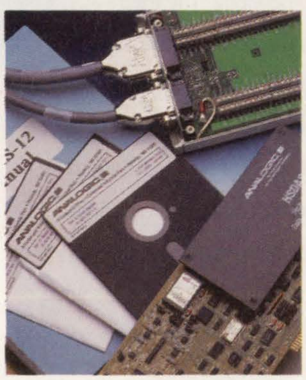

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WORLD NEWS
Special 1983 reprise edition
Borg quits at 26
Standard components launched in miniature
A relatively untapped link in the miniaturisation of electronics – power supply – is now being exploited. A completely new concept has been launched that makes it possible to obtain power in the form of a miniature standard component which is both highly efficient and economically attractive.
The first group in a planned series of new products within the field of power supply for electronic systems has been launched by RIFA – the electronic specialist within the Ericsson Group – through its newly established unit in RIFA Power Products.
The components are extremely small DC/DC converters in thick-film design which have remarkable performance. It has been possible to increase reliability 10-20-fold, while at the same time the products are half the size and five times lighter than all other converters previously used.
World premier for a product set to revolutionise an industry
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.
The award has been attacked by a Polish spokesman as 'political', but the Nobel Committee insists its decision was prompted by Walesa's efforts to extend and uphold workers' rights in Poland.
Walesa plan to donate the prize money that accompanies the award – worth around £100,000 – to a local agricultural project.
Shergar kidnapped
One of Britain's best-known racehorses – Derby winner Shergar – is the latest victim of kidnappers.
The horse disappeared from its stables in Ireland at the beginning of February. The kidnappers have promised to return Shergar, unharmed, on payment of a £2 million ransom.
French aid for Chad
As Libyan troops continue to occupy huge areas of Chad, France has stepped in to help her former colony.
Troops and helicopters have been sent to reinforce the beleaguered government, already struggling to end a long running civil war.
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On-Card DC/DC Converter
In: –(39–64)V
Out: 5V
PKA 4211 P
Pout: 25W
Made in Sweden
ERICSSON
Britain told to belt up
Like it or not, seat belts are here to stay. Prompted by the increasing number of car accidents, the government has made the wearing of belts compulsory.
– but Greens gain ground
tian Democrats, back in power after an absence of 16 years, Herr Kohl is well aware of the unpredictability of political life.
His immediate predecessor, Social Democrat leader 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.
STOP PRESS
• Danish trawlers ignore UK warnings

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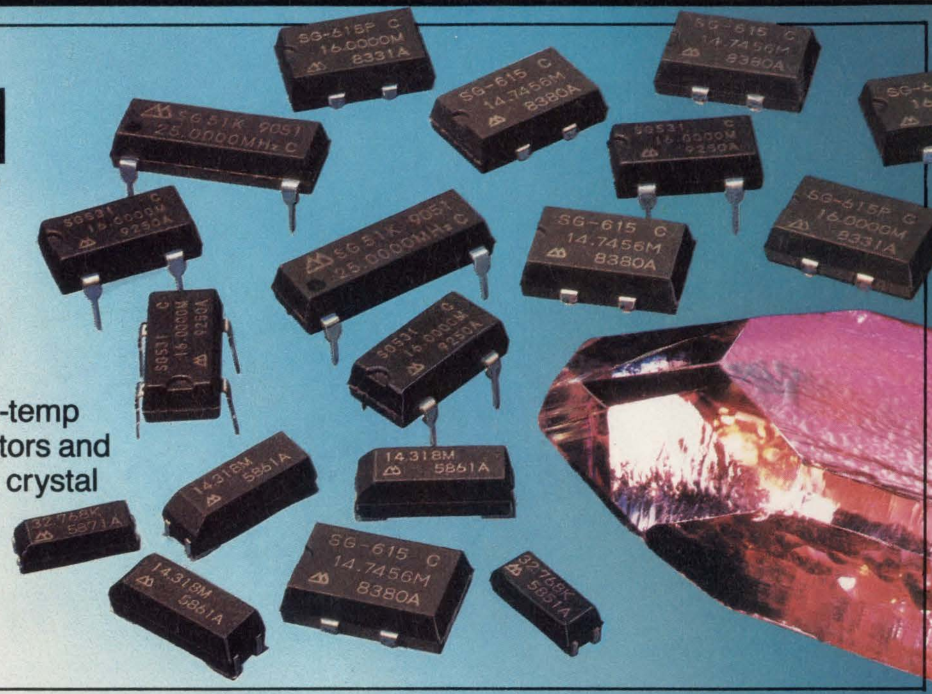

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CRYSTALS AND OSCILLATORS


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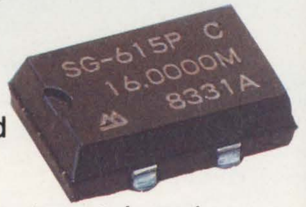

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Rise/Fall Time:	5 nsec (TYP)
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Compatible Technology:	CMOS and TTL
Op. Temp. Range:	−40°C to 85°C

MODEL MA 505/506 CRYSTAL
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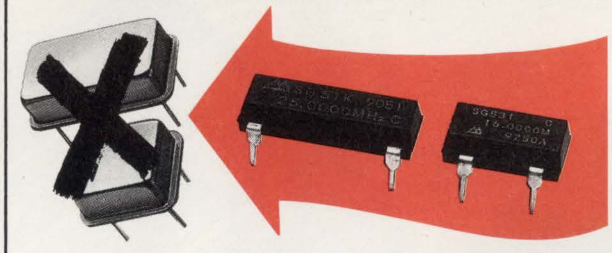


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Compatible Technology:	CMOS and TTL

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CIRCLE NO. 136

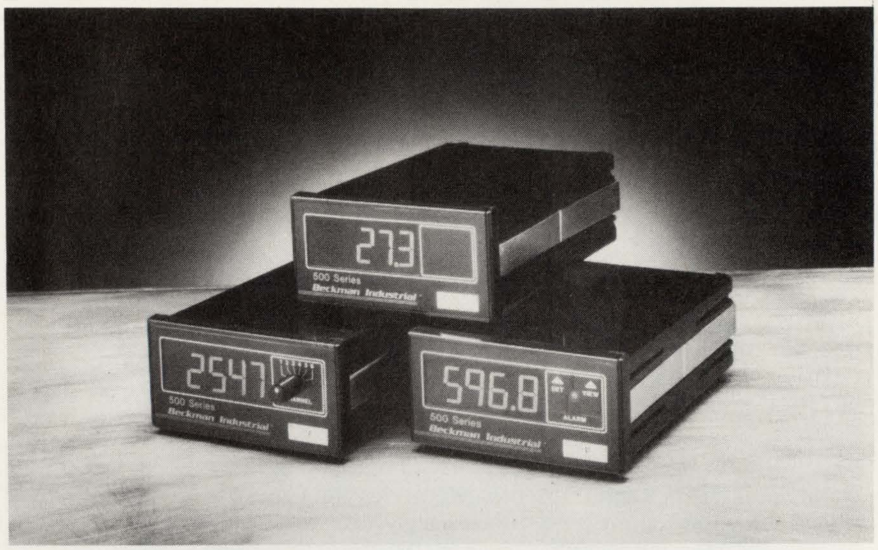
NEW PRODUCTS

COMPONENTS & POWER SUPPLIES

Temperature Indicator

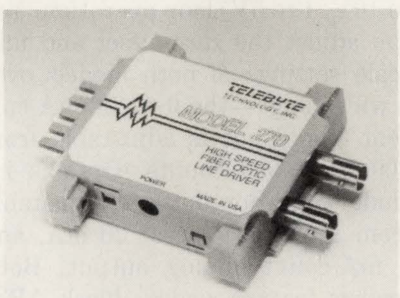
- *Handles nine sensor types*
- *Measures to 3325°F*

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.



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**



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.

Telebyte Technology Inc, 270 Pulaski Rd, Greenlawn, NY 11740. Phone (516) 423-3232. FAX (516) 385-8184. **Circle No. 409**

Photoelectric Controls

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

FE7D Series photoelectric controls are available in through-, polarized-retroreflective-, 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 45×45×20-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-retroreflective models; $112 for through-scan units.

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

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 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

Digital Meters

- *Have a 2.25-in.-high display*
- *Provide current or voltage outputs*

PI700/PI800 process and voltage indicators provide a 4-½ digit LED display which features 2.25-in.-high characters. The 700 and 800 devices are configured for current (0- to 20-mA, 4- to 20-mA,) and voltage (0 to 10V, 1 to 5V) loop operation. You can adjust the zero-offset and full-scale settings of both models over a wide range—the 0- to 20-mA current loop input is adjustable from 300 to 19,999 counts. Options include excitation outputs adjustable from 1.3 to 24V dc at 30 mA, and 1 mA/count analog output. Both models feature sealed, black ABS, surface-mountable cases and have a 2-year warranty. $595.

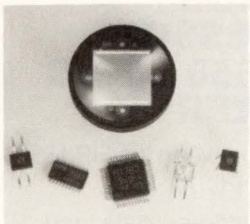
Electro-Numerics Inc, 1811 Reynolds St, Irvine, CA 92714. Phone (714) 250-1501. FAX (714) 250-0958. **Circle No. 412**

EMI Filter

- *Meets MIL-STD-461*
- *Attenuates 40 dB*

The FMB-461 filter reduces the reflected input ripple of more than 30 of the manufacturers' dc/dc converters, bringing them within the noise limits of MIL-STD-461B's CEO3 standard. The unit attenuates 40 dB

Position-Sensitive/ Ranging Components

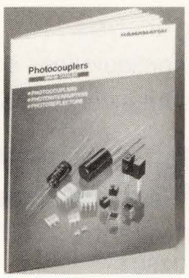


Hamamatsu offers a variety of auto-focus and position detectors especially designed for proximity switching, displacement sensing and optical distance measurements. They are smaller, faster, require less power and feature more stable performance than comparable types.

Applications include auto-focus cameras, computer disc drives, linear motion detection in industrial equipment, beverage dispensers, robotic controls and automated car wash equipment.

CIRCLE NO. 137

Hamamatsu Photocouplers

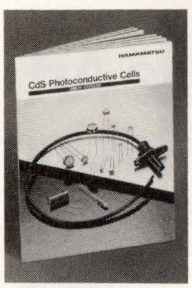


Don't miss our newest catalog. It covers the complete line of Hamamatsu photocouplers including CdS Cell, Photo IC and Phototransistor output types. Also included are photointerrupters and photoreflectors. Many can be used in surface-mount applications for non-mechanical position sensing and high voltage isolation of circuits.

Applications include color video signal interface for TV, high speed I/O computer interface, line receiver interface, electronic motor control and switching regulators.

CIRCLE NO. 138

Hamamatsu CdS Photoconductive Cells



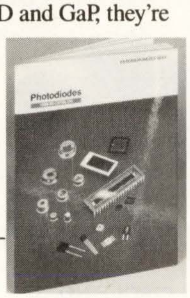
This catalog is a must for every electronics designer. Hamamatsu CdS cells are available in plastic-coated, metal-case and glass-bulb type assemblies for a wide variety of applications.

Applications include exposure meters, light dimmers, musical equipment, flame monitors, street light controls and many others.

CIRCLE NO. 139

Hamamatsu Photodiodes

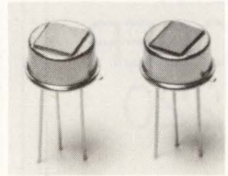
Did you know that Hamamatsu offers a complete line of photodiodes? From UV to IR, GaAsP, SI, PIN, APD and GaP, they're all here in our latest catalog. Send for it today.



