A CAHNERS PUBLICATION

OCTOBER 27, 1988

EDN®

SPECIAL ISSUE
THE MICROPROCESSOR

From the beginning

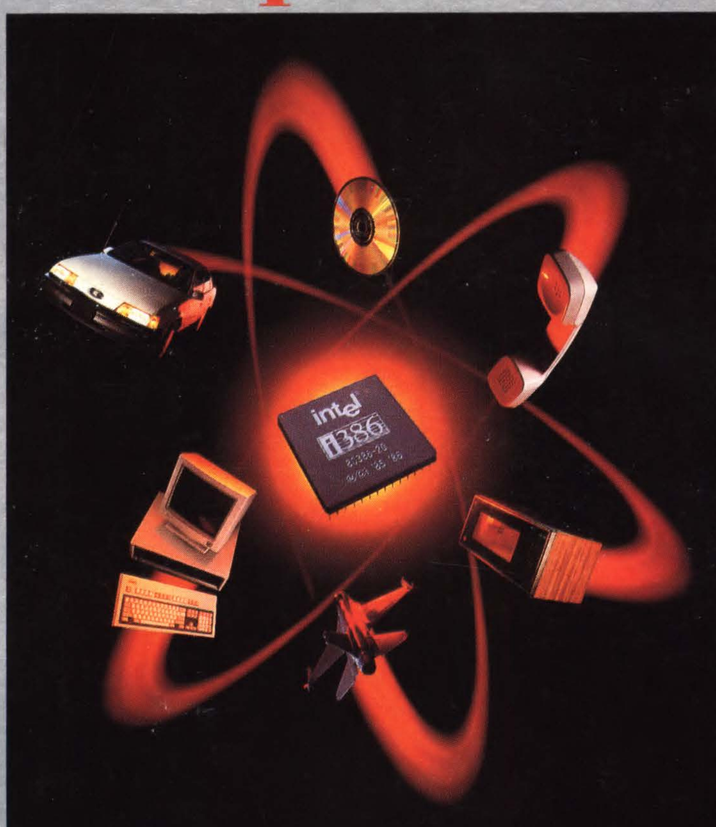
Surveying users' needs

Adding dazzle to toys, movies, cars, computers

Consulting the crystal ball

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

THE Microprocessor

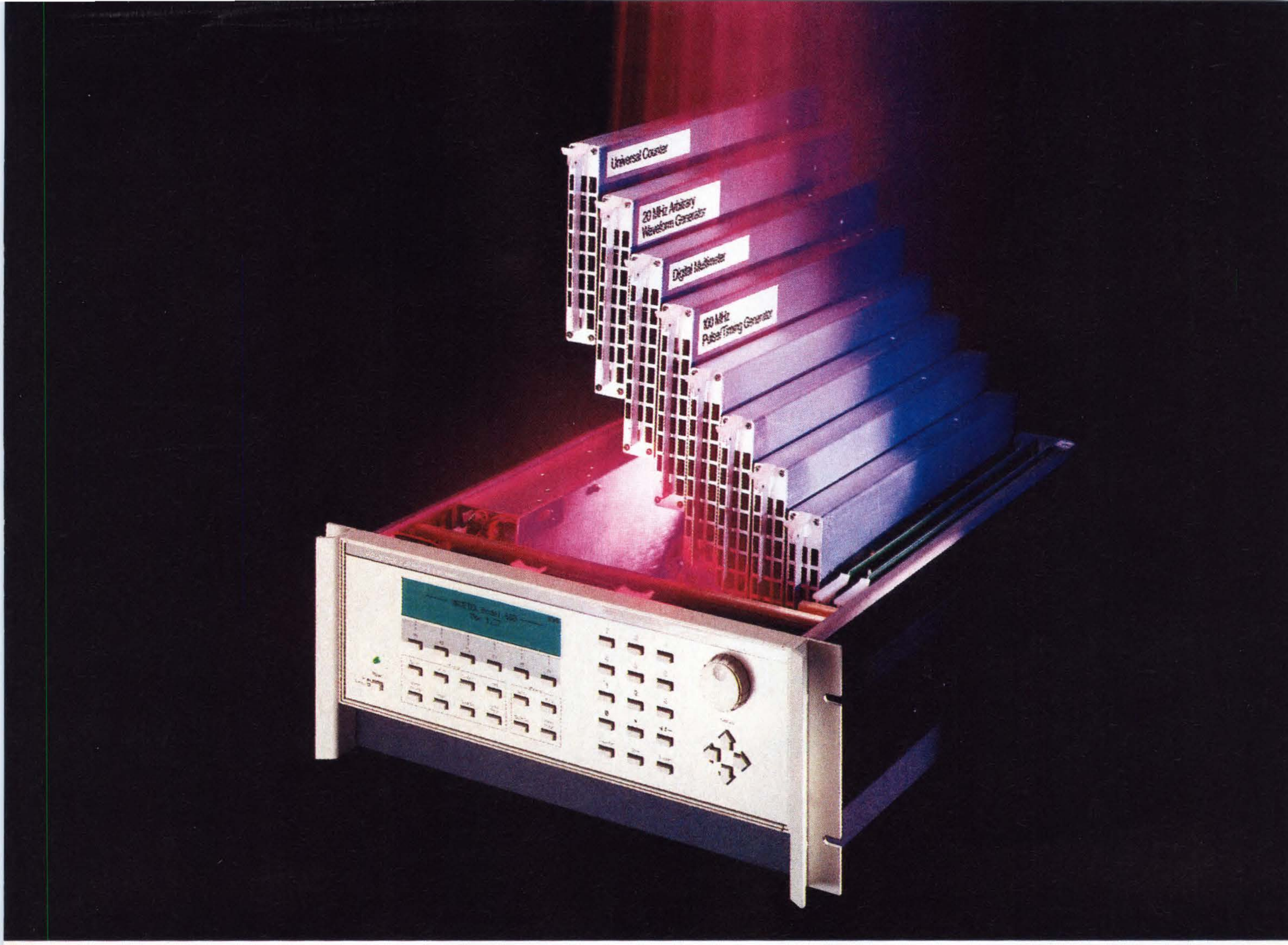


Nucleus for Change

Actually, we couldn't find anyone who wanted to be on this list. What we did find was th
programs for Intel's 386™ chip. And the way its popularity is growing, the list can only g

*OS/2 is a trademark of International Business Machines Corporation. UNIX is a registe

ON THE FOLLOWING PAGE IS A LIST OF ALL THE MAJOR SOFTWARE DEVELOPERS WHO ARE NOT YET WRITING PROGRAMS FOR THE INTEL386™ ARCHITECTURE.


Universal Counter
20 MHz Arbitrary Waveform Generator
Digital Multimeter
100 MHz Pulse/Timing Generator


1971
RHYTHM COMPOSER TR-707
BASEBALL
EAGLES
BUFFALOS
1971
1974
simon
1975
1980

THE SPECIAL REPORT MICROPROCESSOR

The Microprocessor: Nucleus for Change

In less than two decades, a tiny chip—made from little more than sand—has changed the way we live, work, and play. The microprocessor itself is plain, ordinary looking. But the things it has made possible are nothing less than dazzling.

And the dazzle is all around us, thanks to this ubiquitous little chip, and it has become so commonplace that we've come to take it for granted. We see the dazzling color graphics of desktop computers, and we know microprocessors are responsible; but we also see sleek, new, high-performance, fuel-efficient cars, and few of us know that microprocessors deserve the credit for enabling high performance and efficiency to coexist.

We see the effects of microprocessors on the silver screen when we go to the movies. We hear their effects on music when we play our stereos. Our kids play with microprocessors without even knowing it; chips form the hearts of video games, talking toy dogs, even—believe it or not—some special baseballs. And, increasingly, microprocessors are venturing out from the familiar world around us to the far reaches of outer space.

All of these glamorous applications of the microprocessor are documented in this EDN special issue. Other applications, equally glamorous, go unmentioned for the simple reason that there are seemingly infinite applications and only a limited number of pages in which to describe them. Nor can we describe, in the pages of one magazine, the literally thousands of not-so-glitzy applications: the gas pumps, the supermarket scales, the motor controls.

Not even the inventors of the microprocessor anticipated all its far-reaching effects, but the inventors, and EDN's editors in the early 1970s, did recognize that the microprocessor was a revolutionary device. From those early days until now, EDN has reported on the microprocessor's present and future. EDN's early coverage was largely tutorial, explaining to designers of circuits how to design with whole computers that fit on only a chip or two. We've included in this special issue excerpts from past EDN issues, and in them you can see EDN's coverage evolve from the tutorial to the advanced, mirroring our readers' advances in sophistication about microprocessors and their applications.

What you'll see throughout this issue is change—in the things around us, in the products we design and build, in the components we build them with. That the microprocessor itself has changed is relatively unimportant; what *is* important about the microprocessor is that it's a nucleus for change. Because of the microprocessor, the world is different than it was a few short years ago.

"At LTX we evaluated a lot before we chose Vicor."

"As the leading manufacturer of automatic test equipment for linear integrated circuits, we had unique power supply requirements for Hi.T, our new linear test system. Given its advanced resource per pin architecture, we needed new solutions. So we went to the experts. And Vicor delivered.

They delivered a DC power module which lets us achieve low system noise, thus allowing our test equipment to measure signals down to microvolts.

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They delivered a power system that's modular, flexible and reliable. We can add new features to our testers without having to redesign the power distribution system. And high reliability is especially important to us since we offer a limited lifetime warranty on our test systems.

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– *Phil Perkins, Staff Scientist, Co-Founder, LTX Corporation*

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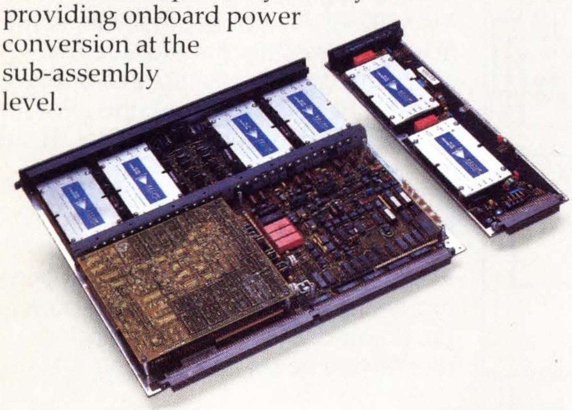

Rear panel of the Hi.T system

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- Flexibility in system configuration
- Enhanced reliability

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VICOR CORPORATION

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CIRCLE NO 4

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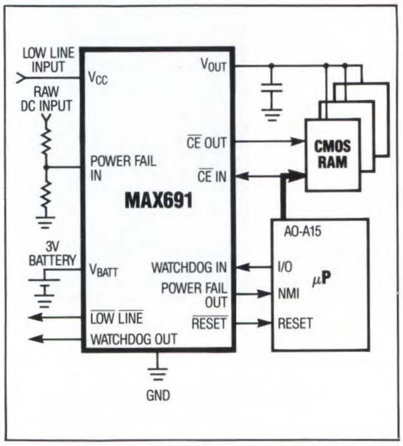
- **200ms Reset Pulse — for Motorola μP compatibility**

Power-On/Low Line Reset

Maxim's supervisory ICs each have a precise factory trimmed or user adjustable threshold detector and timer that generates an accurate, reliable Reset signal for any power-on, brown-out or low battery condition.

Power-Fail Detection

An uncommitted 1.3V threshold comparator is built into each device for use as a power fail indicator or for monitoring the back-up battery voltage.



Watchdog Timer

A watchdog circuit built into every MAX690-697 constantly monitors all μP activity. It detects both hardware and software malfunctions and automatically issues a Reset command to the μP — effectively eliminating 'lock up' conditions.

Memory Protect — Chip Enable Gating

MAX690-697s prevent μPs from writing erroneous data into RAM during power-up, power-down, brown-outs, and momentary power interruptions.

Automatic Battery Switchover

The MAX690-696 monitor incoming power and automatically switch to battery back-up when the power supply drops below the battery voltage. Quiescent current drops to less than 1μA and ensures that the data in CMOS RAM or EEPROM remains intact until power is restored.

Part #	Pins	Reset (Volts)	Isupply (mA)	Reset (ms)	Battery Switchover	Memory Protect (CE)	Low Line In	Low Line Out
MAX690	8	4.65	4	50	Yes	No	No	No
MAX691	16	4.65	4	50*	Yes	Yes	No	Yes
MAX692	8	4.40	4	50	Yes	No	No	No
MAX693	16	4.40	4	50*	Yes	Yes	No	Yes
MAX694	8	4.65	4	200	Yes	No	No	No
MAX695	16	4.65	4	200*	Yes	Yes	No	Yes
MAX696	16	Adj	4	50*	Yes	No	Yes	Yes
MAX697	16	Adj	160μA	50*	No	Yes	Yes	Yes

*Internally preset value, also adjustable

The MAX690-MAX697 are available in DIP or SO packages and — like every other Maxim part — each is tested to rigorous reliability standards absolutely free. They offer you a price-performance value unmatched in the marketplace.

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CIRCLE NO 5

EDN Magazine Edition

Volume 33, Number 22A

October 27, 1988

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

On the cover: *It's well documented—in these pages and many others—how the microprocessor affects the way we work in this industry. But how has it changed our lives outside of the work place? The microprocessor adds a new dimension to our music, makes our toys more fun to play with, and gives our movies stunning special effects. To this tiny piece of silicon we devote our special issue, The Microprocessor: Nucleus for Change. (Photo courtesy Intel Corp)*

SPECIAL ISSUE

The Microprocessor: Nucleus for Change

In less than two decades, a tiny chip has changed the way we live, work, and play. The microprocessor looks plain, but its effects are dazzling. Its history, its future, its glamorous applications—all are documented in this EDN special issue.

