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—J D Mosley, Technical Editor

2-Mbit video RAMs: Standardized feature sets add versatility and speed

Two-Mbit video RAMs offer more features and a wider interface to boost speed beyond that of earlier devices.—Richard A Quinnell, Technical Editor

3½-in. optical drives: Drives meet standards for removable data storage

The all-star companies that are planning to offer industry-standard drives give a good indication of the potential for success.—Maury Wright, Technical Editor

Solid-state relays meet requirements and handle demanding applications
—Tom Ormond, Senior Technical Editor

Continued on page 7
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MARCH 16, 1992

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4-Mbit cached dynamic RAM
High-power op amp

PROCESSOR UPDATES

Microcontroller for secure operations
Simulation kit for 8-bit µCs
16-bit DSP processor
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Welcome to EDN Magazine Edition's computer issue. Most of the feature articles you'll read are devoted to that topic. To start off, we direct your attention to Technical Editor J D Mosley's Special Report on multimedia—a subject that has received a great deal of attention lately. Multimedia applications demand a lot of hardware and software support and processor cycles. However, instead of just focusing on the hardware and software you need to add multimedia features to a computer, Mosley also tells you why you might want to add multimedia capabilities to your next design.

Graphics are a key component of multimedia machines, and Technical Editor Richard A Quinnell looks at a key hardware component for graphics subsystems—video DRAMs—in his Technical Update. The latest devices in the video-DRAM family have 2-Mbit capacities and, unlike earlier video DRAMs, you can count on a set of standard features from all of the 2-Mbit devices. That's good news for companies seeking multiple-sourced products. However, as Quinnell's article explains, the video-DRAM vendors couldn't resist putting unique features into their newest products. Use those features and you'll find yourself in a single-source situation again.

Optical disk drives are also important components for multimedia applications. In his Technical Update on multifunctional 3½-in. optical drives, Technical Editor Maury Wright examines a product group that's likely to become the next de facto standard in personal-computer mass storage. These drives accept rewritable magneto-optical media, optical ROMs that resemble CD-ROM disks but hold "only" 120 Mbytes, and "partial ROMs," which are writeable disks with some prerecorded data.

This issue marks the fourth "enhanced" issue of EDN Magazine, and we would like to know what you think of the changes we've made. Please take a moment to circle a reader service number below or write to us, either on the reader service card or in a separate note. We made the changes based on discussions with readers like you and we continue to ask for your thoughts. Thanks.

Steven H Leibson
Executive Editor

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Clocked memory interface gives 500-MHz access

Rambus Inc. is licensing a technology it developed for high-speed data transfers between CPUs and dynamic RAMs (DRAMs). The RAMbus interface uses a 9-bit synchronous data transfer to achieve 500-Mbyte/sec data rates. The company's technology includes the interface design, serial transfer protocol, and design assistance for semiconductor vendors adding the interface to their DRAMs, CPUs, and ASIC libraries.

The interface comprises 28 lines, including nine data, eight ground, and five power lines. To achieve the high data rates, the interface requires that the components be arranged in a line, with the CPU or bridge at one end. The 250-MHz clock that synchronizes data transfers to the CPU originates at the end opposite the CPU so that the clock and data propagate side by side down the bus. The clock loops back at the CPU end to handle data transfer to the memory devices.

DRAMs based on the RAMbus use their sense amplifiers as an internal cache to speed data access. The devices are self-refreshing and have mapping registers that let you specify their location in address space and mask out faulty memory banks. Each memory device monitors the data lines for a transfer request from the CPU, responding when addressed. The transfer can include from 1 to 256 9-bit words on the same DRAM page.

The company is licensing its technology to IC and ASIC vendors, who pay all the licensing and royalty fees. OEMs wishing to use the RAMbus technology simply purchase standard parts or use ASIC cell libraries as with standard logic. Several manufacturers, including Fujitsu, Toshiba, and NEC, already are developing RAMbus-based DRAMs (512k x 9 bits) and an ASIC bridge between the RAMbus interface and conventional CPUs. Parts should be available this year. Rambus Inc., Mountain View, CA, (415) 903-3800, FAX (415) 965-1528.—Richard A. Quinnell

Program automates test for Windows

Microsoft's Test for Windows lets programmers develop test suites that can run automatically. The tool set is the first automated test tool from a PC software vendor. Test sequences can exercise an application's Windows interface, varying control states and simulating keyboard and mouse inputs. A testing tool compares the test-generated windows with the window interfaces you expect. The tool works on any Windows program and does not require special hooks or debug code. The tool set supports standard bit-mapped monitors including EGA, VGA, and Super VGA.

Automated tests are created using a variation of the Visual Basic language, called Test Basic. The tools contain two programming mechanisms: FastTest, which provides defaults and a set of high-level test functions, and Test Driver, which has a Windows-hosted Basic interpreter.

The $395 test package includes a Basic environment with a recorder and FastTest. The package also performs screen capture and comparison, Windows controls comparison, a keyboard- and mouse-entry simulator, and timing control, which identifies and manipulates any control state. Microsoft Corp., Redmond, WA, (206) 882-8080, FAX (206) 883-8101.—Ray Weiss

Module adds video to VXI and VME

The EXM-14 video-expansion board works in conjunction with a VGA or super-VGA graphics board to add live video to your system display. The EXM-14 is one of a series of expansion boards that plug into Radisys Corp's 386- and 486-based VXI and VME embedded controllers.

The board accepts in-
coming signals in RGB, NTSC, PAL, SECAM, or VHS formats, then stores incoming images in a 1-Mbyte video frame buffer. Then, the board lets you merge that buffer’s data with a VGA controller’s output data stream, either at a specific position or to replace pixels having a specified color. Software supplied with the board includes device drivers and application program-interface libraries for Microsoft Windows and OS/2 Presentation Manager. The board, including software and cables, costs $1400. Radisys Corp, Beaverton, OR, (503) 690-1229, FAX (503) 690-1228.
—Richard A Quinell

Clock-doubling µP retrofits older systems

You can substantially boost the performance of existing 25-MHz, 80486DX-based systems with very little effort by replacing the system’s existing processor with a clock-doubling part. The 80486DX2 µP’s external bus runs at 25 MHz, but the processor core inside the chip runs at 50 MHz. Intel’s performance testing indicates that the 25-MHz clock-doubling processor provides nearly the same performance as the 50-MHz nonclock-doubling processor for code segments that fit entirely inside the processor’s internal cache. For larger programs, the 25-MHz clock-doubling µP’s performance falls between the 33- and 50-MHz nonclock-doubling 80486DXs. Consequently, your design can achieve substantial performance improvements without resorting to special pc-board layouts and high-speed external cache memories that very-high-speed CPUs usually require.

The chip’s clock-doubling circuits convert an external 25-MHz clock into an on-chip 50-MHz clock; the µP’s external bus continues to operate at 25 MHz. Therefore, the part should be electrically compatible with existing 25-MHz system designs. But the clock-doubling part may cause problems for some existing cooling schemes because it draws 40% more power than the existing 25-MHz µP. In addition, the faster speed may once again ruin timing-dependent code, even though programmers should have learned by now that software timing loops don’t make sense in the world of cache-assisted processing, where clock rates double yearly.

The 80486DX2 has the same pinout as the original 80486DX, is already in production, and costs $550 (1000). The µP also incorporates serial boundary-scan circuitry using pins designated “no connect” on the original 80486DX. Later this year, the company plans to build a slightly different version of this µP for upgrading 80486SX systems. This chip will plug into existing 80487SX sockets. Intel Corp, Santa Clara, CA, (408) 765-8080.
—Steven H Leibson

Multimedia tool kit integrates DSP and applications

The lack of a development base for software tools and utilities has been a major barrier to multimedia applications. DSP chip vendors are moving to change this situation. AT&T is introducing an integrated development tool set, the VCOS Multimedia Development Environment (VDME), for its 32-bit DSP3210 processor. The tool set is built around VCOS (Visible Caching Operating System), a DSP operating system that links to a host and provides multitasking DSP-application processing.

The tools support application development for multimedia applications that include real-time speech coding, facsimile, data modem, high-resolution MPEG (Motion Picture Experts Group) and JPEG (Joint Photographic Experts Group) still-image compression and decompression, and high-quality audio. The tool set includes specialized multimedia application development tools.

—Ray Weiss

Specification and IC bow to 3V interfaces

The move from 5 to 3V supplies for battery-powered equipment creates problems for the serial interface because of the lack of 3V-interface ICs and the fact that the serial interface becomes a higher percentage of total power dissipation. The EIA/TIA-562 specification defines a lower-voltage interface—±3.7V is the minimum allowable output voltage at the driver output—which is compatible with existing RS-232C, and EIA/TIA-232-D, and -E serial interfaces. The EIA/TIA-562 has requirements regarding waveform shape and ripple that the original 2232-E standard does not. These additions, plus an increased minimum slew-rate specification, guarantee operation at speeds as high as 64 kbps. The original RS-232C interface’s maximum data rate is 20 kbps.
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PSpice avoids the multi-tasking overhead exhibited by other simulators since the analog and digital simulation algorithms are tightly coupled within the same program. Moreover, one waveform analyzer displays the analog and digital waveform results together along a common time axis. Over 10,000 logic gates and hundreds of analog components can be simulated and analyzed with no performance compromises.

Efficient and Accurate Digital Algorithms
PSpice uses an event-driven logic processing technique supporting 5 logic levels, 64 output strengths, and timing modeling, including worst-case timing simulation. Logic states and propagation delays are computed quickly and accurately. By using efficient digital primitives rather than cumbersome macromodels composed of analog parts, PSpice simulates at speeds that are orders of magnitude faster than simulators using macromodel definitions of digital devices.

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The Max561 is a low-voltage interface IC that meets EIA/TIA-562 specifications and operates to 3V at a data rate of 20 kbps. Onboard charge pumps working with 1-µF external capacitors convert the nominal 3.3V input to the ±6.6V needed to generate the EIA/TIA-562 output levels. The chip contains four drivers and five receivers, and it consumes 8 mA of quiescent current, compared with 15 mA for a similar 5V RS-232C device. A low-power shutdown mode reduces supply current to 1 µA when the serial port is inactive. The $4.19 (1000) IC comes in a 28-pin small-outline package and operates over a temperature range of 0 to 70°C. Maxim Integrated Products, Sunnyvale, CA, (408) 737-7600, FAX (408) 737-7194.

—Anne Watson Swager

Control modules open up industrial networks

Developers no longer have to build their own control modules for Echelon Corp’s Neuron control chip. The company is delivering twisted-pair control modules built around Neuron chips. You can build these modules directly into control electronics and use them to link to a sophisticated control network. The modules support both analog and digital interfaces and can control output devices such as triacs, relays, and industrial displays.

Each chip is really three processors in one, all sharing memory and bus resources. The three processors each take on a major function (control, networking, and I/O). By using three processors, each chip has a minimum of switching overhead because each task resides in a processor. The chips are made under license by Toshiba and Motorola. Echelon sells a development environment, which includes Neuron-C.

Initially, there will be three control modules for the Echelon Lonworks control networks. These are linked to the network via twisted-pair wires. The modules are an RS-485 module (to 78 kbps), a transformer-isolated module (to 78 kbps in noisy environments), and a high-speed transformer-isolated module (to 1.25 Mbps). The transformer-isolated modules use a form of Manchester coding for signals. Each module has a Neuron processor, a socketed PROM, and a communications transceiver. Prices start at $35 (OEM qty) for the RS-485 module.

The company is also releasing the Lonmanager API (application program interface) for MS-DOS machines. This API lets PC applications interact with the network and act as network servers, control points, and graphic-display consoles. The interface costs $9850, plus royalties. Echelon Inc, Palo Alto, CA, (415) 855-7416, FAX (415) 856-6153. —Ray Weiss

Protocol upgrades IEEE-488 to 5 Mbytes/sec

A streaming-data protocol, an upgrade to the venerable IEEE-488 standard for instrument communication and control, will be unveiled within two weeks by Capital Equipment Corp, a supplier of IEEE-488 interface cards for PCs. The new protocol, which transfers data blocks of unlimited size bidirectionally at speeds as great as 5 x the maximum heretofore possible, causes no problems with older instruments; they continue to function as they always have. Capital Equipment Corp, Burlington, MA, (617) 273-1818.

—Dan Strassberg

Single-board computer draws 4.3W

The SBC-SX1p 16-MHz 80386SX-based computer board measures 5.75 × 7.75 in. and draws 4.3W from a single 5V supply. Standard features include keyboard and speaker interfaces, one serial port, one parallel port, a battery-backed clock/calendar, and hard- and floppy-disk interfaces. You can add as much as 4 Mbytes of dynamic RAM, and you can install 1 Mbyte of ROM, static RAM, or flash EPROM for use as a RAM disk. The board also includes a VGA controller that can drive CRT, EL, vacuum-fluorescent, and color and monochrome LCDs. Software support includes an onboard BIOS ROM for running MS-DOS and embedded software that lets you run code developed on an MS-DOS system without buying an MS-DOS license for the single-board computer. Computer Dynamics, Greer, SC, (803) 877-8700, FAX (803) 879-2030. —Maury Wright

VME interface IC handles 64-bit transfers

Cypress Semiconductor’s 64-bit VIC64 is pin and software compatible with the company’s VIC068 VMEbus interface controller. Both parts can serve as master or slave and support read, write, write-posting, and block transfers. During block transfers, however, the 64-bit part can handle either 32- or 64-bit transfers. The part achieves 64-bit transfers by using the VME address lines, which are idle during a block transfer. Samples cost $140 (100) and are available in 144-lead pin-grid arrays and 160-lead plastic quad flatpacks. Cypress Semiconductor, San Jose, CA, (408) 943-2600. —Richard A Quinnell
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CIRCLE NO. 18
dc to 3GHz

lowpass, highpass, bandpass

- less than 1dB insertion loss
- greater than 40dB stopband rejection
- surface-mount
- BNC, Type N, SMA available
- 5-section, 30dB/octave rolloff
- VSWR less than 1.7 (typ)
- rugged hermetically-sealed pin models
- constant phase
- meets MIL-STD-202 tests
- over 100 off-the-shelf models
- immediate delivery

low pass, Plug-in, dc to 1200MHz

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Passband MHz loss &lt;1dB</th>
<th>Stopband, MHz loss &gt;20dB</th>
<th>Stopband, MHz loss &gt;40dB</th>
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<tr>
<td>PLP-3</td>
<td>8-13</td>
<td>10-200</td>
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<tr>
<td>PLP-10</td>
<td>19-24</td>
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</tr>
<tr>
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<td>36-41</td>
<td>41-200</td>
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<tr>
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<td>61-200</td>
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<tr>
<td>PLP-50</td>
<td>70-90</td>
<td>90-200</td>
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<tr>
<td>PLP-70</td>
<td>90-117</td>
<td>117-300</td>
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<tr>
<td>PLP-90</td>
<td>121-137</td>
<td>137-400</td>
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<tr>
<td>PLP-100</td>
<td>146-189</td>
<td>189-400</td>
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<tr>
<td>PLP-150</td>
<td>210-300</td>
<td>300-600</td>
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</tr>
<tr>
<td>PLP-200</td>
<td>230-360</td>
<td>360-800</td>
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<tr>
<td>PLP-250</td>
<td>250-400</td>
<td>400-1200</td>
<td></td>
</tr>
</tbody>
</table>

Surface-mount, dc to 570MHz

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Passband MHz loss &lt;1dB</th>
<th>Stopband, MHz loss &gt;10dB</th>
<th>Stopband, MHz loss &gt;40dB</th>
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</thead>
<tbody>
<tr>
<td>SCLF-21</td>
<td>32-41</td>
<td>41-200</td>
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<tr>
<td>SCLF-30</td>
<td>47-61</td>
<td>61-200</td>
<td></td>
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<tr>
<td>SCLF-40</td>
<td>90-200</td>
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<td></td>
</tr>
<tr>
<td>SCLF-135</td>
<td>210-300</td>
<td>300-600</td>
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</tr>
</tbody>
</table>

Flat Time Delay, dc to 1870MHz

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Passband MHz loss &lt;1dB</th>
<th>Stopband, MHz loss &gt;10dB</th>
<th>Stopband, MHz loss &gt;40dB</th>
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</thead>
<tbody>
<tr>
<td>PRBP-25</td>
<td>13-19</td>
<td>19-239</td>
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<tr>
<td>PRBP-50</td>
<td>20-26</td>
<td>26-230</td>
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<td>PRBP-100</td>
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<td>55-440</td>
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<td>PRBP-150</td>
<td>70-95</td>
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<tr>
<td>PRBP-175</td>
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<td>125-600</td>
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<tr>
<td>PRBP-200</td>
<td>150-160</td>
<td>160-800</td>
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<tr>
<td>PRBP-250</td>
<td>200-175</td>
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</tr>
<tr>
<td>PRBP-300</td>
<td>250-145</td>
<td>145-2900</td>
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</tr>
</tbody>
</table>

High pass, Plug-in, 27.5 to 2200MHz

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Passband MHz loss &lt;1dB</th>
<th>Stopband, MHz loss &gt;20dB</th>
<th>Stopband, MHz loss &gt;40dB</th>
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</thead>
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<td>40-55</td>
<td>55-440</td>
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<td>PHP-150</td>
<td>70-95</td>
<td>95-660</td>
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<td>PHP-175</td>
<td>100-125</td>
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<td>150-160</td>
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<tr>
<td>PHP-300</td>
<td>250-145</td>
<td>145-2900</td>
<td></td>
</tr>
</tbody>
</table>

Bandpass, Elliptic Response, 10.7 to 70MHz

<table>
<thead>
<tr>
<th>Center Freq. (MHz)</th>
<th>Passband 1.5 dB Bandwidth (MHz)</th>
<th>3 dB Bandwidth (MHz)</th>
<th>Stopbands at &gt;35dB at MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPP-10 (10.7)</td>
<td>9.5-11.5</td>
<td>11.6</td>
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</tr>
<tr>
<td>PPP-24 (24.4)</td>
<td>22.4-26.3</td>
<td>26.4</td>
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</tr>
<tr>
<td>PPP-50 (50.0)</td>
<td>49.5-50.5</td>
<td>50.5</td>
<td></td>
</tr>
<tr>
<td>PPP-70 (70.0)</td>
<td>63.0-70.0</td>
<td>70.0</td>
<td></td>
</tr>
</tbody>
</table>

Constant Impedance, 21.4 to 70MHz

<table>
<thead>
<tr>
<th>Center Freq. (MHz)</th>
<th>Passband 1.5 dB Bandwidth (MHz)</th>
<th>3 dB Bandwidth (MHz)</th>
<th>Stopbands at &gt;35dB at MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPP-10 (10.7)</td>
<td>9.5-11.5</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>PPP-24 (24.4)</td>
<td>22.4-26.3</td>
<td>26.4</td>
<td></td>
</tr>
<tr>
<td>PPP-50 (50.0)</td>
<td>49.5-50.5</td>
<td>50.5</td>
<td></td>
</tr>
<tr>
<td>PPP-70 (70.0)</td>
<td>63.0-70.0</td>
<td>70.0</td>
<td></td>
</tr>
</tbody>
</table>

Price (1-9 qty.), all models: plug-in $14.95, BNC $32.95, SMA $34.95. Type N $35.95.

Surface-mount, dc to 570MHz

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Passband MHz loss &lt;1dB</th>
<th>Stopband, MHz loss &gt;10dB</th>
<th>Stopband, MHz loss &gt;40dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCLF-21</td>
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<td>41-200</td>
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<td>SCLF-40</td>
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<tr>
<td>SCLF-135</td>
<td>210-300</td>
<td>300-600</td>
<td></td>
</tr>
</tbody>
</table>

Price (1-9 qty.), all models: plug-in $14.95, BNC $36.95, SMA $38.95. Type N $39.95.

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- Non-inverting Octal
- Non-inverting Octal
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- 10-bit Inverting
- Inverting Octal
- Non-inverting Octal
- Non-inverting Registered
- Inverting Registered
- Inverting Bus Transceiver w/ 3 States
- Non-inverting Bus Transceiver w/ 3 States
- Non-inverting Buffered
- Non-inverting Registered
- Inverting Registered
- Non-inverting Registered
- Non-inverting w/ Odd/Even Parity
- 10-bit Non-inverting Transceiver
- 8-bit Non-inverting Transceiver
- 9-bit Non-inverting Transceiver

Transceivers
- Inverting Registered
- Non-inverting Registered
- Inverting Registered
- Non-inverting Registered
- Inverting Bus Transceiver w/ 3 States
- Non-inverting Bus Transceiver w/ 3 States
- Non-inverting Buffered
- Non-inverting Registered
- Inverting Registered
- Non-inverting Registered
- Non-inverting w/ Odd/Even Parity
- 10-bit Non-inverting Transceiver
- 8-bit Non-inverting Transceiver
- 9-bit Non-inverting Transceiver

Latches
- Octal Non-inverting Transparent
- Octal Transparent w/ Inverted Outputs
- Octal Transparent w/ Flow Thru Pinout
- 9-bit Non-inverting Buffed
- 8-bit Non-inverting Buffed

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- Multilevel Pipeline w/ Dual 2-Level Shift
- Octal Non-inverting Transparent
- Octal Transparent w/ Inverted Outputs
- Octal Transparent w/ Flow Thru Pinout
- Octal Non-inverting Buffed
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- 1-of-N Decoder
- Dual 1-of-N Decoder

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- Synchronous Binary w/ Synchronous Reset
- Up/Down Binary Counter

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- Non-inverting Quad 2-input w/ 3-State
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- 8-bit Identity Comparator

For more information call (408) 734-9000

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CIRCLE NO. 21
Coping with automatic telephone systems
In response to the letter from Ken Wood in Newport, Wales (EDN, November 7, 1991), I agree that the default mode for automatic telephone systems should revert to the operator. However, if you try calling Analog Devices at midnight, you'll get worse than that.

I think even in Wales, you can buy from Tandy, for barely $30, a telephone that can start out in pulse mode. But when you want to play games with tones, they switch over. I have one of these myself.
Robert A Pease
San Francisco, CA

Offer free software for basic PLDs in small companies
I agree with Charles Small's editorial, “Make FPGA design easier” (EDN, October 10, 1991, pg 49). I work for a small company, and we simply aren't willing to spend the money to get involved with PLDs. Years ago, as mentioned, the software was free. However, it costs quite a bit to get involved with programmable devices today. The software is usually limited to a specific manufacturer's devices, or you can spend more to get more versatility. At any rate, we don't even consider PLDs as an option in our designs. If the device manufacturers wish to increase the sale and usage of their parts, they need to change this situation.

At the very least, I'd like to see some free software, even if it had reduced capabilities, for more basic PLDs. Even if we didn't use it for our daily designs, I could certainly use it as a learning tool so I would have a better understanding of PLD capabilities. I might even be able to better explain and justify the cost of a more complete software to my managers so we could at least consider using PLDs for future designs.

Personally, I feel the companies involved should decide whether they are hardware or software vendors. If their intent is to sell their devices, they need to provide free or low-cost software to their prospective customers. Perhaps they should engage in a software developer's effort, in which they would provide assistance to programmers who might wish to develop shareware software for them.

Timothy A Rusco
Electronics Engineer
Radiographic Equipment Services
Riverside, CA

Correction
In the Product Showcase Issue (EDN, December 5, 1991, pg 133), the write-up about the ADXL-50 acceleration sensor contains an error in the first paragraph. It describes Analog Devices' model ADXL-50 as a bulk-micromachined (membrane) device that uses thin-film resistors.

The fact that the ADXL-50 is not a bulk-micromachined type is what makes it unique. The device is a single monolithic chip that incorporates an interdigitated “floating” sensor with diffused resistors and all the necessary signal-processing circuitry. It eliminates the temperature-sensitive and costly bulk-micromachined sensor and the need for thin-film resistors.

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. Send your letters to Signals & Noise Editor, EDN Magazine, 275 Washington St, Newton, MA 02158. You can also send a note via MCI mail at EDNBOS or use EDN's bulletin-board system at (617) 558-4241: From the Main System Menu, enter SS/SOAPBOX, then W to write us a letter. You'll need a 2400-bps (or less) modem and a communications program set for 8,N,1.

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Innovation working for you™
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Peter Gottlieb is a self-employed engineer who recently wrote to Ask EDN about the difficulty he has getting small quantities of state-of-the-art parts. His customers require prototypes that they can evaluate before committing to production. He says, however, that the high-end components he needs for building prototypes are not available from hobbyist suppliers, and nationwide distributors, such as Digi-Key and Newark Electronics, often don’t carry such parts.

Gottlieb has resorted to ordering initial production quantities of hard-to-get parts. When he orders such large quantities, he risks losing a lot of money if requested changes eliminate the need for those parts. In closing his letter, Gottlieb asked “What can be done to keep the small engineer alive in this country?” and I asked readers whether Gottlieb’s experiences were typical.

During the time I’ve been editing Ask EDN, no other letter has struck such a nerve. Dozens of engineers have written in to second Gottlieb’s complaint. These readers added that they also have trouble getting small quantities of parts for designing test equipment and making repairs.

Engineers can’t design-in parts they can’t get their hands on. It’s that simple. And they’re not looking for freebies or handouts: These engineers are willing to pay full—or even higher—prices to get the small quantities they need.

Component-company sales people are usually too busy giving out sample parts to big companies to have time for the little guy. Also, it’s not in their interest to go after small companies that would only buy a couple dozen parts when so many big companies are willing and able to buy thousands.

But at least one company doesn’t subscribe to this reasoning. Dallas Semiconductor (Dallas, TX) has made getting small quantities of its parts as easy as making a phone call. Engineers dialing (800) 336-6933 can use a personal or corporate credit-card number to order any size quantity of any part—from the lowest-cost chip to the most sophisticated IC—the company has in stock. What’s more, the parts arrive in two or three days, rather than the two to three weeks engineers must often wait to get parts from distributors. Certainly, there’s a demand for this service: Dallas Semiconductor generates $7000 to $8000 a week via credit-card orders.

More companies should follow Dallas Semiconductor’s example by making available small quantities of both low-end and sophisticated parts. Not only would such companies generate additional income, they would also be laying the groundwork for future, potentially large orders.

Julie Anne Schofield
Associate Editor

Send me your comments via FAX at (617) 558-4470, or on the EDN Bulletin Board System at (617) 558-4241 300/1200/2400, 8, N, 1.
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36 • EDN March 16, 1992 CIRCLE NO. 28
Emerging 2-Mbit video RAMs offer more features and a wider interface to boost speed beyond that of earlier devices. Different manufacturers' products also conform more to a single standard, coming a bit closer to eliminating second-sourcing problems.

2-MBIT VIDEO RAMs

Standardized feature sets add versatility and speed

RICHARD A QUINNELL, Technical Editor

During the four years since the introduction of 1-Mbit video RAMs (VRAMs), manufacturers have been listening to users. The 2-Mbit devices now appearing attend to users' needs for second sourcing by offering a standardized array of features, including the most popular 1-Mbit functions and some user-suggested functions unique to the 2-Mbit generation.

The feature sets of most 2-Mbit devices conform to a JEDEC standard jointly developed by the major manufacturers. The devices' organization is also standard at 256 x 8 bits—twice the width of older, 1-Mbit devices (256 x 4 bits). The effort to standardize came in reaction to the varied options available in 1-Mbit VRAMs (Ref 1). Because each manufacturer offered a different mix of functions, parts seldom had many features in common. To make second sourcing possible, designers had to use only the few common features, sacrificing much of the parts' capabilities. By offering broader standard feature sets in 2-Mbit parts, manufacturers now aim to minimize that sacrifice.

The feature sets constitute a hierarchy, offering foundation, core, and extended functions. The foundation of all VRAMs is a dual-memory structure: a dynamic-random-access-memory (DRAM) array coupled to a serial-access-memory array (SAM). The DRAM array behaves like a conventional page-mode DRAM, requiring the same address, control, and refresh signals. The SAM array provides a second port into the DRAM array, allowing you to transfer a row of DRAM data to the SAM in a single cycle, then shift out the SAM data independent of the DRAM array's operation.

In some cases, the SAM array can also accept serial data for transfer to the DRAM array. Using both ports, you can transfer data into and out of the VRAM simultaneously.

Several core functions taken from the 1-Mbit VRAM generation build on this foundation. One such core function is the split data transfer. A basic data transfer has you provide row and column addresses to the DRAM along with a transfer command bit. The row address selects the DRAM row to transfer into
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2-MBIT VIDEO RAMS

the SAM; the column address selects a tap point (the location in the SAM that is first in the serial output stream). A drawback to the basic transfer becomes apparent if you attempt to produce a continuous serial data stream. When the SAM reaches its last location, you only have one clock period in which to execute the next transfer.

The split data transfer extends this time window by allowing you to load one half of the SAM while the other half is shifting data. To use the split transfer, you first execute a basic transfer. Once the first half of the SAM has shifted out, you can execute a split transfer to refill that half anytime before the second half finishes shifting.

When the second half of the SAM has finished shifting, the memory pointer automatically wraps around to the beginning of the first so that shifting continues uninterrupted. You can then execute a split data transfer to the second half, and so on. The device automatically controls which half-transfer occurs, so you can maintain a continuous data stream by performing a succession of split transfers.

Another core function that adds to the foundation VRAM is the ability to perform a masked write, a fast alternative to the read-modify-write cycle. The masked write, also called write-per-bit, lets you prevent alteration of selected bits within a word during a write operation.

Two types of masked write are available, persistent, and nonpersistent. In nonpersistent masked write, you must provide the mask pattern during the row address portion of each write cycle. In persistent write, you first load a mask register. The device will then apply that mask during all succeeding write operations until the mask is cleared.

Multiple-location writes

A third core function is the ability to write the same data to multiple DRAM locations simultaneously. The duplicated data comes from an internal register called the color register, which you must load beforehand.

The ability to write to multiple locations takes on two forms, a block write and a flash write. The flash write replicates the color register data into an entire row of the DRAM array. The block write writes to as many as four adjacent memory locations (columns) in a single row. You can selectively mask out columns in the block write, but not in the flash write. Both forms include the option of performing write-per-bit.