Applications include high speed light sensors, CAT scanners, X-ray monitors, illuminance meters, light absorption meters, light-to-logarithmic voltage conversion circuits and more.

CIRCLE NO. 140

P2288 and P2613 Pyroelectric Detectors

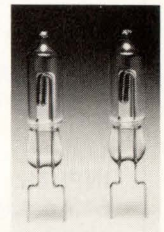


These competitively priced devices feature a large sensitive area and offer optimal spectral response in the near IR. Built-in impedance converting circuitry makes them easy to design into equipment.

Applications include intrusion and fire detectors, industrial robots and other electronic sensing devices.

CIRCLE NO. 141

Hamamatsu UVtron R2868 Flame Sensor



The UVtron flame sensor can detect the ultraviolet radiation of a match from distances greater than 15 feet. Quick detection, wide directivity and compact design make it easy to integrate the R2868 into your products.

Applications include flame detectors for industrial, automotive and petroleum plant environments; also in horse or livestock stables.

CIRCLE NO. 142

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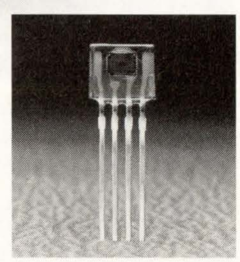

Hamamatsu's new S3599 Modulated Photo IC rejects background light up to 10,000 lux (5,000 minimum) without even squinting. That makes it ideal for component environments found in office equipment, industrial control equipment or anywhere photo switches are used.

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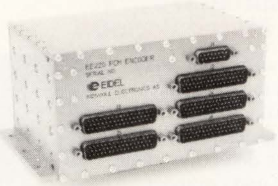

PCM ENCODER EE 220

INPUTS:
64 Analog inputs with individual selection of gain, single ended or differential, unipolar or bipolar. 56 Bit Digital Parallel and 17 Word Serial inputs. Selectable commutation rates for all inputs. Expandable to >30000 inputs. Support of Slave Encoders.

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Bit frequencies to 5 MHz from an internal synthesizer. Word length: 8-16 Bit. The maximum PCM Format size is 2048 Words per Frame and 256 Frames, total max. 32768 Words. Up to 8 totally different Formats in one PROM. Compatible to IRIG std. 106.

PROGRAMMING:
All Format structure and Signal select information are located in one user programmable PROM. The PROM contents are designed with the EIDEL software EE200 Format Generator running on a PC. The Encoder EEPROM is loaded through an RS 232 link.

EIDEL of America, Box 683, Midlothian, VA 23113, USA. Tel: 804 744 8186. Fax: 804 744 2961.

EIDEL

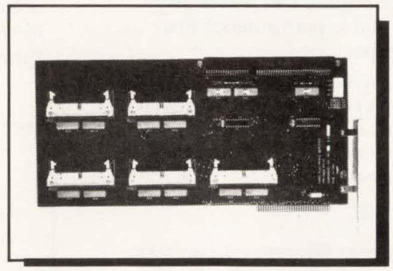
Eidsvoll Electronics AS
Box 38, N-2081 Eidsvoll, Norway
Tel: +47 6 964230. Fax: +47 6 962048

CIRCLE NO. 34

NEW PRODUCT

PC/AT BUS PRE-PROCESSOR FOR THE HP1650 LOGIC ANALYZER

- Provides a complete interface between the HP 1650 Series Logic Analyzer and the PC/AT BUS.
- Quick and easy access to all address, data, and control lines.



- State and timing analysis.
- Logic analyzer configurations supplied on diskette.
- Can be used as an extender card.

TASCO

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CIRCLE NO. 35

Robotics, Industrial Drives, Railways, U.P.S., Welding Machines COUNT on LEM MODULES

Non-contact Current Sensors

Like an insulated shunt. A perfect feed back system between power current and electronic control.

- Accuracy, stability and linearity guaranteed for life
- Response time better than 1 μs. Bandwidth DC to 100 kHz.
- Reliable in hostile environments MTBF 2 x 10^6 hours.
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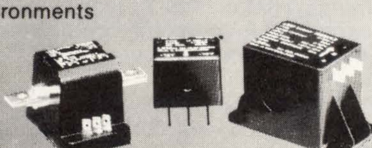

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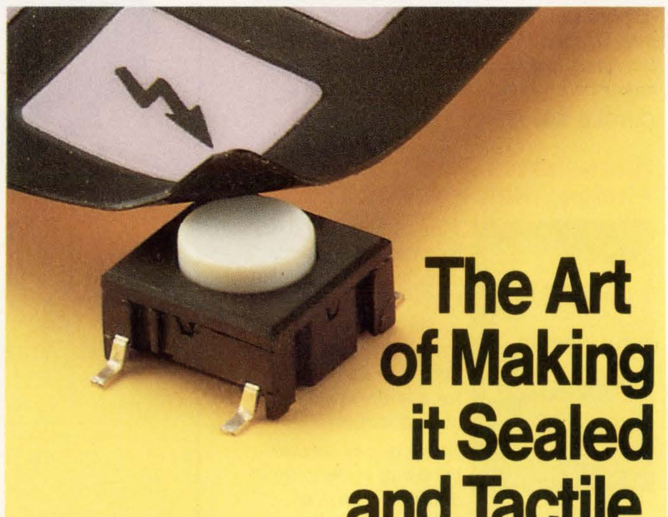
CIRCLE NO. 36



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ELECTRONICA – Hall 16, Stand F 34

CIRCLE NO. 37

of reflected input-ripple current over the 100-kHz to 50-MHz range. It can handle dc/dc converters with as much as 70 watts of output power over a 16 to 40V range. The 5A filter can be used with one 70W converter or can filter several lower-power units. A thick-film hybrid device, the filter is housed in a 1.1×2.1×0.5-in. sealed metal case and comes with an optional flange mounting for high shock and vibration applications. The part operates from −55 to +105°C. Full environmental screening is an option. From $148 (100).

Interpoint Corp, Box 97005, Redmond, WA 98073. Phone (206) 882-3100. FAX (206) 882-1990.

Circle No. 413

Intelligent Display

- *Provides multilanguage character possibilities*
- *Has a 160-nsec access time*

The PDSP211X 8-digit LED display has a 256-character ROM which contains characters for Spanish, German, French, Italian, and Scandinavian languages plus Japanese Katakana characters. The unit also displays numbers and scientific symbols. The displays are available in red, yellow, green, high-efficiency green, and high-efficiency red. You can stack the units end to end with no gaps between the characters of adjacent displays. Access and clear times equal 160 nsec and 2 μsec, respectively. The units are readable from 8 ft and have a ±55° viewing angle. The displays are designed to interface with μPs and are fully TTL compatible. A built-in lamp test provides a positive indication of proper LED functioning. Housed in a 28-pin plastic DIP, the units operate over a −40 to +85°C range. $21.50 to $25 (10,000), depending on color.

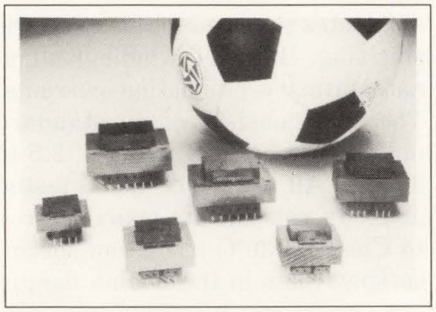
Siemens Components Inc, 19000 Homestead Rd, Cupertino, CA 95014. Phone (408) 247-3526.

Circle No. 414

Split-Bobbin Transformers

- *Meet UL standards*
- *Eliminate the need for electrostatic shielding*

RL-2250 Series split-bobbin transformers meet UL, CSA, VDE, and IEC specifications. The units use a nonconcentric dual bobbin which reduces interwinding capacitance and eliminates the need for electrostatic shielding. Balanced windings eliminate primary circulating currents. The line consists of 40 standard units which cover a range of 2.5 to 56V/A. All units are hipot tested at 4000V rms and are manufactured to Class B 130°C insulation specifications. Slots in the bobbin flanges



eliminate lead crossovers, which eliminate the need for insulating pads when mounting the units to a pc board. From $2.25 (1000). Delivery, stock to eight weeks.

Renco Electronics Inc, 60 Jefryn Blvd E, Deer Park, NY 11729. Phone (516) 586-5566. FAX (516) 586-5562. **Circle No. 415**

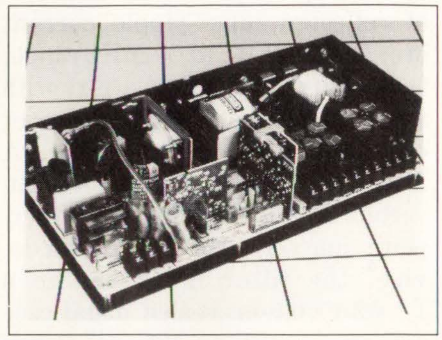
DC/DC Converters

- *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



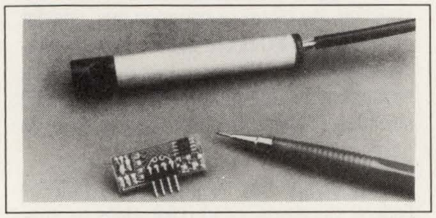
Open Frame Supply

- *Offers five outputs*
- *Outputs 200W*

The SA200 switching power supply offers five outputs in a 200W package; outputs range from 5 to 24V. The main output develops 5V at 100A and has 2% line and load regulation. You can select 12 or 15V for outputs 2, 3, and 4 and −12 or −5V for output 5. You can internally connect outputs 3 and 4 in series to develop a 24V output. Standard features include a built-in EMI filter,

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**

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.

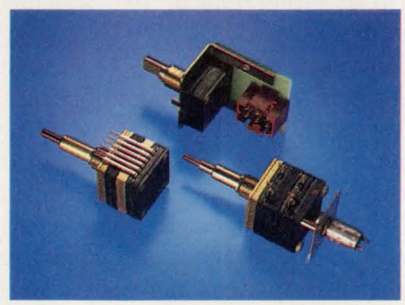
The SG Series KL keylocks are priced at $10.00 in lots of 250 pieces, with delivery in 8 to 10 weeks. Standard Grigsby, Inc., (708) 556-4200.

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. Terminations 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.

Prototype kits are available. Contact factory for specific design, pricing and delivery information. Standard Grigsby, Inc., Aero Park, 88 N. Dugan Rd., Sugar Grove, IL 60554-0890. 708/556-4200 FAX 708/556-4216.