Continued on page 9

BPA ABP

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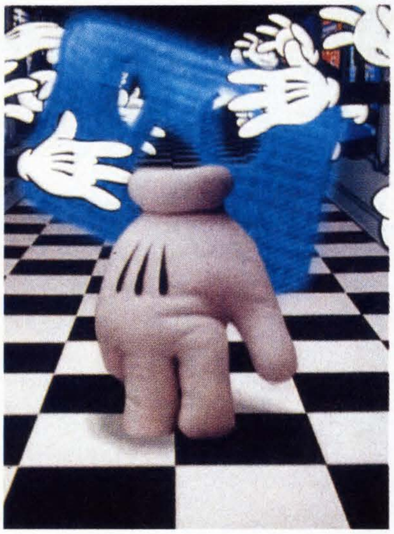
Continued from page 7



If not for the microprocessor, *the dramatic special movie effects we now take for granted would probably not exist (pg 78).*

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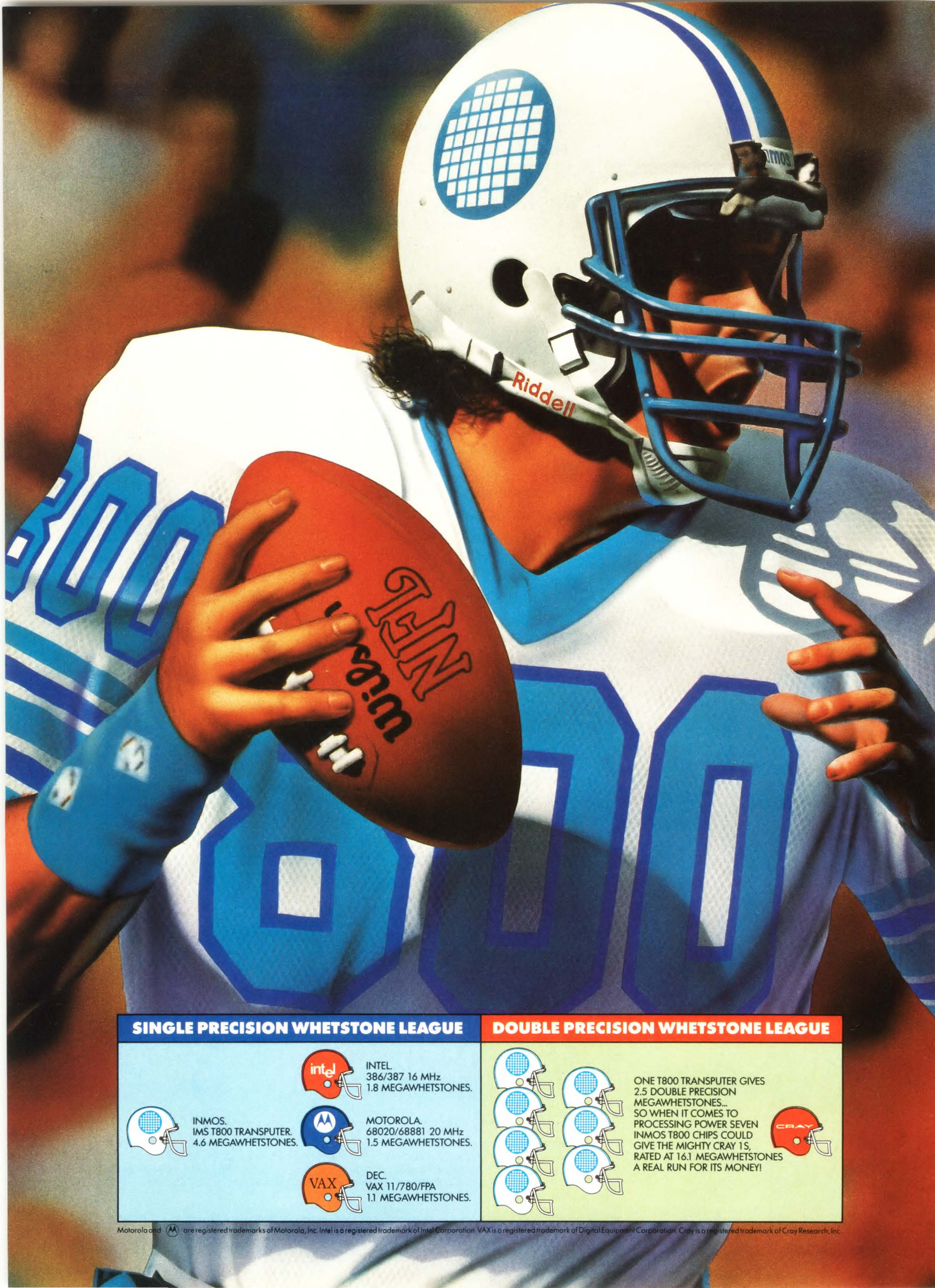
Riddell
NFL
Wilson
SINGLE PRECISION WHETSTONE LEAGUE
INTEL.
386/387 16 MHz
1.8 MEGAWHETSTONES.
INMOS.
IMS T800 TRANSPUTER.
4.6 MEGAWHETSTONES.
MOTOROLA.
68020/68881 20 MHz
1.5 MEGAWHETSTONES.
VAX
DEC.
VAX 11/780/FPA
1.1 MEGAWHETSTONES.
DOUBLE PRECISION WHETSTONE LEAGUE
ONE T800 TRANSPUTER GIVES
2.5 DOUBLE PRECISION
MEGAWHETSTONES...
SO WHEN IT COMES TO
PROCESSING POWER SEVEN
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And, if that's not enough raw power, the T800's links allow multiprocessor systems to be constructed quickly and easily – giving you 6 MFLOPS with four T800's...30 MFLOPS with 20...150 MFLOPS with 100...In fact, there's no limit to the number of Transputers you can use!

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IMS T414-20	32-Bit	20	9500	0.75 Million	Now	Q2 88	84 PGA
IMS T212-17	16-Bit	17	8000	–	Now	Q2 88	68 PGA
IMS T212-20	16-Bit	20	9500	–	Now	Q2 88	68 PGA
IMS M212-17	16-Bit	17	8000	–	Now	–	68 PGA

NETWORK SUPPORT PRODUCTS			AVAILABILITY		PACKAGE
Part No.	Description	Communication Speed	Commercial	Military	
IMS C004	Software configurable 32 way link switch	10 + 20 MBits/sec	Now	Q2 88	84 PGA
IMS C011	Link to system bus	10 + 20 MBits/sec	Now	–	24 Pin DIP
IMS C012	Link to system bus	10 + 20 MBits/Sec	Now	Q2 88	24 Pin DIP

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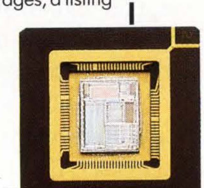

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CIRCLE NO 8

THE SPECIAL REPORT MICROPROCESSOR

Fifteen years and counting...

With this special issue, EDN celebrates its more than 15 years of involvement with the microprocessor revolution. EDN's involvement has not been merely as a spectator; EDN has been an active participant. Our editors are proud that they helped make the revolution happen: EDN was a pioneer in the coverage of the microprocessor.

Let's recap some of EDN's pioneering efforts.

- May 1, 1971. Six months before Intel's 4004 4-bit microprocessor actually came to market, an EDN news story announced that the single-chip CPU, which was developed for the calculator manufacturer Busicom, would become available to all comers. The article prophetically declared, "the package might well induce designers to develop 4-bit applications outside the confines of the calculator market."
- November 5, 1973. An editorial titled "The race belongs to the prepared" stated our belief that new markets would grow around the microprocessor, that engineers were not prepared to use this new design tool, and that EDN was dedicating itself to educating engineers to use microprocessors. Bob Cushman's hands-on μP design in the same issue, the first article of a series that continued for more than 10 years, first coined the μP acronym.
- June 5, 1984. The first multipart Software Design Series published.
- August, 1974. The first comprehensive μP Market Study, conducted among users/potential users. Followed up again in October, 1975, these EDN studies were marketing's bible for many years.
- November 20, 1974. The First Annual EDN μP Chip Directory. 1988 marks the 15th consecutive year that EDN has compiled and published this directory.
- June 5, 1975. EDN sponsored the World's First μP Design Contest.

EDITORIAL

- November 20, 1975. EDN's First Annual µC Systems (board-level products) Directory.
- November 20, 1976. An 11-Chapter "µC Design Course" tutorial published all in one issue.
- June 5, 1977. A 13-Chapter "Software Design Course" tutorial published all in one issue.
- November 20, 1977. EDN's First Annual µC Support Chip Directory. 1988 marks the 11th consecutive year that EDN has published this important directory.
- November 20, 1977. The first seven chapters of EDN's 19-chapter Systems Design Project. EDN's editors learned and wrote about the problems of µC systems design by building an "under $10,000" computer system.
- November 20, 1978. A 7-Chapter Software Systems Design Course published all in one issue.
- March 5, 1979. A 6-Chapter Software Tutorial starts.
- October 20, 1979. A 6-Chapter Advanced Software Systems Design Course tutorial all in one issue.
- January 5, 1980. The start of EDN's first of six Designer's Guides to DSP.
- March 20, 1980. A 4-Chapter Designer's Guide to Testing and Troubleshooting µP-Based Products published all in one issue.
- November 5, 1980. EDN's First µC Operating Systems Directory and a 5-Chapter Operating Systems tutorial.
- April 1, 1981. EDN's landmark 16-bit µP benchmarks.
- May 27, 1981. 3-Part Designer's Guide to µC Buses.
- September 19, 1985. EDN's 4-Part 32-Bit Systems Design Guide starts.

These pioneering efforts are merely a part of EDN's major editorial commitment to the development and growth of µP-related markets. Complementing this work during the past decade and a half were hands-on articles in issue after issue by EDN's Bob Cushman, teaching the joys and pains of designing with µPs and µCs based on his own experiences.

So you can see why EDN has cause for celebrating its 15 years with the microprocessor. We have lived with, learned with, suffered with, and prospered with all those in the electronics industry who have been affected by the mighty microprocessor—and that's just about everyone and every company. Thanks for your support and confidence in EDN.

Roy Forsberg
Vice President, Editorial Director and Associate Publisher

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And since the 147 features both UNIX® and real-time operating system support, you can plug it into your existing 020-based architecture and software base.

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THE SPECIAL REPORT MICROPROCESSOR

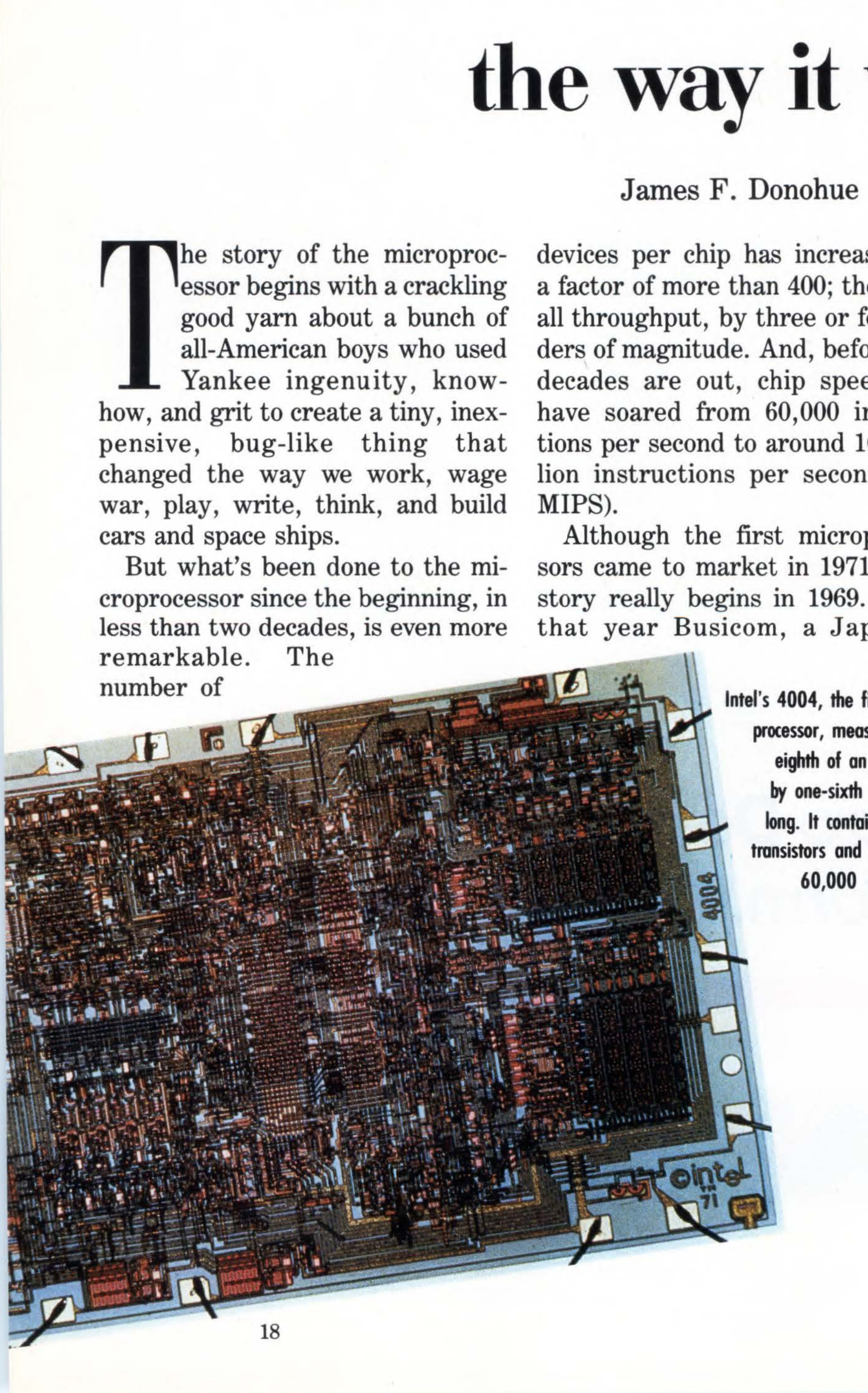
The microprocessor's first two decades: the way it was

James F. Donohue

The story of the microprocessor begins with a crackling good yarn about a bunch of all-American boys who used Yankee ingenuity, know-how, and grit to create a tiny, inexpensive, bug-like thing that changed the way we work, wage war, play, write, think, and build cars and space ships.

But what's been done to the microprocessor since the beginning, in less than two decades, is even more remarkable. The number of devices per chip has increased by a factor of more than 400; the overall throughput, by three or four orders of magnitude. And, before two decades are out, chip speed will have soared from 60,000 instructions per second to around 100 million instructions per second (100 MIPS).

Although the first microprocessors came to market in 1971, their story really begins in 1969. Early that year Busicom, a Japanese maker of electronic desktop calculators, hired a year-old California company called Intel to produce a set of custom integrated circuits that Busicom engineers had designed for a new line of calculators.



Intel's 4004, the first microprocessor, measured one-eighth of an inch wide by one-sixth of an inch long. It contained 2300 transistors and performed 60,000 operations a second.

The cofounder of Intel was Robert Noyce, one of the inventors of the integrated circuit. Integrated circuits, although then ten years old, had hardly achieved sophistication. Developments came more slowly in electronics in those days. In 1969, integrated circuits routinely contained only 500 to 1000 transistors and were hardwired to perform very limited tasks.