The top level in the feature set hierarchy includes two extended functions unique to the 2-Mbit VRAM generation. Both aim at improving the VRAM’s performance during DRAM write operations.

The first of these extended functions is the extended-data-output page-mode access, the NEC µPD422835/6 2-Mbit video RAM is organized as a standard 256k x 8-bit device.

Including such extended functions as stop-column control and extended-data-output page-mode access, the NEC µPD422835/6 2-Mbit video RAM is organized as a standard 256k x 8-bit device.
before the column-control circuits can prepare for the next access. By allowing the two operations to occur in parallel, the latch speeds data access.

The second extended function is a column-stop control on split data transfers. Although this function seems to affect only the SAM, its effect is to improve write access to the DRAM array by simplifying use of a tiled memory-to-display map.

The most intuitive method for mapping memory locations in the DRAM array to pixels on the display is shown in Fig 1a. Each row or page of the array maps to a line of pixels. While this is an intuitive map, it suffers from reduced performance when the system attempts to draw a diagonal line. As the figure shows, the line cuts across multiple pages in the DRAM, using only one or two locations in each page. Having only a few locations to be written in each page, you cannot use page mode’s fast access time effectively.

**Tiled map speeds line draw**

The tiled approach shown in Fig 1b maps a 512-byte DRAM page into two 16x16-pixel display tiles. Any line drawn on the screen will use several pixels from the same tile and thus from the same DRAM page. Access within a page is twice as fast as access between pages. Therefore, by making more effective use of page mode, the tiled map reduces line drawing time.

The drawback to the tiled map is that it complicates the reading of data into the SAM for presentation to the display. You must initiate a basic data transfer at each tile boundary—in this case every 16 bits—under the tight timing conditions needed to maintain a continuous serial data stream. You cannot ease those timing constraints by using a split data transfer because you cannot jump between the split registers when you reach a tile boundary; you can only wrap around register boundaries.

The column-stop control, however, does allow you to jump between split registers. You initiate column stop by selecting one of five column-stop patterns. You can then

---

**Table 1—2-Mbit video RAMs**

<table>
<thead>
<tr>
<th>Manufacturer</th>
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<th>Cycle time (nsec)</th>
<th>Features</th>
<th>Masked write</th>
<th>Extended-data-output page mode</th>
<th>Stop-column control</th>
<th>Stop-column control Price (100)</th>
<th>Unique features</th>
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<td>MIL-STD-883C qualified</td>
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<td>X</td>
<td>Persistent</td>
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**Fig 1**—The mapping you use between VRAM address and display locations affects your line-drawing rate. A direct map (a) allows simple serial data transfers but doesn’t allow line drawing to use page mode effectively. A tiled map (b) allows more frequent use of page mode for drawing but complicates the serial data transfer to screen.
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Fig 2—By permitting the serial data pointer to jump to the other half-register upon reaching a stop point, the stop-column control function simplifies timing of tiled-map serial readout.

specify a tap point with each split transfer. The serial data pointer will jump from the stop boundary in one split register to the tap point you specify for the other split register. Column stops can be as close together as 16 columns. Fig 2 shows the transfer and jump sequence for the tiled map of Fig 1b.

Similar, but not identical

The hierarchy of foundation, core, and extended feature sets is reflected in Table 1. The Mosaic MVM8256 is a foundation part, the Micron devices offer core functions, and the NEC and Toshiba parts have extended functions. Even though several devices have unique additions to the standard feature sets, the commonality is much greater than it is in the 1-Mbit generation. Unless you absolutely need them, sacrificing the extra features to permit second sourcing now presents no great hardship.

Simply comparing feature sets is somewhat misleading, however. You may have to design carefully to accommodate possible physical differences. The Toshiba parts, for example, need an extra I/O pin to activate their pipeline mode. That pin is a ground pin on the Micron parts and a no-connection on the NEC parts. You can't design to accommodate all differences, though. The Mosaic part, for example, has a pinout different from the other VRAMs.

The VRAM evolution won't stop at the 2-Mbit generation. Both NEC and Texas Instruments are working on 4-Mbit devices, organized as 256k x 16 bits, that may be available by year's end. Whether the compatibility trend will continue, however, is uncertain. Manufacturers haven't agreed on any specifications for the 4-Mbit generation.

Reference


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SAM ARRAY POINTER

Fig 2—By permitting the serial data pointer to jump to the other half-register upon reaching a stop point, the stop-column control function simplifies timing of tiled-map serial readout.
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<td>3</td>
<td>16K ROM, 512 RAM, WD</td>
<td>A44, B44, F40, K44, N40</td>
</tr>
<tr>
<td>8XC528</td>
<td>32K</td>
<td>512</td>
<td>4</td>
<td></td>
<td>*</td>
<td>3</td>
<td>32K ROM, 512 RAM, WD</td>
<td>A44, B44, F40, K44, N40</td>
</tr>
</tbody>
</table>

Host — IBM PC/XT/AT, PS/2 or compatible. 640K RAM. Monochrome, CGA, EGA, or VGA in 25, 43 or 50 line mode.
External box — The emulator boards can be installed in an external box with serial 115K Baud communication to the host computer.
Languages supported — Third party assemblers, PL/M-51 and C-51 compilers.
Source level debugging — Window for source level debugging. Single Step or Line Step with breakpoints marked directly in the code. Full support of local and global variables in C-51. We currently support: Franklin/Keil, Archimedes/IAR, Intermetrics/Whitesmiths/Cosmic and BSO/Tasking.
In-line Assembler and disassembler — Full instruction set and symbols supported!
Symbolic Support — Full symbolic debugging and type checking. Same symbols can be used in different modules. All Special Function Registers supported.
File formats Supported — Intel HEX/OBJ/OMF/SYM. Avocet, Archimedes, IAR, Keil, Franklin and many more.
Real time Emulation — Full speed emulation up to 33 MHz. No wait states and no intrusion on memory, stack, I/O or interrupt pins.
Emulation Memory — 64K XDATA memory and 64K CODE memory. Up to 320K Bank switching is supported as an option.
Memory Mapping — Mappable in 4K pages.
Macros — Test session automation and macro command definition. IF/ELSE, REPEAT/WHILE structures.
Debug Session Logging — Record emulation session and all setups to a file.

Breakpoints — 64K program breakpoints. 64K data read and 64K write breakpoints. Break on external signal. Break on direct access to internal bit or byte memory. Break on a range of addresses and high-level language statements. Break on program execution out of boundaries. With the Trace board option it’s possible to break on any 48 bit combination of address, data, RD, WR, OP code fetch, interrupt level, ports or external signals.
Single Stepping — Single or multiple instruction stepping. Step over calls and interrupts. Line stepping in high level languages.
Execution timer — Resolution down to 182 ns.
Real Time Trace Memory (optional) — 256K deep by 64 bits wide. Trace address, data, ports, control signals, external signals, and time stamp.
Filter/Trigger — Eight sets of triggers with 2 qualifiers each. Trigger on combinations of the qualifiers including sequential combinations and loop counter. Qualifiers can be AND/OR/NOT combinations of addresses, data, ports, op-code fetch, RD, WR, EXT0, EXT1 and interrupt levels. Trigger point can be selected anywhere within the 256K buffer to give pre/post trigger alignment. Trigger can be modified and restarted without stopping emulation.
Trace Display — Display trace in disassembled symbolic or binary/hex form, or as high level source code. Up to 256K source lines can be captured. Display and setups can be saved to a file. Trace can be started, stopped and displayed independent of program execution.
Program Performance Analyzer — Histogram and statistical information of program execution in real time.
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MULTIFUNCTIONAL 3½-IN. OPTICAL DRIVES

Drives meet standards for removable data storage

MAURY WRIGHT, Technical Editor

The emerging class of 3½-in. multifunctional optical disk drives stands a good chance to become a widely accepted standard for desktop computers. Previous classes of optical drives have failed to achieve this status because of a lack of industry standards. The new drives meet ANSI and ISO standards for MO (magneto-optical) drives that store 128 Mbytes on a rewritable cartridge that resembles a 3½-in. floppy disk.

What makes the 3½-in. drives multifunctional is that they can also use two other media. The drives can read 120-Mbyte O-ROM (optical ROM) prerecorded disks, which software publishers can produce much like they do the larger CD-ROMs (compact-disc read-only memory). The drives can also use a medium called partial ROM. On partial-ROM disks, some sectors have prerecorded data and others can be written to using the MO capability of the drive.

Mike Helsel, manager of tape and optical products at Teac, maintains that 3½-in. optical drives have a shot at eventually replacing the floppy-disk drives used in every system. Helsel qualifies his statement by saying that the transition might take 10 years and that standards must be strictly maintained for the scenario to occur.

Low price ultimately will key the acceptance of these multifunctional drives into mainstream office use. An end user will pay approximately $2000 for a drive right now, but drive manufacturers have just begun volume production. According to Robert Abraham, vice president of Santa Barbara, CA, research firm Freeman Associates, the average OEM price for 3½-in. optical drives shipped in 1992 will be $810. Therefore, you can expect end-user prices less than $1500.

The optical-drive industry has failed to deliver optical drives that achieve the performance and price of magnetic disk drives more times than anyone cares to
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MULTIFUNCTIONAL 3½-IN. OPTICAL DRIVES

remember. No optical drives—including the 3½-in. units—have reached the performance level of magnetic drives. The average access times and data-transfer rates the small drives offer match those of a 20- to 40-Mbyte hard drive shipped in the typical PC a few years ago.

But optical drives in general can perform the primary-storage role in place of hard-disk drives in applications in which fast data-access times and data-transfer rates aren't paramount. And the random-access capability of optical drives makes them preferable to tape drives in some secondary-storage applications including archival storage and disk backup. However, optical storage can't come close to the drive or media price tape storage offers.

Applications open niches

Optical drives have found niches in which high-capacity random-access removable storage proves invaluable. In fact, desktop publishing and emerging multimedia applications have essentially created the need for a third class of storage that complements traditional disk and tape drives. Optical drives can be used to store images, encyclopedias, music, and video on high-capacity removable cartridges. Optical disks can also be used for software distribution in this graphics age where a word-processing program can require a dozen floppy disks.

These applications have created a potentially large market for all optical drives, but several factors have stymied growth in the market. Certainly high price and low performance don't help. But lack of standards and disarray in the optical-drive industry have been the biggest obstacles to success. For example, optical drives use media ranging in diameter from 3½ to 14 in. And drives from different vendors that use the same size media often used different recording formats. Finally, customers have had to choose between WORM (write once, read many), rewritable, and CD-ROM drives.

Standardization, multifunctional capability, and size set the new class of 3½-in. drives apart from the grab bag of larger optical drives. ANSI and ISO committees had defined standard recording formats for MO and O-ROM 3½-in. media before any companies produced drives. Thus, all potential 3½-in. optical-drive manufacturers could produce standard drives from the start. And media-interchange standards are key for removable storage technologies. You only have to look at the stalled market for 20-Mbyte floppy-disk drives to see how incompatibility can hurt a new class of storage products.

Manufacturers of the 3½-in. drives say their products suit desktop personal computers and workstations rather than LAN servers, where larger optical drives often see duty. The small form factor matches the physical space provided in newer desktop computer cabinets. And the 128-Mbyte capacity of the rewritable MO cartridge matches the needs of a single-user graphically-user-interface-based computer.

You can argue that 5¼-in. optical
MULTIFUNCTIONAL 3 1/2-IN. OPTICAL DRIVES

drives provide more capacity than the 3½-in. drives and that more is usually better. Available 5¼-in. drives store more than 500 Mbytes on an MO cartridge yet cost only double what the 3½-in. drives do. However, the 5¼-in. drives are not multifunctional, and industry observers expect the smaller drives to drop in price quickly.

You can't directly compare the 3½-in. drives with other optical drives because no other drives combine the same capabilities. For example, no 5¼-in. MO drives also read CD-ROMs. The 3½-in. drives can read O-ROMs, which are similar to CD-ROMs. Software publishers can mass-produce O-ROM cartridges using the same stamping process they use to make CD-ROMs and their close relative, the audio compact disc. Thus, O-ROMs and CD-ROMs share the characteristic of being cheaper than paper for distributing large amounts of data.

O-ROM drives have several advantages compared with CD-ROM drives, however. O-ROM disks use a sector-and-track format geometry just as magnetic disk drives do. Most of the 3½-in. drives discussed in this article feature average access times between 40 and 50 msec and can sustain data transfers at more than 600 kbytes/sec.

CD-ROMs, however, feature a single spiral track much like a groove in an audio record album. State-of-the-art CD-ROM drives have 300-msec average access times and data-transfer rates in the 150-kbyte/sec range. Furthermore, CD-ROM disks' spiral track and need for a variable-speed spindle motor that produces constant linear veloc-

The "Free Format" 265-Mbyte mode that the Most RMD-5200 can operate in doesn't prevent the drive from using standard 128-Mbyte cartridges as well.

Corel Systems (Ottawa, Canada) on O-ROM today. And Autodesk (Sausalito, CA) has created a sample image library on O-ROM using animations created via its CAD and drawing software packages. Other publishers are waiting for more widespread use of drives that can use O-ROM media before offering titles.

Art Rancis, vice president of data-storage products at Sony, says that O-ROM will be a more affordable medium than CD-ROM for many publishers. Rancis heads up Sony's operations that produce 3½-in. O-ROM and MO media. He says CD-ROM production facilities have been geared toward producing hundreds of thousands of copies of a title. But Rancis also says Sony has used the experience gained in producing CD-ROMs to create smaller O-ROM production facilities. He predicts that smaller satellite O-ROM production facilities will enable publishers to use the medium cost effectively for much smaller production runs.

Partial ROM adds flexibility

The 3½-in. drives can also use a third type of medium called partial ROM. On partial ROM cartridges, some sectors are prerecorded data and others can be written to using the MO capability of the multifunctional drives. Clip-art libraries are an example of a partial-ROM application. You might buy a library of such art and add your own variations. Most industry experts predict that O-ROM and partial ROM will ultimately ensure success for 3½-in. optical drives.

So, the keys to success are in place for this new class of optical drives. And you won't find many PC or workstation users who couldn't find uses for these small drives. Therefore, drive and media price will determine how quickly the drives proliferate.

The list of manufacturers lining
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CIRCLE NO. 36
MULTIFUNCTIONAL 3¼-IN. OPTICAL DRIVES

up to produce 3¼-in. optical drives reads like a who's who of the computer-peripheral business. IBM, Most Inc, Panasonic, Ricoh, Sony, and Teac have all started shipping these small optical drives. Epson (Torrance, CA), Fujitsu (San Jose, CA), and NEC (Melville, NY) will be making the drives as well. And Mitsubishi (Torrance, CA), Olympus (Torrance, CA), and Toshiba (Irvine, CA) have manufactured optical drives and could introduce products any day now. Sony, according to most sources, has shipped more drives than any other manufacturer.

These companies don't target niche markets with their new data-storage products. Count on volume production from multiple sources for 3¼-in. optical drives. Freeman Associates reports that shipments of these drives totaled 14,600 units in 1991, but estimates that shipments will grow to 137,000 units in 1992. And volume production should soon lead to low prices.

Users want prices below $1000

Freeman's Abraham says end-user prices must drop below $1000 before the market takes off. Currently, subsystem manufacturers such as Storage Dimensions (Milpitas, CA) and PLI (Fremont, CA) offer 3¼-in. optical subsystems at retail prices ranging from $2000 to $2500. These subsystems include the optical drive, SCSI host adapter, and software. IBM introduced a drive last June both for OEM sale and for use with its PS/2 family of computers. The PS/2 add-on drive costs $1795, but that price does not include a host adapter because PS/2 computers already have one.

OEM prices have already begun to drop. IBM states the OEM price for its 3¼-in. optical drive is $803, but the drive offers considerably lower performance than others. The other five vendors shipping drives peg the OEM price between $900 and $1000 for volume purchases. A buy rate of around 3000 units per year will get you the lowest price available.

A bargain per megabyte

The MO cartridges the optical drives use cost approximately $70 each. Sony and 3M (Minneapolis, MN) will be the major name-brand providers of the cartridges. At $70, the cartridge is a bargain if you compare its cost per megabyte with that of other media. But consumers will surely demand lower prices. According to several drive vendors, other media vendors private-label cartridges for as little as $25 per cartridge now, so media prices are well on the way to being reasonable.

Deciding to use a 3¼-in. optical drive in your next system or subsystem design may be simpler than actually choosing a specific drive. Because the drives were designed to promote media interchange, manufacturers have a hard time differentiating their products via performance specs. You'll end up choosing a drive based on your vendor preference.

IBM's $803 drive spins the disk inside the cartridge at 1800 rpm, and therefore trails the other drives slightly in access time and performance. Most's drives spin at 2400 rpm; drives from the other vendors spin at 3000 rpm. Average access time for IBM's drive is approximately 70 msec. The other drives have average access times ranging from 40 to 50 msec.

Drives from IBM and Most read data at 500 kbytes/sec; drives from the other four vendors can sustain 640 kbytes/sec. All the drives write data at about one-third the read-data rate because MO technology requires erase, write, and verify passes on write operations. Vendors gearing up to enter the market might boost performance even more.

All of the drives use SCSI as a host interface. Both Teac's OD-3000 and Panasonic's LF-3000 include a 128-kbyte buffer compared with the 64-kbyte buffers on the other drives. The larger buffer should boost performance, although you can't discern the improvement on a spec sheet.

The drives all use 3¼-in. media but don't all fit in the standard 3¼-in. form factor. For example, the RMD-5100 and RMD-5200 drives from Most require a half-height 5¼-in. mounting slot. The rest of the drives meet the 3¼-in. form factor in the 41.3-mm height and 101.6-mm width dimensions, but only Teac's OD-3000 and Ricoh's Transporter stay within the 146-mm
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depth spec including the SCSI controller. However, many computer cases can provide the extra depth some drives require.

**Higher capacity emerges**

Most Inc has broken from the pack by including what the company calls a “Free Format” mode in its RMD-5200 optical drive. This mode enables the drive to store 256 Mbytes on a cartridge—standard cartridges store 128 Mbytes. Most has preproduction units available and expects the drive to cost about $1300 in OEM volumes. The drive requires special cartridges to attain the large storage capacity, but also maintains full read/write compatibility with standard cartridges.

Some industry participants are uneasy about Most’s higher-capacity product, which doesn’t conform to a standard. These people are especially concerned because higher-capacity 3½-in. optical drives are still in the developmental stages and are a product class dependent on standardization. Jeff Segers, vice president of marketing at Most, says the company does not intend to upstage the standards effort, but rather produced the product in response to customer demand.

The ANSI and ISO committees are committed to defining standards for doubling and tripling the 128-Mbyte storage capacity of 3½-in. optical media. But onlookers report that agreement on a 256-Mbyte standard is probably a year away. The efforts of the standards committees might hold the last key for the long-term success of 3½-in. optical drives. Standards are absolutely necessary to make these drives widely accepted. Unfortunately, standards also slow the introduction of new technology into the marketplace.
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Solid-state relays meet requirements and handle demanding applications

TOM ORMOND, Senior Technical Editor

The solid-state relay (SSR) has not totally supplanted the older electromechanical relay and probably never will. But many design engineers are finding that optically coupled MOSFET SSRs provide the leading-edge technology needed to handle the demands of the telecommunications world and meet UL, CSA, VDE, and FCC requirements.

SSRs can switch both resistive and inductive loads at voltage levels ranging from millivolts to hundreds of volts. The devices suit modem switching, central-office equipment, communications equipment, data-access arrangements, and industrial control applications.

In the telecommunications area, the trend is toward SSRs with very low on-resistance, low drive current, and surface-mount packaging. In industrial control, SSRs are achieving higher surge-current ratings, zero-crossing detection, and higher blocking voltages. As the number of SSR sources increases and size and prices decrease, the devices should find their way into more industries.

SSRs have an impressive list of advantages compared with electromechanical relays. SSRs have lives as long as tens of millions of operations and outlive electromechanical relays by about a hundred thousand operations. The switching speeds of SSRs are measured in microseconds and sometimes nano-seconds. These speeds are 6 to 1000 times faster than electromechanical relays' switching speeds. SSRs require minimal maintenance and are immune to shock, vibration, and environmental problems. Most are logic compatible and are not plagued by EMI or RFI problems. The solid-state relay has no contact bounce, arcing, or chattering problems—in fact, there is no audible noise problem at all. Finally, the SSR is the best choice in applications involving explosion hazards because it doesn't suffer from arcing.

However, the SSR also has some drawbacks. For one, an SSR can cost a good deal more than an electromechanical relay. Military-grade SSRs can cost $100 each. Secondly, the SSR has a nominal voltage drop when the output switch is closed or on—the output switch is not a perfect short circuit. As a result, the SSR can generate heat, which you must take into consideration when laying out your pc boards.

Unlike electromechanical relays, SSRs have leakage current. In the off state, the output of an SSR isn't a true switch.
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SOLID-STATE RELAYS

open circuit—there's always some leakage current flowing in the output switch. In high-power SSRs, this leakage current can be significant, reaching tens of milliamps.

Finally, the SSR does not offer the same variety of switching functions typically available in electromechanical relays. For the most part, SSR configurations are restricted to single or dual Form A (spst NO) or Form B (spst NC) configurations.

When you add up the pros and cons, the bottom line usually favors the SSR. Table 1 illustrates the capabilities of some of today's SSRs. As you can see from the data, you should have little trouble finding a relay to handle your load's requirements. The numbers also highlight the fact that SSR input circuitry is indeed logic compatible. Today's SSRs are reasonably priced and have wide operating ranges.

Small size is also a key feature of today's relays. The smaller DIP housing has become more popular than the standard hockey-puck package. Also, more relays are available in surface-mount packages.

Gordos Inc has followed the miniaturization trend with its GSAC-01 solid-state relays. These units are housed in a SIP (single in-line package) that measures 0.7 x 1 x 0.18 in. The devices offer a 12 to 240 V ac output rated at 2 A rms at a 25°C ambient temperature. The relays feature zero-voltage turn-on, 3750 V ac optical isolation, and 10-mA dc input sensitivity.

Photo-MOS relays from Aromat are the result of combining photo-electric technology with MOSFET technology. The relays have some of the features of solid-state relays such as long life, high reliability and sensitivity, and quiet operation, but also provide some of the benefits associated with electromechanical relays.

In standard SSRs, the input signal is transferred via an LED to a photocell and then output through a triac or other solid-state device. Standard SSRs are primarily used to control comparatively large power loads—typically in excess of 1 A—and they have problems handling signals less than 100 mA because of high leakage-current ratings and distortion problems caused by offset-voltage ratings.

The Photo-MOS relays operate as follows: Current flowing to the input terminals activates an LED. Emissions from the LED pass through a transparent material to a photocell, which converts the light into a voltage. This voltage passes through the MOSFET gate-controlling circuit to the relay output. Standard SSRs require a power supply to drive the output MOSFET. In the case of the Photo-MOS relays, the built-in photoelectronic device makes the supply unnecessary.

Table 1—Representative solid-state relays

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Load current (A)</th>
<th>Load voltage (V)</th>
<th>Control input (V)</th>
<th>Leakage current (mA)</th>
<th>Operating Range (°C)</th>
<th>Price</th>
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</table>
SOLID-STATE RELAYS

Aromat's solid-state relays suit applications involving high packing densities. The relays measure 4.4 x 6.3 x 2 mm and are available in 1 Form A and 1 Form B contact arrangements. They feature a 1-µV offset-voltage specification, which lets the units provide distortion-free control of 0.1A/400V signals. The maximum on-resistance is 50Ω at 400V, and the switching speed is 0.25 m sec.

Let's get smaller

The LBA Series devices from C P Clare are one Form A and one Form B relay combined in a miniature 8-pin DIP. This pair of independent relays have enhancement- and depletion-mode MOSFETs as the output elements.

The LBA devices can provide a normally closed and normally open switch combination even if you apply no bias or external power. This capability makes the devices ready replacements for bulkier electromechanical relays. The LBA relays suit a wide range of applications in telecommunications, data acquisition, and instrumentation. The units are compatible with CMOS logic levels, so they eliminate the need for driver-buffer circuit components. The units are available in through-hole and surface-mount housings. They feature a 3750V rms input-output isolation rating and come with UL, BS415, and BS6301 approvals.

The AT&T LH1500 family of high-voltage relays mirrors the trend toward smaller, faster, and more reliable SSRs. The line includes 21 products that cover the most common contact configurations: Form A, Form B, Form A/Form B, Form C (spdt), dual Form A, and dual Form B.

The Series 1500 relays employ a GaAlAs LED for actuation control and an integrated monolithic die for the switch output. The die is fabricated in high-voltage, dielectrically isolated BCDMOS (bipolar complementary double-diffused MOS). The die includes a photodiode array, various switch-control circuitry, and DMOS (double-diffused MOS) switches.

Some of the AT&T relays employ current-limiting circuitry, which enables the units to pass FCC and other regulatory voltage-surge requirements. And with a 3750V rating, the relays also meet or exceed domestic and international standards for input-output isolation. The Form A/B relays have integral make-before-break circuitry, which eliminates the need for additional timing logic and provides a true Form C switching function.

You can configure all units in the line for ac-dc or dc-only operation.

Dissipating heat is key to SSR design

Excessive heat remains the greatest enemy of semiconductors. Power semiconductors are especially at risk. Because transients add to the high power already being dissipated, power devices require additional design considerations. In the case of solid-state switches, the package's ability to distribute and dissipate heat is often the limiting performance factor. To gain insight into this design problem, look at the way C P Clare Corp designs its SSRs.

SSRs from Clare include three major circuits: an input drive circuit, conversion circuitry, and the output circuitry. The drive circuit must provide a reliable means of converting input drive power to infrared light. This light activates the conversion circuitry, which is an integrated array of photovoltaic devices. The conversion circuit generates the voltage needed to control the two output MOSFETs.

The output-drive MOSFETs handle high power, so they generate heat. In addition, the MOSFETs must provide the relay with its overall characteristics—speed, along with current and voltage specifications.

The Clare design employs four chips to achieve these objectives. One chip contains the input-drive circuitry. The second chip converts light to voltage, and the remaining two chips are the output MOSFETs. The first two chips are optically connected with a material that transfers light without transferring heat. Neither of these chips is exposed to the self-heating effect of the output circuitry. Each of the four chips is mounted on an extension of the package lead frame. Each extension serves as an individual heat sink to remove the generated heat.

EDN Technology Update
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SOLID-STATE RELAYS

Packaging options include 6-pin DIPs and surface-mount gull-wing housings.

Shrinking innards
Surface-mount-technology assembly let Grayhill Inc rate its Mini Puck SSR at 25A even though the unit is about half as high as a standard hockey-puck package. The size reduction has no effect on the device's operating life or efficiency ratings. In fact, the design lends itself to better thermal management in the power-switching and input-control sections of the relay. The unit has a mounting footprint identical to that of a standard hockey-puck package, so you can interchange the two units with no problems.

The Mini Puck relay’s 250A surge-current rating and 0.4 min power-factor circuit design lets it easily switch motor and inductive loads. Output-circuit characteristics include transient protection, a 400 or 600V blocking-voltage rating, and a dV/dt of 3000V/µsec. Low voltage-offset characteristics minimize line-interference problems. The Mini Puck relays are optically isolated and logic compatible and require no additional driver circuitry.

Using surface-mount components lets Potter & Brumfield house its OACM-UJ solid-state relays in a pc-board-mountable module that measures 0.37 x 1.7 x 1 in.—somewhat small for a 6A device. The relays are UL recognized and CSA certified and meet VDE requirements. The OACM-UJ relays incorporate a dV/dt snubber network across the output. This network protects the relay against false triggering by restricting the rise of most voltage transients within acceptable limits. The relays are available in zero-voltage and random-turn versions. Both versions...
Experience the advantages of CP Clare Solid State Relays

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- Small 6 & 8 pin mini-DIP packages
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- UL recognized/BSI certified
- Surface mount and Tape/Reel available

Industrial Control
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- Low drive current, 5 mA
- Zero-crossing detection
- Superior noise immunity with compliance to NEMA IC's 2-230 "Showering Arc Test"
- UL, VDE approval
- UL508 "1A Pilot Duty"

For free samples, literature and pricing, call Linda Taylor - ext. 220
Tel: 617-246-4000 Fax: 617-246-1356

CP Clare Corporation
Solid State Products Division
8 Corporate Place
107 Audubon Road
Wakefield, MA 01880
Tel: 617-246-4000 Fax: 617-246-1356

CIRCLE NO. 44
SOLID-STATE RELAYS

feature 4000V rms input-to-output optical isolation.

Teledyne screens its LD SSRs to MIL-R-28750 and packages them in low-profile hermetically sealed cases. The relays feature floating power-FET outputs. This technology lets you connect the load to either output terminal and provides a low on-resistance. The input and output are optically isolated to protect input logic circuits from output transients.

LD Series relays are available with options such as short-circuit and current-overload protection, which provides complete protection for both the relay and the system within. In addition to providing protection when a short or overload occurs when the relay is on, the circuitry also provides protection should the relay be switched into a short.

An output status line is another option. The line indicates the status of the output switch and is optically isolated from the load. Status indication is independent of the relay control circuitry. The status line provides a logic low when the relay output is off and load voltage is present, and a logic high when the relay output is on.

Designers of industrial lighting, heating, motor control, or other high-load-bearing systems will find that the 575D45-12 relay from Opto 22 delivers all the transient voltage protection they need. The three models can handle power voltages ranging to 277, 480, and 575V, and all three combine high-current capacity (45A) and high-voltage (2000V) transient protection in a single package.

The extended protection the 575D45-12 relay provides lets designers maintain an adequate margin of operational safety while eliminating the need for additional external protective components. The transient-proof relay can actually help designers lower overall end-product costs.

The relay is TTL compatible. It features 4000V optical input-to-output isolation, zero-voltage turn-on, built-in snubber circuitry, and a rugged encapsulated housing that has a die-cast mounting base.

A SIP measuring 0.7 x 1 x 0.18 in. houses the GSAC-01 relay from Gordos Inc. The relay can switch 2A at 12 to 240V ac loads and features zero-voltage turn-on and 3750V ac optical isolation.