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

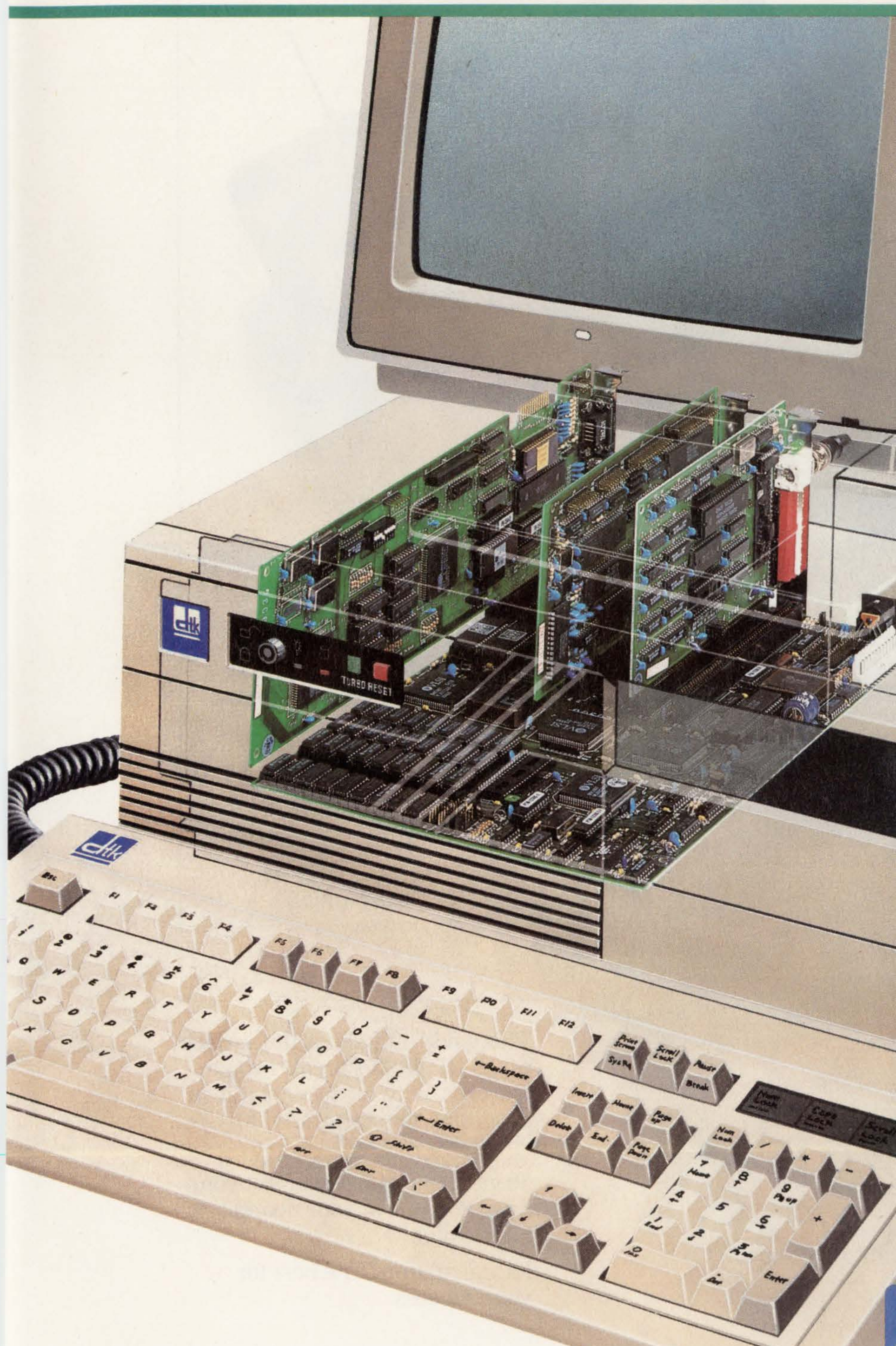
Insert molded contacts ensure proper registration and precise performance. Gold contact inlays are optional. External terminals are solder plated (except on die cut edges).

Enclosed, high temp.-resistant design makes the switch ideal for wave soldering. Electron-welded PC terminations permit easy PC board insertion. Dual and triple shafts are available to match the application. Applications: mobile radio, avionics, machine control, agriculture, military, office products, and more.

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

CIRCLE NO. 147

We've got the guts, you get the glory.



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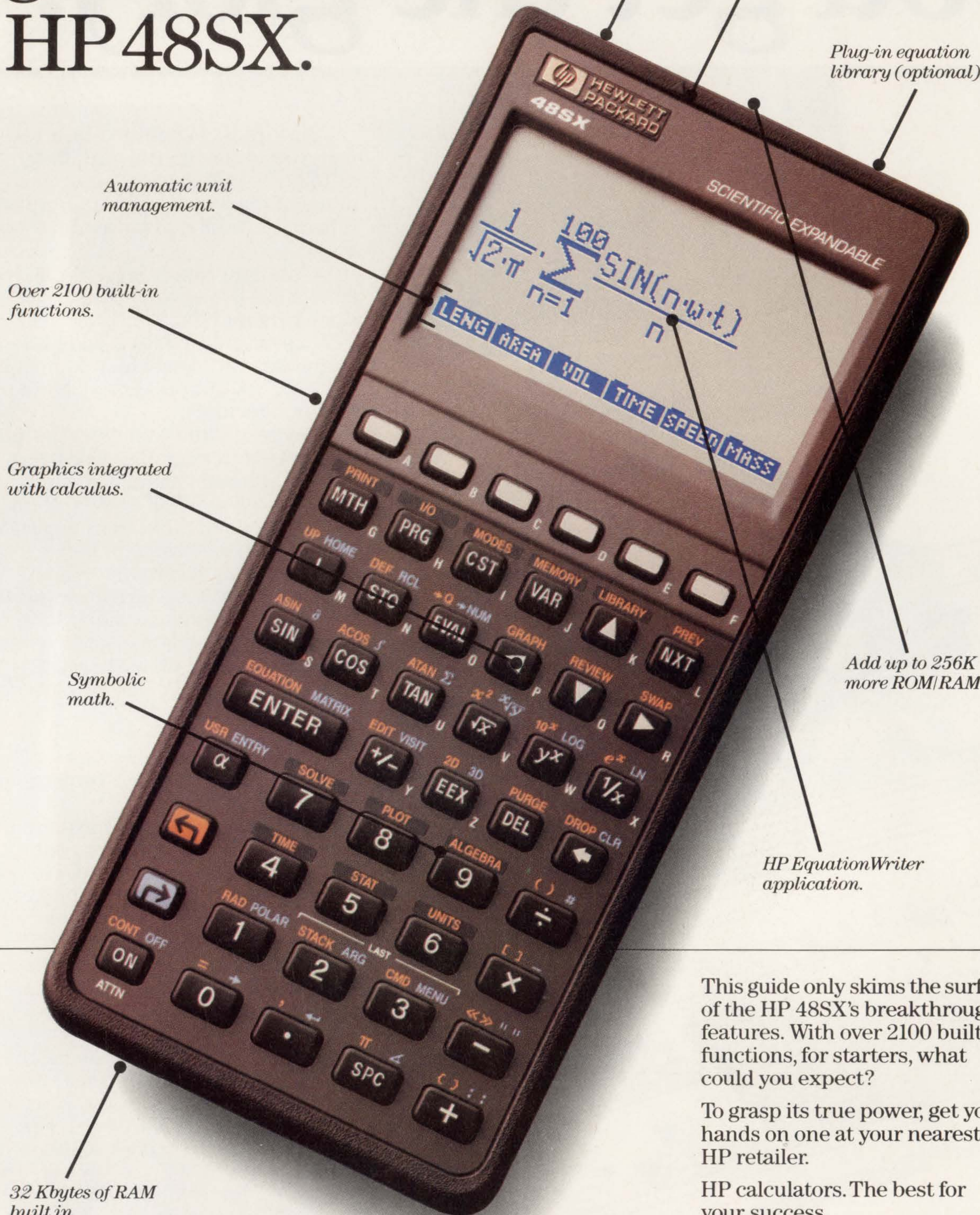
Tel: (818) 333-7533
Fax: (818) 333-5429
Ask for OEM sales.

Clearly superior.

The power-user's guide to the new HP 48SX.



This guide only skims the surface of the HP 48SX's breakthrough features. With over 2100 built-in functions, for starters, what could you expect?

To grasp its true power, get your hands on one at your nearest HP retailer.

HP calculators. The best for your success.

HEWLETT PACKARD

Simulated screen.

CIRCLE NO. 148

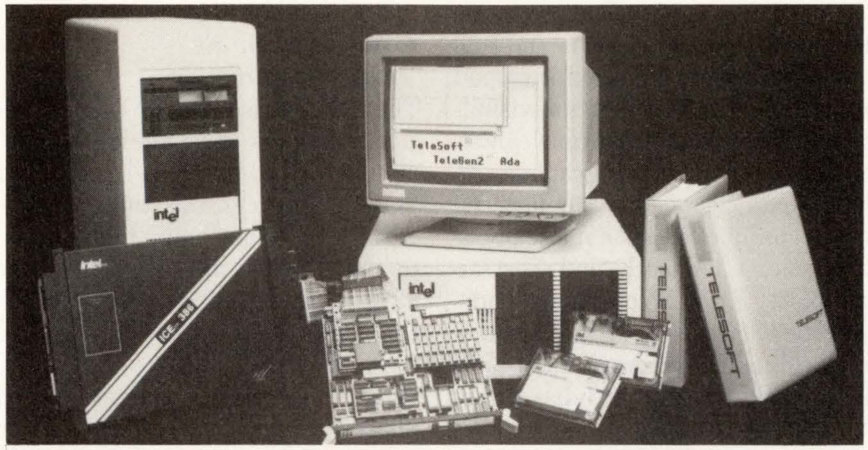
NEW PRODUCTS

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, 5959 Cornerstone Ct W, San Diego, CA 92121. Phone (619) 457-2700. FAX (619) 452-1334. **Circle No. 420**

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 IDT-7RS355 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. 421**

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 extenders 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 5¼-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

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**

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

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.

Hughes Computer Services, 2401 NE Cornell Rd, Suite 155, Hillsboro, OR 97124. Phone (503) 648-7150. **Circle No. 429**

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CIRCLE NO. 222

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3	LOGIC SIMULATION.....165-STATE
4	PARTS LIBRARY........VHDL
5	DESIGN SIZE...........200K+ GATES 1MB = 20K GATES

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CIRCLE NO. 223

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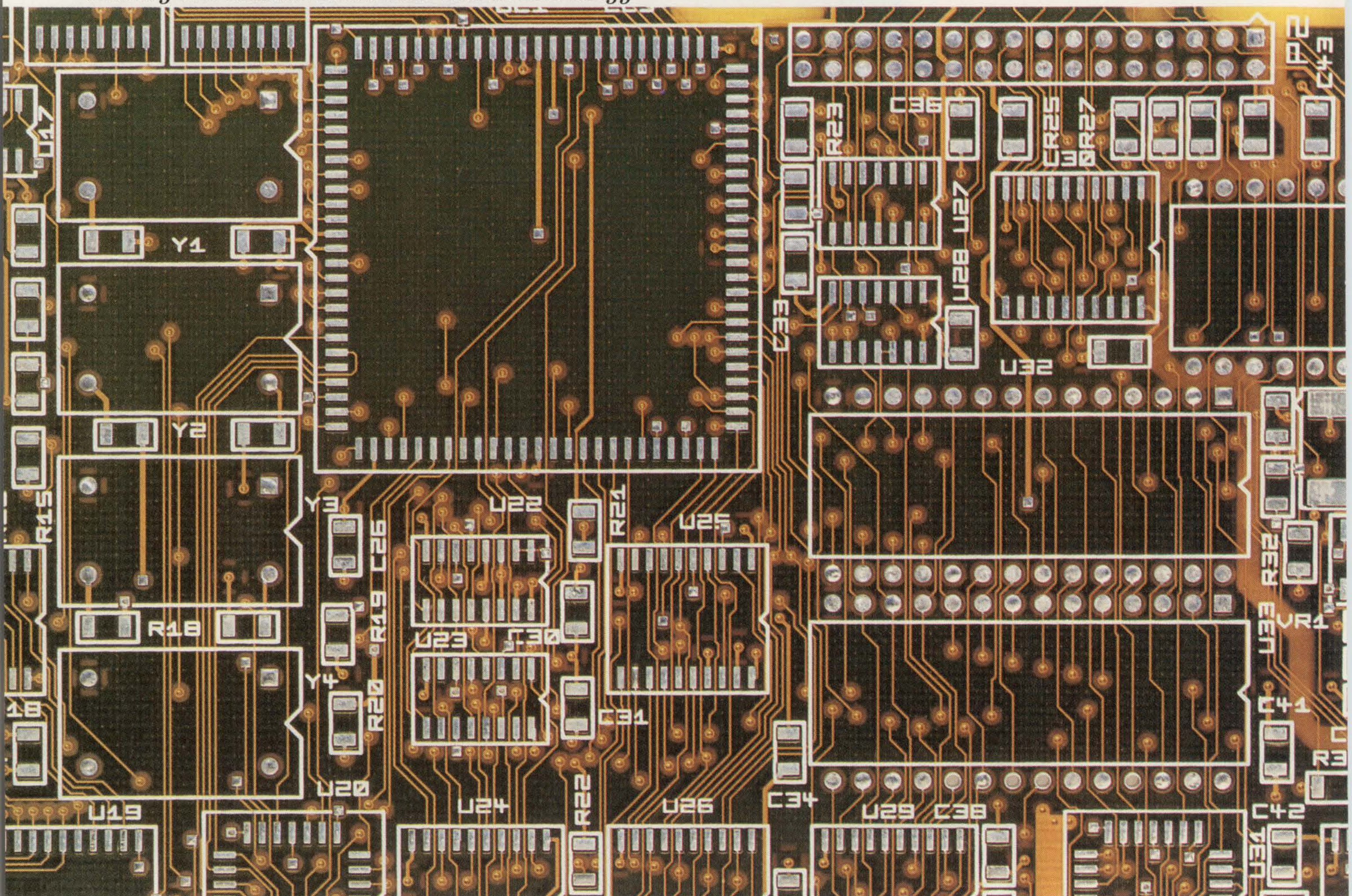