The Japanese, however, were looking for a technological Great Leap Forward. They wanted 3000 to 5000 transistors on their chips. Noyce turned Busicom's visiting Japanese designers over to a 31-year-old electrical engineer with a doctorate from nearby Stanford University, Marcian E. (Ted) Hoff, Intel's twelfth employee.

If Richard Wagner were alive and writing an opera about electronics, he would have scored this scene with a roll of kettle drums and a clap of thunder and a soaring phrase in the horns. In young Hoff, Noyce, only 40 himself, had found the fire that would forge his chip into a dynamo that, after some fits and starts, would power so much of the world's industry.

More than tripling the number of transistors on the chip probably wouldn't have been such a tough nut to crack. Intel already had found a way to put 2000 transistors in silicon, and techniques to squeeze on even more were in place. A much bigger problem, for Hoff, was the maddening inflexibility of the chip's hardwired circuits and logic gates.

Electronic calculators in the late 1960s contained chips of two varieties: memory chips and logic chips. The memory chips weren't one of Hoff's problems. There were RAMs for storing the numbers entered by the user and ROMs for holding operating instructions (how to add, subtract, find a square root).

Hoff's problem was with the logic chip. It was hardwired to do only one chore. Not one chore at a time. One chore, period. Because of that, electronic calculators needed many logic chips: one chip to perform calculations, another to control a printer, another for the LED readout.

Typically, the calculator of 1969 contained six chips. But the Japanese came to Intel with grandiose plans for calculators that would offer users many more options and control many more peripheral devices. So, of course, they would have to contain many chips, about 12 per calculator.

Hoff studied the Busicom design and decided it was much too complicated to work economically. More important, it was much too complicated for a little startup like Intel to do at all. Recalls Federico Faggin, a chip designer at Fairchild at the time, "Intel was in no position to bid for this totally custom contract. The company had no in-house expertise in random logic design, and it would have taken too many engineers to do the job."

But, luckily, about this time chip technology took a little jog forward. Intel had found a way to pack a kilobit or more of ROM on a chip. Hoff figured that, with so much memory, he could write a more powerful instruction set into ROM. Furthermore, he asked, with the capability to put 2000 transistors on a chip, wasn't it possible to design a general-purpose logic chip that could use these more powerful ROM instruction sets to do multiple jobs?

Why not, he asked, create a microprocessor? "Instead of making their device act like a calculator. I wanted to make it function as a general-purpose computer programmed to be a calculator."

Did the Japanese appreciate Hoff's idea? Get real. Hoff remembers that the reaction of the Japanese engineers was, "We know what we're doing. Why don't you go away and let us do our thing. You don't know about calculators."

Noyce encouraged Hoff to pursue his idea anyway, as a backup to the Japanese' efforts. In the fall of 1969, the top brass of Busicom came to

Japanese manufacturer Busicom asked Intel to build 12 hardwired logic chips for use in its calculators, and Intel responded by proposing to do the job with only four chips, one of which became the 4004 microprocessor.

California. The Japanese engineers presented their idea for the calculators, and Hoff presented his. Hoff won. Busicom agreed to pay Intel $60,000 to build a chip set for the calculators.

The chip set was called the 4000 family and comprised four 16-pin devices. These were the 4001, a 2k-bit ROM with a 4-bit mask programmable input-output port; the 4002, a 320-bit RAM with a 4-bit output port; the 4003, a 10-bit serial-in, parallel-out shift register to be used as an input-output expander; and the 4004, a 4-bit CPU.

The 4004 was a puny little thing: its 2300 MOS transistors chugged along at 60,000 operations a second. The first microprocessor measured one-eighth of an inch wide by one-sixth of an inch long. Yet it had the computing power of the first electronic computer, the fabled ENIAC, which filled 3000 cubic feet and had 18,000 vacuum tubes.

Intel didn't design the 4004 without delays and difficulties, of course. History blurs memories, but it appears that six months went by with little activity. The main problem seems to have been a lack of manpower at Intel. "We only had Hoff and two other designers in the company at the time," Noyce says. "I couldn't afford to put them to work in silicon. Hoff had other things to do."

In the spring of 1970, to push things along, Noyce hired Faggin from Fairchild to put Hoff's concept of the microprocessor into silicon. At Fairchild, Faggin had developed a new technique (silicon gate technology) for the design of MOS ICs. "It was my strong desire to design complex integrated circuits with this technology that attracted me to Intel," Faggin recalls.

It took Faggin nine months to make the microprocessor, and during the early months, he encountered a lot of problems.

He remembers, "I was told that Hoff and Mazor (Stan Mazor, an application engineer working for Hoff) had already completed the architecture and logic design and only some circuit design and chip layout were left to do. But that is not what I found." What he found, Faggin says, were a lot of unresolved chip architectural issues and nobody around to solve them.

To make matters worse, Faggin was on the job only two days when one of the lead Busicom engineers, Masatoshi Shima (who later worked for Intel and for Zilog) came in from Japan to review the work that Intel had been authorized to do six months before. He looked around the Intel lab, and, finding little progress having been made on the new chip set, blew his stack. "Shima was furious," Faggin says. "He kept on saying in his broken English, 'I came here to check. There is nothing to check. This is just idea.' And he was mad at me since I was the official Intel project manager."

Federico Faggin, the 4004's designer, had been on the job only two days when Masatoshi Shima came in from Japan to review the work that Intel had been authorized to do six months before. Finding little progress, Shima blew his stack.

In time, Faggin calmed Shima. In fact, Faggin remembers that Shima eventually "let go of the animosity and became very helpful doing a number of technical chores for me." Intel finished the chip, and Busicom made its calculators, eventually selling 100,000 units.

Since Intel had developed the 4004 under contract to Busicom, the Japanese had exclusive rights to it. But Noyce and Ed Gelbach, Intel marketing director, thought there were more worlds for the microprocessor to conquer than just calculators. "We weren't sure where Busicom was headed or if it would succeed," Gelbach remembers. "But we did agree that we could do a lot more with this set of parts then sell it for calculators."

Noyce and Gelbach flew to Japan in 1971 intending to do no more than negotiate a new contract with Busicom for the production of the 4004. On the long plane ride, they talked about what might become of the microprocessor and what Intel might do with it. They decided "then and there," Gelbach recalls, "to offer Busicom a price reduction for the 4004 in return for marketing rights."

Worldwide, times were tough in the electronics industry. In the

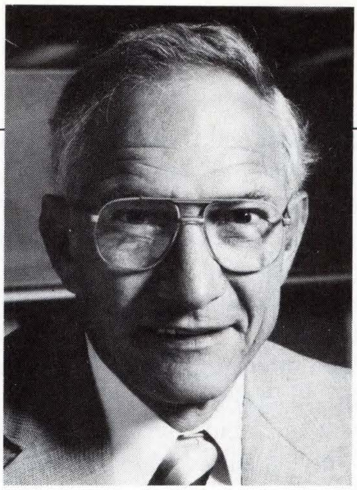
Good times in the pear orchard

Venture capital money was practically growing on the fruit trees in northern California in 1968 when Robert Noyce and Gordon Moore, two of the eight founders of Fairchild Semiconductor, left Fairchild to start yet another company. Noyce and Moore put up $245,000 each of their own cash and picked up $2.5 million in venture capital. With that, they founded Intel Corp. The first offices were in Mountain View; in less than two years, Intel moved to a nondescript concrete building on a 26-acre abandoned pear orchard in Santa Clara. The name, Intel, was shorthand for "Integrated Electronics."

Santa Clara, government seat of Santa Clara County, once the world's leading producer of dried prunes, had become a center for another kind of produce: The county bloomed with flat-roofed, rectangular, one-story industrial buildings that housed companies like Fairchild, which pumped out mostly electronics products, like Noyce's chips.

There was a kind of joke in vogue among the hot-shot engineers around Santa Clara in 1968. They gave the nickname "Silicon Valley" to the long, flat sprawl of land that crawled along Interstate 101 on the peninsula that forms the western shore of San Francisco Bay. Hardly anybody outside the Valley knew the nickname. It wasn't until 1971 that trade magazine writer Don Hoefler popularized it.

Robert Noyce: Creator of the chip



If Ted Hoff is the father of the microprocessor, Bob Noyce is the grandfather. And not just because Noyce hired Hoff at Intel and shepherded his concept of the microprocessor into silicon. There's more to it than that. There wouldn't have been a microprocessor at all if Noyce had not first invented the integrated circuit, or "chip."

That was in 1958, when Noyce, the son of a Midwestern Congregational minister, was research director at Fairchild Semiconductor. He had been looking for a better way to make transistors, which had been invented in 1948 at Bell Telephone Laboratories. A big improvement over its predecessor, the vacuum tube, the transistor nevertheless had a passle of problems. For one thing, it tended to break off its circuit board.

The remedy, hit on simultaneously and independently by Noyce and by Jack Kilby at Texas Instruments, was to make the crystal in the transistor serve as the circuit board. In the process, Noyce and Kilby discovered that they could etch large numbers of transistors and their connections on a piece of silicon. That was the chip.

Noyce hired Ted Hoff as Intel's twelfth employee.

Does anything stand out in Noyce's mind about Hoff? "He was a very bright kid who knew more about these things (computers) than I did," he says. Noyce's expertise was in memory chips, and that was to be Intel's core business. But Noyce saw the bright future of computers, and he went to nearby Stanford University looking for a whiz kid in computers. He hired Hoff primarily on the recommendation of the young man's professors. "They said he was very bright," Noyce remembers. "About the brightest kid they'd had in their courses."

Was there any sense, 20 years ago, that this small group of scientists was doing work that would change the world? Just barely. "We saw the microprocessor as solving a bottleneck," Noyce says. "There just weren't enough designers to custom design every chip. And we did recognize the importance of computers. But, no. We didn't see that microprocessors would bring computers to Everyman."

Today, Noyce recognizes the importance not only of microprocessors, but of the entire American semiconductor industry. He recently agreed to become chief executive of Sematech, the consortium of semiconductor manufacturers that is performing research to maintain American competitiveness in world markets.

United States, the orgy of venture capitalism of the late 1960s had spawned a vast army of new electronics companies. Competition was fierce, and in 1970-71 a lot of these little outfits folded. Competition among makers of electronic calculators was especially fierce. Busicom, feeling the pinch, agreed to Intel's proposal to exchange a lower price for the marketing rights to the 4004.

That fall, Intel ran the first ads ever for the microprocessor. "Announcing a new era of integrated electronics," the headline trumpeted about the 4004. "A microprogrammable computer on a chip."

The world reacted to the 4004 with a big yawn. After all, what could you do with a 4-bit microprocessor, except run a calculator which worked in binary-coded decimal? Even Hoff didn't see much use for the chip beyond calculators and, in limited use, in minicomputers. The calculator business certainly was promising enough, but only about 20,000 minicomputers were being sold annually in the early 1970s, and Intel could expect only a piece—maybe 25 percent—of that pie.

So, what to do with the 4004? Well, Intel was in the business of selling memory chips, like the 1k-bit 1103. Couldn't the microprocessor help sell memory?

Fortunately, there were visionaries at Intel. Company cofounder Moore remembers, "As soon as the microprocessor was a reality, we recognized that this was the next thing we wanted to do after semiconductor memory—a new direction in LSI (large-scale integration). By programming, we could make a standard LSI circuit perform in a wide variety of applications. We seized it as another step in the direction we wanted to go."

Hoff, Gelbach, and others began compiling lists of product applications for the microprocessor. An early magazine ad lists many of them: "Computer terminals, traffic light controllers, medical instruments, business machines, mass-transit equipment, reservation systems, cash registers, inventory computers for fast-food restaurants, process controllers, electronic test instruments, and even pinball and slot machines."

There was, of course, little software for any of this. Intel knew it had to rely on its potential customers for the applications work. Moore remembers going to an industry conference in 1972 and saying, "Hey, we've got this thing; here's what it'll do. Now, how can we in the industry figure out a need for 100,000 of them a month?"

Intel also produced the electronics industry's first development aids, elementary programming tools. Intel sold these development kits for $5000 and, at one point, was spending more to print and mail operating manuals than the company generated in microprocessor sales.

And, Intel was not without competition, although most of the electronics industry didn't know it yet. Even as development of the 4004 proceeded, both Intel and chip maker Texas Instruments were proposing microprocessors to a company other than Busicom.

The company was CTC (Computer Technology Corp., now Datapoint Corp., San Antonio, Texas). CTC had asked both Intel and Texas Instruments to design logic chips (not necessarily microprocessors) for a line of intelligent terminals it planned to build. CTC eventually rejected the idea of a microprocessor entirely and opted for the tried and true hardwired logic chip for its terminals, but the design work at Intel and TI was not to be wasted.

TI demonstrated a "CPU on a chip" in March 1971, and a "computer on a chip" (with added ROM) in July of that year. Building on those accomplishments, the company later produced a device used in calculators of its own manufacture as early as 1972. In 1974, TI offered the device to the rest of the world as the now-legendary TMS 1000 4-bit processor.

TI's work eventually led to the 8-bit second-generation TMS 9980 and, eventually, to the 16-bit third-generation MSS9900/9940. At Intel, the work for CTC led to the 8008, introduced in April 1972. This second-generation microprocessor contained 45 instructions, addressed 16k bytes of memory, and ran at 300,000 instructions a second.

About this time, Intel went to the Kiddy Korps again, hiring a 33-year-old public relations and advertising specialist by the name of Regis McKenna. Now a legend in Silicon Valley, McKenna was then an undersized college dropout looking to make a buck. He took Intel's message to the trade press with ads featuring bright photographs and sprightly writing: One ad showed ticker-tape machines to stress the financial benefits of the microprocessor and hamburgers to show that they could be popped out in droves, like hamburgers at a fast-food joint, and customized for many different jobs.

"When all the world was convinced our micro was the way to go," says Noyce, "they all wrote software for it, so it became the

Ted Hoff: Architect of the concept

Ask Ted Hoff if he, or anybody back then in 1969-71, recognized the importance of the microprocessor, and he responds with a wry grin and a dry chuckle. "When people ask me that question," he says, "I tell them to read the first advertisement for the 4004." That ad, published in the fall of 1971, spoke of "A new era in integrated electronics." Says Hoff, "That is not exactly a modest statement. Yes. We recognized that it was important."