Article Interest Quotient
(Circle One)
High 473 Medium 474 Low 475

ASK EDN

Have you been stumped by a design problem? Got too many bugs in your software? Can’t interpret a spec sheet? Ask EDN.

The Ask EDN column serves as a forum to solve nagging problems and answer difficult questions. EDN’s editors will provide the solutions. If we can’t solve a problem, we’ll find an expert who can, or we’ll print your letter and ask your peers for help.

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SPEED

ProTracer is fast and quiet because it uses the latest inkjet technology and an Intel i960 processor. Just compare it to any other large format plotter and you’ll see. A complex C-size drawing often takes over half an hour on a pen plotter, while ProTracer completes the same drawing in only five minutes!

HIGH QUALITY OUTPUT

ProTracer achieves its high quality output by utilizing a 64 nozzle printhead to deliver crisp lines and bold, high contrast blacks. Its 360 dpi resolution assures sharp lines needed for everything from the most complex engineering drawings to sophisticated text and graphics used in letters and reports.

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Unlike other large format devices, ProTracer isn’t limited to plotting. Instead, it can produce high quality finished output for a variety of
applications including word processing, spreadsheets, and desktop publishing. Start with the ProTracer base unit that incorporates resident IBM ProPrinter and Epson LQ-1050 emulations, as well as an ADI plotter driver for AutoCAD users. Then, depending on your needs, choose from a variety of easily installable upgrades and accessories including HP-GL and PostScript® language emulations, and memory.

**Optional Printer Accessories**

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<tr>
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<td>(AppleTalk interface module)</td>
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*Sheet feeder I is required for use

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The EDN sponsored "traveling trade show" hits the road again this spring. This modern version of the trade show delivers "hands on" working exhibits directly to the engineers' business doorstep. Over 100 leading electronic equipment manufacturers across the country will host the EDN Caravan Show on-site. Factory and local experts will staff exhibits on-board the customized mobile showroom. In a matter of minutes, engineers can watch or operate demos, ask questions and learn about up-to-the-minute product developments.

Check EDN Caravan Show schedule and mark your calendars now for the date we visit your company. Make it a point to attend this unique electronics exhibit and look for the suppliers listed here. (Schedule subject to change.)
| DATE      | TIME          | LOCATION                                      
|-----------|---------------|-----------------------------------------------
| 3/16      | 9:00-11:00    | BOEING HUNTSVILLE                            
| Monday AM |               | 499 Boeing Blvd., Huntsville, AL              
| 3/16      | 12:30-2:30    | INTERGRAPH CORPORATION                       
| Monday PM |               | Intergraph Way, Huntsville, AL                
| 3/17      | 8:30-10:00    | ACUSTAR INC.                                 
| Tuesday AM|               | 100 Electronics Blvd., Huntsville, AL         
| 3/17      | 11:00-12:30   | AVE X ELECTRONICS                            
| Tuesday AM-PM |           | 4807 Bradford Drive, Huntsville, AL          
| 3/17      | 1:30-3:30     | TELEDYNE BROWN ENGINEERING                   
| Tuesday PM |               | 5021 Bradford Blvd., Huntsville, AL          
| 3/18      | 9:00-11:00    | SCI TECHNOLOGY (Plant 3 & 13)                
| Wednesday AM |            | 13000 So. Memorial Parkway, Huntsville, AL   
| 3/18      | 12:30-2:30    | SCI TECHNOLOGY (Plant 1)                     
| Wednesday PM |           | 8600 S. Memorial Parkway, Huntsville, AL     
| 3/19      | 1:00-3:00     | BNR/NORTHERN TELECOM                         
| Thursday PM |             | 705 Westch Drive, Norcross, GA               
| 3/20      | 9:00-10:00    | OKI TELECOM GROUP                            
| Friday AM |               | 437 Old Peachtree Road, Suwanee, GA          
| 3/20      | 12:30-2:00    | RELIANCE ELECTRIC                            
| Friday PM  |               | Collins Industrial Blvd., Athens, GA         
| 3/23      | 9:00-10:30    | NCR CORPORATION                              
| Monday AM |               | 7240 Moorefield Hwy., Liberty, SC             
| 3/23      | 1:00-3:30     | NCR CORPORATION                              
| Monday PM  |               | 3325 W. Platt Springs Rd., W. Columbia, SC    
| 3/25      | 8:30-11:00    | AT&T PARADYNE CORPORATION                     
| Wednesday AM |           | 8545 126th Avenue N., Largo, FL              
| 3/25      | 1:00-3:00     | GROUP TECHNOLOGIES CORP.                     
| Wednesday PM |           | 10801 Malcolm McKinley Dr., Tampa, FL        
| 3/26      | 9:30-12:00    | HONEYWELL, INC., Avionics                     
| Thursday AM |             | 13350 US Highway 19 So., Clearwater, FL      
| 3/26      | 1:00-3:00     | SMITHS INDUSTRIES, Aero. & Defense           
| Thursday PM |             | 14180 Roosevelt Blvd., Clearwater, FL        
| 3/27      | 8:30-11:00    | E-SYSTEMS, INC., ECI Div.                    
| Friday AM |               | 1501 72nd Street N., St. Petersburg, FL      
| 3/27      | 1:00-2:30     | LORAL DATA SYSTEMS                           
| Friday PM  |               | 6000 Fruitville Road, Sarasota, FL          
| 3/30      | 9:00-11:00    | RACAL-DATACOM, INC.                          
| Monday AM |               | 1601 N. Harrison Parkway, Sunrise, FL        
| 3/30      | 12:30-3:00    | MOTOROLA INC.                                
| Monday PM |               | 8000 W. Sunrise Blvd., Plantation, FL        
| 3/31      | 8:30-10:30    | BENDIX/KING, Air Transport Avionics          
| Tuesday AM |             | 2100 N.W. 62nd Street, Fort Lauderdale, FL   
| 3/31      | 12:30-3:00    | IBM CORPORATION                              
| Tuesday PM |               | 1000 N.W. 51st Street, Boca Raton, FL        
| 4/1       | 8:30-10:00    | ROCKWELL INTL., Collins Aviation             
| Wednesday AM |           | 600 John Rodes Blvd., Melbourne, FL          
| 4/1       | 11:00-1:00    | HARRIS CORPORATION, ESD                      

| DATE      | TIME          | LOCATION                                      
|-----------|---------------|-----------------------------------------------
| Wednesday AM-PM |          | Palm Bay Road, Palm Bay, FL                   
| 4/1       | 2:30-4:00    | GRUMMAN MELBOURNE SYSTEMS                     
| Wednesday PM |             | 2000 NASA Blvd., Melbourne, FL               
| 4/2       | 9:00-12:00   | MARTIN MARIETTA CORP., ESD                   
| Thursday AM |             | 12506 Lake Underhill Road, Orlando, FL       
| 4/2       | 1:30-3:30    | MARTIN MARIETTA CORP., MSD                   
| Thursday PM |             | 5600 Sand Lake Road, Orlando, FL             
| 4/3       | 9:00-11:00   | SIEMENS STROMBERG-CARLSON                    
| Friday AM |               | 400 Rinehart Road, Lake Mary, FL             
| 4/3       | 1:00-3:00    | GENERAL ELECTRIC, Simulation & Control       
| Friday PM  |               | 1800 Volusia Avenue, Daytona Beach, FL       
| 4/6       | 9:00-11:30   | IBM CORPORATION                              
| Monday AM |               | Research Triangle Park, RTP, NC              
| 4/6       | 12:30-2:00   | NORTHERN TELECOM, INC./BNR                   
| Monday PM  |               | 4001 E. Chapel Nelson Hwy., RTP, NC          
| 4/6       | 2:45-4:15    | NORTHERN TELECOM, INC.                       
| Monday PM  |               | 400 Perimeter Park Dr., Morrisville, NC      
| 4/7       | 9:00-11:00   | ALCATEL NETWORK SYSTEMS                      
| Tuesday AM |             | 2912 Wake Forest Road, Raleigh, NC           
| 4/7       | 1:30-4:00    | AT&T TECHNOLOGIES, Guilford Center           
| Tuesday PM |             | Mount Hope Church Rd., McLeanesville, NC    
| 4/8       | 9:00-11:00   | GENERAL ELECTRIC COMPANY                     
| Wednesday AM |           | 1501 Roanoke Blvd., Salem, VA                
| 4/9       | 9:00-11:00   | ERICSSON/GE Mobile Communications            
| Thursday AM |             | Mountain View Road, Lynchburg, VA            
| 4/9       | 12:30-2:30   | SPERRY MARINE, INC.                          
| Thursday PM |             | Route 29 North, Charlottesville, VA          
| 4/10      | 8:30-11:00   | GE FANUC AUTOMATION NA, INC.                 
| Friday AM |               | US 29 & Rt 606, Charlottesville, VA         
| 4/10      | 12:30-2:30   | E-SYSTEMS, INC., Melpar Div.                 
| Friday PM  |               | 7700 Arlington Blvd., Falls Church, VA       
| 4/13      | 9:00-10:30   | E-SYSTEMS, INC., Melpar Div.                 
| Monday AM |               | 11225 Waples Mill Road, Fairfax, VA          
| 4/13      | 1:30-3:30    | PULSECOM INC.                                
| Monday PM  |               | 2900 Towerview Road, Herndon, VA             
| 4/14      | 9:00-10:30   | LITTON SYSTEMS, Amecom Div.                  
| Monday PM  |               | 5115 Calvert Road, College Park, MD          
| 4/14      | 11:30-2:00   | FAIRCHILD COMM. & ELECTRONICS                
| Tuesday AM |             | 20301 Century Blvd., Germantown, MD          
| 4/14      | 9:00-12:00   | HUGHES NETWORK SYSTEMS, INC.                 
| Tuesday AM-PM |           | 11717 Exploration Lane, Germantown, MD       
| 4/15      | 9:00-12:00   | WESTINGHOUSE CORPORATION (BWI)               
| Wednesday AM |           | Route 170, Linthicum, MD                     
| 4/16      | 9:00-11:00   | ALLIED SIGNAL AEROSPACE                      
| Thursday AM |             | 1300 E. Joppa Road, Baltimore, MD            
| 4/16      | 12:30-2:30   | AAI CORPORATION                              
| Thursday PM |             | 110 Industry Lane, Cockysville, MD           

CIRCLE NO. 157
NICE and simple math exposes the myth of ST-NIC.

It doesn't take a mathematical wizard to see the superiority of the NICE® Ethernet solution from the Advanced Products Division of Fujitsu Microelectronics. We think the numbers speak for themselves.

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4-Mbit DRAM integrates SRAM cache for 10-nsec cache-hit access

The greatest drawback to cache-memory subsystems is their miss penalty—that is, the time required to fill the cache with new data from main memory. The M5M44409TP cached dynamic RAM (CDRAM) reduces that penalty to a single 70-nsec access by integrating a 4k x 4-bit static-RAM (SRAM) cache with a 1M x 4-bit dynamic RAM (DRAM).

The SRAM has an access and cycle time of 10 nsec. The DRAM array has a 70-nsec access with a 140-nsec cycle time. The two memory blocks connect internally through a 64-bit bus, allowing the cache to receive a block of 16 lines with a single DRAM access. The device, therefore, can return data in 10 nsec during a cache hit and 70 nsec during a cache miss.

The internal data path has two 64-bit data-transfer buffers that let an external controller device use a fast copy-back operation to maintain coherency between the two memory blocks. When a cache miss occurs, the CDRAM transfers the cached block being replaced into one data buffer while the new data from the DRAM moves into the second buffer, then into the cache.

If the data in the first buffer is "dirty," meaning it was altered while in the cache, the external controller can then have the CDRAM copy the new data back into the DRAM array. Because the CDRAM has separate address buses for the two memory blocks, this copy-back operation can occur concurrently with subsequent cache accesses, hiding most of the DRAM's cycle times. In the worst case of back-to-back cache misses, the cycle time would be 280 nsec.

The CDRAM is a synchronous device with several modes of operation. It uses registered input lines, but, by programming various command registers, you can select transparent, latched, or registered output operation at the device's full 100-MHz clock speed. You can also select a transparent-output, low-power mode that lets you use an intermittent clock to control the device.

Write operations to the device can also take on several forms. The data input and output lines are separate, allowing you to begin a write cycle while the read data is still available. Alternatively, you can use the separate data lines to perform a masked write to the device.

The CDRAM comes in a 44-pin TSOP (thin small-outline package) with an 0.8-mm lead pitch. Samples will be available in the second quarter; production is scheduled for the third quarter. Three speed grades are available with cache access times of 10, 15, or 20 nsec. Initial pricing is $16.20, $15.50, and $15, respectively (100).

—Richard A Quinnell
Mitsubishi Electronics America Inc, 1050 E Arques Ave, Sunnyvale, CA 94088. Phone (408) 730-5900. FAX (408) 720-0429.
High-power electromechanical and audio applications can literally get a boost from the PA05 power op amp. The 250W device operates with power-supply voltages to 100V and can source or sink as much as 30A. Further, the amp has a 100V/µsec slew rate and exhibits less than 0.02% THD operating at 200W over a 30-Hz to 30-kHz frequency range. The device has a 360-kHz power bandwidth and at dc the amp exhibits an open-loop gain of at least 94 dB. The device costs $189 (100).

Several features let this amplifier safely operate at high power levels. Because the amp is designed for very high power applications, it offers a 4-wire current-sensing technique to limit the output current. Two current-sensing pins on the amp connect to a current-sensing resistor that you place in series with the load circuit. Because the amp’s output and ground pins are not used as the sense inputs, this approach eliminates sensing errors that can be created by the parasitic series resistances of sockets and solder joints at high-output power levels.

The amp also provides a voltage-boost feature that lets you run the lower-powered input stages from a higher power supply voltage. An additional 5V of supply voltage for the input stage lets the amp’s output swing closer to the output stage’s supply rails, to the saturation point of the output transistors. You can also run the amp from one set of supply voltages by busing the input- and output-stage power pins together.

Thermal-limiting circuitry in the amp shuts down the output stage when junction temperatures exceed 175°C. In addition, you can use an external signal to disable the op amp’s output stage by shunting the device’s shutdown pin to ground.

—Steven H Leibson
Apex Microtechnology Corp, 5980 N Shannon Rd, Tucson, AZ 85741.
Phone (602) 742-8600. FAX (602) 888-3329. TLX 170631. Circle No. 730
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In fact, depending on the amount and nature of processing you do, high-performance drives like these can save you enough to pay back your disc drive investment within weeks—or days. For help in selecting the drive you need, or for more information about any Seagate drive, call Seagate at 408-438-6550 or contact your authorized Seagate distributor.

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Enhanced 8051 delivers secure operation and protects software

Dallas Semiconductor's DS5002FP µC (microcontroller) offers security for a range of applications such as electronic-fund transfer, ATMs (automatic teller machines), secure pay services (cable TV), point-of-sale applications, and electronic locks.

The DS5002FP incorporates the 8-bit 8051 microcontroller (µC) with modifications for secure operation. The architecture supports the public data-encryption-standard (DES) algorithm, holding a 64-bit encryption key in secure memory. Using the 64-bit key, the µC encrypts both memory contents and addressing. Thus, an application can use external RAM or ROM and remain protected from exposing system operation to bus monitoring.

The system's other security features include random key generation, a vector RAM area that hides reset and interrupt vectors from tampering, a security lock, and a built-in self-destruct that wipes out memory and internal keys if tampering occurs. In addition, the chip die is protected with a metallic-die layer that prevents microprobing.

To ensure an orderly shutdown, power-monitoring features provide an early warning of power failure. The chip also includes a watchdog timer to detect runaway code or operation timeouts.

A key feature of the DS5002FP is a form of limited memory and address encryption—not full DES encryption, however, which reduces memory-operation speed. Bus activity is scrambled using nonsequential addresses with scrambled data. The running processor makes dummy fetches to confuse bus monitoring; it pretends to fetch program code from a random address, but the code isn't used. As a result, a code pirate can't trace application execution by using a bus analyzer or dumping an EPROM.

The DS5002FP is a second-generation encryption chip; this version has extended the internal address encryption key from 40 to 64 bits. Also, this chip's memory addressing has been opened to 128 kbytes of data and instruction memory.

The chip also comes in a single in-line memory module (SIMM) called the DS2252(T) Secure Mikrostik. The module integrates the DS5002FP with as much as 128 kbytes of SRAM, a lithium battery cell, and an optional real-time clock. The SIMM provides nonvolatile system memory with easy reprogramming. Battery life is more than 10 years.—Ray Weiss

Dallas Semiconductor Corp,
4401 S Beltwood Pkwy, Dallas, TX 75244. Phone (214) 450-0400. FAX (214) 450-0470.

Circle No. 732

Security demands more than an EPROM; this chip combines an 8051 with program and data encryption. It uses a random 64-bit key to encrypt data. Program addresses are encrypted and randomized, preventing bus analysis.
Kit simulates 8-bit processor and links to target-board I/O

Simulation has never done well in the 8-bit microcontroller (µC) world. One reason for this failure is the chasm between the simulated processor and board and system hardware. Motorola’s 68HC05K Designer’s Kit includes an in-circuit simulator that accommodates low-end 8-bit µCs. With the kit, users can simulate code running in a host PC. At the same time, the code can read and write I/O pins on the target board’s µC socket.

The kit includes a circuit board or pod, a cable, and PC-based application development software. The software tools are integrated in a windowed development environment with a common debugger interface. They include a circuit simulator, a source-code debugger, an editor, an assembler, and a communications program to drive a ROM monitor-based µC. The pod plugs directly into the host PC’s parallel port and has a programmer to burn in 68HC05K code.

Also in the kit are the tools needed to build and debug a 68HC05K application. You can write the code with the editor, assemble it, simulate the code to catch the early bugs, and then run the code in a target under host control.

The in-circuit simulator represents a unique approach to simulation-based debugging. It overcomes limitations of software-only simulation by allowing simulated code to interface to the target-board hardware. Users benefit from a controlled simulation environment because they can update their code without having to burn in new chips or download code. At the same time, users don’t have to build software models of the surrounding hardware: They can interface directly to it.

There is, however, a price to pay for simulation: code execution and debugging takes place at simulation, not processor rates. The simulated clock rate of a 20-MHz 386 host CPU is roughly 59 kHz; it is 118 kHz for a 33-MHz 486.

Application code executes in the in-circuit simulator on the PC host, which simulates 68HC05K CPU execution. The simulated application code links directly to the target board via the PC’s pod at the parallel port. This pod has its own µC, a 68HC05J1, which interfaces to a 25-pin cable and header that, in turn, plugs into the target board’s 68HC05K socket. The software also runs without a target board.

The simulated code generates application program outputs and passes them through the parallel port to the pod processor. The 20-bit packets carry data between the pod and simulator via a serial duplex channel. The pod’s µC decodes the packets, setting the appropriate output pins. For inputs, the pod processor monitors target-µC socket-input pins. Changes are picked up, placed in a packet, and shipped to the simulator for processing. Approximately 400 bytes of code are needed in the pod µC to monitor and drive the target-board I/O pins.

P&E Microcomputer Systems Inc (Woburn, MA) designed the Developer’s Kit for Motorola. It will be available in April from Motorola distributors for approximately $50.

—Ray Weiss

Motorola Microprocessor Products Group, 6501 William Cannon Dr, W Austin, TX 78735. Phone (512) 440-2000.

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Pipelined DSP combines 16-bit data with 32-bit instructions

Sixteen-bit DSP processors are a source of cheap, embedded MIPS. DSP CPUs support high throughput, math-intensive processing via built-in mechanisms for table walking, and multiply/accumulate operations. NEC's 16-bit DSP, the µPD77016 SPX, runs at an internal 33 MHz, delivering 30-nsec pipelined execution for high-throughput processing. SPX, according to NEC engineers, does a complex 1024 x 1024 FFT in 2.1 msec.

SPX has a true Harvard architecture, separating data and instruction memory. It combines 16-bit data paths for mid- to low-end DSP processing with 32-bit instructions for fast processing (fixed instruction length, three operand operations). Memory interfaces include one for instructions and one for data. The SPX supports two 64k-word data spaces (X, Y memories) and a 64k-word (double word) instruction space.

This DSP features a set of eight general-purpose registers, improving earlier accumulator-based designs. The processor supports 40-bit operands internally. The adder, multiplier, registers, shifter, and internal data paths are all 40 bits wide. These 40 bits comprise lower and higher 16-bit words and an extended byte. The DSP chip supports 16-, 32-, and 40-bit extended data types. For the 40-bit word, the sign

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This 16-bit DSP, the SPX, supports complex processing and has a 32-bit instruction with as many as three operands. The chip's architecture contains dual addressing engines, loops, and a 40-bit multiply/accumulate unit.

86 • EDN March 16, 1992
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50-MHz DSP chip draws 10 µA in power-down mode

Sixteen-bit, fixed-point DSP processors offer a high performance-to-price ratio for math-intensive, embedded applications. The TI TMS320C25’s $16 (10,000) price tag, however, complements a 100-nsec instruction-cycle time and 8 kbytes of on-chip program memory.

The TMS320C25 low-power DSP processor has an internal power-down mode with a backup for the 534 bytes of internal RAM. In power-down mode, supply current drops to 10 µA typical, compared with 50 mA for the TMS320C25.

Power-down mode adds three pins to the processor’s I/O: a non-maskable interrupt pin (PDI) to initiate the power-down sequence; a power-down interrupt acknowledge (PDACK); and a power-down reset (WAKEUP). A memory-mapped register, PDC, is added for power control at address 0006H. In addition, two interrupt vector entries are added for the PDI and WAKEUP interrupts.

The TMS320C25/28 second-generation DSP processor has a specialized architecture with distinct data- and program-processing areas. The data portion has a built-in 32-bit multiply/accumulate (MAC) unit fed from an internal data bus. The processor has two data RAM blocks (288 x 16 bit and 256 x 16 bits) and a set of eight auxiliary data registers to supplement the 32-bit accumulator. The data segment handles a multiply/accumulate in a single cycle.

TI is upgrading other members of its TMS320 family DSP processors. Among the new chips is the TMS320LC16, a 3.3V version of the TMS320C16 DSP controller. Chip
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CIRCLE NO. 51
supply voltage can range from 3.0 to 3.6V, with 3.3V typical. The external-clock rate ranges from 4.0 to 16.1 MHz. The TMS320C16 has 256 words of on-chip RAM, 8k words of program ROM (64k words off-chip address space), and a 114-nsec instruction-cycle time. The chip costs $7.60 (10,000).

The TMS320C53 is an upgrade to the TMS320C5x series of 16-bit, fixed-point DSPs with 35- and 50-nsec instruction-cycle times. The TMS320C53 expands on-chip program ROM to 16k words (32 kbytes), from 8k words for the TMS320C51. The TMS320C53 has 4k words of on-chip RAM, organized as 1056 words of dual-access RAM and 3072 words of single-access RAM. The single-access RAM can be configured as program or data. The chip costs $54 (10,000).—Ray Weiss

Texas Instruments Inc., Application-Specific Products Div, Box 1443, Houston, TX 77001. Phone (713) 274-2340. Circle No. 735

8051 derivative kicks clock rate to 22 MHz

Microcontroller (µC) applications such as 1.8-in. hard-disk controllers, tape controllers, and PCMCIA (PC Memory Card Interface Association)-based modems can benefit from the 83C154, a 16-kbyte version of the 8051, crammed into a 1.1-mm-high thin quad flatpack (TQFP).

The TQFP’s height, including lead space, is 1.1 mm ±0.2 mm. In contrast, a standard plastic leaded chip carrier’s (PLCC) height is 4.35 mm, and a quad flatpack’s height is 1.5 mm ±0.25 mm. The TQFP provides an extremely low profile, suiting height-critical applications. Lead pitch is 0.8 mm with 0.35-mm leads. For example, TQFP chips enable board circuits to meet the stringent PCMCIA standards for plug-in memory and peripheral cards for PCs.

The 83C154 is an enhanced version of the 8051 µC family. ROM based, it has 16 kbytes of program ROM and 256 bytes of data RAM. And, similar to the 80951, it supports a dual 64-kbyte address space for program and data memory.

The µC is a static design and has power-management functions with a power-down maximum current of 50 µA. At 12 MHz, the 83C154 is approximately a 1-MIPS processor, with a minimum instruction cycle of 1 µsec.—Ray Weiss

Oki Semiconductor, 785 N Mary Ave, Sunnyvale, CA 94086. Phone (408) 720-1900. FAX (408) 720-1918. Circle No. 736

ICE includes source-level debugger

ICEs (in-circuit emulators) remain a key tool for engineers designing µP-based systems. Huntsville Microsystems just added a 68040-µP model to its HMI-200 series of emulators. The ICE provides real-time emulation for 68040, 68EC040, and 68LC040 µPs operating at speeds as fast as 25 MHz with zero wait states. Furthermore, the ICE includes the company’s Sourcegate high-level-language (HLL) debugger.

The emulator offers four break and trigger points that you can individually configure to respond to address, data, or status bit patterns, or to events monitored by 16 external trigger inputs. You can also set the ICE to trigger based on the occurrence of sequences of trigger events. Two 4k × 104-bit trace buffers store captured data including the 16 external trigger lines.

Two RS-232C 115.2-kbaud interfaces provide communications between the host computer and the ICE. And a parallel port can provide even faster transfers of large binary files. The units come equipped with 256 kbytes of program storage memory, and you can expand the memory array to a capacity of 1, 2, or 4 Mbytes.

The ICE hardware is closely coupled to the Sourcegate HLL debug software. You can buy versions of the product for IBM-compatible PCs, and for Apollo and Sun workstations. The Sourcegate software supports C, Pascal, and Ada compilers from most of the major compiler suppliers.

Sourcegate includes a windowed user interface that lets the operator set ICE parameters such as breakpoints or control single stepping. Code windows display your choice of assembly or HLL. And a mixed mode shows HLL statements and the corresponding assembly code. You can set other windows to monitor specific memory locations or variables including structures, arrays, and stack-relative variables.

The company also offers a performance-analysis feature as an option to the ICE. The analysis capa-
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EDN-PROCESSOR UPDATE

Testing a zero-wait-state 25-MHz 68040-based system requires an ICE, such as the HMI-200-68040, with a strong high-level-language debugger and fast hardware.

Able operability operates transparently to the system under test, and collects data in real time to create a performance profile of software execution. You can set eight code modules to be tested. The analysis software determines the time elapsed in each subroutine within a module, and the total time required for a module to execute. The analysis software can also display histograms of elapsed time for each module relative to the total time the system was under test.

The performance-analysis package also tracks which code the modules execute during a test. And the software can trigger a breakpoint when program execution leaves the bounds defined for the test. Finally, the analysis option adds a 100-nsec-resolution time stamp to data in the trace buffer, and adds four address breakpoints.

Available now, the ICE costs $25,000 for PCs and $26,000 for workstations. You can expect the company to add support for more variations of the 68040 as Motorola introduces them. The performance-analysis option costs $2500.

—Maury Wright

Huntsville Microsystems Inc, 3322 S Memorial Pkwy, Huntsville, AL 35801. Phone (205) 881-8065. FAX (205) 882-6701.

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By using state-of-the-art communications peripherals, multimedia lets you circle the globe without leaving your office. (Photo courtesy Multimedia Div of Autodesk Inc)
Multimedia offers audio and video capabilities that can revolutionize the way you design circuits, discuss concepts, and interact with colleagues. But as usual, the primary issues revolve around compatibility and standardization.

J D Mosley, Technical Editor

Although on the surface multimedia looks like a gimmick to boost sales of computer peripherals in a mature market, it is much more than that. The software components that drive this technology include programs that control hypertext interaction, audio cues and annotations, voice and music synthesis, object animation, and the creation of digital motion video. Available hardware includes CD-ROMs, audio boards, videotape players, videodisk players, and an assortment of computer-controlled musical instruments.

The most serious multimedia devotees will invest in the biggest, fastest CPUs and hard-disk drives they can afford, even though the Multimedia PC (MPC) Marketing Council's specification for a minimum configuration only calls for a 10-MHz 80286-based computer with 2 Mbytes of RAM and a 30-Mbyte hard-disk drive. However, if you are considering incorporating multimedia into an engineering environment, you will need a PC with enough power to run both your existing engineering applications and the additional software necessary to drive the animation and audio functions offered by multimedia peripherals.

One of the most vociferous companies on the multimedia bandwagon is Microsoft, the corporation that has sold more than six million copies of the Windows 3.0 graphical user-interface. Last August, Microsoft released Windows
MULTIMEDIA with Multimedia Extensions 1.0, spurring several MPC upgrade kits from some of the companies listed in Table 1.

Multimedia Windows includes a media control interface that controls such time-based media as videotape, animation, and audio. Included among the 144 new application programming interfaces (APIs) are such accessories as a sound recorder, a music box, and a media player. As of October 1991, Microsoft announced that the company had delivered 1700 Windows Multimedia Development Kits, which should soon translate into a wealth of applications. (You can obtain a copy of the MPC Titles Catalog from Glenn Ochenreiter or Jim Hassert of the MPC Marketing Council.)

Yet, you can't obtain a copy of Multimedia Windows for your existing PC without also buying hardware from a member of the MPC Marketing Council. And by agreement, the Council has stipulated that MPC upgrade kits include an audio board, a CD-ROM player, and Windows Multimedia 1.0, thus making it impossible to simply upgrade one component. Although that ensures that Multimedia Windows users will have MPC-compatible components attached to their PCs, people may balk at the limited selection currently offered. Therefore, they will simply delay their plunge into multimedia until more vendors join the Council, thus giving them more choices. If so, the Council may actually alienate the early technology adopters who are so critical in driving the demand for new products.

More than a million non-MPC audio boards have been installed in PCs. But since you can't buy an upgrade kit for the board alone, many of the people who are already dabbling in multimedia have dismissed Multimedia Windows in anticipation of Windows 3.1, which Microsoft promises will have audio support. An object linking and embedding protocol will let developers draw upon the audio services code in Windows 3.1 for integrated audio and voice annotation in their applications. A subset of Windows 3.0 with Multimedia Extensions 1.0, Windows 3.1 is currently in beta test with release scheduled for the end of the first quarter of 1992. However, if you currently use a non-MPC CD-ROM player, you won't be able to circumvent the Council because Windows 3.1 will not have CD-ROM support.