Printed circuit board provided courtesy of Western Digital Corporation.

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No one offers a wider range of proven, quality photoimageable solder mask products than Du Pont. More importantly, no one knows more about how solder mask technology can affect your design, fabrication or assembly process.

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COMPUTERS & PERIPHERALS

VGA Video-Matrix Switch

- *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 8.5×11.5×12 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 8×2.7×5 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 company's Officepower 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 Inc, Box 19593, Irvine, CA 92713. Phone (714) 458-7282. FAX (714) 458-6257. **Circle No. 431**

EISA Prototyping Board

- *Uses universal pattern on 0.1-in. grid of pads*
- *Operates from ±5V to ±12V*

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 ±5V to ±12V, 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**

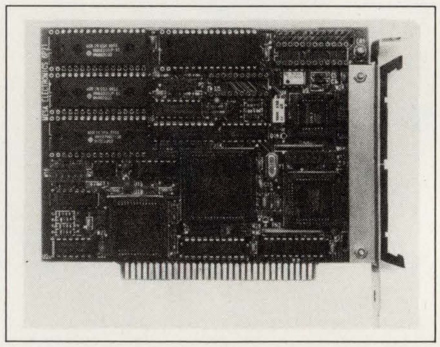
80386 Portable Computer

- *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 640×480 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, 5¼-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 800×600 color VGA monitor. The computer has two full-sized expansion slots and measures 16×9×7.5 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 4.2×5.5-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,

CIRCLE NO. 55

CIRCLE NO. 56

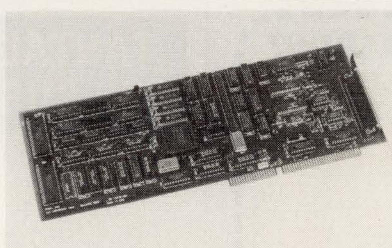
it runs on code compiled for standard languages. Local memory and I/O resources include 8k to 512k bytes of RAM, an RS-232C port, 24 digital I/O lines, six 16-bit timer counters, a 4-channel 8-bit A/D converter sampling at 400 kHz, and two 8-bit analog-output channels. $335.

Mesa Electronics, 1329-D 61st St, Emeryville, CA 94608. Phone (415) 547-0837. FAX (415) 547-4738.
Circle No. 435

DSP Board

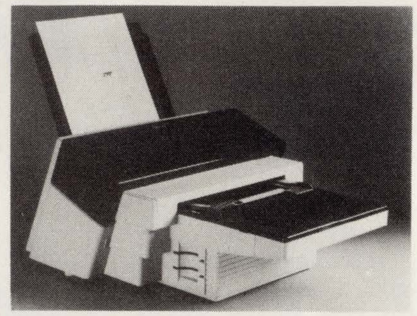
- *Utilizes 40-MHz TMS320C25 DSP chip for ISA bus*
- *ADC samples eight channels at 300 KHz with 12-bit resolution*

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 × 300 dpi for paper sizes to 11 × 17 in.*
- *Has 64 ink-jet nozzles and prints at 2 pages/minute in draft mode*

The EPI-4000 ink-jet printer provides 300 × 300-dpi resolution on paper sizes as large as 11 × 17 in. The printer utilizes 64 ink-jet nozzles arranged in a 16 × 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

1985
TLC549
8 Bit A/D
Introduction of LinCMOS Technology

1986
TLC1540
10 Bit A/D
12 Channel LinCMOS Technology

1987
TLC7524 (AD7524)
1st D/A Converter
Introduction of Advanced LinCMOS Technology

1987
TLC7528 (AD7528)
1st 8-bit D/A Dual Channel
Advanced LinCMOS Technology

1988
TLC10 (MF10)
1st Dual-switched Capacitor With Filter
Advanced LinCMOS Technology

1989
TLC32044
1st 14 Bit A/D, D/A And Filter On Same Chip
Advanced LinCMOS Technology

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CIRCLE NO. 226

16-Bit Resolution, 3 Channels plus Noise, and a Whole Lot More.

That's Pragmatic!

16-bit resolution at 2MHz: 65,536 points of vertical resolution. 65,536 memory locations per channel.

Easy to use: the keypad and rotary knobs provide an easy method of entering numerical parameters.

Three phase-coherent channels that operate independently, or can be linked to form a single channel of 196,608 memory locations, or summed with other channels or noise to produce composite waveforms.

Easy to use: the backlit LCD screen is menu driven, providing two 40-character lines that report instrument status.

Built-in pseudo-random-sequence noise generator provides an independent source which can be summed to channel one.

Easy to use: the front panel design is arranged in logical functional groups.

Easy to use: the mouse creates ARB waveforms graphically on a monitor scope.

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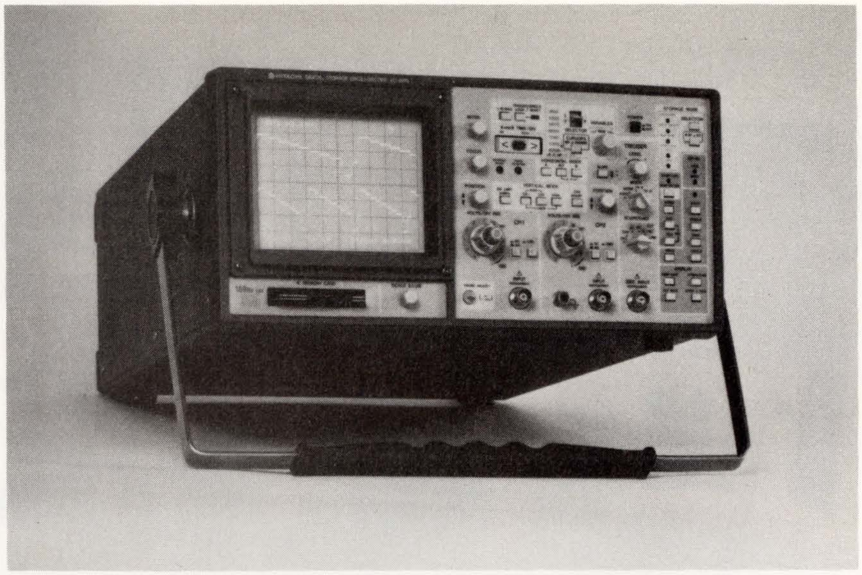
100-MHz-Bandwidth Digital/Analog Scopes

- *Have 100-MHz bandwidth as DSO for repetitive signals*
- *Have 25-MHz single-shot bandwidth*



The 6x65 and 6x75 families of 2-channel digital/analog oscilloscopes each include three members. Of these, all have an analog bandwidth of 100 MHz and, as DSOs, resolve 8 bits and store records 4k bytes long. All units have a single ADC. The fastest units take 200M samples/sec. The 100-MHz bandwidth is obtainable when you use the scopes as conventional analog units or when you sample repetitive waveforms in DSO mode. When capturing transients in real time in the DSO mode, the units that take 100M and 200M samples/sec have 25-MHz bandwidth; those that take 50M samples/sec have a 12.5-MHz bandwidth. Units in the 6x75 series can read and write data on credit-card-sized RAM modules. Each module stores 15 waveforms. The connector that accommodates the RAM modules also lets you connect the scopes to a personal computer equipped with an appropriate interface. $3995 to $4495.

Hitachi Denshi America Ltd, 150 Crossways Park Dr, Woodbury, NY 11797. Phone (516) 921-7200.

Circle No. 438

10M-Sample/Sec Transient Recorder

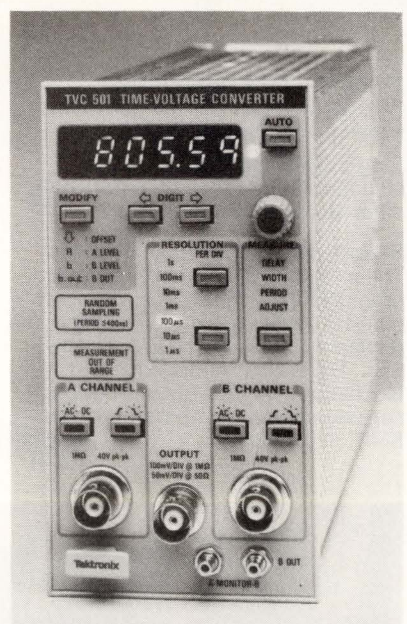
- *Includes eight flash ADCs*
- *Has 32k bytes of battery-backed RAM for each channel*

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 ±½ of full scale, and you can connect the input for an impedance of either 50Ω or 2.5 kΩ. $4900.

DSP Technology Inc, 48500 Kato Rd, Fremont, CA 94538. Phone (415) 657-7555. FAX (415) 657-7576. **Circle No. 439**

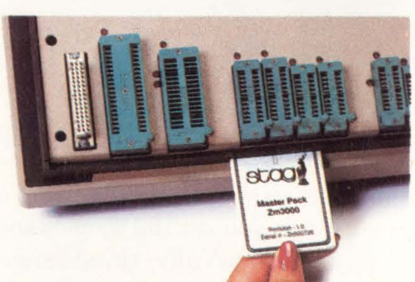
Time-To-Voltage Converter

- *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

System 3000
stag System 3000 Universal Programmer
stag Z-Module
Zm 3000
LOAD
I/O
TEST
PROG
RESET
ENTER



stag
Master Pack
Zm3000

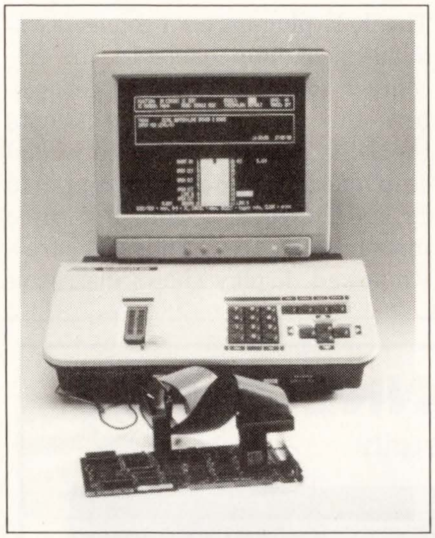
observe small variations in large time intervals, the module lets you enter offsets as large as 30,000 div. $2500; required TM 500 mainframe, from $395.