Hoff continues, "We recognized that we as engineers had numerous applications right there in our lab that, if it [the microprocessor] had been available, we would have designed it right in. And we believed that if we felt that way then other engineers, with their problems, would feel that way, too." He adds, "But that's a far cry from saying that we knew it would lead to a computer in every home."

Hoff was born in Rochester, New York, on Oct. 28, 1937. He took a bachelor's degree in electrical engineering from Rensselaer Polytechnic Institute in 1958 and his graduate degrees from Stanford University, getting a doctorate in electrical engineering there in 1962. He stayed on at Stanford after graduation, in the middle of what was becoming "Silicon Valley," specializing in the then primitive science of computer pattern recognition. His doctoral thesis was entitled, "Learning Phenomena in Networks of Adaptive Neurons."

In the fall of 1968, recommended by the Stanford faculty, he took the design-chief job at startup Intel. He remained with Intel, through the heart-years of the development of the microprocessor, until 1983. Then he went to Atari, still in technology development. About a year and a half later, he set out on his own as a consultant, working out of his home in Los Altos Hills, California.

Today, Hoff has come almost full circle, returning to the study of artificial intelligence and of how computers can be taught to become more like humans. "The question," he says, "is whether we can improve the interface to computers with some of the things that artificial intelligence and neural research are both addressing. We need to look for better handling of natural communication—speech recognition input, pattern recognition input, more-natural language communications. You probably won't see this in the next ten years, but I hope that with the kind of processing power that we have available that we'll see more progress in those areas."

way to go. It was a battle of opinion, and Regis' marketing ploys had a lot to do with winning it." A competitor, L.J. Sevin, founder of Mostek, remembers, "Regis clobbered us by positioning Intel as the technology leader. They had an easier time hiring hotshot engineers and getting through to their customers' executives, not just to the purchasing managers."

Indeed, things were looking up in Silicon Valley. While nobody had quite known what to do with the 4004, there were plenty of hot shots around with good ideas for the 8008. For one, they used it to invent the microcomputer. In 1973, Scelbi Computer Consulting Inc. and RGS Electronics introduced microcomputers based on the 8008. In July of the next year, *Radio-Electronics* magazine published a cover story by another young tinkerer, Jonathan Titus, describing how he built the Mark-8, an 8008 microcomputer. Titus' article was a landmark. It was the first article to appear in a magazine that went into great detail about microcomputer technology. (The Smithsonian Institution recently acknowledged the historical significance of the Mark-8, acquiring it for a future exhibit.) Titus is now the editor of *EDN*.

By now, events were hurtling along in the microprocessor business. Competitors were everywhere. Noyce remembers that, in 1974, "the number of available or announced microprocessors jumped to 19, as companies such as Fairchild, National Semiconductor, Signetics, Toshiba, and AMI introduced products."

At Intel, Faggin proposed the design for an improved 8-bit microprocessor. The 8008 had really been only a first-generation-and-a-half product, a sort of 4004 version 1.5. Faggin proposed a true second-generation device. It would contain 75 instructions and address 64k bytes of memory.

Ted Hoff figured a kilobit of ROM would allow him to write a more powerful instruction set and design a general-purpose logic chip that could use those instructions to do multiple jobs. Why not, he asked, create a microprocessor?

Do you hear Wagner's horns starting up again? It was the 8080.

The history of the microprocessor is full of ironic twists and turns. Here's another one. Hoff had proposed the 4004, but Faggin had designed it. Now Faggin proposed the 8080, but somebody else designed it. Who? The Japanese engineer, Masatoshi Shima, who had so fussed at Faggin for early delays in the 4004. Intel had gobbled Shima up when the Japanese calculator maker, Busicom, went bankrupt, a victim—despite the concessions wrung from Intel—of the price wars in the early 1970s.

Among the competitors snapping at Intel's heels was a giant. Motorola had decided that there was too much money in microprocessors for it to stay on the sidelines any longer. At Motorola were designers Tom Bennett and Chuck Peddle, a chubby (he peaked at 230 pounds) engineer who had been trying to design point-of-sale credit-verification machines at a struggling little company in Phoenix when Bennett hired him. Together, they led the team which produced the 6800.

The people Bennett assembled to make the 6800 were typical of design teams of the early 1970s. "It was made up of very young, local guys, right out of school," Peddle recalls. Their product was to set new standards for the microprocessor industry.

The 6800 represented a major departure from the Intel design. When Hoff, Faggin, and Shima designed the first microchips, memory was expensive, so they relied on internal registers to store and transfer data. Peddle moved temporary data storage to external memory and gave the chip only enough registers to keep track of the data.

There are advantages and disadvantages to both design philosophies. The Motorola design makes the chip go to external memory more often, but it enables it to do so more quickly. In addition, Motorola implemented the "zero page," a 2-byte addressing instruction that permits about a 30-percent speedup in accessing the first 256k bytes of memory.

You can get into heated arguments about the 6800, but it remains today—along with the Intel design—one of the two foundation architectures of virtually all microprocessors, right down to the current fifth-generation varieties.

Motorola also gets credit for introducing the first line of microprocessors designed to control peripheral devices. The 6820, for example, controlled parallel I/O; the 6850, serial I/O.

Perhaps even more important than working on the design of the 6800 was the fact that Peddle was the catalyst for the dramatic price reductions (25 percent a year, on average, for two decades) that has helped spread the microchip across the world.

Here's how he did it: In late 1973

or early 1974 (he's not sure which), Peddle left Motorola to join MOS Technology (now owned by Commodore Business Machines) of Norristown, Pennsylvania, a maker of chips for scientific calculators. Peddle had an idea of how to make a very inexpensive microprocessor to meet what he perceived was a huge demand for such an inexpensive device.

At MOS Technology, he found a bright, ambitious group of designers. And, a little more than a year later, in the summer of 1975, MOS Technology ran ads proclaiming that it would introduce—and have available for sale—the 6501 and 6502 microprocessor at Wescon, the electronics exhibit, in September. The chips would be plug-compatible with the 6800. And the price that incredible: $20 for the 6501, $25 for the 6502.

At the time, Intel's 8080 and Motorola's 6800 were selling for $179 in single quantities. A hue and cry went up in Silicon Valley. Such a staggering price cut was an insult of the worst possible kind: It came from the hated East.

Silicon Valley fought back with what, years later, seems almost hysterical vigor and with what today might be called "disinformation." Design engineers remember being told that the MOS Technology ads were a hoax, that nobody could sell microprocessors for less than $100.

But MOS Technology showed up at Wescon with chips in hand at the price advertised (they had to sell them out of their hospitality suite because exhibitors weren't permitted to sell products on the show floor). On the first day of the show, Intel and Motorola cut the prices of their chips to $69.95.

Motorola sued MOS Technology, charging that Peddle stole the design for the chips. MOS Technology agreed to drop the 6501. Peddle says the company never really

> MOS Technology ran ads proclaiming that it would have the 6502 at Wescon in September. The chip would be plug-compatible with the 6800, and it would sell for $25. At the time, Intel's 8080 and Motorola's 6800 were selling for $179.

planned to sell it. "The 6502 was the product we intended to sell," he says. And the 6502 went on to glory, designed into early personal computers such as the Apple I and II, the Atari machines, and Commodore's PET and VIC-20.

The 6502 was a souped-up version of the 6800. Among its advantages were an on-chip clock generator, an improved instruction set, new addressing modes, faster access to the stack, and built-in BCD arithmetic.

By this time, brain drains were happening all over Silicon Valley. It was a silicon version of the Invasion of the Body Snatchers, or what became known as the Silicon Valley effect: top designers leaving one company to found a new company nearby.

In the most significant body snatch, Faggin left Intel to found Zilog, taking Shima with him. Shima later returned to Intel, but in the meantime Zilog made the Z80, an enhancement of the 8080 that ran at up to 4 MHz, twice as fast as the 8080, and contained 176 instructions, including all the 8080 instructions as a subset.

Spurred to react, Intel tried to throw the 8085 into the fray, but the device was too slow: a horse-and-cart 3 MHz. The 8085A was better—it required fewer voltages and had a simpler clock circuit. But there were problems with it. The 8085A attempted to simplify the complex I/O of the 8080 by dedicating more pins to I/O. That required Intel to multiplex the data bus, and it meant the 8085A needed external latching.

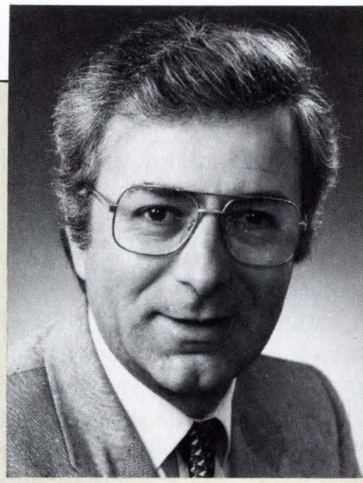
Tandy used the 8085A in its portable computers, but otherwise the chip generated little excitement or business. Clearly, something better was needed. Something faster, more dramatic. Something, perhaps, of the 16-bit persuasion.

Sixteen-bit chips were already out there. National Semiconductor had the Pace, the first 16-bit device. Others in the field included General Automation, with the LSI-16; Western Digital, with the WD-11; General Instruments, with the CP1600; and Texas Instruments, with the TMS9900.

But Intel didn't think any of these had been successful, and the company thought it knew why. These microprocessors were not software compatible with 8-bit chips that had gone before.

Intel started work on its 16-bit microchip, the 8086, in 1976, intending it to be code compatible with the 8080. The designers were not entirely successful in this endeavor, but they came close enough for the time. The 8086, when it was announced in 1978, did not preserve direct code compatibility. But each 8080 register did have its 8086 counterpart, making code translation possible.

Having come close to software compatibility, Intel decided to make a run at hardware compatibility as well. The result was the 8088, which ran as a 16-bit microproces-



Federico Faggin: Master of the silicon

Federico Faggin, who founded Zilog in 1975, was the man hired by Intel from Fairchild in 1970 to put Ted Hoff's idea of the microprocessor into silicon. Hoff had proposed the microprocessor as a means to build a better desktop calculator.

"In those days," Faggin recalls, "there was a controversy in relation to the design of calculators: standard versus custom. The proponents of the custom view were the majority. They argued that it was not cost-effective to design a general-purpose calculator chip or chip set because the needs of the user were so diverse that the chips would need to incorporate all kinds of options, and this would be bigger and more costly than custom-tailored ones.

"The other view was that by properly structuring the system as a small programmable computer, one could in fact achieve both versatility and cost-effectiveness. Pioneering work in this area had already been done at Fairchild, where a 1-bit serial CPU architecture had been developed, and at Rockwell, where a more sophisticated CPU had been designed by Michael Ebertin and coworkers, and at other organizations."

"Ted Hoff," says Faggin, "was clearly in the second group. He proposed to use computer architecture to define a small set of standard components that could satisfy current and future calculator needs."

Faggin came to Intel expecting to find the architecture and logic design of the microprocessor already done "and only some circuit design and chip layout" left for him to do. Instead he found a project already very late and getting later.

"I worked furiously 12 to 16 hours a day," Faggin says. "First, I resolved the remaining architectural issues. Then I laid down the foundation of the design style that I was going to use for the set. Finally I started the logic and circuit design and then the layout of the four chips."

In the process, he says, "I had to develop a new methodology for random logic design with silicon gate technology which had never been done before. To make the circuits small in size, it was necessary to use bootstrap loads, which no one at Intel thought possible with silicon gate." Faggin proved that it was possible.

Shortly before the end of 1970, Faggin recalls, came the first run of the microprocessor, the famed 4004. "It was a major disappointment," he says, "because one of the masking layers was left out in the wafer processing, making the run unusable."

He tried again, three weeks later. "My hands were trembling as I loaded the 2-inch wafer into the probe station," he says. "I was praying for it to work enough to enable me to find all of the bugs so that the next run would yield shippable devices. My excitement was growing as various areas of the circuit were found working.

"By the time the testing was finished, only a few minor errors were found. I was elated. All that work suddenly was rewarded in that moment of intense satisfaction."

Faggin now is president of Synaptics Inc., a San Jose company studying how the workings of the animal nervous system might be applied to computer technology.

sor but faced the world as an 8-bit processor: It pulled in data one byte at a time, combining bytes for 16-bit processing inside the chip. The 8088's 8-bit face to the world made it easy for designers familiar with existing Intel 8-bit chips, like the 8085, to upgrade to the 16-bit world.

Intel built a second processor into the 8088, the bus-interface unit (BIU), which, among other things, queued up data and instructions for the 8088. So, despite being able to pull in data at only half the speed of the 8086, this queuing enabled the 8088 to run only about 20 percent slower than the full-blown 16-bit chip. The 8088 was the first microprocessor to use queuing.

Although the 8088 was less powerful than the 8086, IBM chose it for the PC. The chip's friendly relations with software written for the 8080 was a key reason for Big Blue's choice. After all, the 8080 was the principal chip of the suddenly explosive home computer industry. Why? In 1973, an associate professor, Gary Kildall, working as a consultant for Intel, wrote a disk-based operating system for the 8080 and called it CP/M (Control Program/Microcomputers).

CP/M had it faults, but it was the only microcomputer disk operating system around, and that made the 8080 the principal chip for the booming market for personal computers. And that made compatibility with the second-generation 8080 of critical importance for the third-generation chips.

Intel racked up more than 2000 design wins with the 8088, but the IBM PC coup was the greatest win of all. And for almost half a year, Intel could say nothing about it.

The PC win "was proprietary information," remembers Dave House, general manager of Intel's Microprocessor and Peripheral Operation at the time, "and we couldn't announce anything for four or five months. We knew Apple was going with the 68000, so we kept the Crush program (designed to crush the 68000) going and toughed it out, all the time wanting to tell the world about the IBM win."

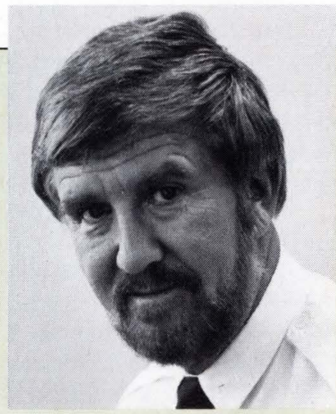
With its innovative 8/16-bit chips, Intel also introduced the concept of the coprocessor. The most successful of these was the 8087 math coprocessor, which added a set of floating-point instructions to the 8086/8088 set.