Of course, the one business computer that has always had a way with pictures and sound is the Apple Macintosh. Therefore, many of the standards issues plaguing PC users will not affect Mac users. And engineers who

Table 1—Multimedia workstations and videoconferencing systems

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Communication coverage</th>
<th>Price</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commtex</td>
<td>Multimedia LAN</td>
<td>Novell Netware LAN</td>
<td>From $78,000</td>
<td>Includes one Cx-90 hub unit and 8 sets of demultiplexers, camcorders, headsets, and speakers.</td>
</tr>
<tr>
<td>Compression Labs</td>
<td>Rembrandt</td>
<td>Wide-area; multisite</td>
<td>$4595</td>
<td>33-MHz 80386 CPU; MPC-compatible.</td>
</tr>
<tr>
<td>IBM</td>
<td>PS/2 Ultimedia M57 SLC</td>
<td>Workstation</td>
<td>$5995</td>
<td>20-MHz 80386-based CPU, 4-Byte RAM, XGA, CD-ROM, musical-instrument digital interface.</td>
</tr>
<tr>
<td>PictureTel</td>
<td>System 4000</td>
<td>Workstation</td>
<td>From $19,900</td>
<td>Low-priced videoconferencing system uses integrated dynamic echo cancellation technology.</td>
</tr>
<tr>
<td>Tandy</td>
<td>4033 LX Multimedia</td>
<td>Workstation</td>
<td>$5499</td>
<td>33-MHz 80386 CPU, 4-Byte RAM, 105-Byte IDE hard disk drive, Super VGA, CD-ROM, musical-instrument digital interface.</td>
</tr>
<tr>
<td>Videotelecom</td>
<td>Mediamax</td>
<td>Workstation</td>
<td>$34,950 to $85,000</td>
<td>Wide-area videoconferencing; based on 80386 or 80486 ISA PC, LAN compatible; graphics.</td>
</tr>
</tbody>
</table>
have relied upon Macs for test and measurement applications from such companies as National Instruments (Austin, TX) and IOtech (Cleveland, OH) will be pleased to know that Apple's latest operating system now comes with a multimedia extension called Quicktime. (See box, "How many standards can the market bear?")

Spectral Innovations' Signal Analyzer/QT lets you create video and audio animations with engineering data. You can use this program to create, compress, and play back data sets of time-sequenced information. In a typical application, a researcher who is sampling signals and displaying their frequency components on a color display in real time can compress that data and store it on disk for subsequent playback. Using a mouse, the researcher can shift between the time domain and the frequency domain to view different aspects of the data set by selecting from a variety of display options, including histograms and spectrograms.

**Sounds good to me**

However, multimedia includes sound as well as video. And although the audio capability of multimedia is one of its most potent tools, most design engineers

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**How many standards can the market bear?**

Comprising 40 software firms and 30 hardware manufacturers, the Multimedia PC (MPC) Marketing Council includes vendors such as AT&T Computer Systems, Compaq Corp, Creative Labs Inc, Fujitsu, Headland Technology, Media Vision, NEC Technologies, Olivetti, Philips, Tandy, Zenith Data Systems, and (of course) Microsoft. A subsidiary of the Software Publishers Association (Washington, DC), this council endorsed a specification in May 1991 for a standard ISA multimedia-PC platform.

The council estimates that 1.5 million PCs worldwide are upgradable candidates for meeting the MPC spec. As a minimum configuration, the spec calls for a 10-MHz 80286 CPU, 2 Mbytes of RAM, a 1.44-Mbyte 3½-in. floppy-disk drive, a 30-Mbyte hard-disk drive, a CD-ROM drive, a VGA graphics adapter, an 8-bit audio board, and a musical-instrument digital interface I/O port. This basic configuration was established in an effort to provide a low-cost entry-level machine for home and small business usage. Unfortunately, such a computer realistically lacks the power to be effective in a multimedia environment, and the council is currently reassessing its edict.

Meanwhile, Tandy has launched a line of multimedia PCs ranging from the $2799 2500 SX with a 16-MHz 80386SX CPU and a 40-Mbyte hard-disk drive to the $5499 4033 LX that sports a 33-MHz 80386 CPU and a 105-Mbyte hard-disk drive. Each of the five PCs in this family comes with the MS-DOS 5.0 operating system, Windows 3.0 with Multimedia Extensions 1.0, a Tandy CDR-1000 CD-ROM drive, and an 8-bit audio board. You have to pay an extra $400 to $629 for a VGA monitor.

**Big Blue eschews convention**

IBM, on the other hand, has elected to ignore the MPC bandwagon and has introduced its PS/2 Ultimedia Model M57 SLC. Instead of 8-bit audio, the Ultimedia has enhanced internal speakers and contains a 16-bit audio capture and playback adapter. Its digital-video-interface-compatible CD-ROM/XA has an extended architecture that Multimedia Windows can't even communicate with.

The IBM machine comes with OS/2 2.0 and Multimedia Presentation Manager and a shipping date of March 1992 for OS/2 2.0. The Ultimedia comes with an 80-Mbyte SCSI hard-disk drive and a high-density 2.88-Mbyte 3½-in. floppy-disk drive.

**It's Quicktime for Apple**

And in the Apple arena, Macintosh users receive a free operating-system upgrade with multimedia extensions for System 7.0, called Quicktime. A Mac user can now drop a Quicktime icon into the screen's System Folder to manipulate animation sequences and audio just like any other type of data. Quicktime specifies a standard way of displaying, compressing, cutting, and pasting multimedia information.

So, once again, users seem to be faced with the dilemma of selecting an off-the-shelf machine that either lacks state-of-the-art performance or lacks the massive amount of software support generated by the sheer volume of MS-DOS machines in existence. Except, this time it seems that IBM is playing the part of the nonconformist renegade, while the ISA-proponents struggle to maintain the status quo. Meanwhile, Apple continues to set its own standards and ignore the DOS world.
fail to consider its value beyond background music and sound effects. Computers have always been capable of displaying information in a visual way, but now your PC can become a vocal member of your design team by providing voice annotation capabilities and explanatory dialogue.

You can add audio to your PC by plugging one of many available sound boards into an expansion slot. The two de facto standards that software and hardware vendors have embraced for compatibility purposes are Creative Labs' Soundblaster and Adlib's sound board (also called Adlib). However, if you find that all of your expansion slots are currently occupied, you can still use a product such as ATI Technology's VGA Stereo-F/X. This ISA board not only combines 32,768-color SuperVGA graphics with 8-bit stereo sound and a musical-instrument digital interface, but even includes a Microsoft-compatible mouse port and mouse.

Ed Callway, multimedia engineering manager at ATI agrees that the value of audio in engineering applications is often overlooked. "Adding sound to PCs brings users closer to real-world experiences—audio cues are just as important to people as video cues and tasks that include any kind of matching provide better retention when coupled with sound," Callway says. For example, a common engineering task involves comparing two listings. But instead of glancing continuously between the listings—and running the risk of losing your place—you can compare strings by having the computer read one to you while you keep your eyes on the other.

Callway further observes that digital-audio utilities included with ATI's multimedia boards will let you add voice annotations to your schematics. In fact, he suggests that audio would provide a useful enhancement for a schematic rule-checker, so that instead of generating page upon page of printed warning messages, a verbal message could be associated with a visual flag on the schematic itself. That way, the engineer could continue looking at the screen, listen to the error message, and fix the problem.

Similarly, CD-ROMs can replace service manuals. Beyond the obvious benefits of compact size and the simplicity of issuing revisions, these disks can include a voice narration that talks the technician through the repair process, explains what should be visible, and describes any processes that are occurring. These verbal messages provide insight without popping up a window that could cover much of a PC screen.

Likewise, a sound track can make product prototypes, presentations, and walkthroughs more effective because audio helps to focus your audience's attention. And as Callway observes, a single-slot portable PC coupled with a board such as ATI's VGA Stereo-F/X card provides a completely transportable multimedia presentation system that you can plug into any available VGA or multisync monitor.

The magic of multimedia will also let you tackle those
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Price</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almtech</td>
<td>Iconauthor</td>
<td>$4995</td>
<td>Graphical interface, flowchart design for branching applications.</td>
</tr>
<tr>
<td>Asymetrix</td>
<td>Multimedia Toolbook</td>
<td>$695</td>
<td>Cut and paste simplicity, 250 prescripted objects, plays Animator .FLI files, C-language compatible.</td>
</tr>
<tr>
<td></td>
<td>Toolbook1.5</td>
<td>$395</td>
<td>Same object-oriented features as Multimedia Toolbook, but without MPC- compatibility.</td>
</tr>
<tr>
<td>Authorware</td>
<td>Authorware Pro for Windows</td>
<td>$8000</td>
<td>Integrates text, graphics, sound, video, animation; no scripting language-flowchart design.</td>
</tr>
<tr>
<td>Autodesk Inc</td>
<td>3D Studio</td>
<td>$2995</td>
<td>3-D animation with modeler, materials editor, renderer, and keyframer.</td>
</tr>
<tr>
<td></td>
<td>Animator Pro</td>
<td>$795</td>
<td>2-D animation with tweening, color cycling, and optical and cel animation.</td>
</tr>
<tr>
<td></td>
<td>AutoCAD for Windows</td>
<td>$495</td>
<td>DDE facility, on-line reference manual.</td>
</tr>
<tr>
<td>Brown-Wagh Publishing</td>
<td>Curtain Call</td>
<td>$119.95</td>
<td>Windows-based multimedia authoring program; includes automatic rendering and paint box.</td>
</tr>
<tr>
<td>Compton’s Newmedia</td>
<td>Smartbuild</td>
<td>$7000</td>
<td>Multimedia database-building software; retrieves objects such as pictures, audio, and animation.</td>
</tr>
<tr>
<td></td>
<td>Smartdoc</td>
<td>$1000</td>
<td>Provides Windows 3.0, DOS, and Macintosh user interfaces for Smartbuild databases.</td>
</tr>
<tr>
<td></td>
<td>SmartAPI</td>
<td>$20,000</td>
<td>Set of C callable subroutines for custom development of DOS TSRs; Windows DLL and DDE.</td>
</tr>
<tr>
<td>First Byte</td>
<td>Monologue for Windows</td>
<td>$149</td>
<td>Speech synthesizer for Windows text and Excel spreadsheets, customizable dictionary.</td>
</tr>
<tr>
<td>Gold Disk Inc</td>
<td>Animation Works Interactive</td>
<td>$495</td>
<td>Vector-based animation, imports .FLI files, audio capabilities, Multimedia Extensions 1.0 recommended.</td>
</tr>
<tr>
<td>IBM Corp</td>
<td>Storyboard Live!</td>
<td>$495</td>
<td>Combine audio and video graphics for electronic slide show-style presentations.</td>
</tr>
<tr>
<td>Instant Replay Corp</td>
<td>Instant Replay Professional</td>
<td>$595</td>
<td>Authoring program with support for touchscreens, VCR output, frame capture, audio, and hypertext.</td>
</tr>
<tr>
<td>Jovian Logic Corp</td>
<td>Audio/Visual Link</td>
<td>$245</td>
<td>Interface program for firm’s video and audio boards; JPEG compression, $295 PAL version.</td>
</tr>
<tr>
<td>Logos Systems Intl</td>
<td>AV4 Programmer’s Toolkit</td>
<td>$300</td>
<td>Subroutine libraries for the firm’s Doubletake AV+ audio/video-capture boards.</td>
</tr>
<tr>
<td></td>
<td>Doubletake Runtime</td>
<td>$350</td>
<td>File viewer/player for runtime distribution of multimedia presentations; no special hardware required.</td>
</tr>
<tr>
<td></td>
<td>Verify!</td>
<td>$250</td>
<td>dBASE-compatible program that integrates photo, signature, and voice with ASCII text.</td>
</tr>
<tr>
<td>Macromind Inc</td>
<td>Macromind Director</td>
<td>$995</td>
<td>Multiple-award-winning multimedia authoring package for the Macintosh; dual sound channels.</td>
</tr>
<tr>
<td></td>
<td>Action!</td>
<td>$495</td>
<td>Windows 3.0 program with more than 100 presentation templates; sound and graphics library.</td>
</tr>
<tr>
<td>Matrox</td>
<td>Personal Producer</td>
<td>$695</td>
<td>Edits video, audio, graphics, titles, and digital video effects; Includes Multimedia Extensions 1.0.</td>
</tr>
<tr>
<td>MP Technologies Inc</td>
<td>Sound Palette</td>
<td>$69</td>
<td>DLL and control program with DDE support, plays digitized sound through PC speaker.</td>
</tr>
<tr>
<td>Ntergaid Inc</td>
<td>Hyperwriter 3.0</td>
<td>$495</td>
<td>DOS authoring program for interactive hypermedia and multimedia documents; $895 pro version.</td>
</tr>
<tr>
<td></td>
<td>Hyperwriter 3.0 for Windows</td>
<td>$495</td>
<td>Windows authoring program for interactive hypermedia/multimedia documents; $895 pro version.</td>
</tr>
<tr>
<td>Paul Mace Software Inc</td>
<td>Grasp version 4.0</td>
<td>$349</td>
<td>Synchronized digital sound, creates run-time files, plays Autodesk Animator files, image capture.</td>
</tr>
<tr>
<td>Pix-L Laboratories</td>
<td>Tap Plus</td>
<td>$299</td>
<td>Audio/Video authoring program provides an automatic interface with firm’s touch-screen monitors.</td>
</tr>
<tr>
<td>Spectral Innovations Inc</td>
<td>Signal Analyzer/QT</td>
<td>$495</td>
<td>Multimedia authoring software for engineering signal-analysis, runs on Macintosh computers.</td>
</tr>
<tr>
<td>Texas Instruments</td>
<td>Multimedia Developer’s Toolkit</td>
<td>$5000</td>
<td>DSP development board and software kit for implementing PC-based multimedia capabilities.</td>
</tr>
<tr>
<td></td>
<td>Multimedia Evaluation Toolkit</td>
<td>$2000</td>
<td>For system developers who need to determine whether DSP would be useful in their application.</td>
</tr>
<tr>
<td>Turtle Beach Systems</td>
<td>56k Digital Recording System</td>
<td>$1995</td>
<td>Hardware/software combination for creating CD-quality audio on your hard disk drive.</td>
</tr>
<tr>
<td>Vision Imaging</td>
<td>Multimedia Studio</td>
<td>$295</td>
<td>Database and presentation authoring software that combines graphics, text, sound, and animation.</td>
</tr>
<tr>
<td></td>
<td>Imagebase</td>
<td>$595</td>
<td>Multimedia database package; image capturing and scanning into user-defined fields.</td>
</tr>
<tr>
<td></td>
<td>Media Master</td>
<td>$995</td>
<td>Creates self-running interactive multimedia presentations, Hyperbutton, screen editing.</td>
</tr>
</tbody>
</table>

Note: 1. DLL=dynamic link libraries, DDE=dynamic data exchange, TSR=terminate and stay resident.
long-distance design problems that require face-to-face brainstorming without requiring you to hop on a plane. With PC-based video conferencing you can meet with engineers scattered across a local-area network (LAN) or even across the world. By taking the multimedia concept to its logical climax, video conferencing lets separated members of a design team observe, comment upon, and even manually annotate or alter files, such as schematics, graphs, photos, animations, and videos.

Suppose a designer in Silicon Valley needs to present the current revision of her latest circuit to an analyst in New York, a colleague in Houston, and a field engineer in Denver. Instead of spending her time trying to arrange air travel, hotel rooms, and meals, she could instead schedule a video conference for a fraction of the expense and personal-productivity downtime that cross-country travel entails. An actual example offered by Todd Clayton, vice president of Marketing at Videotelecom involves the common scenario of a corporate moratorium on all but essential travel. When nine engineers at Motorola in Austin, TX were faced with such an edict while developing ICs for Chrysler’s 1996 cars, they conferred with the Detroit-based auto engineers via Videotelecom’s video conferencing studios and Mediamac equipment. Their meeting cost $1800, but Motorola estimated that a business trip from Austin to Detroit for this design team would have cost the company around $27,000.

The Mediamac equipment is based upon an 80386 or 80486 PC with open expansion slots that let you customize the system to suit your needs. You can use your own MS-DOS-based software and plug the equipment into your company’s LAN to share and manipulate files interactively with the other conference participants, print and review hard copies, and then send each participant away with the revised data on a floppy disk. Mediamac uses an in-band fax, which transmits on the same carrier that transmits the video and audio data, thus letting you exchange written documents during the conference. You can make interactive annotations of drafts and revisions using the systems graphics capability. You can also use an electronic white-

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Price</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptec</td>
<td>Multimedia Connection</td>
<td>$179</td>
<td>SCSI host adapter interface for CD-ROM.</td>
</tr>
<tr>
<td>ATI Technologies Inc</td>
<td>VGAStereo-F/X</td>
<td>$449</td>
<td>32,768-color VGA graphics with musical-instrument digital interface, stereo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>generator, and mouse port; $499 for 1-Mbyte version.</td>
</tr>
<tr>
<td>Cardinal Technologies Inc</td>
<td>Soundvision</td>
<td>$459</td>
<td>Single ISA card contains SuperVGA, stereo sound, and CD-ROM interface,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1-Mbyte RAM)</td>
<td>Multimedia PC-compatible.</td>
</tr>
<tr>
<td>Compaq Inc</td>
<td>Multimedia Upgrade Kit</td>
<td>From $1069</td>
<td>Includes an audio board, Sony CD-ROM drive, MS-Windows 3.0 with</td>
</tr>
<tr>
<td></td>
<td>AM/FM Tuner</td>
<td>$299</td>
<td>Multimedia Extensions 1.0.</td>
</tr>
<tr>
<td></td>
<td>TV/Video Board</td>
<td>$525</td>
<td>Integrates audio and full-motion digitized video.</td>
</tr>
<tr>
<td>Creative Labs</td>
<td>Multimedia Upgrade Kit</td>
<td>From $849.95</td>
<td>Includes Soundblaster Pro audio board, Panasonic CD-ROM drive, lots of software.</td>
</tr>
<tr>
<td>Dolch</td>
<td>Multimedia PAC</td>
<td>$3995</td>
<td>Upgrades the company’s line of portable computers to meet MPC standards.</td>
</tr>
<tr>
<td>Jovian Logic</td>
<td>SuperVIA</td>
<td>$895</td>
<td>Captures 640x480-pixel images with 65,536 colors in 1/30th of a sec; RGB and S-Video inputs.</td>
</tr>
<tr>
<td></td>
<td>Gloria</td>
<td>$695</td>
<td>8- or 16-bit digital audio-capture and playback adapter; CD quality, software included.</td>
</tr>
<tr>
<td>Logos Systems Intl</td>
<td>Doubletake AV+Monochrome</td>
<td>$295</td>
<td>8-bit audio and video digitizer for NTSC and PAL; ports for composite video input, mic, and audio.</td>
</tr>
<tr>
<td></td>
<td>Doubletake AV+Color</td>
<td>$495</td>
<td>24-bit color video-capture board with 8-bit audio I/O.</td>
</tr>
<tr>
<td>Media Vision Inc</td>
<td>MPC Upgrade Kit</td>
<td>$995</td>
<td>Pro Audio Spectrum sound board, Sony CD-ROM drive, multimedia encyclopedia, software.</td>
</tr>
<tr>
<td></td>
<td>Pro Audiospectrum</td>
<td>$389</td>
<td>22-voice musical-instrument digital interface-compatible stereo synthesizer, conforms to MPC spec, Audiomate TSR software.</td>
</tr>
<tr>
<td>New Media Graphics Corp</td>
<td>Super Videowindows</td>
<td>$895</td>
<td>Full-motion digital video in a window with stereo audio capability; runs under Windows or DOS.</td>
</tr>
<tr>
<td>Radius Inc</td>
<td>RadiusTV</td>
<td>$1699</td>
<td>Video-processing engine with external audio-video input and TV tuner for the Macintosh.</td>
</tr>
<tr>
<td>Tandy Corp</td>
<td>Multimedia PC Upgrade Kit</td>
<td>From $799.95</td>
<td>16-bit audio board, Tandy CDR-1000 CD-ROM drive, Windows 3.0 with Multimedia Extensions 1.0.</td>
</tr>
<tr>
<td>Video Seven</td>
<td>Multimedia Upgrade Kit</td>
<td>From $749</td>
<td>Texas America CD-ROM drive, MS-Windows 3.0 with Multimedia Extensions 1.0.</td>
</tr>
<tr>
<td></td>
<td>Media FX</td>
<td>$349</td>
<td>Upgrades PC audio to digital stereo.</td>
</tr>
</tbody>
</table>

Table 3—Multimedia boards
You can really jazz-up a presentation by adding sound to clarify your point and focus your audience's attention. ATI Technologies' VGA Stereo-F/X board lets you add audio capability to your PC without sacrificing another expansion slot.

board (the electronic equivalent of a blackboard, which all participants can write on at the same time) for brainstorming.

But what if our hypothetical designer needs to confer with engineers in the Pacific Rim and Europe? The time differences involved would seem to make video conferencing an inappropriate forum. However, Media­max lets you send all of your video, audio, documents, and computer information to remote sites for later re­view by distant colleagues. A video tape that illustrates these and other video conferencing scenarios is avail­able upon request from the company.

The disk is in the mail

Yet, even at the current price of $400 per hour on a high bandwidth video conferencing telephone line, such a solution may be too costly for some projects. But with a bit of work, you can stay within your budget and still provide interactive, animated, voice-annotated information to members of your design team who may be in different locations. Asymetryx’s Multimedia Tool­book and Paul Mace Software’s Grasp version 4.0 are multimedia authoring programs that let you develop and distribute runtime versions of your presentation that will operate on almost any engineer’s PC with a VGA monitor. Then transmit the data via modem or download the presentation onto a floppy and mail it. Make sure your presentation is limited to the hardware capabilities of the recipient’s PC.

If you are a Windows 3.0 devotee, Toolbook is an icon-driven authoring program that lets you write multime­dia applications for MPC platforms. Using a simple copy-and-paste approach to building applications, you can tap a library of more than 250 multimedia-script objects, which the company calls widgets. So, by point­ing and clicking to access engineering drawings stored on the Windows Clipboard, you can create a multi­media presentation without learning yet another paint program or programming language.

More experienced programmers can combine Tool­book’s prescribed widgets with their own C-language subroutines. A graphics display facility lets you store as many as 256 bitmaps for display as pop-up or overlap windows. So you can actually add hundreds of annota­tions to your schematic without obliterating the screen with messages. Incidentally, for PCs that aren’t yet running Windows 3.0 with Multimedia Extensions 1.0, Toolbook 1.5 is a similar Windows authoring program. It includes a runtime module for free distribution of interactive applications that don’t include MPC-compatible audio and video capabilities.

On the other hand, if you want to create a disk-based presentation that combines both MS-DOS and Win­dows 3.0 images, Steven Belsky, Business Manager for Paul Mace Software, suggests using Grasp 4.0. Like Toolbook, Grasp offers a runtime module that lets you distribute tamper-proof executable files that incorpo­rate sound, animation, and text. Belsky notes that you can use Grasp to capture a CAE drawing of a circuit, access Grasp’s Pictor paint program to draw bright dots representing electrical signals, and then tap

Multimedia Toolbook is an MPC-compatible authoring program that lets you combine text, graphics, digital video, audio, and animation to create multimedia presentations within Windows 3.0 and distribute your presentations for free.
Grasp's Artools module to animate those dots for illustrating signal flow, delays, and critical paths. The Real sound enhancement for Grasp lets you add verbal comments as clarification, questions, or warnings.

Of course, the limiting factor for such disk-based distribution techniques is the size of the disk you are sending. A floppy disk gives you little more than 1 Mbyte in which to get your point across. Even with compression techniques such as those offered by the JPEG and MPEG standards, you will probably find that a floppy will provide minimal options for a multimedia presentation. You can send greater amounts of information via modem, but the recipient's available disk space may not be sufficient to accept all of it.

Obviously, the opportunities for engineers to exploit the technology promised by the ensuing multimedia tidal wave of applications is limited only by imagination, budget, CPU power, and storage capacity. Just as a slide rule on someone's desk is a nostalgic oddity in today's design departments, it may not be long be

<table>
<thead>
<tr>
<th>Manufacturers of multimedia products</th>
</tr>
</thead>
<tbody>
<tr>
<td>For more information on multimedia products 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.</td>
</tr>
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fore a silent, text-based computer is considered a relic for any engineering team.

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Piecewise analysis and accurate emulation yield precise power estimates

William Hall and Ray Mentzer, National Semiconductor Corp

Newer logic-IC families let you obtain high speed and low power simultaneously. But with these ICs, if you use time-honored ways to estimate system power consumption, the errors can kill your design.

Designers have long sought low-power components for their system designs. Low power dissipation allows denser component packing, reduces the temperature inside equipment, and permits the use of batteries. These three advantages facilitate miniaturization, increase reliability, and make portability possible. In addition, low power dissipation reduces or eliminates the need for cooling hardware and decreases system cost.

In the past, to obtain low power you had to pay a steep price in operating speed. Now you don't have to choose between high speed and low power. Using advanced CMOS and BiCMOS logic-IC technologies, several IC families combine microwatt power dissipation with speed similar to that of ECL. At low frequencies, CMOS logic families clearly are the minimal power consumers; but at higher frequencies, the need to continually charge and discharge CMOS device capacitances raises the ICs' current requirements. Above some crossover frequency, CMOS actually draws more current than bipolar TTL or BiCMOS.

Many engineers have tried to define the crossover frequency by using data-book calculations and data collected from standard test fixtures. Using these approaches can yield crossover frequencies anywhere from 3 to 50 MHz. Because of their unrealistic load values and their inability to compute average power over time as devices change operational modes, these approaches fail to emulate actual system conditions. For example, they ignore the effects of 3-state devices going in and out of the high-impedance (high-Z) state.

Determining total system power requires a piecewise analysis of a system's many circuit structures and an accurate emulation of those structures. Such an analysis will help you minimize a system's power dissipation by tailoring your selection of ICs to the system's specific parameters and configuration.

Start with a single device

The following equation describes the energy used in any electric circuit:

$$W = \int_{t_1}^{t_2} v(t)i(t)dt,$$

where

- \(v\) = voltage across the two nodes where power is measured,
- \(i\) = current through the two nodes where power is measured, and
- \((t_1, t_2)\) = interval of time in which total power is measured.

For a trapezoidal waveform, you can break time into segments and develop a piecewise solution to the energy equation. IC vendors have simplified this approach by providing all of the key parameters you need to determine the power for a single device. A plethora of specifications exists: \(I_{CC}, I_{CCQ}, I_{CCP}, I_{CCD}, C_{PD}, I_{CCL}, I_{CCB}\), and \(I_{CCZ}\), for example, each specify different aspects of power-supply current. Which parameter is most significant at any instant depends on the I/O conditions, the operating mode, and the state of the device's outputs.
POWER OPTIMIZATION

The normal starting point for calculating the power dissipation of any digital IC is to break power into its three main components:

Power = static power + dynamic power + TTL power.

Static power is the easiest to calculate. Bipolar ICs consume significant amounts of static power because their circuit structures have transistor bias currents that always flow from \( V_{cc} \) to ground. The amount of current flowing depends on the ICs’ output state. Therefore, bipolar ICs specify three static-power components: \( i_{ccL} \) in the output-low state, \( i_{ccH} \) in the output-high state, and \( i_{ccZ} \) in the high-Z (output-disabled) state.

For a 74F245, the maximum data-book specifications are \( i_{ccL} = 120 \) mA; \( i_{ccH} = 90 \) mA; and \( i_{ccZ} = 110 \) mA. The total static power dissipated by active and output-disabled bipolar devices is

\[
I_{\text{STATIC (ACTIVE)}} = DDC \times i_{ccH} + (1 - DDC) \times i_{ccL},
\]

\[
I_{\text{STATIC (HIGH-Z)}} = i_{ccZ},
\]

where \( DDC \) is the data duty cycle (% of time high).

The total static power consumed by a bipolar IC takes into account the percent of time that the outputs are active vs disabled, and is given by the equation

\[
I_{\text{STATIC (TOTAL)}} = EDC \times I_{\text{STATIC (ACTIVE)}} + (1 - EDC) \times I_{\text{STATIC (HIGH-Z)}},
\]

where \( EDC \) is the enable duty cycle (% of time the outputs are enabled).

**BiCMOS spec’d in manner similar to bipolar**

BiCMOS logic families have specifications equivalent to the bipolar \( i_{ccL}, i_{ccH}, \) and \( i_{ccZ} \). Moreover, you calculate the total static power dissipation in the same way. The major difference results from BiCMOS’s strategic use of MOS devices that switch to a high-impedance state to block the flow of dc current in 3-state enable paths. This approach lowers \( i_{ccZ} \) to about one-sixth of the value in bipolar devices. The data-book maximum specifications for a 74BCT245 are \( i_{ccL} = 90 \) mA; \( i_{ccH} = 57 \) mA; and \( i_{ccZ} = 15 \) mA.

Pure CMOS logic families have long been known for their extremely low static-power characteristics. The input, internal, and output stages of CMOS devices consist of pairs of PMOS and NMOS transistors in the \( V_{cc} \)-to-ground path (more properly, in the \( V_{dd} \)-to-ground path). If the input of any of these stages is at one of the power rails (\( V_{cc} \) or ground), either the PMOS or the NMOS device will be in a high-impedance state, limiting the flow of current to microamperes. Because the current is negligible no matter what the output state, data books provide only one specification for CMOS static current drain: \( i_{cc} \) (some CMOS logic families call it \( i_{ccQ} \)). The maximum data-book specification for a 74ACT245 is 80 \( \mu \)A.

Dynamic power dissipation is misunderstood much more often than static power dissipation is. Dynamic dissipation consists of the power dissipated under switching conditions within the IC and the load. In CMOS devices, under dynamic conditions, three factors cause large amounts of current to flow:

- CMOS ICs have output swings as much as 50% greater than those of bipolar ICs.
- CMOS ICs have more capacitive stages in parallel than bipolar ICs have.
- When the voltage to an NMOS/PMOS pair is in transition, both transistors turn on partially, creating a relatively low impedance path from \( V_{cc} \) to ground (a phenomenon called simultaneous conduction).