Tektronix Inc, Box 19638, Portland, OR 97219. Phone (800) 426-2200. **Circle No. 440**

Static In-Circuit Tester For Digital PC Boards

- *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

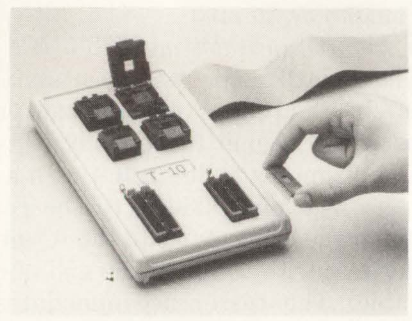
ICE And Development Tool For AT&T DSP16A

- *Plugs into IBM PC/AT bus*
- *Accepts plug-on Codec board*

The Right Tool consists of an IBM

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**



Universal Device Programmer Series

- *Identifies IC vendor and part number automatically*
- *Has programmable pin driver on every pin*

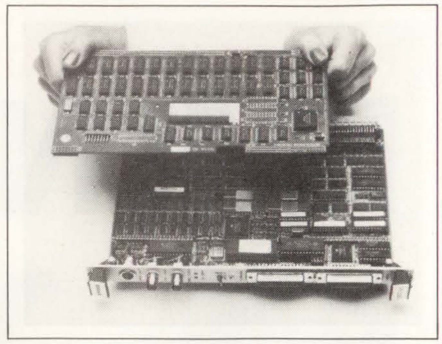
The T-10 series of universal device programmers handles EPROMs, EEPROMs, bipolar PROMs, and PLDs. You use the programmer with an MS-DOS-based PC; the attachment is via an I/O card that plugs into a half-length slot. The programmer can detect the vendor and type of the device to be programmed. It automatically chooses the fastest algorithm for programming the part. Each pin has its own pin driver circuit, and the vendor supports new devices by distributing disks containing updates to the device library. The $9.8 \times 5.6 \times 1.2$-in. unit weighs less than 2 lb. Equipped to program DIP-packaged devices, $999; devices in DIPs, and in LCC and surface-mount packages, $1599.

Sunrise Electronics Inc, 524 S Vermont Ave, Glendora, CA 91740. Phone (818) 914-1926. FAX (818) 914-1583. **Circle No. 444**

VMEbus Timing Analyzer

- *Performs timing analysis on 103 channels at 100 MHz*
- *Supports VME and VME64 buses*

The TIM100 103-channel, 100-MHz timing analyzer plugs onto the vendor's VBT-321 VMEbus analyzer. The bus analyzer is a module that plugs into the VMEbus and, using an RS-232C ASCII terminal as a display device, performs state analysis on 95 channels. The timing analyzer's memory can store 16k frames of data. In each frame, 99 of 103 bits are VME signals. To display the timing diagrams generated by the timing analyzer, you must use a terminal that has at least minimal graphics capabilities—for example, a VT100 or a personal computer emulating a VT100. $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

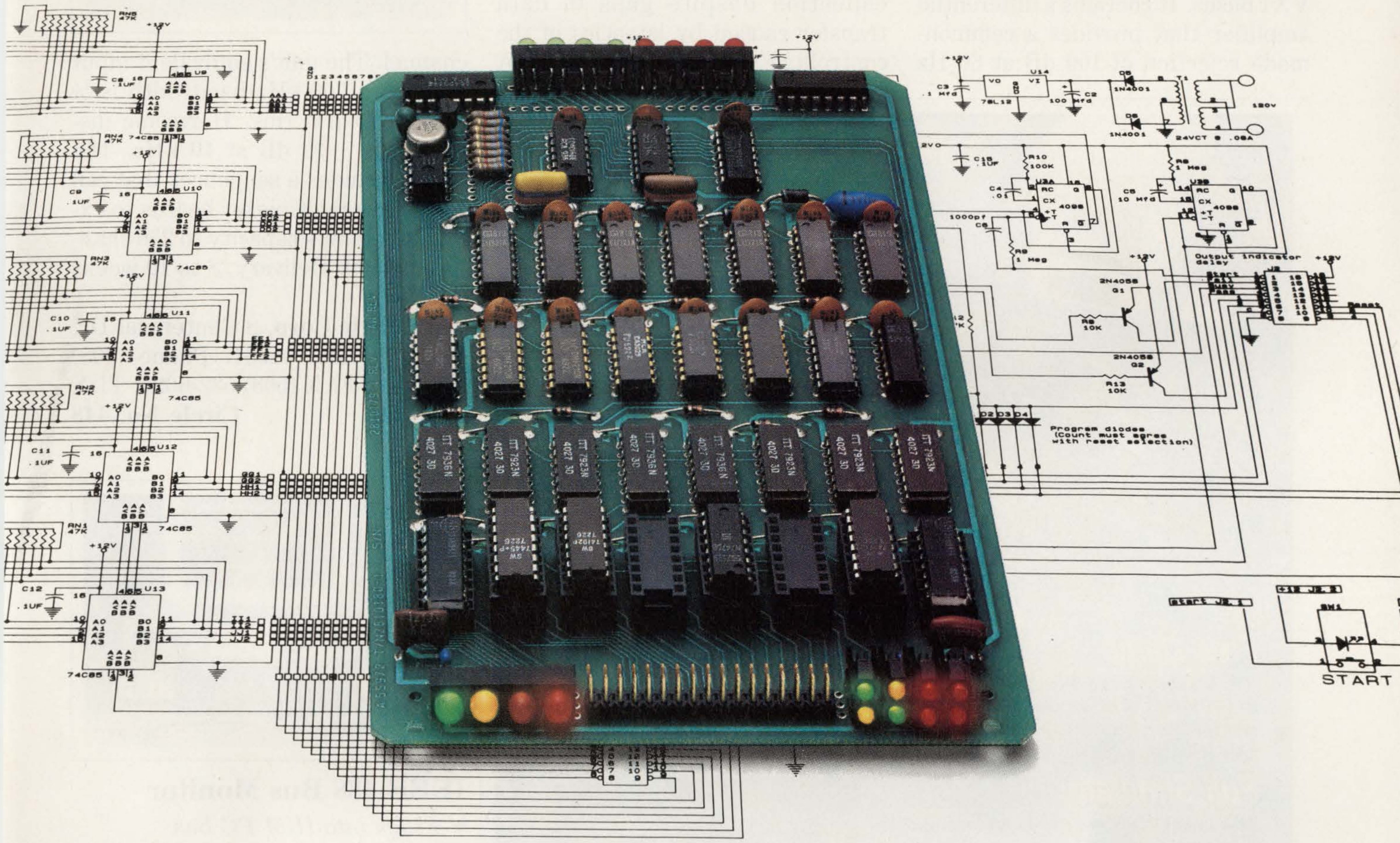
Self-Calibrating D/A Card For Macintosh II

- *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

IDI Packaged LEDs bring your design to light.



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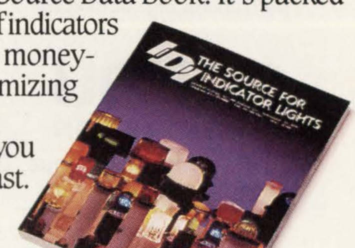

IDI

Industrial Devices, Inc. 260 Railroad Avenue, Hackensack, NJ 07601 (201) 489-8989 (201) 489-6911 (FAX)

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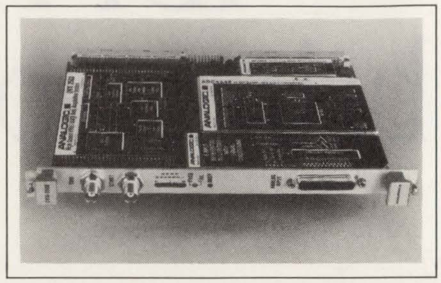
CIRCLE NO. 230

VME/VXIbus Data-Acquisition Module

- *Makes 400,000 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 ½ LSB ±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.

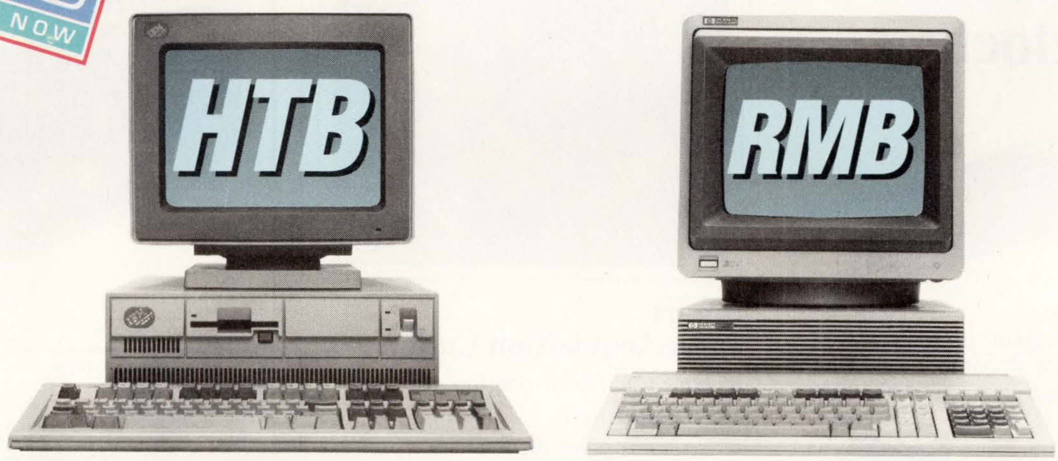
Analogic Corp, 8 Centennial Dr, Peabody, MA 01961. Phone (508) 977-3000. FAX (508) 532-6097. TLX 6817144. **Circle No. 448**

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

All the features of HP BASIC, and more. For less.



HTBasic	BASIC FEATURES:	HP BASIC
YES	IEEE-488 GPIB (HP-IB), RS-232 Instrument Control	YES
YES	Integrated Environment: Mouse, Editor, Debugger, Calculator	YES
YES	Supports 16 Megabytes of Memory (breaks DOS 640K barrier)	YES
YES	Engineering Math: Matrix Math, Complex Numbers	YES
YES	High Level Graphics: Screen, Plotter, Printer	YES
YES	Structured Programming with Independent Subprograms	YES
YES	Runs on Industry Standard Personal Computers	NO*
YES	Industry Standard Graphic Printer Support: Epson, IBM, lasers, etc.	NO
YES	Industry Standard Network Support: Novell, IBM, Microsoft, NFS, etc.	NO
YES	Industry Standard IEEE-488 Support: National Instruments, IOtech, etc.	NO
YES	Exchange data files with Industry Standard PC applications	NO*
YES	No-charge Telephone Technical Support	NO
YES	Instant on-line HELP system	NO

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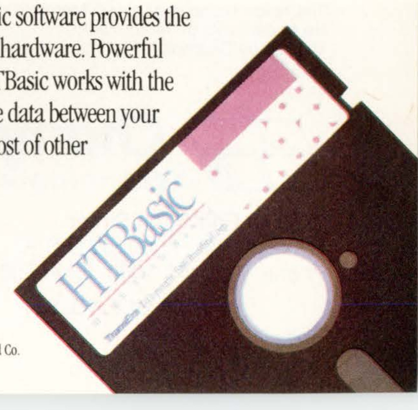
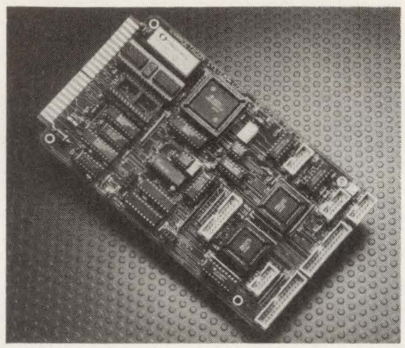


CIRCLE NO. 231

can also operate in the background while the PC performs foreground tasks unrelated to instrument control. A 512k-byte FIFO memory prevents data loss. $995.