The concept of a chip running at one speed on the inside while addressing data at another speed outside caught on. At Motorola, designers in 1977 went to work on a chip for the 16-bit market that would run at 32 bits on the inside. They also set out to design orthogonality into the chip by eliminating all special-purpose instructions. The result was the 68000, the chip that Apple chose for the overpriced, and unsuccesful, Lisa and for the highly successful Macintosh.

The 68000 was a mighty 16-bit chip indeed. Motorola designed the instruction set so that there could be as many as 64,000 instructions, compared to 256 instructions for the Intel chip. And its 16-bit registers permitted the 68000, through a virtual memory scheme, to address 4 billion bytes of memory.

A key reason for the success of the 68000 was that, beginning in

Ed Gelbach: Marketer of the idea



One of the more eventful trips in microprocessor history was in 1971 when Ed Gelbach, the new marketing director at Intel, and his boss, Bob Noyce, flew to Japan to negotiate a continuation of Intel's contract with Busicom for producing the 4004 microprocessor and related chips. Gelbach, just hired by Noyce and Intel cofounder Gordon Moore, had been manager of sales at Texas Instruments.

In the plane, Gelbach says, he and Noyce concocted the idea of getting marketing rights to the 4004 in return for price concessions to the Japanese. "I'm not going to say for 100 percent that the idea wasn't discussed back at the plant" before he and Noyce took off for Japan, Gelbach says. "But I don't remember that it was one of the major points we were going to go into the negotiations with."

And so, in the air over the Pacific, Noyce and Gelbach decided that there was a future for the microprocessor and that Intel wanted to be part of it. Says Gelbach, "We hadn't completely thought out what we were going to do, but we did want to offer the Busicom chip set as a general-public product line."

Busicom agreed to the Intel offer, and Gelbach came back to California to look for jobs for the microprocessor. "I made a commitment to Bob then and there that I would set up a separate group to pursue this," he says. "The first applications were the really mundane things—things like traffic-light control."

Gelbach recalls that, "Originally, I think we saw it as a way to sell more memories, and we were willing to make the investment on that basis. We ked for applications in anything that needed some ROM control. There was a lot of ROM around. It was starting to get popular."

A major reason for the success of the microprocessor, Gelbach says, was Intel's introduction, in 1971, of the EPROM. Now the ROM could be as flexible as the microprocessor. "It made sense," Gelbach says, "to be able to reprogram the microprocessor instead of buying fixed ROMs for it. People could breadboard the microprocessor and use the EPROM. They could change their system overnight or every five minutes with an EPROM."

Gelbach marketed the microprocessor and the EPROM together, pitching that, "if you made a mistake, it wouldn't kill your project. You had the flexibility of trying out many different applications specific only to you, of modifying them until you came up with the right one. And this would not cause you a 6-month delay."

Gelbach also began turning out primitive programming kits, priced at about $5000 each, to help engineers put function into the 4004 and its successors. "In our own design labs," he says, "we realized that you needed to put some software into the microprocessor. Our own experience said that ordinary engineers had no experience with software. So any aids that we could give them would be a benefit for selling components."

Eventually, the kits did help sell chips. But, in the early days, Intel made as much selling the kits as it did selling microprocessors.

Gelbach, who took an engineering degree from the University of Southern California in 1959, retired from Intel this year as a senior vice president and a member of the board of directors.

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CIRCLE NO 12

1979, Motorola started upgrading it. The original 4-MHz 68000 evolved into the 12.5-MHz 68010, and that evolved into the 20-MHz 68020, a full 32-bit device that today is the backbone of many Unix-based computer systems. Motorola's computer customers include Apple, Atari, Commodore, NCR, Sun Microsystems, and Unisys.

Most recently has come the 32-bit 68030, which runs at up to 30 MHz. Compare that to Intel's 80386, which tops out at 20 MHz. The 030 has 300,000 transistors and processes more than 7 MIPS, about twice the speed of the 020.

In pushing the 68030 to 7 MIPS, Motorola put the memory-management unit (MMU) on the 030 chip; the 68020 required another chip, the 68851, to perform the MMU function. In addition, Motorola put both the data cache and the address cache on-chip, linking them in the "Harvard" dual, parallel-bus architecture. The 68020 has only the address cache on chip.

While Motorola's innovative designs got it microprocessor design wins, especially in the booming market for graphics workstations, Intel was falling on hard times. Intel's microprocessor business did okay; the success of the IBM PC, with the 8088 inside, assured that. But the rest of Intel's semiconductor business was struggling—or falling before foreign competition. For example, Intel lost the DRAM market, which it had created, to the Japanese.

"Intel introduced the DRAM," says cofounder Gordon Moore, now Intel chairman, "We used to have a 100-percent share of the market. And we went from 100 percent to zero percent over time."

These and other problems brought Intel to a sorry pass: a loss-year. In 1986, the company reported losses of $173 million. The entire semiconductor business was in the second year of a slump in

The 68000 was a mighty 16-bit chip indeed. Motorola designed the instruction set so that there could be as many as 64,000 instructions. And its 16-bit registers permitted the 68000, through a virtual memory scheme, to address 4 billion bytes of memory.

1986, of course. But, no matter. Intel formulated a plan. Microprocessors had made Intel rich and famous, and microprocessors would lead the recovery.

Indeed, there has been a turnaround.

A key to the rebound (profits were $248 million in 1987, the highest in this decade) was the success of the 80386, the heart of the new IBM PS/2 and Compaq Deskpro 386 computers. Intel sold 700,000 of the 386 chips in 1987 and expects to sell 2 million of them this year at an average price of $250 each. That means the 386 all by itself represents a $500 million market.

Noyce describes the 80386 as having "a physical-address space of 4 billion bytes, a virtual-memory addressing capability of 64 trillion bytes, and processing speed up to 10 times faster than the previous generation's." He adds, "It also realizes a significant qualitative breakthrough with its ability to run applications from multiple operating systems, like Unix and DOS, simultaneously."

The road to the 386 was not without its bumps and potholes, however. In 1983, Intel introduced the 80186 and 80188 chips as upgrades of the 8086 and 8088, respectively. But neither was much of an upgrade, and neither scored major design wins. Next came the 80286, which IBM chose for the PC/AT computers.

While that was a major design win, the 286 won little else. It certainly won little praise. Customers said the 286 came out of Silicon Valley's ivory towers. It was as if, they said, Intel had designed the 286 in an intellectual vacuum. "Intel screwed up," complains Gary Stimac, vice president for systems engineering at Compaq. "We still don't have a major 286 operating system. All the major applications had to be rewritten for the 286."

When it started on the design of the 386, Intel showed it had listened to the complaints. It began to work closely with customers. Says Stimac, "We were an integral part of the 386 design team. We shared an incredible amount of confidential information."

Another result of this cooperation with customers was the introduction of the 16-MHz 80386SX chip, which runs software developed for the 386 while using lower-cost components designed for 286 architectures. The result: a less efficient—but substantially less expensive—device. The chip runs internally as a 32-bit device, but it uses a 16-bit external data bus. While a 16-bit bus performs less efficiently, it results in a cheaper computer: about $1000 off the list price of a full 32-bit 80386-based computer, according to Bruce Schechter, Intel 386SX product manager. Computers based on the 386SX have been announced or are planned by AST Research, Compaq, NCR Corp., and NEC Information Systems.

Intel and Motorola don't domi-

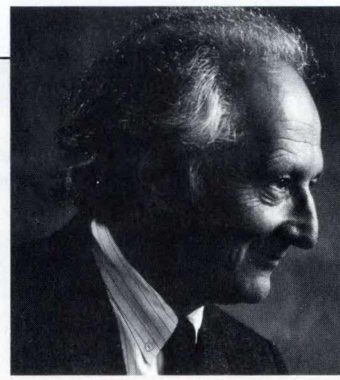
nate the entire semiconductor business, but they are at the top of the microprocessor business. For a time, major competition came from Zilog's 8-bit Z80, and the company's 16-bit Z8000 for a time was a contender for the IBM PC. Many industry observers say the Z8000 was more powerful than the 8086, but with the commercial microcomputer industry pretty well locked up by the 8086 and 68000, Zilog's market for the Z8000 has been primarily in the military in real-time control applications.

Zilog took years and many false starts—including a short-lived joint project with AMD in the early 1980s—to come up with a 32-bit chip. The long and rocky road led to the Z80000, a powerful chip that's code compatible with the Z8000. The Z80000, like its little brother, the Z8000, targets military applications.

With the Z8000/Z80000, Zilog moved into a distant third in the microprocessor race behind Intel and Motorola, but ahead of National and its 32000 series, even though National was first to market with a chip having a working 32-bit CPU.

Since the early days of microprocessors, chip developers have crafted general-purpose processors—devices that were suited for use in everything from cars to televisions to missiles. Now, however, chip makers are taking an additional approach, designing processors that can be tailored for different embedded-control applications. These chips tackle specific jobs with

Chuck Peddle: Creator of the affordable



When Chuck Peddle talks about the design team at MOS Technology—the team that gave birth to the 6501 and the 6502 microprocessors—his voice gets very warm.

"It was one of those projects that you're really pleased you worked on," he says. "We had a very sharp team. Everybody was focused and dedicated. Everybody was trying to make something happen. We met every scheduled milestone on that product. The chip worked the first time it came out. And we met the cost target: a $25 microprocessor, quantity one. That was the thing that changed the world."

That breakthrough price was about $150 less than what other microprocessors were selling for at the time.

The days at MOS Technology might have been great. But, in a real way, the 6502 (the 6501 never made it to market) might never have seen the light of day if Peddle had not first become frustrated at the corporate infighting he ran into at another company he worked for: giant Motorola Inc.

Peddle, born in Bangor, Maine, in 1937 and a graduate of the University of Maine (engineering and physics), was plucked in the early 1970s by Motorola's Tom Bennett from a little, struggling company in Phoenix called Intelligent Terminal Systems. Bennett already was at work on what became the 6800.

"He hired me," Peddle says of Bennett, "to do the architectural support work for the product he'd already started."

If Peddle has a hero, it's Bennett. "He shepherded that product [the 6800] through Motorola," Peddle says. "Motorola tried to kill it several times. Without Bennett, the 6800 would not have happened, and a lot of the industry would not have happened, either."

As far as Peddle was concerned, Motorola—at least at first—didn't know what to do with the 6800. "We had to find a way to sell it," he says. "The sales force really didn't understand it very well. They were used to selling gates and elements like that."

Peddle started going around with the sales people on customer calls. "The thing that came out of every meeting was that, while this [the 6800] was a wonderful idea, it cost too much."

So Peddle did what to him was the logical thing: He looked for ways to make the chip cheaper. "I would ask potential customers what they would give up out of the 6800 if I was going to give them a cost-reduced version. It turned out that most everybody had the same set of things they would give up."

Wind of what he was up to got back to the brass at Motorola, of course. Not everybody liked the idea of producing a cheap microprocessor. "Some guys at Motorola who still wanted to be in the minicomputer business went around and said I should be stopped from doing what I was doing. So I went out looking for somebody who wanted to pursue it," Peddle says. He found MOS Technology.

How did the MOS Technology design team get the price down so much? First and foremost, he says, it was because of the high quality of its people. "That team has never been matched," he says.

Peddle also drew on the work done at Carnegie-Mellon University on the instruction set for Digital Equipment Corp.'s PDP-11 minicomputer. From that work, he says, "we learned which instructions matter and which don't." He adds, "We would trade silicon for architecture whenever we could."

Peddle cofounded Sirius Systems Technology Inc. in 1980 and currently is president of Tandon Computer Corp. in Chatsworth, California.

CIRCLE NO 14

efficiencies that general-purpose processors find difficult to match. Intel's 80960, AMD's 29000, and Harris' RTX 2000 are some of the more prominent embedded-control devices.

Perhaps the hottest battle in the microprocessor business concerns the RISC (reduced instruction set computer) architecture. Many engineers describe RISC as a "streamlined" architecture. By simplifying the instruction set—to prioritize the 20 percent of instructions that do 80 percent of the work—and by employing other tricks (like separating paths for instructions and data), RISC architecture cuts the number of clock cycles required to execute programs.

Tricks learned by architects in designing RISC chips are also bringing about some dramatic improvements in efficiency in non-RISC processors. For example, the average number of cycles needed to execute an instruction for Motorola's 68000 has dropped from 12 for the 8-MHz 68010 to 5.5 for the 20-MHz 68020. The goal of RISC developers is one instruction per clock cycle.

There are several RISC vendors, including AMD (with the AM29000), Apollo (with the Prism) and Intergraph (with the Clipper). But the battle lines are forming primarily around three armed camps:

- backers of MIPS Computer Systems' R3000
- backers of Motorola's 88000 and
- backers of Sun Microsystems' SPARC (scalable processor architecture) chip.

MIPS Computer Systems, which in 1984 was one of the first companies to employ RISC architecture, claims a 50-percent speed improvement over competing RISC chips with the R3000. This summer, MIPS used the R3000 to enter the crowded market for mid-range computer systems. Its M/2000 is rated at 20 MIPS.

A users' group, 88open Consortium Ltd., has already been formed to promote standards for the Motorola 88000. Among the founding members are Convergent Technologies, Stratus, and Tektronix. In addition, Motorola has teamed with DEC to develop a 100-MIPS version of the 88000 implemented in emitter-coupled logic. The CMOS 88000 currently performs at 14 to 17 MIPS.

Sun Microsystems designed the SPARC RISC chip, then turned production over to a group of semiconductor vendors, including Bipolar Integrated Technology (BIT), Cypress Semiconductor, and Fujitsu Microelectronics. As do Motorola and DEC, Sun and its vendors plan to reach 100-MIPS performance for the chip. Target date: 1990.

From 60,000 operations a second in 1970 to 100 MIPS in 1990. That's a lot of progress in two decades.

Even the pioneers admit they didn't see what the microprocessor would become and what it would make possible. They saw only enough to push forward with their work. "As obvious as such inventions as the microprocessor may appear to be later, they are frequently born out of struggle," says Faggin. "The struggle of a few believers against those who have something to lose from changes, set in a background of indifference."

Ah, recalls Ed Gelbach, "those were the good old days." EDN

James F. Donohue is managing editor of *Mini-Micro Systems*.

8051 Emulator Has Innovative Breakpoint Features

Nohau Corporation's 8051 emulator, the EMUL51-PC, uses a 64K bit RAM to generate breakpoints. Each of the 65,536 possible combinations of the 16 address lines corresponds to one bit in the breakpoint RAM. The "break bit" coming out of the RAM is then qualified with RD (read), WR (write), FB (first byte of instruction) and an optional user-chosen external signal.