For these reasons, CMOS-device vendors specify a dynamic power component for an IC, whereas vendors of bipolar and BiCMOS devices do not. For bipolar and BiCMOS logic families, you need to consider only the dynamic power dissipation caused by the load.

The dynamic power for a CMOS device is specified in one of two ways: as \( i_{cd} \) or as \( C_{pd} \). \( i_{cd} \) is the dynamic current as a function of frequency. Each of the noninverting buffers in a 74FCT245 has a maximum \( i_{cd} \) of 0.25 mA/MHz. Therefore, at 10 MHz, each buffer has a guaranteed dynamic current of less than 2.5 mA. Instead of \( i_{cd} \), some logic families choose to specify dynamic power via \( C_{pd} \) (power dissipating capacitance—a misnomer; capacitors don’t dissipate energy, they store it). Both \( C_{pd} \) and \( i_{cd} \) come from the same JEDEC equation for power; however, \( C_{pd} \) lets you represent the device as a capacitance and integrate it more easily into an analysis that accounts for the power consumed by both the IC and its load. For ICs having the same output frequencies and loads:

\[
I_{\text{DYNAMIC (TOTAL)}} = (C_{pd} + C) \times V_{sw} \times f \times N,
\]

where:
- \( C \) is the total load capacitance, including transmission-line capacitance, IC input capacitances, and termination capacitance,
- \( V_{sw} \) is the output voltage swing of the device (for CMOS, \( V_{sw} = V_{cc} \)),
- \( f \) is the output frequency, and
- \( N \) is the number of outputs toggling.

The data-book specification for a 74ACT245 is
CPD = 45 pF. Note that for bipolar and BiCMOS devices, you can consider CPD to be zero, but you must still calculate the dynamic power needed to drive the load capacitance.

The final component of total CMOS-IC power dissipation is “TTL power.” Contrary to its name, this component is associated only with CMOS devices. Bipolar and BiCMOS devices have no TTL-power component. This power component is the steady-state power consumed by a CMOS device whose input is at a voltage between the power rails. Logic levels between the rails are common in mixed CMOS/TTL systems where a TTL output drives a CMOS input. In such cases, both transistors of an NMOS/PMOS input pair turn on and allow a large dc current to flow from Vcc to ground. (The most common TTL output levels are 2.4 to 3.4V.) The additional current beyond the standard ICC is called I_{CCT}. The data-book specification for a 74ACT245 is I_{CCT} = 1.5 mA for each high input (defined as V_{IN} = Vcc - 2.1V). To calculate the total TTL power, you must also incorporate the input-data duty cycle, DDC, and N, the number of high inputs:

\[ I_{TTL(TOTAL)} = I_{CCT} \times N \times DDC. \]

The complexity of static, dynamic, and TTL power components has led many designers to develop comparisons from data gathered in simple lumped-load test fixtures. Unfortunately, data gathered using such industry-standard fixtures does not give designers an “apples-to-apples” comparison of power consumed by different logic families.

**Data from classic test fixtures can mislead**

Test fixtures have evolved over the last 20 years to provide repeatable standards for measuring ac and dc specifications. Test-fixture data is easy to measure in any laboratory and is also readily available from most IC vendors. In addition, some data-book specifications (like CPD and ICC) are based on measurements from industry-standard fixtures. However, the fixtures don’t accurately simulate the power consumed by real systems, nor do they predict which logic family will dissipate the least power in a particular application.

The fixtures use lumped loads, whereas real systems present distributed loads. A fixture’s standard load is a 50Ω resistor in parallel with a 50-pF capacitor from output to ground (see Fig 1). The 50-pF load capacitance, standardized in the late 1970s, represents 10 5-pF IC inputs. The 500Ω resistor provides a convenient 10:1 voltage divider with the 50Ω input impedance of an oscilloscope. Yet, for all its convenience, this setup often yields misleading measurements.

Dynamic power measurements in a test fixture also can prove misleading. The problem arises from test fixtures’ favorable bias toward logic families that produce TTL output swings—for example, bipolar and BiCMOS. The power dissipated in the test-fixture load for an 8-bit device is calculated below:

\[ I_{TEST\ FIX} = I_{CAPACITOR} + I_{RESISTOR} = V_{SW} \times f \times C_{T} \times 8 + (V_{SW}/R_{L}) \times DDC \times 8. \]

Because the CMOS output swing is 5.0V (if V_{CC} = 5.0V) and the TTL-output swing is 3.4V, the additional current used by a CMOS-populated test fixture vs a TTL test fixture is

\[ I_{DELTA} = (5.0 - 3.4) \times f \times 50 \times 10^{-12} \times 8 + ((5.0 - 3.4)/500) \times 0.5 \times 8 \]

\[ = 0.64 \text{ mA/MHz} + 12.8 \text{ mA}. \]

From the equation, you can see that the power consumed in the 500Ω resistor provides a constant 12.8-mA bias in favor of families that have TTL output swings. The power difference in the 50-pF load capacitor is a linear function of frequency. At 20 MHz, the capacitor would contribute another 12.8 mA to the CMOS-based test fixture.
POWER OPTIMIZATION

The graph in Fig 1 shows an actual test fixture comparison of CMOS (FACT—Fairchild Advanced CMOS Technology), bipolar (FAST—Fairchild Advanced Schottky TTL), and BiCMOS (BCT—Bipolar CMOS Technology). In the test fixture, CMOS begins to draw more current than BiCMOS at 16 MHz and to draw more current than bipolar at 19 MHz.

In a pure CMOS system, the load’s resistance measures in the megohms, reflecting the ultra-high input impedance of CMOS. Even TTL loads approach 100 kΩ for logic-high input signals. CMOS systems designed for low power generally don’t use parallel or Thevenin terminations. Thus, they eliminate other possible low-output-state resistive paths. The test fixture’s 500Ω load therefore does not accurately represent the megohm load of a CMOS system and overstates the power dissipated by CMOS.

The 50-pF capacitive load may or may not correlate to that of a real system. If the real system has fewer than 10 IC input loads, minimal distributed capacitance, and no termination capacitance, the test fixture will again be overly pessimistic when measuring CMOS power consumption. However, if the equivalent load capacitance is higher than 50 pF, the test fixture may understate CMOS power. This confusion reinforces the point that to obtain a true picture of system power or to select a logic family, you must analyze the actual system.

Application determines capacitance

Three circuit applications: pipelines, bus drivers, and memory-array drivers (Fig 2), tend to dominate in many systems. Radically different capacitive loads and active duty cycles distinguish these applications.

The capacitance associated with a pipeline is small (on the order of 5 to 10 pF) and consists of input and trace capacitance. As shown in Fig 2, pipelines generally have small fanouts and usually drive a single load. Typical embodiments include pipeline registers and serial structures in DSP systems, synchronization blocks, and clock rejuvenation circuits. Reducing the power consumption of these circuits depends largely on selecting a logic family or on using a power-down scheme to shut down entire sections of logic when they aren’t in use.

Bus driving is perhaps the most common digital circuit application and definitely is the most complex
from a power perspective. A bus-driver IC drives several listeners; a listener is any IC other than the driver itself whose inputs or outputs load the bus. Commonly, a bus driver drives longer traces than pipeline or memory-array drivers do. In addition to IC loads, bus drivers often drive such elements as the bus trace, edge connectors for daughter boards, pin sockets, ribbon cables, connectors, and plated through holes. Because buses are usually terminated, you must also consider the termination elements. The sum of all capacitive elements may range from 30 to 70 pF for a small internal bus to 220 pF for an EISA-bus application. A fully configured VMEbus—21 slots at a maximum of 20 pF per slot—can present a severe, worst-case, 420-pF bus load.

You can minimize bus power consumption through logic-family selection, termination selection, and the design of bus loads and enable schemes. More importantly, the enable cycles of the bus elements significantly affect the power consumption of complex buses. A later section covers this topic in detail.

### Take your lumps from a memory array

Memory arrays usually are densely packed, and their data and address drivers are apt to have very high fanouts. Typical values of total capacitance are on the order of 200 pF, but this value can vary widely with the size and composition of the array. Memory-array designers can control the amount of power dissipated in an array by carefully selecting the array organization.

Consider a memory-array architecture commonly found in personal computers: 4M words deep by 16 bits wide. Table 1 gives the fan-in capacitances for seven configurations using 5 pF per input; this example neglects other capacitive elements that add to the values shown—traces and sockets, for example. In Table 1, observe that the address load depends directly on the number of ICs in the array. Using higher storage capacity devices will reduce the address load in proportion to the storage capacity of the individual ICs. If you fix the memory size, choosing to maximize the memory depth will save power by reducing the datapath fan-in.

When you make comparisons among logic families, segmenting systems into capacitive categories can be very useful. You can use this approach, for example, when you compare an ACMOS (advanced CMOS) function to a bipolar or BiCMOS one. The plots at the bottom of Fig 2 come from data gathered in a realistic system environment. The plots show the effect of load capacitance on different families. As you increase the capacitance from 5 to 200 pF, the CMOS crossover frequency decreases from the 40-to-50-MHz range to the 10-to-20-MHz range. Therefore, you can see that not just the architecture, but also the external capacitive load dictates the choice of logic family.

So far, the examples and discussions have taken a worst-case approach; all data bits were assumed to be switching at the highest frequency. This situation is likely to occur only in a subset of clock-distribution applications. If you were to design for this case everywhere, power supplies would need unrealistic excess capacity to account for an unlikely set of conditions. Consider the clock-distribution example shown in Fig 3. Also recall the results in Fig 2, where the plot shows that with a 50-pF load, the data-pattern frequency at which FACT begins to draw more current than BCT is 28 MHz. In the same plot, FACT begins to draw more current than FAST at 39 MHz. In Fig 3, the

![Diagram](image-url)

**Table 1—Capacitive loads presented by different memory configurations**

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<th>Memory IC size</th>
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<th>No. of ICs</th>
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<td>16</td>
<td>5 pF</td>
<td>80 pF</td>
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<tr>
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<td>1M x 4</td>
<td>16</td>
<td>20 pF</td>
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<tr>
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<td>64</td>
<td>20 pF</td>
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<tr>
<td>1 Mbit</td>
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**Fig 3**—Above 30 MHz, a single-frequency clock-distribution system will dissipate the least power if you implement it with BiCMOS (BCT) or bipolar (FAST) logic. Because many circuit elements operate well below the clock frequency, CMOS (FACT) can be a better choice in multifrequency systems—even at 50 MHz.
POWER OPTIMIZATION

FACT/BCT crossover lies beyond 50 MHz. The change really shouldn’t surprise you; in effect, the circuit is operating at a lower frequency. The general equation for $I_{\text{dynamic}}$ is

$$I_{\text{dynamic}} = N' \times f \times V_{\text{sw}} \times C_i,$$

where $N'$ equals the effective number of bits switching at the maximum clock frequency, $f$. For the multifrequency case of Fig 3:

$$N' \times f = f + f/2 + f/4 + f/8 = 1.875f.$$

Therefore, in this case, $N'$ and the resulting dynamic power are 46% of the equivalent quantities in the case where four outputs are toggling at $f$.

System emulation predicts power precisely

The right kind of emulation board can help designers think about system power and get away from a test-fixture mindset. To accomplish this objective, a universal bus board emulates a generic bus architecture with enough flexibility to allow measuring the effect of the following variables on $I_{\text{cc}}$:
- Frequency
- Termination
- Enable duty cycle
- Bus data pattern
- Listener load
- Logic family

The authors have constructed a multifunction bus-emulation board that makes its LCD’s ammeter reading tell the whole story about complex-system power dissipation.

At the core of the board is a 16-bit bus that drives 18-in.-long traces (see Fig A). Along the traces are sockets that accommodate a maximum of 32 listeners per bit. A listener is an input, output, or I/O device that loads the bus.

A fully configured board, with 32 listeners per bit, yielded unrealistically low effective line impedances. (Moreover, there was horrendous noise when all bits switched at once). The low impedance limited the bandwidth of the board system.

As a result, testing involved 16 or fewer listeners per bit. Even with this number of listeners, the effective line impedances still ranged from 30 to 550. Driving these impedances was a device of the same logic family as the listeners.

Because of Miller capacitance in the pull-down transistors, bipolar and BiCMOS devices generally produced the lowest impedance lines. The bipolar devices also include an output short-circuit current-limiting resistor that raises their output impedance under some conditions. The result is lower bandwidth for these families than for CMOS or BiCMOS.

At the end of the bus are pin sockets that accept ac, parallel, or Thevenin SIP terminators. The component values in the terminations are appropriate for each logic family and for the number of devices connected to the bus.

Load with representative $C$

Each of the listeners has pads to permit loading its output with a chip capacitor. The goal was to choose capacitor values that have a basis in practice. The options are 5-pF "pipeline," 50-pF "bus-driver," and 200-pF "array-driver" capacitances. The board has five layers. Among them are two $V_{\text{cc}}$ planes, one for the listeners and one for the control logic. This setup allows isolating the $I_{\text{cc}}$S of the devices under test (DUTs).

The only way to meet the test-flexibility goals was through automation (Fig B). A personal computer with an IEEE-488 interface card controls the system. At the heart is a Hewlett-Packard word generator that can operate at 50-MHz. Downloading vectors from the PC to the word generator is quite flexible and permits generating any data pattern and emulating any enabling scheme.

System designers often use several bus architectures in a single product. Multiple architectures are also an issue when upgrading an existing design. The flexible evaluation board satisfies the multiple-architecture requirement and reduces project cost and evaluation time.

The graph in Fig A is one example of data taken on the power-emulation board. The setup had 16 listeners per bit, for a total of 34 monitored devices. The enable duty cycle was set to 6.25% × $1/16$. Hence, at any instant, only one pair of listeners was enabled.

In conjunction with the control logic, the word generator writes two bytes of checkerboard data to the enabled bank and then steps through the banks one by one before looping back to the beginning. Because of Fig A’s low enable duty cycle, the ac termination’s capacitance controls the shape of the curve. Compare the curve shapes in Fig A with the ac-termination curve in Fig 5 (see main text). The low enable duty cycle also demonstrates the differences between families with high and low $I_{\text{cc}}$ values (note that FAST’s typical $I_{\text{cc}}$ is 85 mA).

When you compare the measured results with the calculations of Table 2, you can see that, at
Though this example is for clock distribution, you can apply its principles more broadly. Power measurements are almost always based on "worst-case" checkerboard data patterns. Average system power will be considerably lower than the worst case because of the random nature of most data. In addition, some system structures have frequencies predictably lower than the maximum. You should take this effect into account during circuit design and logic-family selection. Examples of lower frequency structures include clock and memory-address generators, address comparators, circuits that perform some arithmetic operations, and virtually all circuits that use counters.

Resistors serve many purposes in system design, but no resistors have a larger impact on power consumption than those used as terminators. Termination different frequencies, the calculations exaggerate the CMOS power requirements by 10 to 50%. For battery-operated designs, the calculations' pessimism will most certainly be critical. In other designs, the pessimism may cause you to add an unnecessary cooling fan, or change from a 150W supply to a 225W supply.

You can use the hardware model for more than just power measurement; you can use it to evaluate crosstalk and ground bounce, as well as line-driving and termination schemes. For your next design, give some thought to using hardware modeling for comparing logic families. The technique can be a quick and easy route to accurate power optimization, and more.

---

**Fig A**—A bus-emulation system is the best tool for predicting how much power a complex bus will consume. Although the calculations of Table 2 predict that FACT will consume more power than BCT above 28 MHz, the actual crossover occurs at 48 MHz.

![Diagram of bus-emulation system](image)

**Fig B**—Although the bus-emulation board is the heart of a system for predicting bus power consumption, the test setup includes a personal computer, a word generator, several power supplies, and three multimeters. The Keithley meter monitors the current from the Vcc1 supply.
resistors can appear in series, in parallel, in Thevenin-equivalent networks, or in conjunction with a capacitor in ac-termination schemes. As long as terminations properly match the transmission-line impedance, their topology will have little affect on the degree of noise reduction they achieve. Termination topology will significantly affect cost, circuit-board area, and power dissipation, however. When you choose a termination design, you must thoroughly understand how to apply each type of termination network.

Of the possible termination styles, the parallel configuration has a reputation for dissipating the most power. When the driver output is high, parallel terminations introduce an \( I_{CC} \) component equal to \( V_{CC}/Z_{in} \). You can select an optimum form of termination only if you know the signal pattern traveling down the transmission line. For instance, suppose you are considering termination styles for a control line or a set of control lines driving a distributed load. If these lines dwell low (Fig 4a), a parallel termination might be a good choice. However, if the dwell is high (Fig 4b), parallel termination quickly becomes the worst choice.

Clock-distribution structures usually represent electrically long transmission lines having distributed loads that normally are terminated. A relationship exists between the length of the transmission line (in nanoseconds) and the frequency of the signal passing down the line. For example, if the line is 15 nsec long and the signal has a duty cycle of 50% at 40 MHz, the pulse will be high for 12.5 nsec, which is 2.5 nsec less than the length of the line. The driver therefore has no insight into what is at the end of the transmission line. The load current for the driver, although still equal to \( V_{CC}/Z_{in} \), is now totally independent of any termination at the end of the line. For this example, a parallel termination might be the best choice; such a single-component solution would be more reliable and less expensive than ac or Thevenin configurations, which use multiple components.

Like its parallel counterpart, a Thevenin termination also consumes relatively large amounts of dc power. The Thevenin termination is a paradox: Its strength is also its weakness. Its strength is its effect on the driver circuit's power consumption. In the high state, a Thevenin termination dissipates roughly half the power a parallel termination does. However, in the low state, the Thevenin termination consumes an additional \( I_{CC} \times V_{CC} \). The actual power savings for the driver depend on the difference between \( V_{CC} \) and \( V_{CC} - V_{OL} \). Because ACMOS devices have approximately equal source-to-drain voltage drops across their pull-up and pull-down transistors, the choice of Thevenin or parallel terminations has little effect on such circuits' dissipation. However, Thevenin terminations reduce the chip power used by logic families such as bipolar or BiCMOS that don't switch from rail to rail.

In bipolar circuits, halving the source current of the pull-up Darlington pair has little effect on the voltage across the pull-up; that voltage may change by as little as 100 mV, yielding a dissipation decrease of nearly 50%. That reduction exceeds the additional power dissipated in the pull-down transistor. The Thevenin termination's weakness is its constant current drain; that is, the addition of an \( I_{CC} \) component. There is no way to define data patterns or system characteristics that reduce \( I_{CC} \).

For terminating transmission lines that have distributed taps, ac terminations can be the lowest power choice. The dc-blocking capacitor allows current flow only during signal transitions. The current drain of the termination is therefore a function of frequency and is described as

\[
I_{TERM} = \text{frequency} \times C_{TERM} \times V\text{SWING}.
\]

For a signal with a 50% duty cycle, the current in the termination will increase monotonically with frequency until the termination time constant, \( \tau \), comes into play—at a signal period of approximately 6\( \tau \). As the period of the incoming signal decreases below 6\( \tau \), the termination current's rate of increase decreases. At periods below 3\( \tau \), you can consider the voltage change across the capacitor to be negligible, and thus assume a termination current of approximately \( V_{SW}/2 \times Z_{in} \).

The following example compares the power consumed by a 50\( \Omega \)/300-pF ac termination with that consumed by a 50\( \Omega \) parallel termination. In both cases, the signal is at 10 MHz, and has a 50% DDC and a 5V swing.

- For a parallel termination:
  \[
  I_{TERM} \text{(parallel)} = (V\text{SWING}/Z_{in}) \times \text{Duty Cycle} = (5.0V/50\Omega) \times 0.5 = 50 \text{ mA}.
  \]

- For an ac termination:
  \[
  I_{TERM} \text{(AC)} = \text{frequency} \times C_{TERM} \times V\text{SWING} = 10^{3} \times 300 \times 5.0 \times 10^{-12} \times 5.0 = 15 \text{ mA}.
  \]
In this and many other examples, ac terminations save significant power compared with dc terminations. Therefore, ac terminations are an excellent choice in many systems, particularly those using battery power. (To conserve board space, passive component manufacturers make off-the-shelf ac terminators in various RC combinations in a SIP format. If you buy sufficient quantities, you should be able to find vendors that will manufacture custom termination networks in several standard packages.)

The series termination is far and away the lowest power consumer (Fig 5). At 50 MHz, series terminations consume half the power of parallel or Thevenin ones. However, in many situations, series terminations are not useful. A series-terminated driver sends a half-height signal down the trace, preventing incident-wave switching at any tap along the line except the one at the very end. The series termination actually uses reflections to achieve full-voltage swings. Until the initial wave has made its round trip from the driver to the end of the line and back, the logic levels at stubs along the line may not be valid. This phenomenon can cause oscillations (which raise power) and can raise the TTL current drawn by CMOS devices. Thus, series terminations are effective only in point-to-point connections.

The power and noise benefits of series terminations come from the series resistor's limiting of the dynamic current that flows into and out of the driver. Limiting the dynamic current reduces the \( \frac{\text{di}}{\text{dt}} \) seen by the inductance of the driver's power leads. Therefore, both power and noise (that is, the undershoot and the transient-peak low-state output voltage, \( V_{\text{OL,2}} \)) decrease. This noise reduction is the reason that many designers of memory arrays use series limiting resistors.

When implemented in an integrated resistor package, series termination requires twice as many pins as the other termination forms. Driver ICs can easily integrate series terminations, however. Such terminations are especially attractive to ASIC designers. IC vendors already implement 25 or 330 \( \Omega \) series resistors within standard devices.

Proper selection of termination schemes and components is essential to reducing power consumed by a bus; however, numerous other factors affect bus power.

Bus power is a function of the logic family, load, data characteristics, and the amount of time that bus elements are enabled and disabled.

As stated earlier, the input and output capacitance of the bus elements and the capacitive loading on those elements dictates the load on the bus. In addition, pc-board trace capacitance, termination capacitance and resistance, and other stray loads affect a bus's power dissipation.

The data pattern and duty cycle will also affect the dynamic, static, and TTL power components. In power tests that exercise all bits, checkerboard patterns are the worst case, pseudo-random patterns are middle-of-the-road, and counting patterns consume the least power. You usually assume the duty cycle to be 50%. If the duty cycle is greater than 50%, TTL power for CMOS suffers; if it is less than 50%, static power for bipolar and BiCMOS suffers. As discussed, the duty cycle also has a major effect on the termination power.

The most important factor on bus power is bus-enable duty cycle (EDC). This factor determines the average amount of time the bus elements are active vs disabled. Typically, two bus elements (one talker and one listener) are active at any instant. If there are eight listeners, each one has EDC = 12.5%. EDC determines if the bus power is mostly static or mostly dynamic.

The following data-book calculation and logic-family comparison illustrate how complex determining bus power can be. Fig 6 represents a complex bus that exercises all of the power-dissipating mechanisms of the different logic families. In this example, a CPU...
with a 3V output swing drives a transceiver (IC₁) that in turn drives a 16-bit bus loaded with 16 ports. (The ports consist of pairs of 8-bit transceivers.) Each port sends and receives 10-MHz data to and from 10 5-pF loads. The bus is terminated in a 300-pF ac termination.

If you implement the circuits of Fig 6 all in CMOS, you can divide the power calculation into two parts: \( I_{\text{IC1}} \) and \( I_{\text{IC2 through IC17}} \).

In this case, the number of outputs switching (eight because of the checkerboard data pattern) will dictate the dynamic power of IC₁. The voltage swing, \( V_{\text{SW}} \) equals 5.5V, because IC₁ has a CMOS output swing and \( V_{\text{CC}} \) equals 5.5V. The frequency, \( f \) equals 10 MHz. \( C_{\text{PD}} \) of IC₁ equals 45 pF and is the total capacitive load on IC₁. The capacitive load on IC₂ through IC₁₇ consists of a 300-pF termination capacitor and the 200-pF distributed capacitance of the transmission line. The TTL power component comes from the fact that a CPU with a 3V output swing and a standard 50% data duty cycle drives IC₁. Once again, because of the checkerboard data pattern, all outputs of the 8-bit 74XXX245 are switching, so you multiply the TTL power by 8 (\( N₁ = 8 \)). IC₁ is enabled 100% of the time, so its power in the output-disabled state doesn’t enter into the calculation. Multiply the total power by 2 to account for the 16-bit function’s two 8-bit ICs.

Total power = static power + dynamic power + TTL power

\[
I_{\text{IC1}} = 2(I_{\text{CC}} + N₁ \times V_{\text{SW}} \times f \times (C_{\text{PD}} + C_{\text{TERM}} + C_{\text{DIST}}) + N₁ \times I_{\text{CCT}} \times DDC)
\]

\[
= 2(80 \times 10^{-6} + 8 \times 5.5 \times 10^{6} \times (45 \times 10^{-12} + 300 \times 10^{-12} + 200 \times 10^{-12}) + 8 \times 1.5 \times 10^{-12} \times 0.5)
\]

\[
= 160 \times 10^{-6} + 479 \times 10^{-6} + 12.8 \times 10^{-6}
\]

\[
= 492 \text{ mA}
\]

For this example, the fact that IC₁ passes data through only one of the other 16 (\( N₂ = 16 \)) bus transceivers at a time heavily influences the total power consumed by IC₂ through IC₁₇. The enable duty cycle is 6.25% x 1/11. Also, because IC₁ has CMOS output swings, the steady-state inputs to IC₂ through IC₁₇ will always be at one of the power rails, eliminating any TTL power components. You can also assume that IC₂ through IC₁₇ each drive 10 5-pF devices, so the total load on each output is approximately 50 pF. The total power dissipated by IC₂ through IC₁₇ is

\[
I_{\text{IC2 through IC17}} = 2N₂ \times (I_{\text{CC}} + EDC \times V_{\text{SW}} \\
\times f \times N₁ \times (C_{\text{PD}} + C_{\text{TERM}}))
\]

\[
= 2(16(80 \times 10^{-6} + 0.0625 \times 5.5 \times 10^{6} \\
\times 8 \times (45 \times 10^{-12} + 50 \times 10^{-12})))
\]

\[
= 86 \text{ mA}
\]

The total power for the CMOS system of Fig 1 is

\[
P_{\text{CMOS}} = V_{\text{CC}} \times (I_{\text{IC1}} + I_{\text{IC2 through IC17}})
\]

\[
= 5.5V \times (492 \text{ mA} + 86 \text{ mA})
\]

\[
= 3.179\text{W}
\]

If you implement the circuit in Fig 6 in a bipolar logic family, you can calculate the power using the same approach as with CMOS but with these differences:

- Divide the static component into a high and a low component. Devices that are in the output-disabled state have an \( I_{\text{CC2}} \) component.
- The bipolar circuit has no TTL power component or dynamic power-dissipating capacitance (except for the load).
- The voltage swing on the bus is 1.6V (\( 2 \times V_{\text{BE}} \)) less than \( V_{\text{CC}} \).
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SPECIFICATIONS

<table>
<thead>
<tr>
<th>RATING</th>
<th>VALUE</th>
<th>UNIT</th>
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<tr>
<td>OPER. VOLTAGE</td>
<td>5 ± 0.5</td>
<td>V</td>
</tr>
<tr>
<td>OPER. TEMPERATURE</td>
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<td>°C</td>
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<td>CURRENT CONSUMPTION</td>
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<td>mA</td>
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<tr>
<td></td>
<td>STAND-BY: 2 (MAX)</td>
<td>μA</td>
</tr>
<tr>
<td></td>
<td>BACK-UP: 0.5 (TYP)</td>
<td>μA</td>
</tr>
</tbody>
</table>

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Calculate the power as:

$$I_{IC1} = 2(DDC \times I_{CCCH} + (1 - DDC) \times I_{CCCL} + N_1 \times V_SW \times f \times (C_{TERM} + C_{DIST}))$$

$$= 2(0.5 \times 90 \times 10^{-3} + (0.5) \times 120 \times 10^{-3} + 8 \times 3.9 \times 10^6 \times (300 \times 10^{-12} + 200 \times 10^{-12}))$$

$$= 210 \times 10^{-2} + 312 \times 10^{-2}$$

$$= 522 \times 10^{-3}.$$

$$I_{IC2 \text{ THROUGH } IC17} = 2N_2 \times EDC \times (DDC \times I_{CCCH} + (1- DDC) \times I_{CCCL} + N_1 \times V_SW \times f \times C_1)$$

$$+ (1 - EDC) \times I_{CCZ}$$

$$= 2(16(0.0625 \times (0.5) \times 90 \times 10^{-3} + 0.5 \times 120 \times 10^{-3} + 8 \times 3.9 \times 10^6 \times 50 \times 10^{-12} + 0.938 \times 110 \times 10^{-3}))$$

$$= 3542 \text{ mA}.$$

$$P_{BIPOLAR} = V_{CC} \times (I_{IC1} + I_{IC2 \text{ THROUGH } IC17})$$

$$= 5.5V \times (522 mA + 3542 mA)$$

$$= 22.35W.$$

The method for calculating the power of a BiCMOS system is identical to that for a bipolar one except that BiCMOS has much lower I_{CCZ} components than bipolar. The circuit of Fig 6 implemented in BiCMOS would have a total power of $$P_{BICMOS} = 5.9W.$$
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POWER OPTIMIZATION

The example, Fig 7 shows a standard personal-computer system. The piecewise approach would divide the system into sections in which you calculate power using capacitive and frequency-based approaches. For example, you would separately calculate the power dissipation in the clock generator/buffer and in the subsequent loads. Keep in mind that the system operates at several frequencies and you should calculate the power at the average frequency. For subsystems of this type, if the crystal is toggling at less than 66 MHz, CMOS logic families will usually use the least power.

The video controller and peripheral controller represent pipeline elements. For pipeline elements operating at speeds above 40 MHz, if CMOS-voltage-level compatibility is not an issue, bipolar or BiCMOS will normally yield the lowest power. For pipeline systems, data-book calculations are normally accurate.