National Instruments Corp, 6504 Bridge Point Pkwy, Austin, TX 78730. Phone (800) 433-3488. FAX (512) 794-8411.

Circle No. 449



Smart Data-Acquisition Card

- *Has ten 12-bit analog I/O channels*
- *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 CamBasic, 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.

Octagon Systems Corp, 6510 W 91st Ave, Westminster, CO 80030. Phone (303) 430-1500. FAX (303) 426-8126. **Circle No. 450**

 CIRCLE NO. 149

UXART

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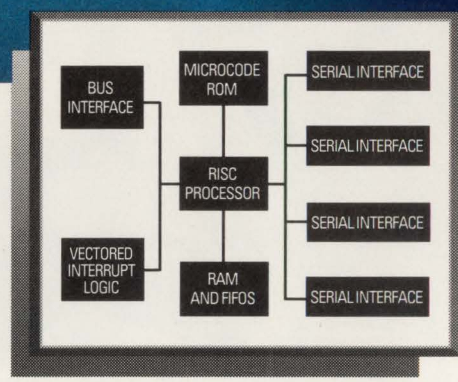

An on-chip 10 MIPS RISC-based processor handles transmit and receive functions, buffer management, flow control, and all special character processing. 84-pin FIFOs reduce host interrupts to give you more efficient interrupt handling. The result: faster system throughput, lower host overhead, and less waiting.

For years, dumb UARTs have been the standard datacom solution. Now there's something better for today's multi-user, multi-protocol datacom environment. Our single-chip solution gives you multiple channels, and replaces up to 10 chips – with higher performance levels.

Cirrus Logic introduces the UXART- the first and only UART with specific features to simplify and speed up serial I/O efficiency by a factor of ten or more. So your UNIX® system can support more users, with better response time — and less waiting.

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For high line count, cost-effective applications, there's the CL-CD180. It offers performance gains similar to the CL-CD1400, plus the advantage of 8 channels in a single 84-pin package.

The CL-CD2400 adds synchronous capability. It offers 4 independent, multi-protocol channels, plus an on-chip DMA controller for fast, efficient I/O.

For all your multi-protocol, multi-user datacom needs, the Cirrus Logic family of intelligent, high-performance data communications controllers gives you superior throughput in less space — with less waiting.

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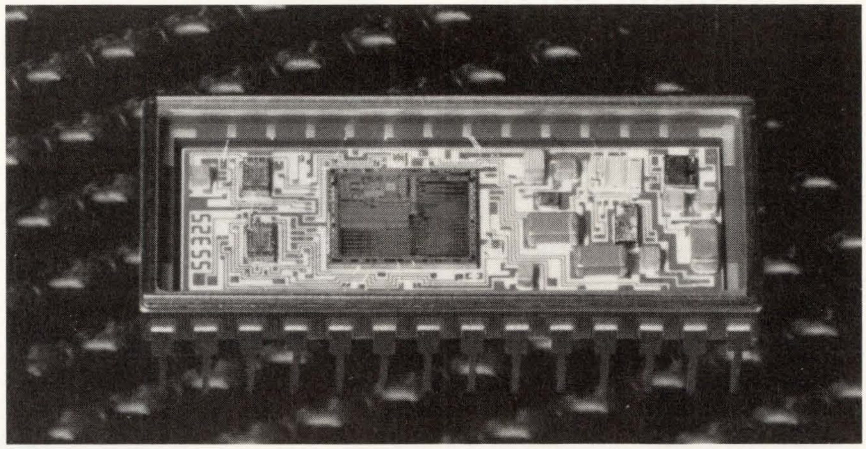
- *Self calibrating*
- *Digitizes at a 50-kHz rate*

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). Delivery, 8 to 12 weeks ARO.



Micro Networks, 324 Clark St, Worcester, MA 01606. Phone (508) 852-5400. FAX (508) 853-8296.

Circle No. 402

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).

Plessey Semiconductors Corp, 1500 Green Hills Rd, Scotts Valley, CA 95066. Phone (408) 438-2900. FAX (408) 438-7023.

Circle No. 403

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).

Philips Components-Signetics Co, Box 3409, Sunnyvale, CA 94088. Phone (408) 991-2000.

Circle No. 404

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. In standby mode, the ROMs draw only 100 μA. Package options include 28-, 32-, and 40-pin DIPs; 32- and 44-lead PLCCs; and 44-lead quad flatpacks. In plastic DIPs, $8.10 (5000).

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

Low-Power CMOS Comparators

- *Replace bipolar devices*
- *Offer faster response times*

Designed to replace traditional bipolar parts such as the LM393 and LM339, the pin-compatible TS372 (dual) and TS374 (quad) comparators offer reduced power consumption and faster response times. Typically, the TS374 quad comparator has an input bias current of 1 pA, compared with 25,000 pA for the LM339. The per-comparator supply current is reduced from 200 μA to 135 μA. Measured with the standard 100-mV input step with 5-mV overdrive, the TS374's typical response time is 600 nsec, compared with 1300 nsec for the bipolar device. The comparators are available in commercial, industrial, and military temperature ranges. The TS372 and TS374, from $0.61 and $0.76 (1000), respectively.

SGS-Thomson Microelectronics, 1000 E Bell Rd, Phoenix, AZ 85022. Phone (602) 867-6200.

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Series	Input	Output	IF (mA)	CTR (%)	V_{CEO}	Package
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2705	AC	Transistor	80	50 to 300	40	4-pin SOP
Dial-pulse generation circuits						
2532	DC	Darlington Transistor	80	1500 to 6500	300	4-pin DIP/SMD
2533	DC	Darlington Transistor	80	1500 to 6500	350	4-pin DIP/SMD
263X	DC	Darlington Transistor	80	1000 to 15000	300	6-pin DIP/SMD
Line supervisory circuits						
262X	DC/AC	Transistor	150	20 to 50	80	6-pin DIP/SMD

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UK Tel:0908-691133. Telex:826791. Ireland Tel:1-6794200. Telex:90847. Hong Kong Tel:755-9008. Telex:54561. Taiwan Tel:02-719-2377. Telex:22372.
Korea Tel:02-551-0450. Fax:02-551-0451. Singapore Tel:4819881. Telex:39726. Australia Tel:03-267-6355. Telex:38343.

NEC

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.

INQUIRE DIRECT

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.

Dynalab Inc, 555 Lancaster Ave, Reynoldsburg, OH 43068.

Circle No. 398

Aid To Designing Customer-Specific Products

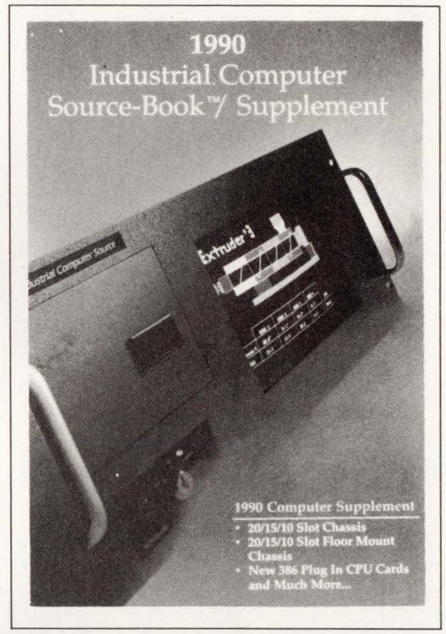
When you're called upon to computerize data-acquisition systems, *Computer-Based Data Acquisition Systems: Design Techniques* can help guide you through the design process. The volume contains analytical techniques for creating a functional design. Included in this second edition are sections on measurement 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.

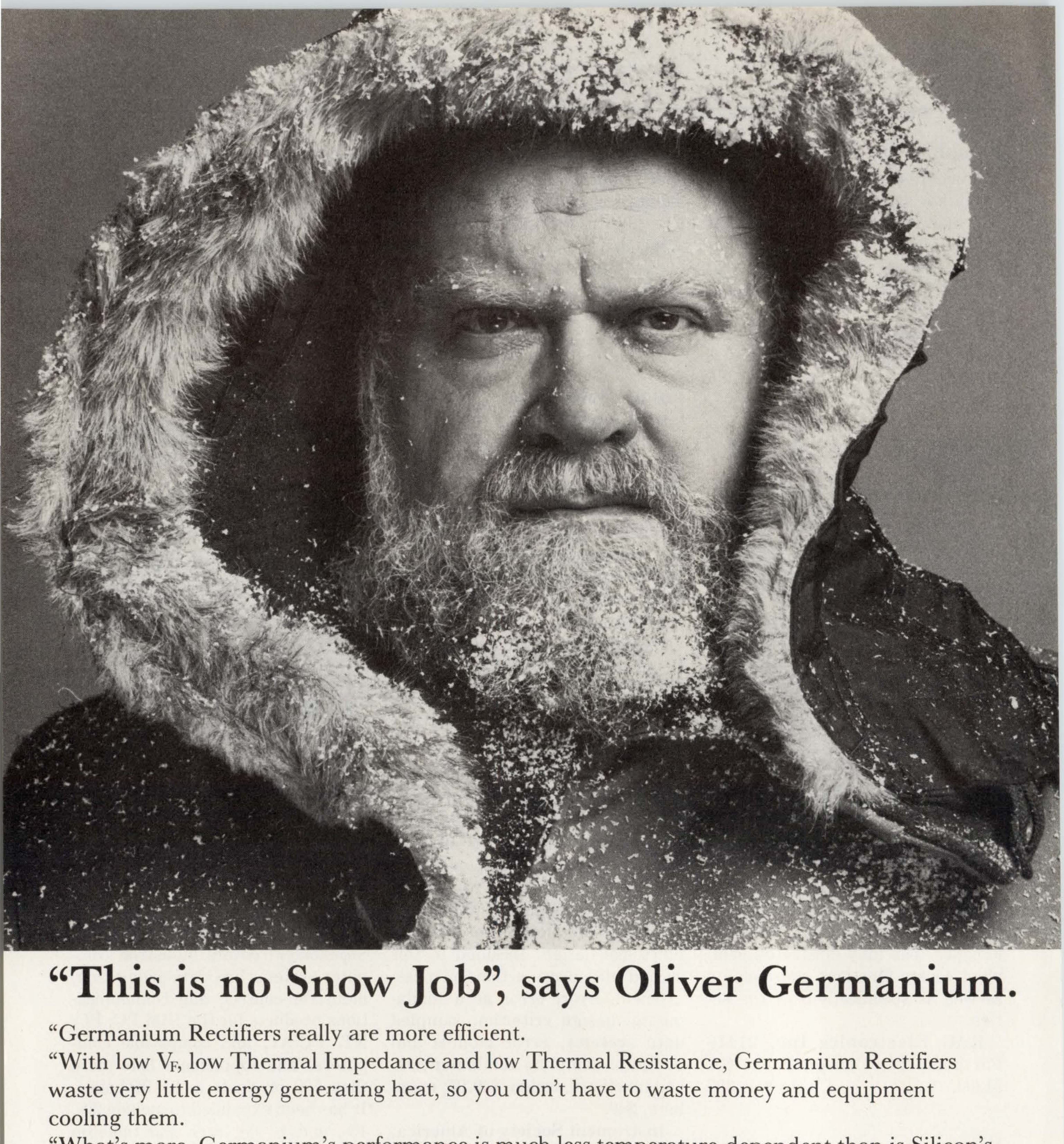
Wavetek RF Products Inc, 5808 Churchman Bypass, Indianapolis, IN 46203. **Circle No. 400**



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.