The concept of calculating and writing relevant patterns into the breakpoint RAM results in a number of sophisticated breakpoint features. Individual addresses, ranges of addresses and "wild-carded" addresses are among the most obvious useful setups.

Using line numbers and the corresponding values from symbol lists generated by C-compilers and PL/M compilers, breakpoints can be set on the first assembly instruction in each source line. The result is a "high-level" single step function.

Everyone who has debugged 8051 code has probably wished for the ability to break on a change of value in internal data RAM and special function registers. This feature is made possible by scanning the entire code memory for instruction patterns which would write to a specified byte or bit if they were executed. Memory changes caused by indirect writes and stack manipulations cannot be detected this way in real time, but a pseudo-real-time feature of the EMUL51-PC makes even this kind of breakpoint possible.

Every software engineer's nightmare is to have a program that crashes in a random way, especially if the crash happens only once a day, or once a week. Bugs like these may be virtually impossible to find, and they can cause severe problems for end users. A crash often results in the loss of program control, with instructions being executed outside the legal program area, in data tables, or even on second and third bytes of legal instructions.

The emulator can be set up to break when the program goes out of control. This setup is accomplished by first setting the entire breakpoint RAM so that every address would generate a breakpoint, then defining the starting and ending points of all blocks of legal instructions and finally by removing breakpoints on every valid FB (first byte of instruction).‡ Execution will then break as soon as the program goes outside of legal program blocks. By looking back in the EMUL51-PC's 16K trace buffer (described in a separate article), the engineer has a very good chance of seeing the cause of the problem.

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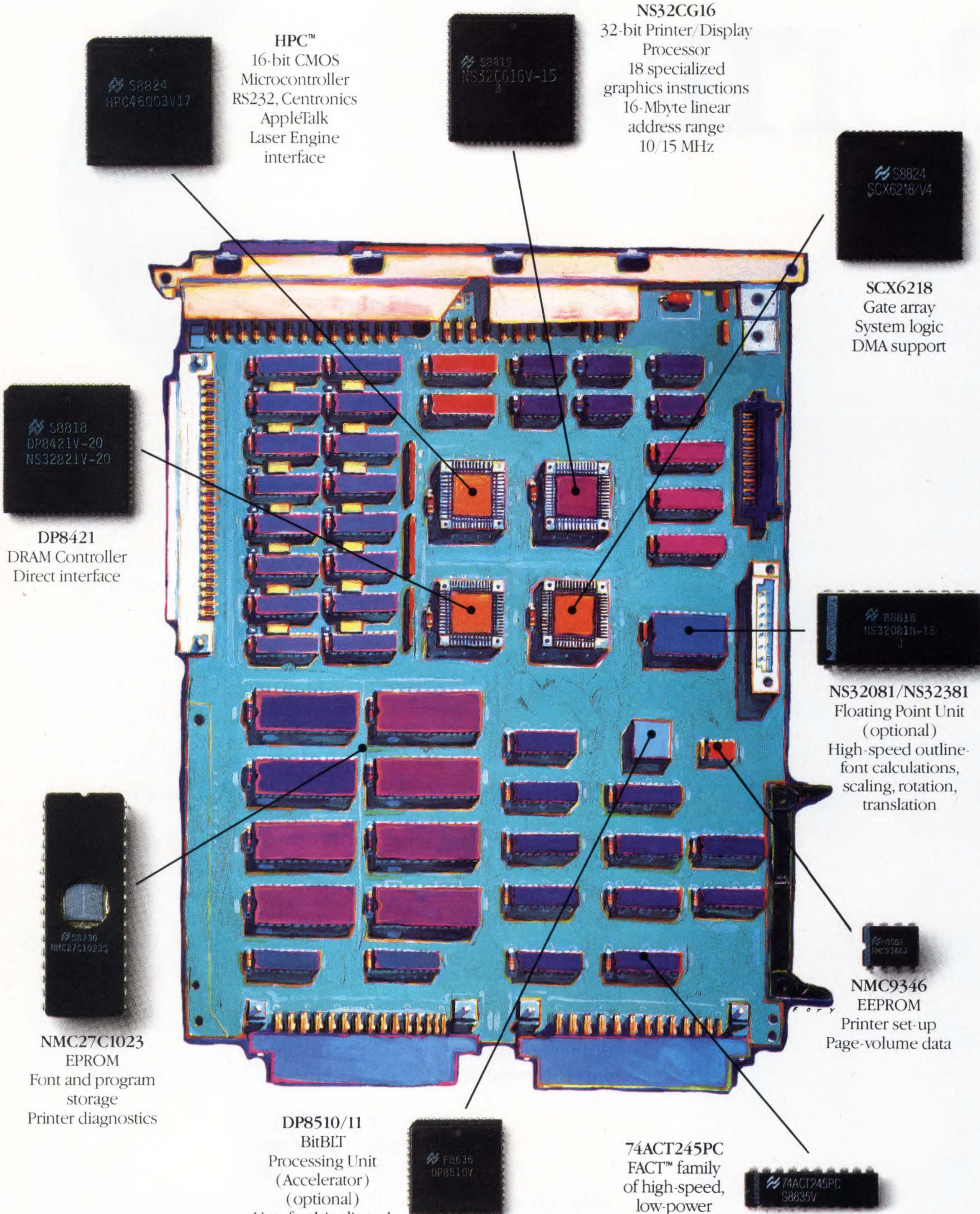

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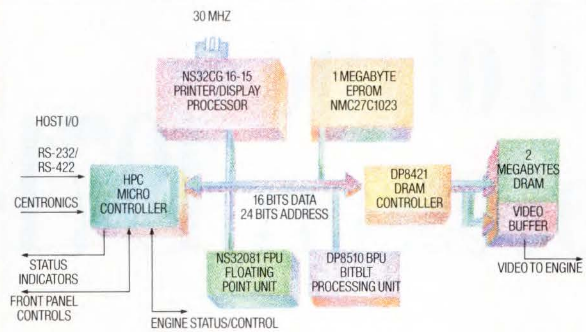

The NS32CG16 is the heart of a high-performance, cost-effective systems solution for applications like this page-printer controller.

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The NS32CG16 combines the programmability of a high-performance 32-bit microprocessor with the power of a specialized graphics coprocessor. It includes 18 dedicated graphics instructions for:

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- pattern drawing, replication, and filling (60 Mbits/sec)
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- binary data compression/expansion for compact font storage under run-length-limited (RLL) encoding
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- on-chip clock generator
- programmable power-down modes
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A true 2-address machine (for direct memory-to-memory graphics operations), the NS32CG16 has a 16-Mbyte linear address space to support large font storages, high-dpi (dots-per-inch) page buffers, and memory-intensive page-description languages (PDLs).

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The NS32CG16 is supported by a full range of peripheral devices, available now:

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  - —optimizing compilers for C, Pascal, FORTRAN 77, and Ada®
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CIRCLE NO 17

The world of the microprocessor: 1971-1988

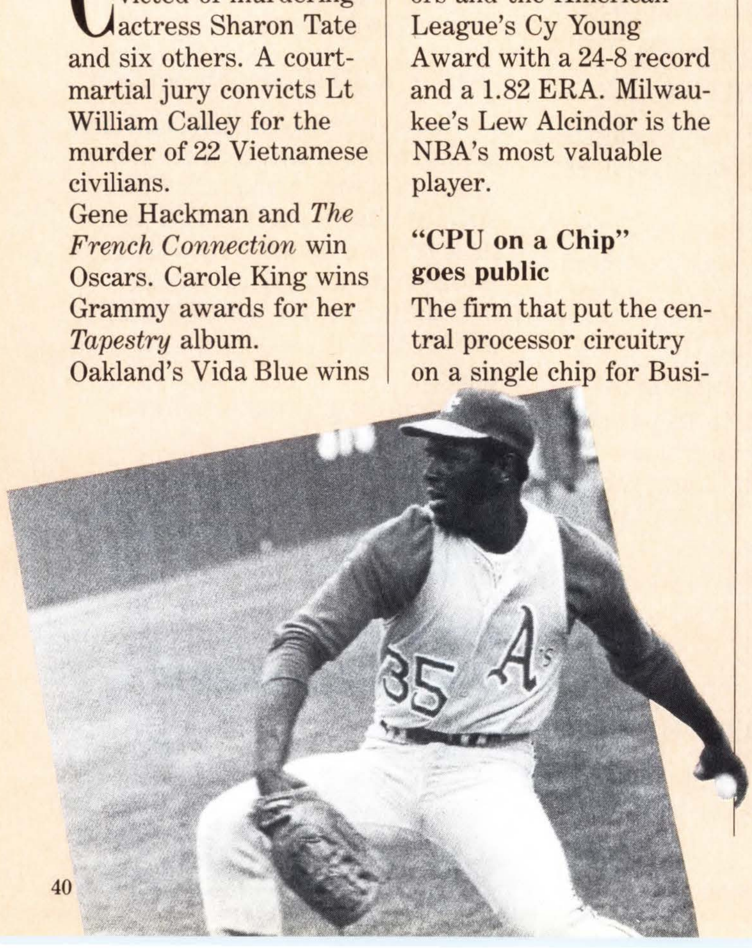
Events of the world at large, as we remember them, and events in the world of the microprocessor, as reported in the pages of EDN.

1971

Charles Manson is convicted of murdering actress Sharon Tate and six others. A court-martial jury convicts Lt William Calley for the murder of 22 Vietnamese civilians.

Gene Hackman and *The French Connection* win Oscars. Carole King wins Grammy awards for her *Tapestry* album.

Oakland's Vida Blue wins Rookie-of-the-Year honors and the American League's Cy Young Award with a 24-8 record and a 1.82 ERA. Milwaukee's Lew Alcindor is the NBA's most valuable player.



"CPU on a Chip" goes public

The firm that put the central processor circuitry on a single chip for Busicom, Japanese calculator manufacturer, is now offering it to all comers. There's a string on Intel's deal, though—Busicom Corp. must approve the sale.

In addition to its 4004 processor on a chip, the Mountain View, Calif. firm is offering its 4001 2048-bit read-only memory, 4002 320-bit random-access memory and 4003 6-bit shift register. These are designed to be controlled by the 4004 in numbers up to 32 ROMs and 16 RAMs. Intel also is quoting bulk price ranges, in the 100,000 quantity bracket. At 100k, the 4001 ROM and 4002 RAM will go for $10-$15; the 4003 shift register for $2-$3; and the 4004 processor for $35-$50.

The devices come with a 34 instruction set and a "jump instruction" capability. Together, the package might well induce designers to develop 4-bit applications outside the confines of the calculator market.

1972

The Watergate "plumbers" burglarize the offices of the Democratic National Committee. Alabama governor George Wallace is shot while campaigning for president.

The US resumes bombing Hanoi after a four-year hiatus.

The Godfather wins an Academy Award for best picture; Marlon Brando wins, but refuses, an Oscar for best actor.

Milwaukee's Kareem Abdul-Jabbar wins the NBA's MVP award.

Frank Shorter becomes the first American to win an Olympic marathon, and American swimmer Mark Spitz wins seven Olympic gold medals.

Industry: A lot of chips, and a lot of good stuff cheap.
Elsewhere: Watergate rates as one of the country's better scandals.

1973

Nixon aides H R Haldeman, John Erlichman, and John Dean resign, casualties of the Watergate scandal. Vice President Spiro Agnew resigns after pleading no contest to charges of tax evasion. Attorney General Elliot Richardson and deputy William Ruckelshaus resign after Nixon fires Watergate prosecutor Archibald Cox.

UCLA's basketball team, coached by John Wooden, wins its seventh consecutive national championship. Jack Nicklaus is the PGA's leading money winner for the third consecutive year, racking up $308,362. Kathy Whitworth is the LPGA's leader for the fourth straight year and for the eighth time in nine years; her 1973 winnings are $82,854.

The Sting wins Best Picture honors; Stevie Wonder wins a Grammy for *You Are the Sunshine of My Life*.

Blitz of chips

Microprocessors are available off-the-shelf from Intel, Rockwell International, Fairchild, and National Semiconductor. They are projected to be available in 1974 from Signetics, Microsystems International (Canada), American Micro-systems, Motorola, and Western Digital. Other semiconductor houses such as General Instruments, Texas Instruments, RCA, and Hughes have been making microprocessors but have not formally announced products. British and Japanese firms are also showing an interest in microprocessors.

Powerful, but no speed demon

The National IMP-16C has a long enough word length—16 bits—to be the equivalent of existing minicomputers like, say, the NOVA 1200, though with only about ⅕ the speed.

Good stuff cheap

The Rockwell PPS μP is way at the bottom end of the GP computer spectrum as far as parts cost goes. You can buy a set of its three basic chips for under $30 in large quantities.

A new dimension in design

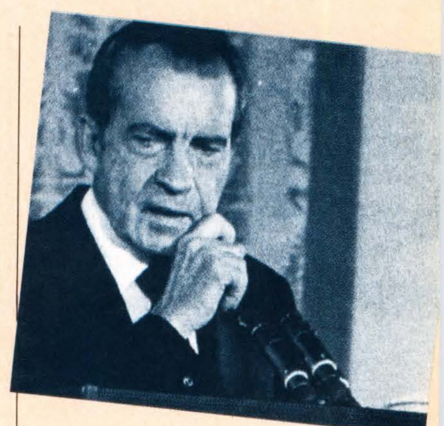
[Microprocessors] are powerful, flexible, compact components whose uses are limited only by the equipment designer's ingenuity and capability.

Never before have designers had such off-the-shelf "components" to design into their systems. They can now bring computer capability to bear in applications where it was previously unheard of—or thought of—and at reasonable cost. But to do so will require a knowledge of and familiarity with things that are alien to many designers today. Words like software,programming, and polling and priority interrupt will have to become more than just words. A working knowledge of these and a lot of other areas previously considered as strictly within the domain of computer people will be essential for engineers using the new processors.

Encouraging words

Do not be dismayed by software. First of all, programmers are not likely to take over your jobs. It will be much easier for you to learn software than it will be for them to learn circuitry.

1974



President Richard Nixon resigns under threat of impeachment. Gerald Ford succeeds Nixon and pardons him a month later.

Muhammed Ali knocks out George Foreman to regain the world heavyweight championship, which he relinquished in 1967 for refusing military service.

Grammy awards: Paul McCartney & Wings are the best pop group; Olivia Newton-John is best female pop vocalist.