You should treat the dynamic-RAM array as a highly capacitive load. Once you have determined the memory organization and you know the capacitance, you can determine the power by emulating the subsystem in a test fixture. You should remove the load resistor bias (either mechanically or mathematically) before comparing logic families. In most cases, BiCMOS and bipolar are preferable for driving memory arrays at frequencies above 20 MHz.

Finally, analyze the bus itself. A complex data-book calculation can point you in the right direction, but a power emulation tool, such as the one discussed in the box, “System emulation predicts power precisely,” will more accurately predict which logic family will dissipate the least power. Moreover, an emulation tool can help in selecting a termination scheme or in segmenting the number of loads. In most cases, to conserve power, you should use CMOS to implement bus elements that have low EDCs (for example, keyboards, peripherals, BIOS ROMs, and video transceivers). On the other hand, you should implement the CPU transceiver, which toggles constantly, in bipolar or BiCMOS.

---

Fig 7—When you determine a strategy for minimizing a system’s power consumption, you may want to implement different portions of the system using different IC families. The major subsystems of a high-performance personal computer are no exception.
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POWER OPTIMIZATION

Of course, these steps are just guidelines. The real keys to designing low-power systems are having an intimate understanding of the systems' requirements, being aware of the complexities of power, and being willing to use several logic families in a single design.

Authors' biographies

William M Hall is National Semiconductor's advanced CMOS logic marketing manager for its Standard Products Div. He is a graduate of Drexel University in Philadelphia, PA. Prior to joining Fairchild Semiconductor in 1985 (which later became part of National Semiconductor), he was responsible for designing and testing radar-based digital signal processors at RCA. Bill has written numerous papers on topics ranging from device and system noise to high-speed-design techniques.

Ray Mentzer is National's staff advanced bipolar design engineer for the FAST, FASTr, BCT, and F100K/300 Series ECL logic families. With more than 10 years in design, applications, and product engineering at Fairchild and National Semiconductor, his expertise covers bipolar, BiCMOS, and ECL device design as well as board-level design. A graduate of Purdue University, Ray has authored several papers on topics that include designing to deter metastable conditions, ground bounce, and EMC faults. He has one patent pending and has developed 18 new products.

WHAT'S COMING IN EDN

EDN Magazine's April 9, 1992 and April 23, 1992, issues will present a 2-part, hands-on FPGA (field-programmable gate-array) project. EDN Regional Editor Doug Connor takes you through an actual FPGA design from start to finish. Part 1 describes the design specifications, what the circuit does, and differences between FPGAs and tools. Part 2 picks up with the FPGA's place-and-route and timing-verification functions and an analysis of the completed design.

In addition, the News edition's April 30, 1992, Product Watch section will examine FPGAs and EPLDs. This round-up will look at what silicon is on the market as well as the availability and cost of related tools. Look for both editions of EDN for complete coverage on FPGA design.
The following tables form a shortform component selection guide for a collection of commonly used battery powered DC to DC conversion applications. No design is required since inductor, capacitor and resistor values are completely specified. Choose the appropriate LTC DC to DC converter for your application from the following tables.

### Step Up From One Cell (1V)

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<tr>
<th>V&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>I&lt;sub&gt;OUT&lt;/sub&gt;</th>
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<th>C</th>
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<td>33µF</td>
<td>0Ω</td>
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*ADJUSTABLE VERSIONS ALSO AVAILABLE FOR V<sub>OUT</sub> UP TO 50V

### Step Up From Two Cells (2V)

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<td>90mA</td>
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<td>350µA</td>
<td>18µH</td>
<td>33µF</td>
<td>47Ω</td>
</tr>
<tr>
<td>12V</td>
<td>150mA</td>
<td>LT1073-5</td>
<td>95µA</td>
<td>100µH</td>
<td>100µF</td>
<td>47Ω</td>
</tr>
<tr>
<td></td>
<td>150mA</td>
<td>LT1110-5</td>
<td>350µA</td>
<td>33µH</td>
<td>33µF</td>
<td>47Ω</td>
</tr>
<tr>
<td>20mA</td>
<td>20mA</td>
<td>LT1109CZ-5</td>
<td>1mA</td>
<td>33µH</td>
<td>10µF</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*ADJUSTABLE VERSIONS ALSO AVAILABLE FOR V<sub>OUT</sub> UP TO 50V

### Step Up From 5V To 12V

<table>
<thead>
<tr>
<th>V&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>I&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>P/N</th>
<th>I&lt;sub&gt;D&lt;/sub&gt;</th>
<th>L</th>
<th>C</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>12V</td>
<td>90mA</td>
<td>LT1173-12</td>
<td>110µA</td>
<td>120µH</td>
<td>100µF</td>
<td>0Ω</td>
</tr>
<tr>
<td></td>
<td>90mA</td>
<td>LT1111-12</td>
<td>350µA</td>
<td>47µH</td>
<td>33µF</td>
<td>0Ω</td>
</tr>
<tr>
<td>175mA</td>
<td>175mA</td>
<td>LT1073-12</td>
<td>95µA</td>
<td>180µH</td>
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<td>0Ω</td>
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<tr>
<td>175mA</td>
<td>175mA</td>
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<td>60µH</td>
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<td>1mA</td>
<td>33µH</td>
<td>10µF</td>
<td>N/A</td>
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</table>

*ADJUSTABLE VERSIONS ALSO AVAILABLE FOR V<sub>OUT</sub> UP TO 50V

### Flash Memory Vpp (12V) Generation

<table>
<thead>
<tr>
<th>V&lt;sub&gt;IN&lt;/sub&gt;</th>
<th>V&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>P/N</th>
<th>I&lt;sub&gt;D&lt;/sub&gt;</th>
<th>L</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5V</td>
<td>12V</td>
<td>LT1109-12</td>
<td>350µA</td>
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<td>22µF</td>
</tr>
<tr>
<td>120mA</td>
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<td>LT1109A-12</td>
<td>350µA</td>
<td>27µH</td>
<td>47µF</td>
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<tr>
<td>2 Cells</td>
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</table>
**Step Down Conversion to 5V**

<table>
<thead>
<tr>
<th>$V_{IN}$</th>
<th>$I_{OUT}$</th>
<th>P/N</th>
<th>$I_Q$</th>
<th>$L$</th>
<th>$C$</th>
<th>$R$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5V to 12V</td>
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<td>LT1173-5</td>
<td>110µA</td>
<td>47µH</td>
<td>100µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>50mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>18µH</td>
<td>33µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td></td>
<td>90mA</td>
<td>LT1073-5</td>
<td>95µA</td>
<td>47µH</td>
<td>100µF</td>
<td>220Ω</td>
<td>More Output Current/Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>90mA</td>
<td>LT1110-5</td>
<td>330µA</td>
<td>15µH</td>
<td>33µF</td>
<td>220Ω</td>
<td>More $I_Q$/Best For Surface Mount</td>
</tr>
<tr>
<td>9V to 20V</td>
<td>300mA</td>
<td>LT1073-5</td>
<td>95µA</td>
<td>180µH</td>
<td>330µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>300mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>60µH</td>
<td>100µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>12V to 20V</td>
<td>300mA</td>
<td>LT1073-5</td>
<td>110µA</td>
<td>220µH</td>
<td>220µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>300mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>82µH</td>
<td>100µF</td>
<td>220Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>20V to 30V</td>
<td>300mA</td>
<td>LT1073-5</td>
<td>110µA</td>
<td>470µH</td>
<td>470µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>300mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>180µH</td>
<td>220µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>9V to 20V</td>
<td>75mA</td>
<td>LT1173-5</td>
<td>250µA</td>
<td>100µH</td>
<td>100µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>75mA</td>
<td>LT1111-5</td>
<td>650µA</td>
<td>33µH</td>
<td>33µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>12V to 20V</td>
<td>250mA</td>
<td>LT1073-5</td>
<td>110µA</td>
<td>220µH</td>
<td>220µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>250mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>82µH</td>
<td>100µF</td>
<td>220Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>12V to 20V</td>
<td>-5V</td>
<td>75mA</td>
<td>250µA</td>
<td>100µH</td>
<td>100µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>75mA</td>
<td>650µA</td>
<td>33µH</td>
<td>33µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td>12V to 20V</td>
<td>-5V</td>
<td>150mA</td>
<td>220µA</td>
<td>180µH</td>
<td>470µF</td>
<td>100Ω</td>
<td>More Output Current</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>150mA</td>
<td>650µA</td>
<td>180µH</td>
<td>470µF</td>
<td>100Ω</td>
<td>More Output Current</td>
</tr>
<tr>
<td>20V to 30V</td>
<td>-5V</td>
<td>250mA</td>
<td>110µA</td>
<td>470µH</td>
<td>220µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>250mA</td>
<td>330µA</td>
<td>82µH</td>
<td>100µF</td>
<td>220Ω</td>
<td>Best For Surface Mount</td>
</tr>
</tbody>
</table>

**Inductor and Capacitor Part Numbers/Manufacturers**

**Inductor Value**
- 15µH
- 18µH
- 20µH
- 22µH
- 27µH
- 33µH
- 47µH
- 68µH
- 82µH
- 100µH
- 120µH
- 180µH
- 220µH
- 470µH

**Capacitor Manufacturers**
- Best: OS-CON Series
  - Sanyo Video
  - Sumida

**Inductor Manufacturers**
- Caddell-Burns
  - Mineola, NY, USA
  - Gowanda Elect.
  - Coiltronics Intl.
  - Sumida

**Capacitor Manufactures**
- Better: PL Series
  - Nichicon America

**Surface Mount Inductors**

**Call Linear Technology!**
- For a Datasheet: 800-637-5545
- For Applications Help or the Marketing Dept.: 408-432-1900
- FAX: 408-434-0507

---

**Battery Powered DC/DC**

**Step Down Converter**

**Device Pinouts (DIP and SOIC Pkgs.)**

<table>
<thead>
<tr>
<th>Device Pinouts</th>
<th>DIP (P/N)</th>
<th>SOIC (P/N)</th>
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<tr>
<td>Power Stage</td>
<td>LT1073</td>
<td>LT1173</td>
</tr>
<tr>
<td>Feedback</td>
<td>FB (SENSE)</td>
<td>FB (SENSE)</td>
</tr>
<tr>
<td>Power Stage</td>
<td>LT1109</td>
<td>LT1109</td>
</tr>
<tr>
<td>Control</td>
<td>NC</td>
<td>NC</td>
</tr>
<tr>
<td>Ground</td>
<td>GND</td>
<td>GND</td>
</tr>
</tbody>
</table>

† -5,-12 Versions

---

**Positive to Negative Conversion**

<table>
<thead>
<tr>
<th>$V_{IN}$</th>
<th>$V_{OUT}$</th>
<th>$I_{OUT}$</th>
<th>P/N</th>
<th>$I_Q$</th>
<th>$L$</th>
<th>$C$</th>
<th>$R$</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5V</td>
<td>-5V</td>
<td>75mA</td>
<td>LT1173-5</td>
<td>250µA</td>
<td>100µH</td>
<td>100µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>75mA</td>
<td>LT1111-5</td>
<td>650µA</td>
<td>33µH</td>
<td>33µF</td>
<td>100Ω</td>
<td>Best For Surface Mount</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>150mA</td>
<td>LT1073-5</td>
<td>220µA</td>
<td>180µH</td>
<td>470µF</td>
<td>100Ω</td>
<td>More Output Current</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>150mA</td>
<td>LT1111-5</td>
<td>650µA</td>
<td>180µH</td>
<td>470µF</td>
<td>100Ω</td>
<td>More Output Current</td>
</tr>
<tr>
<td>12V</td>
<td>-5V</td>
<td>250mA</td>
<td>LT1173-5</td>
<td>110µA</td>
<td>470µH</td>
<td>220µF</td>
<td>100Ω</td>
<td>Lowest $I_Q$</td>
</tr>
<tr>
<td></td>
<td>-5V</td>
<td>250mA</td>
<td>LT1111-5</td>
<td>330µA</td>
<td>82µH</td>
<td>100µF</td>
<td>220Ω</td>
<td>Best For Surface Mount</td>
</tr>
</tbody>
</table>

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**Capacitor Manufacturers**
- Best: OS-CON Series
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  - Sumida

---

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**Linear Technology Corp.**
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- (408) 432-1900
Multipliers implement tunable filters

Tom Napier, Aydin Computer and Monitor Div, Horsham, PA

The circuits illustrated in Fig 1 use multiplier ICs to implement tunable filters. Tunable filters perform important antialiasing functions in sampled data systems that have variable sampling rates. The circuit in Fig 1a is a simple 1-pole filter. Fig 1b is a form of 2-pole state-variable filter. You can use the same architecture to build higher order filters. The Harris HA-2547 analog multiplier chip is essentially a voltage-controlled transimpedance amplifier with a very high output impedance and a large output compliance. When driving capacitive loads, the multipliers behave like voltage-tunable integrators with a ±6V output. With a 2V control input, the multiplier's effective transimpedance is 2500Ω. With a 100-mV control input, the transimpedance rises to 50 kΩ.

Each filter requires only two or four parts, with the exception of the bypass capacitors. The filters' cut-off frequencies are voltage tunable over a 20-to-1 range and usable from very low frequencies to as high as several megahertz. The filters do exhibit high input impedances and high output impedances. Thus, unless the filter drives a high-input-impedance ADC, it requires an output buffer. Offset trimming may be necessary in critical applications.

The theoretical transfer functions of Fig 1a and Fig 1b, respectively, are as follows:

\[
\frac{1}{1+sT_1}
\]

and

\[
\frac{1}{1+sT_2 + s^2T_1 T_2}
\]

Time constants \(T_1\), \(T_2\), and \(T_3\) equal the variable impedances multiplied by \(C_1\), \(C_2\), and \(C_3\), respectively. In Fig 1b, the product of \(T_2\) and \(T_3\) sets the cut-off frequency, and the ratio of \(T_2\) to \(T_3\) controls the Q. For a Butterworth response, \(C_2\) should be twice \(C_1\). With capacitor values of 62 and 30 pF, the 2-pole filter's tuning range spans 50 kHz to 1 MHz. The filter's useful range is limited to about 5 MHz by the output capacitance of the multiplier, which is approximately 10 pF. The measured response indicates that a zero exists due to feedthrough, but the measured stopband attenuation is over 30 dB. **EDN BBS/DI_SIG #1097**

To Vote For This Design, Circle No. 746
Compiler generates PROM decoder HEX file

Ralph Ursoleo, Inovec Inc, Eugene, OR

PROMs have long been recognized as excellent address decoders because of their great flexibility compared with discrete logic decoders. PROMs can generate contiguous chip-select signals for multiple devices of different sizes without wasting address space, and the PROM implementation uses only one level of logic so it's relatively fast. PROMs also allow for device-size changes without hardware modifications.

Unfortunately, generating the PROM data has always been a tedious, manual process, usually involving large tables of binary/HEX addresses to map the entire PROM. Once you generate the table, you manually enter the PROM data into a programming device and upload to a computer that creates the .HEX file for later use. Entering or changing the .HEX file requires that you use a typically crude programmer editor, which can be a frustrating, error-prone experience.

The compiler called PROMGEN, which you can download using EDN's BBS, lets you describe the decoder in text format using a standard text editor. This text (source) file, which allows descriptive comments, can be as detailed in its explanation as you wish. Once generated, PROMGEN scans the source file for errors and generates an Intel HEX format file for downloading to a programmer. Listing 1 shows the general format of the source file.

Note that there are two keyphrases: DEFAULT OUTPUT XX and DEVICE XX. DEFAULT OUTPUT XX specifies the value for all PROM locations not specified in an address range. DEVICE XX specifies the size of the target PROM and thus the size of the resulting HEX file. The compiler flags many types of errors such as invalid HEX address/data characters, address range overlaps, unrecognizable device sizes, and missing PROM outputs. Optional EQUATE statements, such as those in Listing 2, let you equate PROM output values to text strings for easier reading. Without this feature, you'd have to refer to schematics to decipher exactly what a PROM output of 7E does.

Clock adapter generates 2- and 4-MHz signals

William S JenningsCheck, Level One Communications Inc, Folsom, CA

The LXP600A clock adapter is excellent for many T1/E1 transmission applications because it generates a jitter-free 1.544-MHz clock frequency when locked to a 2.048-MHz master clock or vice-versa. However, some applications require a 4.096-MHz clock with a 244-µsec frame-sync pulse locked to the rising edge. Many of these applications also require a synchronous 2.048-MHz clock. For these applications, you can combine a clock adapter with an HCT4046A phased-locked loop (PLL), two 74HCT00 NAND gates, and three

---

Listing 1—General format of compiler source file

<table>
<thead>
<tr>
<th>DESIGNER</th>
<th>COMMENTS preceded with semi-colon</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESCRIPTION</td>
<td></td>
</tr>
<tr>
<td>REVISION</td>
<td></td>
</tr>
<tr>
<td>COMMENTS</td>
<td></td>
</tr>
</tbody>
</table>

DEFAULT OUTPUT FF

DEVICE 2KX8

<table>
<thead>
<tr>
<th>PROM</th>
<th>PROM</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>range</td>
<td>output</td>
<td></td>
</tr>
<tr>
<td>0000-0005</td>
<td>FE</td>
<td>corresponds to system I/O address 8000H-8005H</td>
</tr>
<tr>
<td>0006-0006</td>
<td>F7</td>
<td>selects the timer chip</td>
</tr>
<tr>
<td>0020-0009</td>
<td>7E</td>
<td>examines the control latch</td>
</tr>
<tr>
<td>0100-0200</td>
<td>55</td>
<td>comments</td>
</tr>
</tbody>
</table>

Listing 2—Equate-statement examples

<table>
<thead>
<tr>
<th>EQUATE</th>
<th>RAM_ENABLE</th>
<th>PROM</th>
<th>ROM.Enable</th>
<th>7F</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDRESS</td>
<td>PROM</td>
<td>output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0000-00A5</td>
<td>RAM_ENABLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00B8-00BA</td>
<td>ROM_ENABLE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SPDT switches with built-in driver

**ABSORPTIVE** or **REFLECTIVE** dc to 5GHz

Truly incredible... superfast 3nsec GaAs SPDT reflective or absorptive switches with built-in driver, available in pc plug-in or SMA connector models, from only $19.95. So why bother designing and building a driver interface to further complicate your subsystem and take added space when you can specify Mini-Circuits’ latest innovative integrated components?

Check the outstanding performance of these units... high isolation, excellent return loss (even in the “off” state for absorptive models) and 3-sigma guaranteed unit-to-unit repeatability for insertion loss. These rugged devices operate over a -55° to +100°C span. Plug-in models are housed in a tiny plastic case and are available in tape-and-reel format (1500 units max, 24mm). All models are available for immediate delivery with a one-year guarantee.

**SPECIFICATIONS (typ)**

<table>
<thead>
<tr>
<th></th>
<th>Absorptive SPDT</th>
<th>Reflective SPDT</th>
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</thead>
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<td>ZYSWA-2-50DR</td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>(MHz)</td>
<td>500 2000 5000</td>
<td>500 2000 5000</td>
</tr>
<tr>
<td>Insertion Loss</td>
<td>1.1 1.4 1.9</td>
<td>0.9 1.3 1.4</td>
</tr>
<tr>
<td>Isolation (dB)</td>
<td>42 31 20</td>
<td>50 40 28</td>
</tr>
<tr>
<td>1dB Comp. (dBm)</td>
<td>18 20 22.5</td>
<td>20 20 24</td>
</tr>
<tr>
<td>RF Input (max dBm)</td>
<td>20</td>
<td>22 22 26</td>
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<tr>
<td>VSWR “on”</td>
<td>1.25 1.35 1.5</td>
<td>1.4 1.4 1.4</td>
</tr>
<tr>
<td>Video Bkthru (mV/p-p)</td>
<td>30 30 30</td>
<td>30 30 30</td>
</tr>
<tr>
<td>Switch Speed (nsec)</td>
<td>3 3 3</td>
<td>3 3 3</td>
</tr>
<tr>
<td>Price, $</td>
<td>YSWA-2-50DR (pin) 23.95</td>
<td>YSWA-2-50DR (pin) 19.95</td>
</tr>
<tr>
<td>(1-9 qty)</td>
<td>ZYSWA-2-50DR (SMA) 69.95</td>
<td>ZYSWA-2-50DR (SMA) 59.95</td>
</tr>
</tbody>
</table>

**Mini-Circuits**

CIRCLE NO. 101

P.O. Box 350166, Brooklyn, New York 11235-0003 (718) 934-4500 Fax (718) 332-4661 Telexes: 6852844 or 620156
74HCT74 leading edge-triggered flip-flops to produce the desired outputs.

Fig 1 shows a clock adapter, IC1, functioning in the 1.544- to 2.048-MHz mode. In this mode, the clock adapter produces a 2.048-MHz clock output plus an 8-kHz frame-sync output. The frame-sync output is a 488-μsec pulse that is locked to the falling edge of the clock output. The potentiometer attached to IC2's PLL's R1 pin lets you tune the PLL's VCO (voltage controlled oscillator) to 4.086 MHz. The VCO's output is synchronized to the clock adapter's clock output. The comparison input is provided by the Q output of flip-flop 1, at one-half the VCO frequency.

The VCO produces both the 4.096- and 2.048-MHz clock frequencies at the $C_4$ and $C_2$ outputs, respectively (Fig 2). IC3A functions as a simple inverter, producing the $C_1$ clock from the clock-adapter-synchronized VCO output. The Q output of IC3A produces the $C_2$ clock, which is also tied back to the D input. Flip-flops IC3H and IC3A, and IC3H produce $F_0$ from the clock adapter's FSO output.

To Vote For This Design, Circle No. 748

EDN BBS /DL.SIG #1098

Fig 1—Adding a phase-locked loop, three flip-flops, and a pair of NAND gates to a clock-adapter IC gives you a 4.096-MHz clock with a 244-μsec frame-sync pulse, plus one synchronous 2.048-MHz clock.

Fig 2—This timing diagram illustrates the relationships between the 2- and 4-MHz clock signals generated by Fig 1's circuit.
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CIRCLE NO. 102
High-voltage regulator has low dropout

Dana W Davis, Maxim Integrated Products, Sunnyvale, CA

The positive voltage regulator of Fig 1 maintains 5V regulation at 1A with inputs as low as 5.02V. The circuit's pass transistor is an n-channel MOSFET. MOSFETs having low $R_{DS(ON)}$ are the key to this application because dropout voltage is proportional to $R_{DS(ON)}$. Fortunately, high-power MOSFETs having extremely low $R_{DS(ON)}$ are both inexpensive and readily available.

IC2, an LM10, contains a precision op amp, a voltage reference, and a variable-gain buffer. External resistors configure the buffer for a gain of 25, boosting the 0.2V reference to a regulated 5V at IC2's pin 1. By comparing this 5V reference with the regulated output, $V_{OUT, IC2}$'s internal op amp produces an error voltage that drives the MOSFET's gate. Powered by the high-side power supply, IC1, IC2 delivers a gate drive of $V_{CC}+11V$ (approximately 16V). At $I_{OUT}=5A$, the resulting dropout voltage is under 400 mV for an IRF541 MOSFET, and under 100 mV for an SMP60N06. The output voltage depends on $R_1$ and $R_2$:

$$V_{OUT} = 0.2(R_2/R_1) + 1.$$  

Gate-leakage current in the MOSFET, unlike base current in a bipolar transistor, does not change with the load current. Therefore, the operating supply current of Fig 1's circuit, drawn only by IC1 and IC2, is relatively independent of the load current.

The ENABLE/SHUTDOWN input controls the regulator and must supply at least 2 mA. Diode D1 shortens the turn-on time following an ENABLE/SHUTDOWN command. During shutdown, the only current that the circuit draws is leakage current through the pass transistor. If you do not need the shutdown function, eliminate D1 and connect $V_{CC}$ directly to the input power.

At power-up with the regulator enabled, the PR output of IC1 remains low, holding the MOSFET off by depressing the reference voltage at the non-inverting input of IC2. The regulator thus remains off until the gate-drive voltage rises to an acceptable level, typically $V_{CC}+8.5V$.

The output capacitor, C1, stabilizes the output voltage against load changes. If your load is relatively constant, you can reduce or eliminate C1.

Input voltage may range as high as 16.5V, but a lower level (produced by a stack of five NiCd cells, for example) offers higher efficiency.

To Vote For This Design, Circle No. 749

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Fig 1—This power supply takes advantage of n-channel MOSFETs' low $R_{DS(ON)}$ to provide dropout voltages measured in hundreds of millivolts.
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Reader questions circuit
I believe the printed schematic of Mr Cuthbert's interesting circuit, "Charge pump halves voltage," on pg 204 of the December 5, 1991, issue of EDN contains a critical error. Q,‘s drain-source connections are across the C, 330-µF capacitor. When Q2 turns on, this connection will create a short circuit across C1. Also, why use two inverters, IC11 and IC1, in parallel?
Finally, there was no mention of another key point. IC,‘s dc supply voltage must be large enough to ensure proper turn on of Q1 to Q4. For example, the gate-to-source voltage of Q1, is IC1’s Vout minus ½ V1IN. Therefore, with an input of 12V, the 4049 inverter should be supplied by at least VGS0ON +6V. So the typical 5V regulated V1IN on IC1 wouldn't work. However, I think he could use the V1IN voltage itself as the supply to guarantee turn on.
Tony Veneruso
Schlumberger
228, rue Einstein
BP 92 77005 Melun Vedex, France

Author reply
Mr Veneruso is correct concerning the circuit connections. The drain-source connections of Q1 connect to the opposite drain lead of Q4, and not to C1 as incorrectly drawn. To address his other questions, I used two inverters in parallel because I had one left over, and the input capacitance of Q1 is double that of Q1, Q3, or Q4. Also, I thought it was implied that the V1IN for IC1 is the same as V1IN.
Two other minor discrepancies exist between my original circuit and the one published. The resistor between IC11 and IC10 was supposed to be 100 kΩ. Also, the gate resistor Q1 is 100 ohms. Neither of these resistor-value differences will degrade the circuit’s performance.
Dave Cuthbert
Tektronix
Box 500, MIS W3-100
Beaverton, OR 97077

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**RAMDAC With Resolution Of 1280 x 1024 Pixels**
- Supports 24-bit color displays
- Features a 5:1 input multiplexer

The Bt464 RAMDAC supports true 24-bit color displays at resolutions to 1280 x 1024 pixels. Multiplexed input ports provide multiplexer options of 1:1, 2:1, 4:1, and 5:1, and a 5:1 frame buffer reduces video RAM (VRAM) memory requirements. With binary frame-buffer addressing, 48 1-Mbit VRAMs are needed to support 1280 x 1024 monitors for 24 bits. With a 5:1 multiplexer, a frame buffer using quinary addressing can reduce the number of VRAMs to 30, lowering memory costs. Other features of the Bt464 include pixel interleaving, which provides the end user with a faster line-drawing time in complex CAD/CAM applications, and the ability to allow users to switch between true color and pseudocolor on a pixel-by-pixel basis. The RAMDAC is available in speed grades of 110, 135, and 150 MHz and comes in a 208-pin, pin-grid-array package. 135-MHz version, $328 (100).

**Brooktree Corp,** 9950 Barnes Canyon Rd, San Diego, CA 92121. Phone (619) 452-7580. FAX (619) 452-1249. TLX 383596. Circle No. 413

---

**Simultaneous-Sampling 4- or 8-Channel ADCs**
- Low channel-to-channel phase delay
- Have track-and-hold circuits for each channel

The MAX155 (8-channel) and MAX156 (4-channel) A/D converters simultaneously sample each analog input signal and sequentially digitize them to 8-bit accuracy in 3.6-μsec/channel. Each channel has its own track-and-hold (T/H) circuit, which reduces channel-to-channel phase delay to less than 4 nsec, compared with several μsec for ADCs with a single T/H circuit. Both devices contain a 2.5V reference, an 8 x 8-bit RAM to store results, and an 8-bit microprocessor interface. The ADCs operate from ±5V supplies or a single 5V supply and perform unipolar or bipolar conversions with either single-ended or differential inputs. The internal data bus provides for bidirectional data flow, allowing user-defined setup and access to stored RAM conversion data. The MAX156 comes in 24-pin DIP and SO packages; the MAX155 comes in 28-pin DIP and SO packages. From $10 (100).

**Maxim Integrated Products,** 120 San Gabriel Dr, Sunnyvale, CA 94086. Phone (408) 737-7600. Circle No. 414

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**Baseband I/O Ports For Digital Radio Systems**
- Combine A/D and D/A converters
- Provide audio-to-IF/RF interface

Designed for digital-mobile-radio systems such as the Pan-European Digital Cellular Telephone, the AD7001 and AD7002 baseband I/O ports provide key functions in the transmit and receive paths. Combining A/D and D/A converters for I and Q channel information, along with filtering, a serial interface, and pulse-shaping ROM, these devices perform signal conversion between the audio section and the IF/RF sections in mobile telephones. By digitizing and encoding the voice at the source and transmitting entirely in digital format, several online users can share each available channel. Although both I/O ports perform similar functions, they use different internal architectures to meet specific user needs. The AD7001 uses a successive-approximation A/D converter; the AD7002 features a sigma-delta converter, along with additional DACs for frequency control, gain control, and signal shaping. Both devices operate from a 5V supply and come in 44-pin quad flatpacks. $25 (1000).