Industrial Computer Source, 4837 Mercury St, San Diego, CA 92111. **Circle No. 401**



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CIRCLE NO. 151

BOOK REVIEW

It's back, and it's better than ever

High-Performance Computer Architecture, 2nd Ed, by Harold S Stone. 459 pgs; $53.25. Addison-Wesley, Reading, MA, 1990.

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 Thiébaut in "On the Fractal Dimension of Computer Programs and its Application to the Prediction of the Cache Miss Ratio." In Thiébaut'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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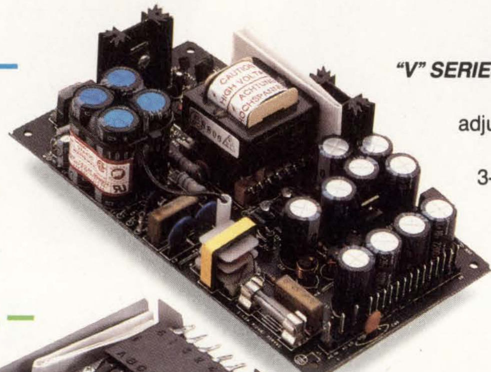

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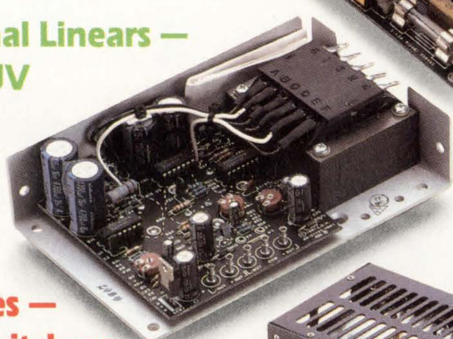

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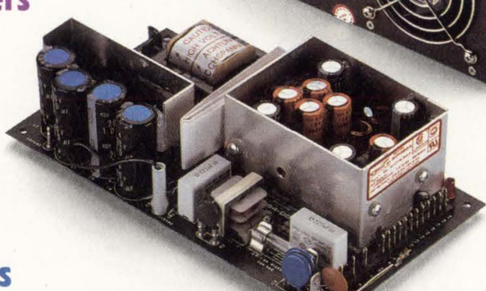

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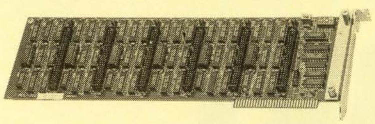

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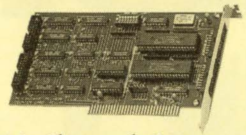

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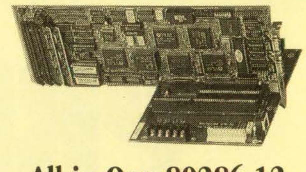

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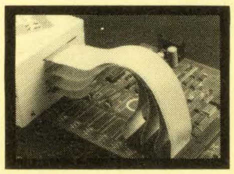

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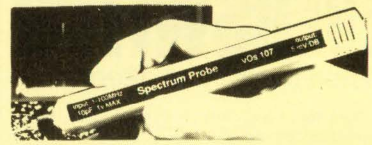

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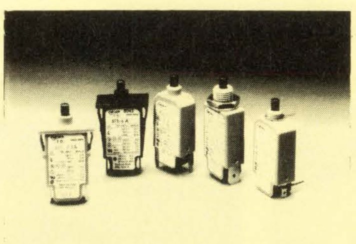

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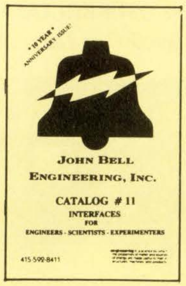

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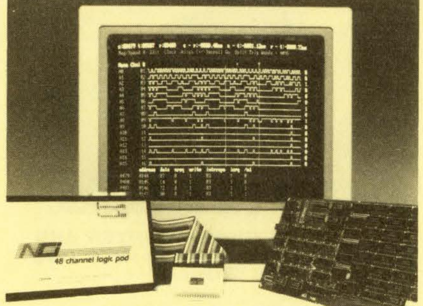

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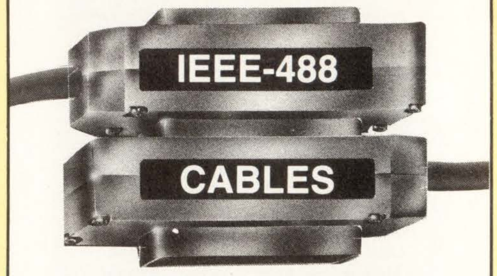

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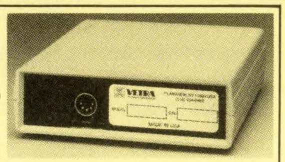

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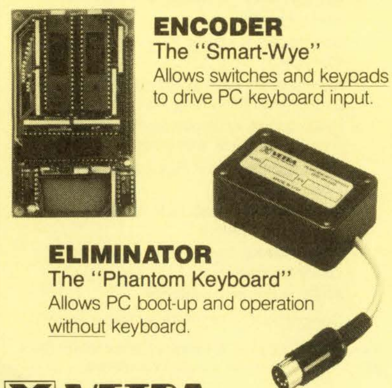

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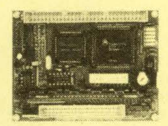

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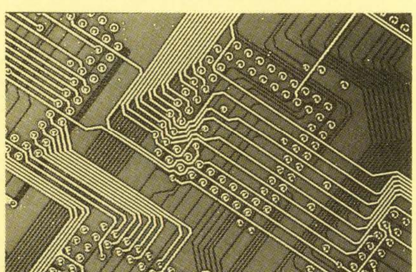

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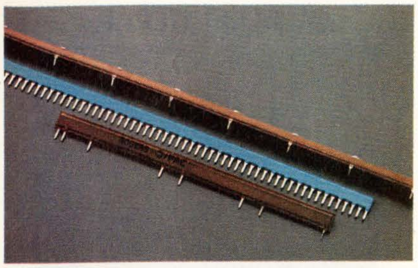

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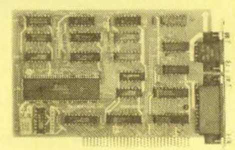

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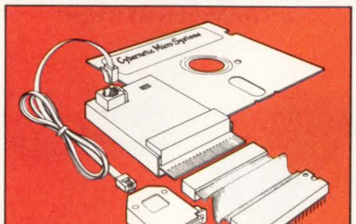

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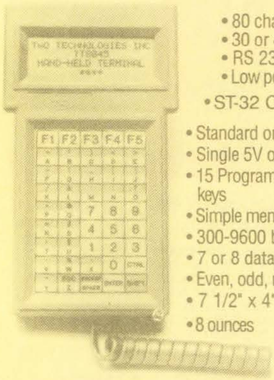

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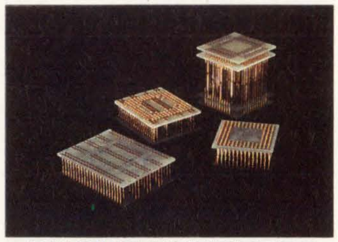

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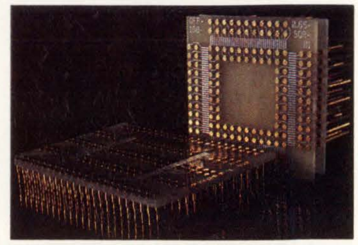

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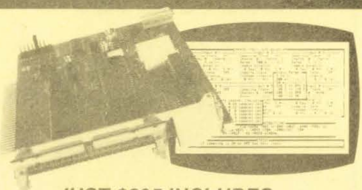

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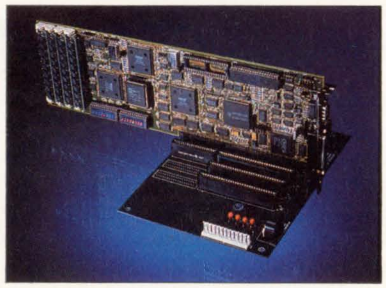

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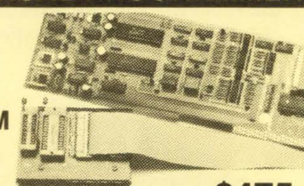

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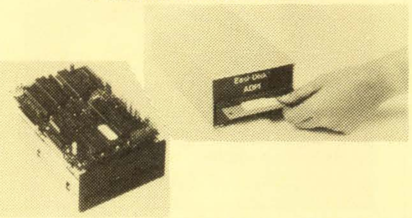

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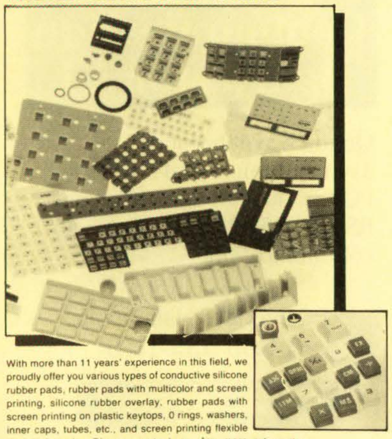

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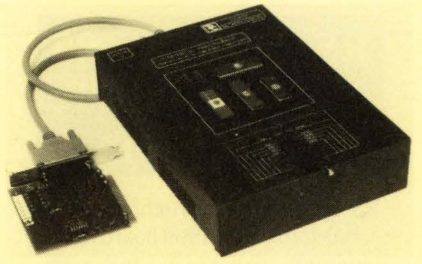

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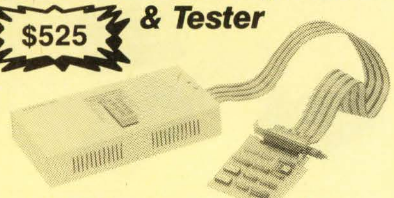

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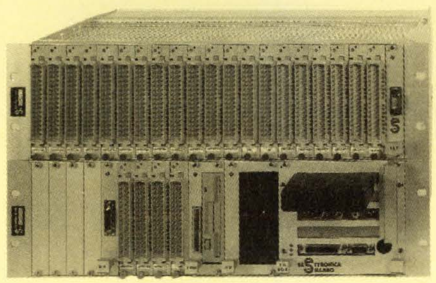

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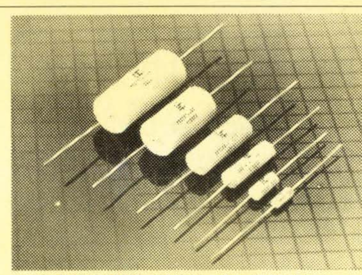

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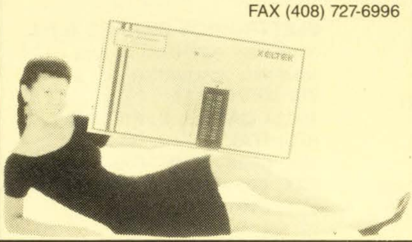