More bargains

National has priced PACE at $141 in hundreds, but the story certainly won't end there. Just think of what NSC could do μP pricing if it decided to be as aggressive in the μP market place as it has been in the

Industry: Dealing with the 2½-generation machines. If we can do it . . . Elsewhere: Resignations galore, jail in store.

pocket calculator market. In the latter, National now sells calculators to the general public at $16 apiece—and claims to be making a healthy profit!

Looking ahead

The first 8-bit machine—the Intel 8008—is constrained by its small 18-pin package.
With 40 pins, it would be possible to have completely separate address buses, and moreover, make these buses so wide— 16 bits—that they could address memories as large as most systems designers would want—65k bytes.

Standards be damned

Rockwell makes no attempt to be compatible with TTL signals and power supplies, as do most of the other microprocessor makers. The PPS-8 has a single −17V power supply and comes in Rockwell's special 42-pin package.

What is it?

The Fairchild PPS-25 has undoubtedly the most obscure architecture of any microprocessor now on the market.

A champ . . .

[The Intel 8080] is serving as the point of comparison for all the other mainstream single-chip 8-bit µPs that other semiconductor manufacturers are scheduling for introduction during 1974 and 1975.

. . . and a challenger

The 6800 is the first 8-bit µP to challenge Intel's very visible position in the µP field.

So, we got a little carried away

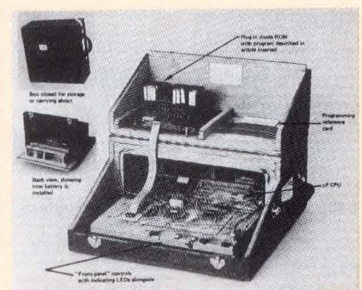
Within the next few months the 16-bit MOS µPs will be out in sample quantities. These "third-generation" machines have completely caught up with minicomputers.

But at least we called this one right

The microprocessor is here to stay. Right now more of the little 4-bit microprocessors are being produced each month than the total number of mini and maxi computers produced to date. The first of the second-generation 8-bit machines is now finally in the hands of equipment designers, and it is certain that the 8-bit devices, too, will start to see volume production before the end of 1975.

1975

John Mitchell, H R Haldeman, and John Erlichman are found guilty of Watergate cover-up charges.
FBI agents capture Patty Hearst, the publishing heiress who was kidnapped by a radical political group a year and a half earlier. Hearst is later convicted of participating in a bank robbery with the group.
One Flew Over the Cuckoo's Nest wins an Oscar for best picture; the Captain & Tennille are Grammy winners for *Love Will Keep Us Together*; and Paul Simon wins for *Still Crazy After All These Years.*
Chris Evert wins the first of four consecutive US Open tennis championships, the Minnesota Twins' Rod Carew wins his fourth consecutive American League batting title, and Boston Bruin Bobby Orr is named the NHL's best defenseman for the eighth straight year.



We built it ourselves

EDN's toy/tool for the MOS Technology 6502 µP was built in about a month. Parts cost, excluding the 6502, was about $50. (The 6502 itself is being sold for $25 in single quantities.) The little skeleton computer system is installed in the plywood box so it can be carried about and stored safely. It has survived coast-to-coast air travel, checked as luggage.

Don't laugh, it works

EDN's initial breadboard for "bringing up" the MOS Technology 6502 µP illustrates how easy it is for users to deal with the

Industry: Handicapping the devices. Elsewhere: A country celebrates a bicentennial with crass commercialism.

hardware of the 2½-generation machines. Although we discovered quite a bit of noise (mostly coupling in of clock pulses) on all of our rather long and spread-out lines, the 6502 operated without malfunction.

One was a real winner

A class of what might be called 2½-generation microprocessors is now entering the marketplace. This includes the MOS Technology 650X family, the National SCAMP and the Electronic Arrays 9002.

It was so affordable

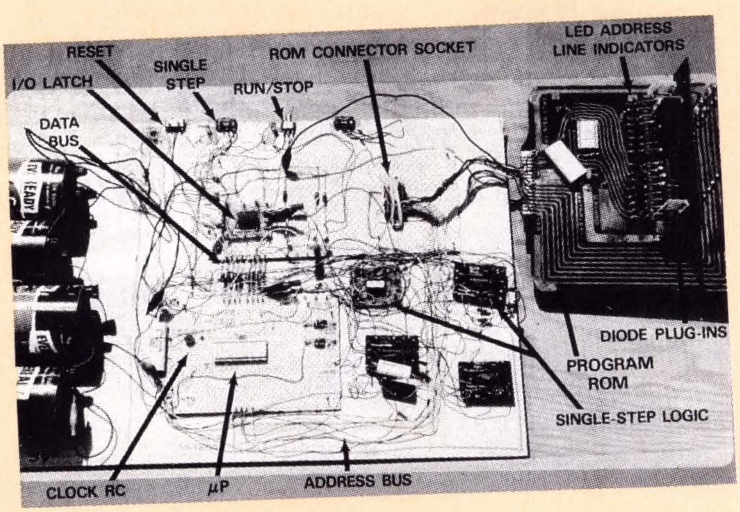
The MOS Technology 650X family represents a conscious attempt by eight former Motorola employees who worked on the development of the 6800 system to put out a part that would replace and outperform the 6800, yet undersell it.

At these prices, they won't last!

The 9209, TMS-1000, and PPS-1 may be slow PMOS machines, but they can sell at $5—which is almost down to the $3 level for calculator chips. For equipment designers, the new 4-bit μPs make economically possible such end products as $70 programmable scientific calculators.

Yeah, sure

Texas Instruments poses perhaps the most fearsome threat to traditional mini houses because the MOS and bipolar manufacturing groups at TI have joined forces with TI's own minicomputer department.



1976

The US celebrates its Bicentennial.
Viking I and Viking II land on Mars.
Detroit's Mark Fidrych, alias "The Bird," talks to the ball while on the mound, delighting fans and racking up a 19-9 record in his rookie year. Bjorn Borg wins the first of five straight Wimbledon titles.
"I'm mad as hell, and I'm not gonna take it anymore!" So yells Peter Finch in his Oscar-winning performance in *Network*. Best Picture award goes to *Rocky*.

The 8080 earns an A

Last year the leader in μPs was Intel's 8080. This year it's the more refined 8080A, but the story is the same: This 8-bit NMOS machine has captured more μP-application slots than any other device.

The spin-off was the winner.

Ever on the offensive, Intel will introduce early in 1977 its next-generation 8080A, the 8085.

Another significant 8080-based product, the sophisticated Zilog Z80, has captured the imagination of many designers.

Tough champion

In 8-bit machines, RCA is the line champion of CMOS. The firm's 1801 was upgraded to the 1802 in 1976, and for many uses— particularly those with severe environmental constraints—this μP finds a loyal and growing following.

Dark horse

EDN's nomination for the "Dark Horse μP of 1976 Award" goes to the [Fairchild] F8. Because this machine handles many admittedly unglamorous but nevertheless very high volume applications with only two chips, it's now undergoing shipment in large quantities.

1977

Jimmy Carter becomes president and immediately pardons some 10,000 Vietnam War draft evaders.

Convicted killer Gary Gilmore is executed by a Utah firing squad; his execution is the first in the US in 10 years.

George Foster swats 52 home runs for the Cincinnati Reds.

Woody Allen experiences angst over lobster and Diane Keaton in *Annie Hall*. The Grammy award for best album goes to Fleetwood Mac's *Rumours*.

Two for the price of one

Suppliers of midrange μPs are compressing whole multichip systems into 1- or 2-chip systems for minimum-cost low-end applications. Examples illustrating this trend include the 3870 version of the F8, the 6801 variant of the 6800, the 6600 outgrowth of the 6500, the 9940 version of the 9900, the Z8 version of the Z80, etc. To this list we might also add the 8048, because although it isn't a software compatible version of the 8080/85 family, it shares much of the same hardware support.

Before they caught the RISC bug

There seems to be a general industry reluctance to risk bringing out a new μC family. Perhaps just too many good μCs are available for any semiconductor supplier to hope at this late date to launch any totally new μC family.

And none too soon

Steady progress in CMOS technology could see CMOS μCs finally coming into their own in 1978.

We read it in the National Enquirer

EDN observes that Intel and Zilog have been widely rumored to be developing advanced machines that will execute higher level languages like PL/M and Pascal directly.

Industry: Instruction sets tell a good story.
Elsewhere: Carter takes over; draft dodgers breathe a collective sigh of relief.

1978

Discos are everywhere. Women of less-than-average intelligence swoon over John Travolta in *Saturday Night Fever*. Men of less-than-average intelligence try to imitate him. The Bee Gees (nobody's fools) win a Grammy for their album from the film.

Painful memories of Vietnam appear on the silver screen. *The Deer Hunter* wins an Oscar for best picture; Jane Fonda and Jon Voight win honors for their roles in *Coming Home*.

Pope John Paul dies after only a month in the Vatican. John Paul II, of Poland, succeeds him, becoming the first non-Italian elected pope since 1522.

Proposition 13 passes overwhelmingly in California.

EDN fesses up

A year ago, EDN expected that at least one μP supplier might produce a radical new architecture in 1978: perhaps a novel stack-oriented machine or a chip to directly implement a high-level language such as Pascal. We regret, however, that we can't report any such architectural innovations.

We liked 'em

Taking a closer look at the Z8000 and 68000 (and the 8086 as well), we conclude that these next-generation 16-bit μPs have indeed impressively enhanced almost every aspect of the standard Von Neumann machine. Their instruction sets tell the story: These μPs can, in varying degrees, manipulate all sorts of data—the 8086 even performs arithmetic on ASCII-coded information. And abandoning the adequate, but hardly elegant, pointer addressing of the 8080, they all feature extensive true indexed-addressing—just like the best minis and maxis.

Joe Isuzu was in electronics then

Will [certain microprocessors] *really* be available in volume in 1979? [There is] a growing tendency among semiconductor manufacturers to preannounce their products, write articles about them and advertise them as though they are currently available, when in reality the products might exist only as logic diagrams on paper.

A welcome trend

Instead of compounding users' specialized development-system in-

Industry: Picking up rumors of 32 bits. Elsewhere: People in Pennsylvania panic.

vestments by offering more \$5000 to \$25,000 development computers, some μP manufacturers suggest instead that their customers buy established minicomputers and use cross software to develop application programs. The designer's remaining needs are then satisfied with semistandalone boxes (\$1000 to \$2000) that provide realtime in-circuit emulation when plugged into the CPU socket on a prototype.

1979

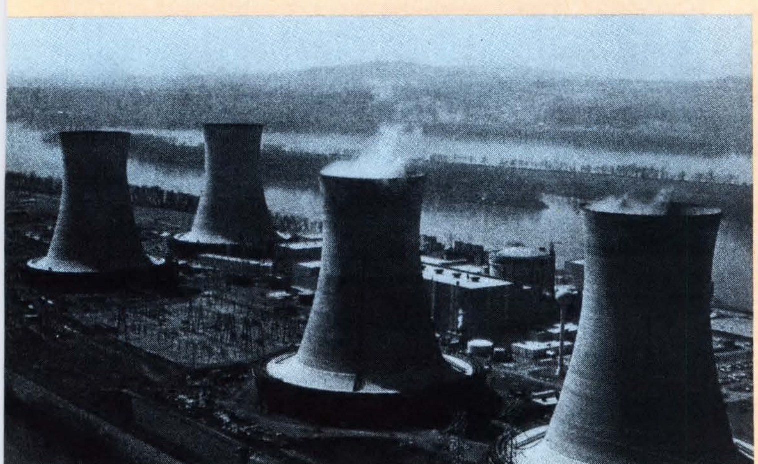
A nuclear reactor on Three Mile Island in Pennsylvania leaks radioactive gases.
The shah of Iran flees the country, and the Ayatollah Khomeini returns.
Iranian militants seize 62 American hostages.
Margaret Thatcher becomes British prime minister.
Dustin Hoffman and Meryl Streep do court battle in *Kramer vs. Kramer*. Billy Joel wins more Grammies.

Safe choices

- The PMOS TMS 1000, with its huge, expected 1979 volume of about 20M units
- Among 8-bit 1-chip μCs, the older 8048 family
- In the mainstream 8-bit multichip-μP application area, the venerable 8080 family
- The Motorola 6800
- The Rockwell/Synertek/MOS Technology 6500 family
- In the specialized area of CMOS 8-bit μPs, RCA's 1802.

Project Aloha, Part 1

Intel's answer to the Motorola 68000 and Zilog Z8000 could be under development at the firm's Aloha, OR facility. Putting together the handful of rumors we've heard about Project Aloha, we speculate that it could be a 32-bit machine resembling the 68000 and Z8000 but with more of the latest bells and whistles.



1980

Mount St Helens, an "extinct" volcano in Washington, erupts.
Eight Americans are killed in an unsuccessful attempt to rescue the hostages held in Iran.
The United States' Olympic hockey teams wins a gold medal. Kansas City's George Brett almost becomes the first .400 hitter since Ted Williams in 1941.

Well, software was simpler then

In the case of the new 8051, Intel has provided not only a much cleaner and more uniform split-memory configuration, but a "big-machine"-type macro assembler as well. The firm is even in the process of providing PL/M high-level-language support for the 8051.

Look no more

The handful of "winners" in the 8-bit μP world have become too deeply locked into large end-user bases for these devices to die away in the foreseeable future. For example, look at the Z80-based TRS-80 and the 6502-based Apple and PET computers.

And that was *before* the IBM PC

Intel appears to be successful in selling its 8088 8-bit-bus version of the 16-bit 8086.

But Microsoft and Borland weren't impressed

Suppliers of 16- and 32-bit μPs have not attempted to pioneer solutions to the problem of software, but rather have assumed that computer-industry leaders such as DEC and IBM have the best answers.

That'll teach 'em to listen to eggheads!

[Microprocessor] suppliers have also been listening to academic computer-science experts, for they have almost unanimously standardized on Pascal as a high-level language.

Project Aloha, Part 2

What about the iAPX 432's advanced features? The advanced scope and power of the Ada language will be used to check users' escalating software costs for large programs.

1981

The 52 American hostages are released by Iran. President Reagan and Pope John Paul II are shot by would-be assassins.
Henry Fonda and Katherine Hepburn quarrel, but eventually make up and suck face in *On Golden Pond.* Accompanied by inspiring music, a group of Englishmen slog along a beach in *Chariots of Fire.*
Edmonton's Wayne Gretzky is the NHL's leading scorer.

At the source

Our directory now prominently lists large Japanese firms (NEC, Hitachi, and Fujitsu) and large European ones (Philips and Siemens) as both prime and second sources.

The low end . . .