**Analog Devices,** 181 Ballardvale St, Wilmington, MA 01887. Phone (617) 937-1428. Circle No. 415

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Field-programmable gate arrays. The CLi6000 series of high-speed, static-RAM-based, field-programmable gate arrays (FPGAs) feature a toggle rate of 150 MHz and run to 70 MHz. Power consumption is less than 2 mA/MHz. The first members of the series are the CLi6002, CLi6003, and CLi6005, with 2000, 3000, and 5000 gates, respectively. Package options include 84-pin plastic leaded chip carriers and 132-pin plastic quad flatpacks. From $58 to $180 (OEM qty). Concurrent Logic Inc, 1290 Oakmead Pkwy, Sunnyvale, CA 94086. Phone (408) 522-8700. FAX (408) 732-2765. Circle No. 417

30-MHz Transputer. A 30-MHz version of the IMS T805 Transputer, the T805-G30S, provides a peak performance of 30 MIPS and 4.3 Mflops, 50% greater than the 20-MHz version. This version features an interrupt response time of 630 nsec and average power consumption of 660 mW. The T805 integrates a 32-bit CPU, a 64-bit floating-point unit, 4-kbytes of memory, a 4-Gbyte multiplexed memory bus and four communications links. In an 84-pin pin-grid array or 100-pin ceramic flatpack. From $890 (500). SGS-Thomson Microelectronics, 100 E Bell Rd, Phoenix, AZ 85022. Phone (602) 867-6228. Circle No. 417

Low-power op amps. The OP-282 (dual) and OP-482 (quad) op amps combine precision and moderate speed with low-power operation. Drawing a maximum supply current of 250 µA, each amplifier features a unity-gain band-width of 4 MHz, a slew rate of 7V/µsec and a settling time of 1.6 µsec to 0.01%. Typical bias current is 3 pA at 25°C. Offset voltage is 3 mV for dual units and 4 mV for quad units. OP282 and OP482, $1.05 and $1.72, respectively, (1000). Analog Devices Inc, PMI Div, 1500 Space Park Dr, Santa Clara, CA 95052. Phone (408) 562-7466. Circle No. 418

20-MHz floating-point DSP. The ADSP-21020 floating-point DSP features a clock speed of 20 MHz (50-nsec cycle time). The DSP performs a 1024-point complex FFT in 0.96 nsec, three times faster than comparable devices. The DSP, which comes in a 223-pin pin-grid-array package, is available in commercial (0 to 85°C) and military (−55 to +125°C) temperature grades. From $198 (1000). Analog Devices Inc, Box 9106, Norwood, MA 02067. Phone (617) 461-3881. Circle No. 419

High-resolution audio DAC. Using bit-stream (delta-sigma) technology, the SAA7350 20-bit DAC interfaces with all known digital input formats, including the Sony serial format and the Philips intersound bus. The DAC pro-
vides a choice of two clock frequencies, which results in internal oversampling factors of 128 or 192. Connecting the SAA7350's third-order noise-shaper outputs to the companion TDA1547 1-bit DAC results in a THD+N of -104 dB (0.0006%), linearity deviation of 0.2 dB, and channel separation of better than 120 dB. The SAA7350 comes in a 44-pin quad flatpack; the TDA1547 comes in a 32-pin DIP. $26 and $17.50, respectively, (100). Signetics Co, Box 3408, Sunnyvale, CA 94088. Phone (408) 991-2111.

Circle No. 420

Low-cost, 8-bit microcontrollers. Combining a 68HC05 CPU with peripherals and memory, the K-series microcontrollers (µCs) offer design flexibility. The 68HC05K0 adds 32 bytes of RAM, 504 bytes of ROM, a 15-stage multifunction timer, 10 bidirectional I/O lines, an oscillator, a watchdog timer, and other features. The 68HC05K1 has all of the common features of the 68HC05K0 plus 64 bits of personality EPROM, programmed via software. The 68HC705K1 incorporates all of the features of the other µCs, 504 bytes of one-time-programmable EPROM that replaces the 504 bytes of ROM, and an EPROM mask-option register. 68HC05K0, 68HC05K1, and 68HC705K1, $1, $1.50, and $2.50, respectively, (50,000). Motorola Inc, 6501 William Cannon Dr W, Austin, TX 78735. Phone (512) 891-2035.

Circle No. 421

High-speed ECL comparators. The MAX905 (single) and MAX906 (dual) edge-triggered, ECL-compatible comparators feature an overdrive-insensitive propagation delay of 2 nsec. Whether the input overdrive is 3 mV or 1V, the propagation delay does not change. You can clock the comparators at speeds to 500 MHz, and both devices have separate analog and digital power supplies to isolate the noisy digital circuitry from the analog input section. The MAX905 (14-pin) and MAX906 (16-pin) come in DIPs and SO packages. From $3.98 and $5.98, respectively, (100). Maxim Integrated Products, 120 San Gabriel Dr, Sunnyvale, CA 94086. Phone (408) 737-7600.

Circle No. 422

Mixed-signal array. Fabricated in a 32V process that supports industrial and control applications, the RLDA80 semicustom array combines analog and digital macrocells on a single chip. The analog macrocells accommodate applications from dc to 1 MHz, and the digital macrocells deliver propagation delays typical of LS TTL logic. RLDA80, in 44-pin ceramic leadless chip carriers and plastic leaded chip carriers, from $30,000 (includes layout 10 prototypes and test development). Raytheon Co, Semiconductor Div, 350 Ellis St, Mountain View, CA 94043. Phone (415) 988-9211.

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<th>MODEL NUMBER</th>
<th>OUTPUT 1</th>
<th>OUTPUT 2 (Peak)</th>
<th>OUTPUT 3</th>
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<td>UPS65-1002</td>
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<td>-12V @ 0.5A (2.5)</td>
<td>3.5 x 6.0</td>
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Radio Modem

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- **Operates over a 450- to 470-MHz FM band**

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Monicor Electronic Corp, 2964 NW 60th St, Fort Lauderdale, FL 33309. Phone (305) 979-1907. FAX (305) 979-2611.

**Circle No. 352**

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Hewlett-Packard Co, Inquiries, 19310 Pruneridge Ave, Cupertino, CA 95014. Phone (800) 752-0900.

**Circle No. 353**
VMEbus MIL-STD-1553 board. The BCU-VME-M 6U VMEbus board has a MIL-STD-1553 interface. It contains 128k x 16 bits of dual-port RAM for storing control block and message data. Modes of operation include bus controller; multiple-remote-terminal simulation; and concurrent monitor. The unit features error detection; bit-error injection; built-in loopback tests on transmissions; and a programmable time lag having 1- or 64-µsec resolution. $5495. SCI Systems Inc, Box 1000, Huntsville, AL 35807. Phone (205) 882-4569. FAX (205) 882-4652. Circle No. 354

VMEbus RISC SBC. The RISQengine/5e is a VMEbus single-board computer (SBC) containing a 25-, 33-, or 40-MHz R3000 RISC (reduced-instruction-set computer) µP. It also contains an 8-kbyte instruction cache; a 2-kbyte data cache; 2, 8, or 32 Mbytes of 2-way interleaved dynamic RAM (DRAM); 256 kbytes of EPROM expandable to 1 Mbyte; two RS-232C ports; a real-time clock; 8 or 32 kbytes of nonvolatile RAM; and three counter/timers. 25-MHz board with 2 Mbytes of DRAM and 256 kbytes of EPROM, from less than $3000. RISQ Modular Systems Inc, 38899 Balentine Dr, #200, Newark, CA 94560. Phone (415) 489-0655. Circle No. 355

Laser printer. The LZR 1560 laser printer incorporates Adobe System's Postscript Level 2 software. The 400-dpi printer handles 11x17-in. paper and prints at 15 pages/minute. Models are available with one to three paper trays. Each model has an Appletalk, RS-232C and a Centronics parallel port. In addition, the printer has a SCSI port to connect a hard-disk drive and you can configure the unit as a network printer. Less than $6000. Dataproducts Corp, Box 746, Woodland Hills, CA 91367. Phone (818) 887-8000. FAX (818) 887-4789. Circle No. 356

Terminal concentrator. The 8/ctcp+ concentrator connects as many as eight terminals to a host containing one of the company's 8 × 4AT, 8 × 4GT, 8 × 4MC, or 8 × 2 adapters. The concentrator has RS-422 or RS-423 ports to communicate with terminals located 2500 ft away. You can connect RS-232C over standard distances. An optional power supply lets you install the concentrator at long distances from the host. $695. Corollary Inc, Box 18977, Irvine, CA 92713. Phone (714) 250-4040. FAX (714) 250-4043. Circle No. 357

MicroVAX memory board. The DCME-576 board provides 4 or 8 Mbytes for DEC's MicroVAX Models 30, 40, 76, and 80 computers. It uses double-sided surface-mount chips on the same form
factor as DEC's MS44-AA memory board. The company provides 24-hour repair or replacement and 24-hour technical hotline support. 4-Mbyte version, $780; 8-Mbyte version, $1560. Clearpoint Research Corp, 35 Parkwood Dr, Hopkinton, MA 01748. Phone (508) 435-2000. FAX (508) 435-7504.

Dot-matrix printer. The NX-2430 24-pin dot-matrix printer has a front-panel LCD. It comes with two 5 1/4-in. floppy disks containing utilities and fonts. The printer's 11 resident fonts include nine letter-quality and two draft fonts. You can download 256 font characters to 16 kbytes of RAM. $399. Star Micronics America Inc, 420 Lexington Ave, Suite 2702, New York, NY 10170. Phone (212) 986-6770. FAX (212) 286-9063.

Transputer graphics system. This graphics subsystem comprises three boards for the company's TIP bus. The TIP-VPU/T8 processor board uses a T805 Transputer and 1 or 4 Mbytes of dynamic RAM. A T400 Transputer serves as the bus controller. The TIP-MFG frame grabber captures images from RS-170- or CCIR-compatible CCD (charge-coupled-device) cameras and video recorders. The TIP-CGD color graphics display generates 800×600- or 1280×1024-pixel images. 1 Mbyte TIP-VPU/T8, $4600; TIP-MFG, $5200; TIP-CGD, $5800. Parsytec Inc, Bldg 9, Unit 60/61, 245 W Roosevelt Rd, West Chicago, IL 60185. Phone (708) 283-5500.

Fax-data modem. The COMstation Five modem sends and receives facsimiles and data for Apple Macintosh computers. It conforms to V.17 fax/modem and V.32 bis data-modem specifications for 14.4-kbps communications. The unit also conforms to V.42, V.42 bis, and MNP5 CCITT standards for error correction and data compression. The unit runs on the System 7.0 operating system and measures 2×8×5.5 in. $899. PSI Integration Inc, 851 E Hamilton Ave, Suite 200, Campbell, CA 95008. Phone (800) 622-1722; (408) 559-8544. FAX (408) 559-8548.


Network hub. The BMX45N bandwidth manager provides hub functions for Synchronous Optical Network

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AT&T Microelectronics
(SONET) OC3, Cell-Relay, and Switched Multigigabit Data Service (SMDS) networks. It provides a nonblocking switching matrix, which allows circuits to be switched from one port to another to achieve load balancing. The unit provides SNMP, OSM Motif/X-Window, and CMIP network management functions. Nonredundant system, from $42,000; redundant system, from $65,000. T3plus Networking Inc, 2840 San Tomas Expressway, Santa Clara, CA 95051. Phone (408) 727-4545. FAX (408) 727-5151. Circle No. 363

SCSI bus switches. The SM-90/R can connect as many as 21 SCSI peripherals to a single host computer. You can switch the units manually or automatically under program control. The SM-90/12 connects a single SCSI port to one of two SCSI branches. The SM-90/13 connects a single SCSI port to one of three SCSI branches. The SM-90/22 connects two SCSI ports to two SCSI branches. From $2290. Ancot Corp, 115 Constitution Dr, Menlo Park, CA 94025. Phone (415) 322-5322. FAX (415) 322-0455. Circle No. 364

Notebook computer. The 20-MHz 86386SX notebook computer has an internal 9600/2400 fax/modem. Standard configuration includes 2 Mbytes of RAM, expandable to 5 Mbytes; an 80 Mbyte 2½-in. hard disk drive; and a 1.4 Mbyte, 3½-in. floppy disk drive. The unit has AMI's BIOS in shadow RAM and a socket for an 80387 coprocessor. The monitor displays 32 gray scales composed of 640×480 pixels. The unit weighs 7.1 lbs, including batteries. $2395. Centrix Computer, 15316 Valley Blvd, Industry, CA 91746. Phone (800) 888-9988; (818) 855-2800. Circle No. 365

Macintosh video board. The EyeQ Authoring System contains a video display board for Nubus Macintosh computers. It uses an Intel i750 video processor chip to implement the digital video interactive (DVI) mode. The board compresses and decompresses 30-frame/sec video data to hard-disk format in real time. The media files produced by MacDV1 software are compatible with files for DVI implementations on IBM PS/2 and DOS-compatible computers. $496. New Video Corp, 220 Main St, Suite C, Venice, CA 90291. Phone (213) 396-4000. FAX (213) 396-0282. Circle No. 366

Ethernet adapter cards. These two Ethernet adapter cards have an RJ-45 connector for 10Base-T twisted-pair and a DB-15 connector for attached-unit interface (AUI), coaxial-cable communications. The Model 513 is an 8-bit ISA bus board, and the Model 615 is a 16-bit ISA bus board. Novell users can switch to 10Base-T communications using existing software drivers. Model 513, $295; Model 515, $355. Telebyte Technology Inc, 270 E Pulaski, Greenlawn, NY 11740. Phone (800) 423-3232. FAX (516) 423-3232. Circle No. 367

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Keithley Instruments Inc, 28775 Aurora Rd, Cleveland, OH 44139. Phone (800) 552-1115; (216) 248-0400. FAX (216) 248-6168.

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DT-Open Layers software provides standard ways for MS-Windows-based data-acquisition application programs to interface with libraries of functions and with instruments. Applications that follow the standards will support new hardware and functional extensions without recompilation. Copies of the standards are free of charge; 1.0 versions of data-acquisition and signal-processing libraries include Global Lab Data Acquisition software, $1495; Global Lab Image software, $1995; data-acquisition library, free with purchase of the firm's data-acquisition hardware, otherwise $95; image library, $1995. Users of Global Lab V2.1, which does not support Windows, will receive a $500 credit when they upgrade to the Windows-compliant version.

Data Translation Inc, 100 Locke Dr, Marlborough, MA 01752. Phone (508) 481-3700.

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There is a far side to the world of oscilloscopes, a place filled with all sorts of bizarre characters. Like those who swear you need digital, for the sole reason that digital is all they wish to sell. Then there's the gang that wants to push nothing but analog. Luckily, there's also a place called Tektronix. Where they manufacture a complete line of analog and digital scopes. Making them uniquely qualified to provide you with a more honest assessment of your needs. With anyone else, you could be hearing only half the story. For complete information on the full line of Tektronix analog and digital oscilloscopes, get in touch with a Tek representative today. TALK TO TEK/1-800-426-2200
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Teradyne Inc, 321 Harrison Ave, MS L-57, Boston, MA 02118. Phone (617) 422-3567. FAX (617) 422-3440. Circle No. 371

Trouble-shooting aid for pc boards. The 9110FT isolates faults to the component level by using emulative functional and stimulus routines and a single-point probe. Among the test techniques the unit uses are signature analysis, logic-level detection, frequency and event counting, and pulsing. From $13,000; typically less than $20,000. Delivery, six weeks ARO.

John Fluke Mfg Co Inc, Box 9090, Everett, WA 98206. Phone (800) 443-5853. Circle No. 372

Philips Test and Measurement, Bldg TQ 111-4, 5600MD Eindhoven, The Netherlands. Phone local office. Circle No. 373

Universal IC programmers. Systems 1040 (40 channels, $2995) and 1084 (84 channels, $3995) are universal IC programmers using a DAC per pin. They accommodate center-ground-pin devices without needing adapters. The programmers interface to the host PC via the parallel-printer port. This arrangement combines the advantages of PC hosting with fast downloading and simplifies moving the programmer from PC to PC. Stag Microsystems Inc, 1000 Wyatt Dr, Santa Clara, CA 95054. Phone (800) 227-8836; (408) 988-1118. TWX 910-339-9607. Circle No. 374

Tester for digital communications links. With the $2280 E1 option, the PF-45 analyzer can drop (separate for analysis) 2.048-Mbit/sec European-standard channels from a 44.736-Mbit/sec signal. Data-link option, $2090; software upgrades to existing PF-45s (for example, to sound an alarm on a bit error), $890. Wandel and Goltermann Inc, 2200 Gateway Center Blvd, Morrisville, NC 27560. Phone (800) 346-6332. Circle No. 375

PC-based emulator for 68HC16s and 68300s. The Emul16/300-PC consists of an ISA bus plug-in emulator board, a 5-ft twisted-pair cable, a pod board, and an optional trace board. The pod board includes 1 Mbyte of breakpoint RAM; the emulator board con-
Digital audio interface. The Proport Model 656 self-contained unit enables PCs and workstations to record studio-quality 2-channel audio via 16-bit oversampling ADCs. You can select sampling rates from 5 to 96k samples/sec. The passband response is flat within ±0.1 dB from 20 Hz to 40 kHz. Interpolating reconstruction filters provide 20-bit output signals that, via DACs, drive balanced, low-impedance line drivers. $1595. Ariel Corp, 433 River Rd, Highland Park, NJ 08904. Phone (908) 249-2900. FAX (908) 249-2123. FAX (908) 249-2123. TLX 4997279. Circle No. 380

PC-based SCSI-bus analyzer. The PED-4752 is a daughter card for the vendor's SCSI bus analyzer. It increases the analyzer's speed and permits tracing signals as brief as 20 nsec (95% of the nominal minimum duration of signals on the bus). Configuration software lets the daughter card work with unshielded single-ended or differential 50-pin connectors. $995, including software. Pacific Electro Data Inc, 14 Hughes, Irvine, CA 92718. Phone (800) 676-2468; (714) 770-3244. FAX (714) 770-7281. Circle No. 377

Memory-IC test systems. The J997, optimized for use in engineering and for wafer probing, runs at speeds to 200 MHz and exhibits an overall timing inaccuracy of 300 psec. It can test as many as 32 devices in parallel on two test stations. The corresponding specs for the J994, a model optimized for final test of packaged ICs, are 120 MHz, 500 psec, and 64 devices. Both models accommodate devices that store as much as 1 Gbit each. Teradyne Inc, 30801 Agoura Rd, Agoura Hills, CA 91301. Phone (818) 991-2900. FAX (818) 707-2805. Circle No. 378

1-MHz to 1-GHz spectrum analyzer. The P-7802 displays center frequencies with ±1% error and 1% resolution. It measures amplitudes from 15 to 129 dBµV with 70 dB of dynamic range. The ac-powered unit weighs 25 lb. $3500. Protek, Box 59, Norwood, NJ 07648. Phone (201) 767-7242. FAX (201) 767-7343. Circle No. 379

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For more information about the new Cinch LGA Socket and your free CIN::APSE Design Guide, call 708.981.6000, Ext. 4291.
CINCH Connectors, 1500 Morse Avenue, Elk Grove Village, IL 60007.

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CIRCLE NO. 122
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So if you're looking for a way to upgrade an existing design, or for the extra performance you need for something entirely new, the smart move is to look to the Z80 MPU family. You'll find the combinations of features that will give you just what you need, including the high-performance Z181,™ Zilog's Smart Access (SAC™) Controller. And best of all, since you're already familiar with the Z80 code, the migration path couldn't be quicker.

Others may choose to concentrate on highly complex solutions for workstation and PC environments. But we think the wiser strategy is to go on developing high integration, value added 8- and 16-bit solutions for the intelligent peripherals, datacommunication and consumer microcontrollers markets. At the same time, we're continuing to develop 32-bit RISC and DSP devices and to produce some of the most sophisticated ASSPs in the industry.

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It's very clear that ASSPs are the best option for a rapidly growing number of designs. At Zilog we've been producing ASSPs and developing Superintegration design methodology longer and better than anyone, which is why we have the largest library of familiar cores and cells in the industry. You can be sure Zilog will continue to develop new members of the Z80 MPU family. And, because we have our own fabrication facilities, you know that every new part will have the same high standards for quality, cost/performance and reliability for which Zilog has always been known.

The smart thing to do is to find out more about the Z80 family of Intelligent Peripheral Controllers, or any of Zilog's rapidly growing Superintegration product families. Contact your local Zilog sales office or your authorized distributor today. Zilog, Inc., 210 East Hacienda Ave., Campbell, CA 95008-6600, (408) 370-8000.
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Introducing new RISC System/6000 POWERstations

If you're interested in open systems but don't want to suffer the slings and arrows of outrageous prices, IBM is about to hit you where you live. The RISC System/6000™ POWERstation 220 gives you more wallop for your money, while delivering a hefty 259 SPECmarks. That's compared to the SUN IPC's™ 13.4 SPECmarks and the DEC5000's™ 17.8.

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<table>
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<th>Model</th>
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get more clout, clobbered.

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slots and upgradable components. And industry-standard memory upgrades and add-ons for both are affordable, so growing won't be a pain.

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The RISC System/6000

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CIRCLE NO. 125
General-Purpose Transponder
- Has an address range of 1 to 255
- Measures 8 x 15 mm

The 3135 general-purpose transponder connects to a 2-wire parallel multiplex bus on one side and to a sensor/contact on the other side. It provides identification to each sensor connected on the bus as well as continuous supervision for reporting failure in normal operation. Key specifications include an address range of 1 to 255, operating voltage of 5 to 15V, and a current drain of 25 µA typ. The transponder measures 8 x 15 mm and operates over a -25 to +70°C range. It provides nonvolatile memory for address storage if desired. $6.95.

Tracer Electronics Inc, 200 Broadacres Dr, Bloomfield, NJ 07003. Phone (201) 338-1234. FAX (201) 338-1125. Circle No. 424

DC/DC Converters For Battery-powered Applications
- Available in surface-mount packages
- Available in adjustable and fixed versions

LT1110 and LT1111 dc/dc converters are available in adjustable versions and in fixed 5 and 12V models. The devices are housed in either 8-pin DIPs or 8-lead SO surface-mount packages. The LT1110 operates from a 1V input, and the LT1111 requires a 2V input. Both devices operate in step-up, step-down, or inverting mode. The 1111 delivers 5V at 100 mA from a 2-cell input; the 1110 delivers 5V at 150 mA from the same input level. The 1110-12 also generates a 12V output. Both units also contain low-battery detector circuitry. In 8-pin DIPs: LT1110, $3.15; LT1111, $2.40 (100); in SO-8 packages: LT1110, $3.60; LT1111, $2.80 (more than 100).

Linear Technology Corp, 1630 McCarthy Blvd, Milpitas, CA 95035. Phone (408) 432-1900, ext 359. FAX (408) 434-0507. Circle No. 425

LCD Module
- Fits in a keyswitch cap
- Features 864 pixels

The D880 LCD module integrates a low-power graphics LCD, which utilizes super-twist technology with a custom IC driver and multicolor backlighting. The entire unit fits in the key cap of an spst momentary-contact switch, which measures approximately 1 in². The display consists of 864 pixels configured in a 24 x 36 matrix that provides full-screen graphics. Using a 5 x 7 font, the display has an 18-character capability—3 lines x 6 characters. You can change the red and green backlighting by reversing the 5V applied to the LED terminals. Amber is obtained by using an ac voltage across the LED terminals. $37.50 (250).

C Itoh Technology Inc, Box 19657, Irvine, CA 92713. Phone (800) 347-2484, ext 4529. FAX (714) 757-4423. Circle No. 426
Surface-mount dc/dc converters. NME Series converters are surface-mount, single-output units. They accept 5V inputs and deliver outputs of 5, 9, 12, or 15V. The units feature 1000V dc isolation, 80% max efficiency, and a –50 to +85°C operating range. $19.50; less than $10 (OEM qty). Delivery, six to eight weeks ARO. International Power Sources Inc, 200 Butterfield Dr, Ashland, MA 01721. Phone (508) 881-7494. FAX (508) 879-8669. Circle No. 427

Why Do So Many Engineers Specify Keeper II® Lithium Batteries?

Because Board Space Is Too Valuable To Waste

At Eagle-Picher, we don’t think you should have to compromise valuable circuit board space simply because some battery manufacturer elected to make round batteries. Electronic circuit board “real estate” is becoming increasingly valuable. Consequently, engineers are faced with more complex decisions regarding their back-up power source. Keeper II’s unique prismatic configuration provides effective utilization of board space with maximum energy density characteristics.

Packaged the way circuit board components were meant to be, the Keeper II has been proven highly dependable in stand-by power applications where years of reliable memory back-up is required. Eagle-Picher manufactures 100% of the Keeper products in the USA.

So, no matter what your power requirements are, count on Eagle-Picher. Because Board Space Is Too Valuable To Waste.

Dielectric filters. Series 4DF surface-mount dielectric filters have center frequencies ranging from 800 to 2500 MHz. The units are available in 2- and 3-pole versions. They offer low loss performance—2 dB max for 2-pole versions. The 2- and 3-pole units measure 12.5 x 14.5 x 5 mm and 17.5 x 14.5 x 5 mm, respectively. From $6 (100). Toko America Inc, 1250 Feehanville Dr, Mount Prospect, IL 60056. Phone (708) 297-0070. FAX (708) 699-7864. Circle No. 428

3-terminal power MOSFET. The BUK101-50 3-pin power MOSFET provides integrated short-circuit, overtemperature, and overvoltage protection. Housed in a TO-220 package, the device can be driven directly from conventional FET driver circuitry. All the protection circuitry is powered from the control input allowing the unit to achieve a 25°C off-state I on rating of 1 µA for a VGS voltage of 12V. 3 gld (50,000). Delivery, eight weeks ARO. Philips Semiconductors, 5000 MD, Eindhoven, The Netherlands. Phone 31 40 722091. FAX 31 40 724825. Circle No. 429

DC/DC converter. The PKA 2411 40W converter is designed for 24V systems. It provides 5V at 8A at 80% efficiency. The unit uses convection cooling and operates over a –45 to +65°C range. Isolation is 500V dc. $105 (100). Ericsson Components Inc, 4631 International Pkwy, Richardson, TX 75081. Phone (214) 997-6561. FAX (214) 680-1059. Circle No. 430

Ovenized oscillator. The 250-0504 ovenized crystal oscillator has phase-noise figures ranging from –100 dBc at 1 Hz to –160 dBc at 10 kHz. The unit develops a 7-dBM output level, operates over a 11 to 15V, and has a stability of 1.5 x 10⁻⁷ over –30 to +70°C. Aging per year is 3 x 10⁻⁶. $355 (1 to 1000). QK Genware Corp, 2 New Pasture Rd, Newburyport, MA 01950. Phone (508) 465-6064. FAX (508) 465-6637. Circle No. 431

Noise-blocking triacs. BT139H Series triacs feature a built-in trigger threshold of 10 mA to eliminate tendencies for the devices to be triggered by noise impulses. They are available with blocking-voltage ratings of 500, 600, or 800V. The units have a 10V/µsec com-
Engineers have been realizing the power of their workstations with MicroSim's popular PSpice simulator for five years. Now, that power, performance, and much more are available with the Design Center — the universal design environment. The Design Center capabilities are masterfully integrated to simplify your circuit design projects from conception through verification. It is cost effective, robust, easy to install and use. The SPICE algorithms have been enhanced for rapid and accurate answers.

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mutating voltage for a commutated current of 7.2A/msec and a peak current rating of 140A. The triacs are housed in TO-220 packages. $0.75 (1000). Delivery, four to six weeks ARO. Philips Components, 2001 W Blue Heron Blvd, Riviera Beach, FL 33404. Phone (800) 447-3762. Circle No. 432

Power supplies. LT-GPIB Series supplies provide outputs as high as 60V at currents ranging to 500A. They feature 3-phase input ranges of 187 to 265, 340 to 455, and 430 to 530V ac. The units operate in both constant-current and constant-voltage modes with automatic crossover. $3745 to $3938 (25). Lambda Electronics Inc, 515 Broad Hollow Rd, Melville, NY 11747. Phone (516) 694-4200. Circle No. 433

Precision termination. Model 6003 is a 50Ω SMA female termination. It is designed for dc to 18-GHz applications and has a 1.2:1 max VSWR. The unit has a 1W average power-handling capability at 25°C and is made of passivated stainless steel. The contact is gold plated. $29.95. Pasternack Enterprises, Box 16758, Irvine, CA 92713. Phone (714) 261-1920. Circle No. 434

SCSI adapters. These units are designed to interconnect SCSI I and SCSI II devices. They are fully EMI shielded and are available with both bail-lock and jack-screw fixtures. The adapters conform to all applicable ANSI standards and FCC specifications. From $20 (1000). Honda Connectors, 960 Corporate Woods Pkwy, Vernon Hills, IL 60061. Phone (708) 913-9566. Circle No. 435

DC/DC converter. The CPS873 device features three outputs—5V at 13.5A, and ±12V at 0.5A. Standard devices operate on a 28V input. The unit is connected to accommodate various power-supply circuits. It is available in versions having 2 to 15 positions with pins on 0.156-in. centers. The connector is color coded for AWG wire sizes from #26 to #18. Contacts are rated for 7A at 250V ac or dc. From $0.04 to $0.25 (OEM qty). JST Corp, 1290 Business Center Dr, Suite 400, Mount Prospect, IL 60056. Phone (800) 947-1110; (708) 803-3300. FAX (708) 803-4918. Circle No. 436

Crimp-style connector. The Type VR insulation-displacement-style connector can be daisy chained or end connected. The connector is color coded for AWG wire sizes from #26 to #18. Contacts are rated for 7A at 250V ac or dc. From $0.04 to $0.25 (OEM qty). JST Corp, 1290 Business Center Dr, Suite 400, Mount Prospect, IL 60056. Phone (800) 947-1110; (708) 803-3300. FAX (708) 803-4918. Circle No. 437
Components & Power Supplies

Alphanumeric and graphics display. The M1000 display combines AlGaAs LEDs, multiple-character fonts, and graphics capability in an extruded NEMA 12 enclosure. Simple escape commands control all display functions. Six different fonts provide 2- to 4.5-in. characters that are easily read from 200-ft distances. Users can mix any of the fonts to the limits of 40 2-in. characters or 10 4.5-in. characters. $1650. Vorne Industries Inc, 5831 Northwest Hwy, Chicago, IL 60631. Phone (312) 775-9440. FAX (312) 775-3854.

Power supplies. LZ Series 1000W supplies feature EMI compliance to FCC Class B and VDE 0871B. They feature an autoselectable 85 to 132V or 187 to 265V input and operate over a −30 to +71°C range. The units feature a power-fail alarm, inverter-good indicator, and overtemperature protection. The supplies are UL, CSA, TUV, and SELV compliant. From $1025 (25). Lambda Electronics Inc, 515 Broad Hollow Rd, Melville, NY 11747. Phone (516) 694-4200.