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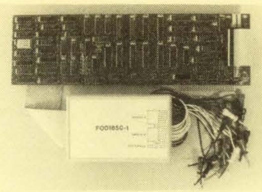

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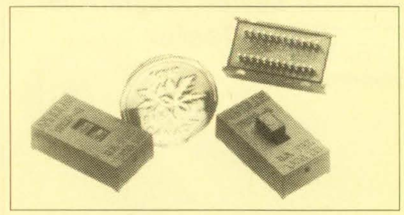

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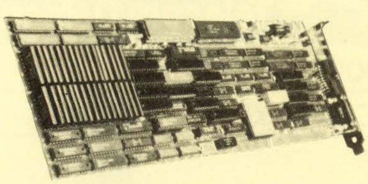

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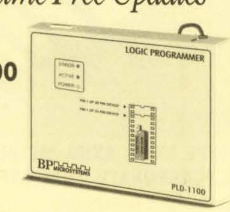

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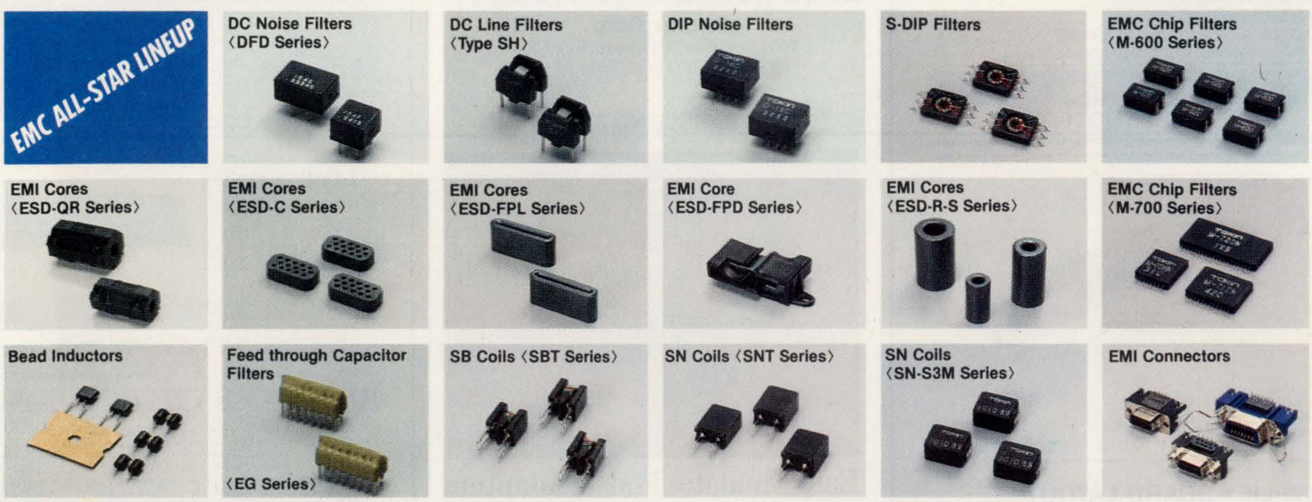

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PROFESSIONAL ISSUES

The *not so* serious business of computer games

Designers of computer games are expert programmers, successful managers, and still kids at heart.

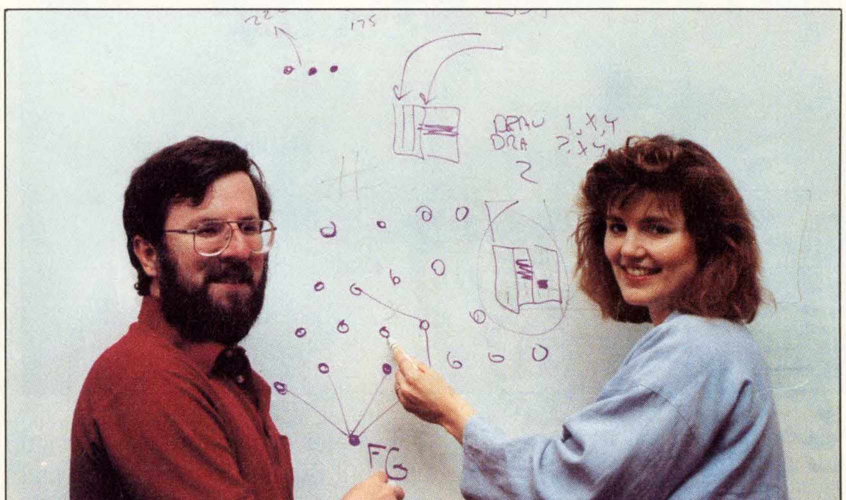
Jay Fraser, *Associate Editor*

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.

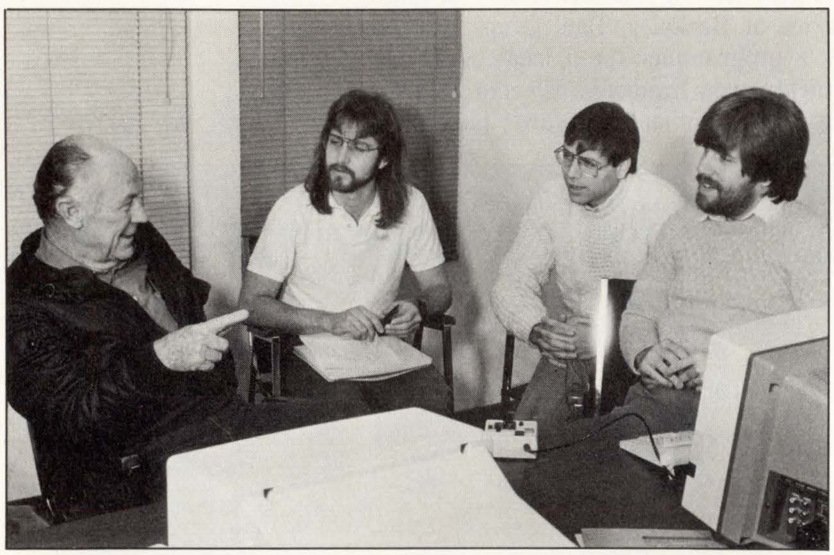
After leaving the University of California at Berkeley, Paul Grace worked as a programmer for a local bank. He quickly grew tired of it. Electronic Arts, an entertainment-software publisher,



Richard and Elaine Ditton work with a game tree, a planning tool that indicates the difficulty of development tasks at various phases of game design.

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.



Paul Grace (far right) and two colleagues talk with General Chuck Yeager (far left) about his "Advanced Flight Trainer" simulation.

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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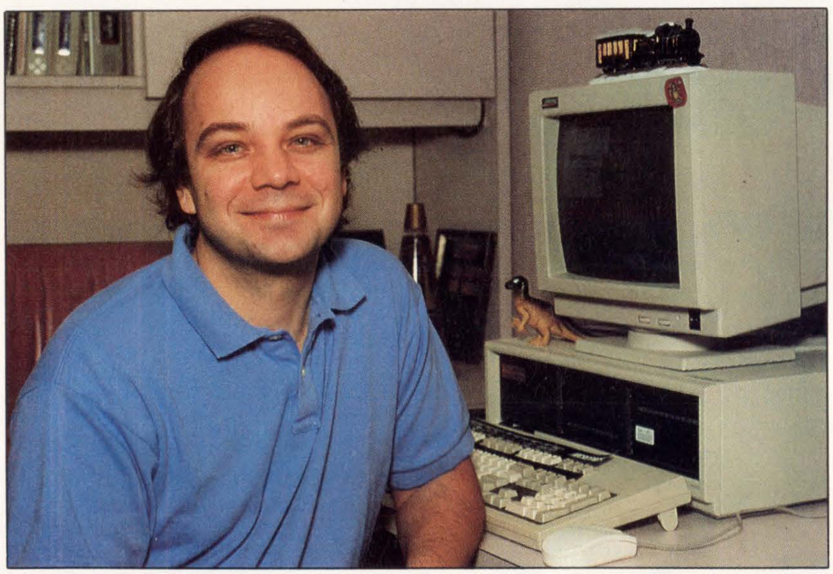
SAMTEC, INC. P.O. Box 1147 • New Albany, IN 47151-1147 USA • Phone 812-944-6733 • Fax 812-948-5047 • TWX 810-540-4095 • Telex 333-918 enormous crash. Atari alone lost more than $500 million that year.

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.



Sid Meier, whose computer games have sold more than 2 million copies worldwide.

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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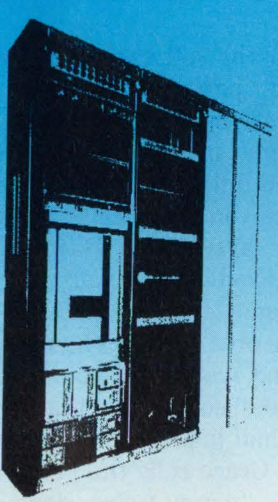

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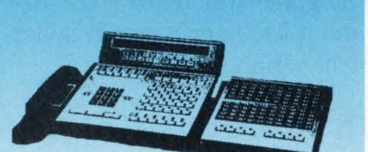

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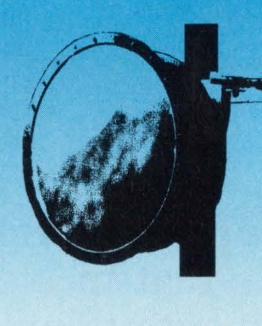

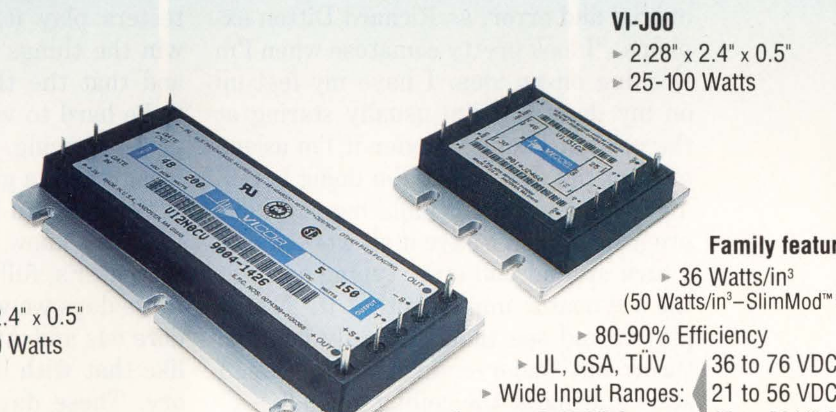

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"It was too slow for a flight simulator, but I thought that a nuclear-submarine game would be fun. There was a book out at that time about submarine warfare that was really enjoyable reading, and I wanted to do something like that. I got in touch with 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-

PROFESSIONAL ISSUES

tive), a multimedia, interactive system for the simultaneous presentation of video, audio, and text, will soon be widely available. These inventions promise huge amounts of storage for images and sound. Some industry observers predict that home computers will soon have the video and audio quality of television.

Significant improvements in hardware are just around the corner—CD-ROM drives and CDI (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." EDN

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News Edition	Nov. 29	Nov. 8	ICs/Communication Controllers/ Microprocessors, DSP, Regional Profile: Illinois, Minnesota & Michigan
Magazine Edition	Dec. 6	Nov. 15	Product Showcase—Volume I: Software, ICs & Semiconductors, Packaging & Interconnect, Power Sources
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Isolation(dB)	typ.	min.	typ.	min.
10-100MHz	60	40	60	40
100-1500MHz	40	28	40	30
1500-3000MHz	35	22	35	22
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10-100MHz	17	6	17	6
100-1500MHz	27	19	27	19
1500-3000MHz	30	28	30	28
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