Sockets. Series 664-SMO plastic-leaded-chip-carrier sockets accept MO-47 and MO-52 devices with 0.05-in. pin spacings. The surface mount units are available in 20-, 28-, 32-, 44-, 52-, 68-, and 84-pin versions. The units have a 0.173-in. mounted profile and feature PPS insulators, which have an open design to facilitate solder-joint inspection. $2.53. Andon Electronics Corp, 4 Court Dr, Lincoln, RI 02865. Phone (401) 333-0388. FAX (401) 333-0287.

Hygristor. The Veco hygristor features a −90 to +50°C operating range. Relative humidity ranges span 0 to 100%. and the nominal time constant is 2 sec. Available in sizes as small as 0.25 x 0.25 in. square and disks of 0.375 in. in diameter, the unit is comes in leaded or unleaded versions. Resistance values of 4 to 20 kΩ are available. From $6 (1000). Delivery, six to eight weeks ARO. Victory Engineering, Victory Rd, Springfield, NJ 07081. Phone (201) 379-5900. FAX (201) 379-5982.

Box-header connectors. Constructed of glass-filled polyester with a UL 94V-0 rating, the NFHL and NFHLR Series box-header connectors feature phosphor bronze contacts plated with 12 µin. of gold in the contact area and 100 µin. of tin lead in the tail area. The contacts are rated for 0.5A. Dielectric voltage is 500V ac, and insulation resistance measures 10 Ω min. Approximately $8.08/contact (1000) for the NFHL header. Circuit Assembly Corp, 18 Thomas St, Irvine, CA 92718. Phone (714) 855-7887. FAX (714) 855-4298.

Each technological terrain has its most prominent landmark

The DSP landscape is dotted with vendors offering products and promises. But only one vendor has loomed large from the very beginning. Atlanta Signal Processors' pioneering DSP experience dates back to 1969. In 1982, ASPI began creating leading-edge DSP design tools and established itself as the DSP workstation source. Today, ASPI continues to cast the longest shadow across the DSP market. ASPI products support the entire range of TI and Motorola DSP processors. Banshee, Vortex, Cheetah™ and DFDP3/plus are our principal product lines. They represent the industry's most significant advancements in DSP development, from 83 MFLOPS processing to simple, intuitive filter design. A variety of daughter boards adds extended features such as expanded memory, A-D/A and D-A conversion, and multiprocessor capability.

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Eris Systems Inc, 2301 Newton Ave S, Minneapolis, MN 55405. Phone (612) 374-2967. Circle No. 381

32-bit extender for MS-Windows.
Ezwin32 allows the company’s numeric data-processing (NDP) Fortran, C, C++, and Pascal compilers to take advantage of MS-Windows’ enhanced mode. The compilers cost $595 each and include one year of upgrades. Compiler owners can purchase the Ezwin upgrade for $395. Micro Way, Box 79, Kingston, MA 02364. Phone (508) 746-7341. FAX (508) 746-4678. Circle No. 382

Project-management software.
CIM/AIT (Concurrent Information Management/Action Item Tracking) manages and tracks projects and activities. The software runs on PCs, Macs, workstations, minicomputers, and mainframes. From $250 for single-user licenses on a networked PC. CIMware Technologies Inc, 3031 E LaJolla St, Anaheim, CA 92806. Phone (714) 666-1200. FAX (714) 666-0400. Circle No. 383

SCSI programming interface software.
The SCSI Software Developer’s Kit simplifies programming for the Advanced SCSI Programming Interface (ASPI). The kit contains a copy of the ASPI specification, programming guides for DOS, OS/2, and Netware, a DOS/ASPI interface to test device drivers, and an exerciser program. $150. Adaptec Inc, 691 S Milpitas Blvd, Milpitas, CA 95035. Phone (408) 945-6761. Circle No. 384

32-Bit Extender. Aimax-Plus/Pro is a DOS Extender for the vendor’s machine-interface control and data-acquisition software. The software provides 4 Gbytes of linear addressing and permits accessing parameters with process controllers. From $4500. TA Engineering Co Inc, 1605 School St, Moraga, CA 94556. Phone (510) 376-8500. FAX (510) 376-4977. Circle No. 385

Data-management system.
Tekbase is a data-management system designed for scientists and engineers who work with large amounts of technical data. It is suited for applications in the aerospace, automotive, telecommunications, and semiconductor industries. Users can create applications based on Motif or Open Look. From $4875/seat for 4-user system. Leading Technology Inc, 6 New England Executive Park, Suite 400, Burlington, MA 01803. Phone (617) 229-8686. Circle No. 386

Prolog Runtime Generator. The Quintas Prolog Runtime Generator moves Quintas Prolog applications from Unix and VAX workstations to DOS 386/486 computers. The supplier charges no runtime fees for the ported applications. The software includes a basic development system, a Prolog compiler, and a link editor. $4000. Quintas Corp, 2100 Geng Rd, Suite 101, Palo Alto, CA 94303. Phone (415) 813-8800. FAX (415) 494-7608. Circle No. 387

OOP for Windows. Version 2.0 of Knowledgepro Windows, an object-oriented programming (OOP) environment, adds visual design tools, simplified access to dynamic-link libraries, and support for Windows multimedia.
400 MOPS FOR 6U VMEbus SYSTEMS

This 6U VMEbus board performs 400 million operations per second and is optimized for frequency domain processing such as FFTs and finite impulse response (FIR) filters using fast convolution. The FDaP features a private 32-bit, 20 MHz high-speed data I/O bus and extensive double buffering for continuous processing of real-time data. An additional 32-bit complex output provides phase/magnitude data. The a66540 is available in 25 MHz and 40 MHz versions. A single 40 MHz version can execute a 1K point FFT in 132.7 µs and a 64K point FFT in 25 MHz and 40 MHz versions. A single 40 MHz version as FFTs and finite impulse response (FIR) filters using fast development system features a DaSP/Pac code generator, output provides phase/magnitude data. The a66540 is available for real-time data. An additional 32-bit complex speed data I/O bus and extensive double buffering for continuous operation can be cascaded to achieve almost linear improvement in FFT performance. Plug 400 MOPS into your system by calling array Microsystems’ Hotline: 719-540-7999.

CORNERTURN PROVIDES QUANTUM LEAP IN 2D IMAGE PROCESSING PERFORMANCE

The a66545 Cornturn™ board, used in conjunction with the a66540 FDaP board for real-time two-dimensional image processing, is the first capable of processing an entire 256 x 256 pixel frame of image data in 15.2 milliseconds. This equates to a continuous, real time rate of 65 frames per second. For 512 x 512 images, the board set transforms images in 71 milliseconds, or 14 frames per second. Designed for medical imaging, radar, sonar, machine vision, and other real-time 2D image processing applications, the board set features performance of 400 MOPS at a clock rate of up to 40 MHz. The Cornerturn accepts 32-bit complex I/O data through 10 MHz double-buffered external I/O connectors or through the VMEbus and stores it in one of four on-board frame store memory buffers. For technical assistance, call array Microsystems’ Hotline: 719-540-7999.

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arraysoft™, a complete DSP software development system supporting array Microsystems’ a66 Family of Products, provides a menu-driven user interface allowing easy access to a suite of powerful development tools at the click of a mouse. This development system features a DaSP/Pac code generator, assembler, disassembler, window generator, full DaSP/Pac program control, on-screen display of data, and board-level diagnostics. For technical information or original program assistance, call array Microsystems’ Hotline: 719-540-7999.
extensions. You can point and click to select from a library of objects and then drop them into a window, specify their size, and choose fonts, colors, and styles. Multimedia support covers CD-ROM and stereo sound. $249. Knowledge Garden Inc, Stony Brook Technology Center, 12-8 Technology Dr, Setauket, NY 11733. Phone (516) 246-5400. FAX (516) 246-5452. Circle No. 388

Solder-process analyzer. PCB Soldersim is a simulation tool for analyzing the preheating, soldering, and curing operations of a pc-board soldering process. It can help you avoid problems such as cold solder joints, solder starvation, poor wetting, board warpage, and interconnect cracking. Boards to be simulated must have been previously analyzed with the supplier’s PCB Explorer product. PCB Soldersim, $10,000; PCB Explorer, $20,000 to $30,000. Pacific Numerix, 1200 Prospect St, Suite 300, La Jolla, CA 92037. Phone (619) 587-0500. FAX (619) 459-4031. Circle No. 389

ASIC-design software. The ASIC Navigator Design System links your graphical ASIC system specification to system design tools by generating behavioral VHDL (VHSIC Hardware Description Language). Simulation of the specification at the behavioral level allows design changes and debugging to occur early in the design process. The package is suited for two types of users: the ASIC end user who is part of a product-design team in a system house and the application-specific standard product designer. From $100,000. Compass Design Automation, Inquiry Dept 231, 200 Parkside Dr, San Fernando, CA 91340. Phone (408) 433-4880. FAX (408) 434-7820. Circle No. 390

GUI development tool. The Teleuse development tool for graphical-user interfaces (GUIs) is now available on the Hewlett-Packard 9000/700 family of workstations and servers. The software is a user-interface management system for interactive development of user interfaces based on OSF/Motif. By letting you paint a static user interface with a WYSIWYG approach, it avoids manually coding calls to the X-Windows System or OSF/Motif. Including OSF/Motif, $7500. Telesoft, 5959 Cornerstone Ct W, San Diego, CA 92121. Phone (619) 457-5700. FAX (619) 452-1394. TLX 885500. Circle No. 391

Object-oriented libraries. CV-DORS (Developers Open-Resource Software) consists of a set of object-oriented software libraries which provide access to the supplier’s CADD5-5, an integrated wire frame, surfaces, and solid-geometric modeler. You can also use the product independently of CADD5-5. The product is available on SPARC-based computers. Development license, $50,000; OEM runtime licenses, $1000 to $2500/seat. Computervision, 100 Crosby Dr, Bedford, MA 01730. Phone (617) 275-1800. Circle No. 392

Imaging library. The T-Base Version 3 software library lets you add pictures and document images to database applications written in C, C++, and most Xbase dialects. It works with any image in the PCX file format. The package includes Chromatools, a color manipulation and image-conversion utility. It works with Super VGA, VGA, EGA, CGA, and monochrome displays and with HP Laserjet II and III printers. $495. Videotex Systems Inc, 8459 Greenville Ave, Suite 205, Dallas, TX 75231. Phone (800) 888-4336; (214) 343-4500. FAX (214) 348-3821. Circle No. 393

RS-232C data trapper. Easysdata helps eliminate manual data entry. While your program is running in the foreground, it traps incoming RS-232C data and fools your program into thinking that the data is coming from the keyboard. The package is compatible with any software that allows manual data entry. $145. Labtronics Inc, 2C-95 Crimea St, Guelph, ON, Canada N1H 2Y6. Phone (519) 767-1061. Circle No. 394


FPGA design kits. These two design kits allow FPGA device models from Actel and Xilinx to run in the Dazix EDA environment for design- and board-level-design analysis, simulation, and test. Additional tools in the environment assist in board, hybrid, and multichip-module design, analysis, layout, and manufacturing. The kits are available as part of the latest Dazix Gemini software release. Each kit, $2500. Dazix, 1 Madison Industrial Park, Huntsville, AL 35894. Phone (205) 730-2000. Circle No. 396

ASIC-design translators. The Ikos Compass tool kit lets users of design tools from Compass Design Automation migrate their designs to Ikos systems for high-speed hardware-assisted simulation. It runs on workstations from Sun and HP/Apollo and supports the Compass Navigator series of ASIC design tools. The Ikos hardware-assisted simulators can simulate as many as 1.2 million gates at speeds as high as 75 million events per second. Tool kit, $10,000. Ikos Systems Inc, 145 N Wolfe Rd, Sunnyvale, CA 94086. Phone (408) 245-1900. FAX (408) 245-6219. Circle No. 397

OCR software tool kit. The Textpert Developer’s Tool kit lets you put optical-character-recognition capabilities into your software applications. The package comes in versions for Macintosh Systems 6 and 7, MS-DOS, OS/2, and Microsoft Windows. It works with numerous scanners. Tool kit with one runtime license, $495. CTA Inc, 25 Science Park, New Haven, CT 06511. Phone (203) 786-5828. Circle No. 398

Database-design tool. DB Designer helps you design and reverse engineer relational databases. It also assists in migrating nonrelational files and databases to Oracle Corp’s Oracle database and IBM’s DB2 database. The tool runs on IBM PS/2 and compatible computers under the OS/2 operating system. From approximately $20,000. Cadre Technologies Inc, 222 Richmond St, Providence, RI 02903. Phone (401) 351-5950. Circle No. 399

Project-management software. Primavera 5.0 is a DOS-based program that combines scheduling; resource allocation and leveling; cost control; custom reporting; and presentation graphics. The software allows for multiproject control. Software licenses, $4000. Primavera Systems Inc, 2 Bala Plaza, Bala Cynwyd, PA 19004. Phone (215) 607-8600. Circle No. 400
Bar-code software. Mac-Barcode Version 2.0 lets Macintosh users design bar codes for labels. This Version 2.0 supports the UCC/EAN 128 application identifiers and the bar codes of Version 1.1: 128, 39, interleaved 2 of 5, Codabar, UPC/EAN, 93, and 11. The software comes with templates for Avery laser-printer labels. $199. Data Capture Institute, Box 1625, Duxbury, MA 02331. Phone (800) 733-7592; (617) 934-7585.

Data-analysis tool. Muse lets users interactively analyze complex data. By combining features of spreadsheets and relational database managers, it helps you answer questions about your data. It also has graphics capabilities. $695. Occam Research Corp, 42 Pleasant St, Watertown, MA 02172. Phone (617) 923-3545. FAX (617) 926-3262.

Design and drafting tool. Version 6.0 of Generic CADD enhances the compatibility of that product with AutoCAD. It directly loads any 2D (.DWG) file for review, editing, printing, and plotting. The software comes with matching AutoCAD Release 11 fonts and hatch patterns. $495. Auto­desk Retail Products, 11911 North Creek Pkwy S, Bothell, WA 98011. Phone (206) 487-2233.

Employee-evaluation software. The Employee Evaluator and Salary Manager, version 3.0 is a tool to standardize review and appraisal of employees. This network version provides centralized control of criteria, salary, and performance. Software, $590; stand-alone version, $195. Hi Tech Enterprises, 857 Taylor St, #5, Monterey, CA 93940. Phone (800) 437-1222; (408) 373-5117.

Microcode development system. This user-retargetable microcode development system lets you create high-level-language compilers and other software development tools for any microprogrammable architecture. Microcode tools include a macropreprocessor, C compiler, peephole optimizer, code converter and compactor, retargetable microcode assembler, linker, object librarian, and vertical-operations level simulator. The system is available for MSDOS and for Unix on 386-based and Sun workstations. $3495 to $4995. Archelon Inc, 460 Forestlawn Rd, Waterloo, ON, Canada N2K 2J6. Phone (519) 746-7925.

PC diagnostic software. The Micro­scope diagnostic software package lets you format—at low level—any IDE hard-disk drive. It can repair IDE drives that have been incorrectly formatted so you don’t have to return them to the factory. It runs under DOS, Nov­ell, OS/2, Unix, Xenix, Pick, PC MOS, C.DOS, and other systems. $449. Micro­2000 Inc, 1100 E Broadway, 3rd Fl, Glendale, CA 91205. Phone (818) 547-0125.

Multiprocessing operating sys­tem. OS/MP 4.1A.2 is a symmetric multiprocessing operating system that has been tuned for database performance. The software, fully compatible with SunOS, will be offered at no cost.

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to existing customers under their maintenance agreements. Solbourne Computer Inc, 1900 Pike Rd, Longmont, CO 80501. Phone (303) 772-3400. FAX (303) 772-3646. Circle No. 407

Expert troubleshooting development tools. Testbench contains the Testbuilder and Testview development and delivery tools. Where the development tool creates and maintains knowledge bases, the delivery tool provides diagnostic assistance to field engineers. A client/server capability lets you embed the software in your applications. Optional modules link the software to existing knowledge bases and generate reports. From approximately $33,000. Carnegie Group Inc, 5 PPG Pl, Pittsburgh, PA 15222. Phone (412) 642-6900. FAX (412) 642-6906. Circle No. 408

Help-system aid. Robohelp assists you in writing help systems for applications that run under Windows. It lets you concentrate on the content of your help system rather than on the Windows help compiler's source-code format. It generates source code for indexes, topics, keywords, categories, defined terms, pop-up definitions, bit maps, cross references, and hypertext links. $495. Blue Sky Software Corp, 7486 La Jolla Blvd, Suite 3, La Jolla, CA 92037. Phone (800) 677-4946; (619) 459-6365. FAX (619) 459-6366. Circle No. 409

Pascal compiler. Version 2.0 of FS:pascal is a protected-mode Pascal compiler that generates native 32-bit code. It does away with the 64-kbyte segment-size limit of real-mode programs and allows variables and arrays to be as large as available RAM. The compiler is compatible with Turbo Pascal; it runs on 80386- and 80486-based computers under MS-DOS versions 3.0 and higher. $149.95. Frontier Software, 66-22 Fleet St, Suite 2C, Forest Hills, NY 11375. Phone (800) 934-3732; (718) 520-4197. Circle No. 410

MAP software. MicroMAP, an implementation of the ISO/IEEE Manufacturing Automation Protocol (MAP), allows communication on the factory floor among computers from multiple vendors. This release works simultaneously with Ethernet and token-ring bus interfaces and also improves the communications stack's performance. It runs on the supplier's DeltaSeries 3000 and 4000 computers. $1250. Motorola Inc, Computer Group, 2900 S Diablo Way, Tempe, AZ 85282. Phone (800) 234-4863. Circle No. 411

Connectivity software for Windows 3. Dynacomm/Elite APPC is a program-to-program communications software tool that generates transaction programs. These programs can communicate on a peer-to-peer basis with transaction programs on other computers. Featuring a nonlanguage-specific application programming interface (API) based on IBM's OS/2 API, you can generate programs using any language offering Windows Dynamic Link Library calling. Stand-alone pricing, from $495. Network Software Associates, 39 Argonaut, Laguna Hills, CA 92656. Phone (800) 352-3270; (714) 768-4013. FAX (714) 768-5049. Circle No. 412

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Test-and-measurement-interface handbook. The Instrument Communication Handbook describes interfaces used for test-and-measurement applications. It focuses on the IEEE-488 and IEEE-488.2 standards and evaluates the RS-232C, RS-422, RS-485, and VXI standards. Topics include SCSI, SCPI (standard commands for programmable instruments), and local-area networking using Ethernet. $14.95. (Free to qualified requesters.) IOTech Inc, 25971 Cannon Rd, Cleveland, OH 44146.

Instrumentation-amplifier guide. The Instrumentation Amplifier Application Guide explains instrumentation amplifiers in medical instrumentation, audio, data acquisition, and high-speed signal conditioning. The 44-pg guide’s three sections cover basic instrumentation-amplifier theory, designing instrumentation amplifiers, and instrumentation-amplifier applications. The guide also contains an introduction to operating this type of amplifier and application notes. It provides two appendices. The first appendix reviews specifications such as operating conditions, gain, gain range, and nonlinearity. The second appendix provides an instrumentation-amplifier selection chart. Analog Devices, Literature Center, 70 Shawmut Rd, Canton, MA 02021. Circle No. 443

Encyclopedia of hard drives. The Hard Drive Encyclopedia is a reference work covering PC-compatible hard drives; it comes with a disk full of utilities. The 3-ring binder holds almost 600 pages, covering ST506, ESDI, IDE, and five other types of interface specifications. The listings present controller parameters, hard-disk parameters, and manufacturers. More than 1600 models are listed by manufacturer. $89 plus shipping. Annabooks, 12145 Alta Carmel Ct, Suite 250-262, San Diego, CA 92128. Phone (800) 462-1042; (619) 271-9526. FAX (619) 592-0061.

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Catalog of CATV products. This 28-pg catalog presents CATV (community-antenna TV) products, including 18 new drop cables and fiber-optic Supertrunk cables. The cable-to-connector cross reference highlights PPC F-connectors and Gilbert and LRC connectors. The CATV technical section features shield effectiveness. Cooper Industries, Belden Div, Box 1980, Richmond, IN 47375. Phone (800) 235-3364. Circle No. 445

Data-acquisition-products brochure. This 4-pg brochure describes Microsoft Windows 3.0-compatible Data-Link Libraries for data-acquisition and instrument control. The products covered in the publication consist of NI-DAQ, NI-488.2, and NI-VXI Windows software drivers. Applications for these products encompass laboratory automation, data acquisition, process monitoring and control, physiological monitoring, personal instrumentation, and automated testing. National Instruments Corp, 6504 Bridge Point Pkwy, Austin, TX 78730. Phone (800) 433-3488; (512) 794-0100. FAX (512) 794-8411. Circle No. 446

Embedded software standards. The Guide to Embedded Software Standards is part of an applications-guide series for developing embedded systems. This set of ground rules for programmers of 8- and 16-bit embedded systems is essentially a pro forma document that even very small companies can use. Softaid Inc, 8300 Guilford Rd, Columbia, MD 21046. Phone (800) 433-8812; (301) 290-7760. FAX (301) 381-3253. Circle No. 447

Demonstration program. Labwindows 2.0 demonstration program provides an overview of the Labwindows 2.0 software development system for programming C and Basic data-acquisition and instrument-control applications. National Instruments Corp, 6504 Bridge Point Pkwy, Austin, TX 78730. Phone in US and Canada, (800) 433-3488; (512) 794-0100. FAX (512) 794-8411. Circle No. 448

Catalog of development tools. This 76-pg catalog is divided into eight sections. The first five sections present development tools for series x86 µPs; MCS-51 microcontrollers (µCs); MCS-96 µCs; i960 µPs; and i860 µPs. The three remaining sections deal with service and support, reference, and resources. Each product section furnishes a development cycle for the products described within the section. Intel Corp, Development Tools Operation, 5200 NE Elam Young Pkwy, MS JF1-15, Hillsboro, OR 97124. Phone (800) 874-6835. FAX (503) 696-4633. Circle No. 449

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Combined catalog and application handbook. This 1992 catalog and application handbook provides a set of application notes on data-acquisition products. The notes discuss topics such as comparisons of program control, program interrupt, and DMA; gain and system resolution; how to select a high-resolution A/D board; and signal-conditioning solutions and techniques. ADAC Corp, 70 Tower Office Park, Woburn, MA 01801. Phone (800) 648-6589; (617) 935-6668. FAX (617) 938-6553.

Catalog of nuclear-research instruments. The 368-pg Research Instrumentation Catalog, summarizes a product line and presents technical data sheets and specifications, application notes, and ordering information. The introductory tutorial deals with research instrumentation and has a glossary of technical terms. Products covered in the publication include instruments in VME, CAMAC, and Fastbus formats. LeCroy, 700 Chestnut Ridge Rd, Chestnut Ridge, NY 10977.

Newsletter of MIL-STD-1553 products. This 4-pg newsletter describes boards, transformers, and development software that meet the requirements of MIL-STD-1553. It features a question-and-answer column and an application note. The newsletter also publishes related information, such as the opening of a manufacturing facility in Ireland, which will export products to the European market, the US, and the Far East. ILC Data Device Corp, 105 Wilbur Pl, Bohemia, NY 11716. Phone (516) 567-5600. FAX (516) 567-7338. TWX 310-685-2203.
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POWER PRODUCTS
## OUTPUT LOCATIONS

### 600 Watt FM Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>12</td>
<td>#1 M5</td>
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<td>24</td>
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<td>26</td>
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<td>#1 M3 #2 J #3 J #4 J</td>
</tr>
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<td>72</td>
<td>#1 M3 #2 J #3 J #4 J</td>
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### 1000 Watt FM Configurations

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<td>AC #1 M7</td>
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<td>21</td>
<td>AC #2 #1 L M6</td>
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<tr>
<td>31</td>
<td>AC #3 #2 #1 L M6</td>
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<td>41</td>
<td>AC #4 #3 #2 #1 L M6</td>
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<tr>
<td>51</td>
<td>AC #5 J #3 #2 #1 L M6</td>
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### 2000 Watt FM Configurations

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<tr>
<td>23</td>
<td>AC #2 #1 M7 M7</td>
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<tr>
<td>33</td>
<td>AC #3 #2 #1 G G M6</td>
</tr>
<tr>
<td>43</td>
<td>AC #4 #3 #2 #1 G G M6</td>
</tr>
<tr>
<td>53</td>
<td>AC #5 J #3 #2 #1 G M6</td>
</tr>
<tr>
<td>63</td>
<td>AC #6 J #7 J #3 #2 #1 G M6</td>
</tr>
</tbody>
</table>

### FM SERIES DIMENSIONS

**View A**
- 6-32 Clinch Nuts (7 Places)
- 2.500 V ADJUST (TYP)
- V Adjust (TYP)

**View B**
- 8-32 Clinch Nuts (4 Places)
- 2.400
- 0.860
- 1.910

**View C**
- 6-32 Clinch Nuts (5 Places)
- 9.725
- 12.600
- 12.250
- 12.250
- 12.250

**View D**
- 6-32 Clinch Nuts (4 Places)
- 2.400
- 0.345
- 0.435

**Notes:**
1. With Top Fan Cover Unit Height (13.100)
2. Terminal Blocks (6-32)
3. Studs (1/4-20)
4. With End Fan Cover Unit Length (13.300)

**View E**
- MOUNTING PER VIEW "A"
- 2.300
- V Adjust (TYP)

**View F**
- MOUNTING PER VIEW "B"
- 2.300
- 5.050
- 12.250

**View G**
- MOUNTING PER VIEW "C"
- Terminal Orientation Rotated 90° CW
- MOUNTING PER VIEW "D"
- V Adjust (TYP)
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 first piece delivery within two weeks and the elimination of engineering costs for qualified "OEM" requirements using stock modules.

FM Series are corrected to produce a 0.99 power factor. The resultant input current waveform is nearly a perfect sine wave compliant to the harmonic requirements of IEC 555-2.

Modular construction permits high volume manufacturing with an outstanding quality level and at competitive cost.

FEATURES

- 0.99 power factor.
- 5 watts per cubic inch.
- 600-2000 watts output.
- 120 kilohertz design.
- TUV/VDE, UL, CSA.
- All outputs:
  - Adjustable
  - Fully regulated
  - Floating
  - Overload and short circuit proof
  - Overvoltage protected
- Standard features include:
  - System inhibit
  - Fan output

MODEL SELECTION

Input modules are available in ratings of 600, 1000, and 2000 watts with corresponding code letters of C, E and G. Refer to Power Code Table.

Output modules are available in ten types ranging in nominal power from 75 to 2000 watts. Refer to Output Code Table for codes and nominal power output.

FEATURES

- 0.99 power factor.
- 5 watts per cubic inch.
- 600-2000 watts output.
- 120 kilohertz design.
- TUV/VDE, UL, CSA.
- All outputs:
  - Adjustable
  - Fully regulated
  - Floating
  - Overload and short circuit proof
  - Overvoltage protected
- Standard features include:
  - System inhibit
  - Fan output

RATINGS OF OUTPUT MODULES

<table>
<thead>
<tr>
<th>Nominal Power</th>
<th>75W</th>
<th>150W</th>
<th>300W</th>
<th>300W</th>
<th>400W</th>
<th>500W</th>
<th>600W</th>
<th>750W</th>
<th>1000W</th>
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<td>10</td>
<td>12</td>
<td>16</td>
<td>21</td>
<td>42</td>
</tr>
</tbody>
</table>

HOW TO ORDER

Select the letter F for power factor correction, then select the letter M to designate the series. Choose the desired configuration of output modules and list the configuration code. Insert the power code letter and follow with the output code numbers for each individual output. Enter a dash and from the option table insert the sum of the option codes. See example below.

OPTIONS

<table>
<thead>
<tr>
<th>Option Code</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power Fail Monitor</td>
</tr>
<tr>
<td>2</td>
<td>Cover (600W only)</td>
</tr>
<tr>
<td>3</td>
<td>End Fan Cover (600W only)</td>
</tr>
<tr>
<td>4</td>
<td>Top Fan Cover (600W only)</td>
</tr>
</tbody>
</table>

The Table of Ratings for the various types of output modules lists the maximum current for each type as a function of corresponding voltage rating.

Ratings in the shaded area are Preferred and are stocked for fast delivery.

Note: When computing output load power, multiply the fraction of actual current to max. rated current by the nominal power rating of the output module.
SPECIFICATIONS

INPUT
90-264 VAC, 47-63 Hz.
190-264 for 2000W units.

POWER FACTOR
0.99 at full load.

HARMONIC CURRENTS
Compliant to IEC 555-2.

INPUT SURGE
230 VAC – 75A max.
115 VAC – 40A max.

HOLDUP TIME
20 milliseconds from loss of 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. Main output is #1 on 600W and 1000W units and #2 on 2000W units.

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 on cooling surfaces over the 600W units for full rating. Two test locations on chassis rated for max. temperature of 90°C. 1000W and 2000W models have built-in ball bearing fan.

TEMPERATURE COEFFICIENT
±0.02%/°C.

EFFICIENCY
70% to 80%.

SAFETY
Units meet UL 1950, CSA 22.2 No. 234, IEC 950, EN 60 950, VDE 0804, VDE 0805, VDE 0806. 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 primary to grounded circuits.

LEAKAGE CURRENT
3.5mA max.

EMISSIONS
Units meet FCC 20780 Part 15 Class A and VDE 0871 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%.
M3, M4, M5, M6, M7, and M9 modules – 200 microseconds.

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.

SOFTWARE
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
600W – Case 1: – 2.5 x 5.05 x 12
1000W – Case 2: – 5.05 x 5.05 x 12
2000W – Case 3: – 5.05 x 6 x 12

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.

FAN COVER
Optional covers with brushless DC ball bearing fan which provides the required air flow for full rating of 600W units. Choice of low profile or top mounted types.

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<tr>
<th>2 PIECE PRICES</th>
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<tr>
<td>LAYERS</td>
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<td>SQUARE</td>
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</table>

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**Up to 35dB**

**10 to 1000 MHz**

**FROM $5995**

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**Price**

- TOAT $59.95/ZFAT $89.95

**Bold faced values are individual elements in the units.**

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