The object is to bring high-level languages down to these lower level μCs. Most significant is probably Intel's effort to make PL/M available for the 8051. But most interesting are the efforts of National and Zilog to incorporate Tiny BASIC in 1-chip μCs: in National's 8073 and Zilog's 8671 version of the Z8.

. . . and the high end

The truly glamorous opportunities for OEM designers this year lie in applying the 16/32-bit machines (Intel 8096, Motorola 68000, Zilog Z8000, and such newcomers as the National 16000 and TI 99000).

Coming soon: the Z80000

The stakes in the 16/32-bit arena are so high that suppliers there will keep upgrading their CPUs into more powerful supersets. And when they run out of coprocessor-type enhancements, they will produce enhancements of the CPU itself—as Zilog has promised with its Z80000 announcement.

Project Aloha, Part 3

[An] opportunity lies in the newly emerging micromainframe area, currently occupied by just one machine: the Intel iAPX 432. Only users with considerable mainframe-computer experience will be able to assess this opportunity, though.

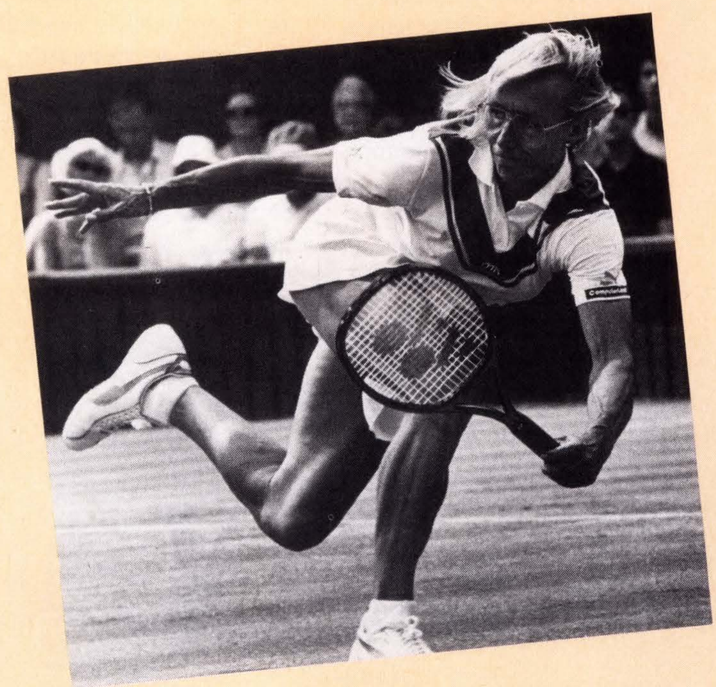
Industry: Japanese and European countries begin to make a big difference. Elsewhere: One female athlete begins a one-woman domination of her sport.

1982

Argentina invades the Falkland Islands, and Great Britain responds by sending naval and ground forces. Six weeks after the fighting begins, the Argentines surrender.
The Justice Department settles its 13-year suit against AT&T; the telephone giant agrees to give up the Bell System companies.
Dr Barney Clark receives an artificial heart.
Martina Navratilova wins the first of five consecutive Wimbledon titles. Baseball's National League celebrates its eleventh consecutive victory (and its nineteenth victory in twenty seasons) over the American League All-Stars.
Meryl Streep wins her second Oscar, for *Sophie's Choice.*

The year for CMOS

CMOS is making serious inroads in multichip 8- and 16-bit devices: Even old stalwarts like the 8085 and Z80 will be available in CMOS versions this year, and at least three of the leading 16-bit μPs have or soon will have CMOS counterparts.



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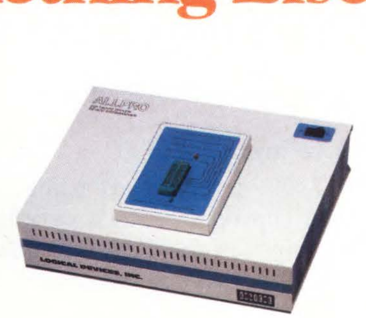

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Industry: There goes the 4-bit market.
Elsewhere: Politics redefined.

1983

The Soviet Union shoots down a South Korean airliner that ventures into Soviet air space. In Beirut, terrorists blow up a barracks, killing 241 US marines and sailors. US troops invade Grenada.
Poland's Lech Walesa wins the Nobel Peace Prize.
Alice Walker wins the Pulitzer Prize in fiction for *The Color Purple*. Michael Jackson wins three Grammies with *Thriller*.
The US sailing team loses America's Cup.

Here come the 32s

Motorola appears to be in the best position in the 32-bit race. While it may not have as much software momentum as Intel, what Motorola and its third parties do have for the 68000 should run more or less directly on the forthcoming 32-bit 68020, because the basic 68000 has had 32-bit CPU registers all along.
National has one impressive advantage in the 32-bit race: It has had a working 32-bit CPU available longer than any other comparable device. From the start, its 16000 has been a full 32-bit µP.

Insult to injury

Many 68000 customers are using National's 16081 floating-point coprocessor (as a peripheral) because of the unavailability of the Motorola floating-point unit—much to Motorola's annoyance.

Oil alone

Zilog has been the subject of a continuous barrage of rumors implying that, since Zilog has never made a profit, parent-company Exxon is trying to sell it. Nonetheless, Zilog continues to keep up with the leaders in putting advanced, large-computer architectures into working silicon. Whatever problems, real or imagined, Zilog may have as an "affiliate" of Exxon, it doesn't seem to have difficulty in finding the $30 million upfront money thought to be required to launch a new 32-bit device like the Z80000. Indeed, based on performance, OEM designers should be glad Zilog persists in the face of Silicon Valley gossip.

1984

Geraldine Ferraro becomes the first woman to run as a major political party's candidate for vice president.
Bernhard Goetz shoots four black teenagers in a New York subway.
The Boston Celtics' Larry Bird wins the first of three consecutive NBA MVP awards. Carl Lewis wins four Olympic gold medals in track and field. Joan Benoit wins the first-ever Olympic marathon for women.

They're everywhere!

Japanese companies have taken over the 4-bit µP markets and have become major second sources of leading 8-bit parts. They are also getting under way with their thrust into 8086-family markets. To date, the 32-bit market hasn't been sufficiently large or mature enough for Japanese interests.

RISC already?

There are three new, impressive 32-bit µPs. Two are microcodable machines: the NCR/32 (mentioned last year) and the very powerful bipolar building-block family, the AMD 29300/400. The third—the Inmos T424 Transputer—incorporates yet another novel architecture. These three parts may herald the advent of the new reduced-instruction-set computer (RISC), which incorporates shorter instructions for greater speed.

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On-Screen Prompt line makes it easy to find the feature you're looking for.

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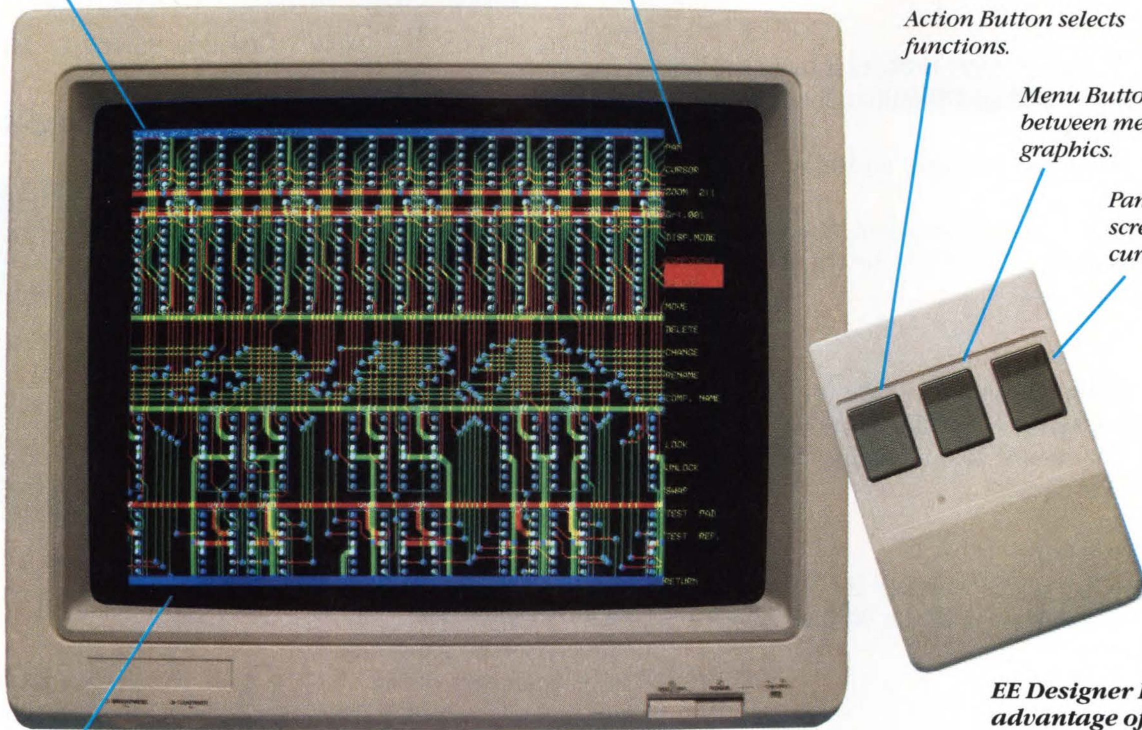

Command Line displays selected function.

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CIRCLE NO 23

1985

"Live Aid," a rock concert broadcast to more than 150 countries, raises $70 million for Africa's starving multitudes.

Hijackers seize the *Achille Lauro*, an Italian cruise ship.

The Mets' Dwight Gooden repeats last year's Rookie-of-the-Year performance. His ERA for the season is a minuscule 1.53.

Best seller

The Z80 is steadily increasing its share (even though it's a 10-year-old design). According to Zilog, approximately 28 million units are sold annually, including units from alternate sources.

Foreign competition

An interesting conjecture is whether the V Series will be as formidable an opponent of the 8086 as Zilog's Z80 was of the 8080.

Intel's 80386:

The competitors have been saying Intel could never extricate itself from the limitations of the 16-bit 8086 architecture and produce a 32-bit machine that could have the performance of the National and Motorola 32-bit-from-the-start machines. But it looks as if Intel has done a credible job.

Fairchild's Clipper:

A new 32-bit machine that goes some steps beyond current 68020, 32000, and 80386 architectures, the Clipper, from its designer's description, appears to be an intelligent mix of RISC and CISC concepts.

Project Aloha, final chapter

Intel deserves an A for effort on the 432 family. The company put in a great deal of honest effort in definition, design, and customer support for the 432, but OEM designers did not respond in sufficient numbers to make the it viable.

1986

The space shuttle Challenger explodes after launch, killing all seven crew members.

US warplanes strike targets in Libya, including the residence of Libyan leader Muammar Qaddafi.

At Chernobyl, in the Soviet Union, a nuclear reactor suffers a core meltdown.

Ferdinand and Imelda Marcos flee the Philippiness; Corazon Aquino becomes the Philippines' new president.

Industry: Start your Unix engines. Elsewhere: To some, Ollie's a hero. To others, well . . .

The Chicago Bears maul the Patriots 46-10 in the most lopsided Super Bowl game ever. The Red Sox, not to be outdone, snatch defeat from the jaws of victory against the Mets in the World Series. Only the Celtics salvage Boston pride; they win the NBA championship.

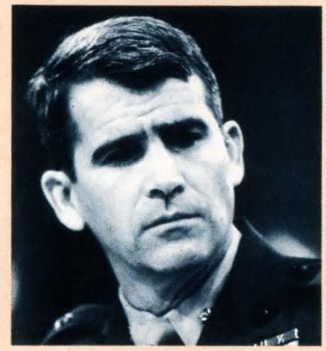
Dynasties prevail

Figures for '85 show the 16-bit members of the 8086 family (including the 80186 and 80286) as having 60% of the unit volume.

The 16-bit members of the 68000 family (68000 and 68010) had 25% of the unit volume in 1985, leaving only 10% for all other 16-bit µPs.

Number crunchers

Inmos says that because its Transputers are the first commercially available µPs designed to be paralleled, they will give OEMs the chance to implement certain algorithms faster than any ordinary µP is capable of. Many industry experts agree that highly parallel µP systems will be the wave of the future but wonder if the Transputer might be somewhat ahead of its time.



1987

Ollie North stirs patriotic passions in the televised Iran-Contra hearings.

Passions of a different kind get Jim Bakker in trouble.

The Dow Jones Industrial Average plummets 508 points in one day.

Start your Unix engines

For systems that run Unix, the µP's task is to be a "good Unix engine." Among other things, this task requires that the µP architecture mate well with an accompanying optimizing compiler. The Motorola 68020 has the lead in this area, and presumably the 68030 will help Motorola retain that lead. But the Unix market is an open field; Motorola's 68000 family now has many competitors, even the 80386.

RISC emerges

There are also new RISC

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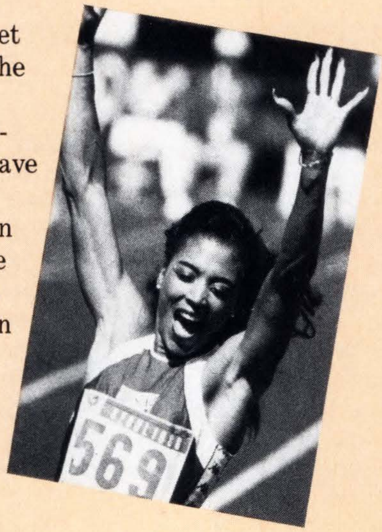
CIRCLE NO 19

Industry: RISC and embedded-controller chips get a lot of publicity. Elsewhere: Setting new speed records and fashion statements.

(reduced-instruction-set computer) μP chips: the Clipper, which has changed ownership recently but now may have found an appropriate home with workstation maker Intergraph; the SPARC chip, which is the basis of Sun's open hardware/software SPARC system; and AMD's 29000.



1988

Soviet leader Mikhail Gorbachev begins massive reforms.

An American warship, on patrol in the Persian Gulf, shoots down an Iranian airliner, killing all 290 people on board. A Naval inquiry finds that the tragedy resulted from a radar operator's error.

Sisters-in-law Jackie Joyner-Kersee and Florence Griffith Joyner rack up gold medals at the Seoul Olympics, and Greg Louganis secures his credentials as the best diver ever.

Guts and glory

This year, new μP chips aimed at embedded-control applications deserve the limelight—even though high-performance RISC (reduced instruction-set computer) chips have garnered most of the headlines.

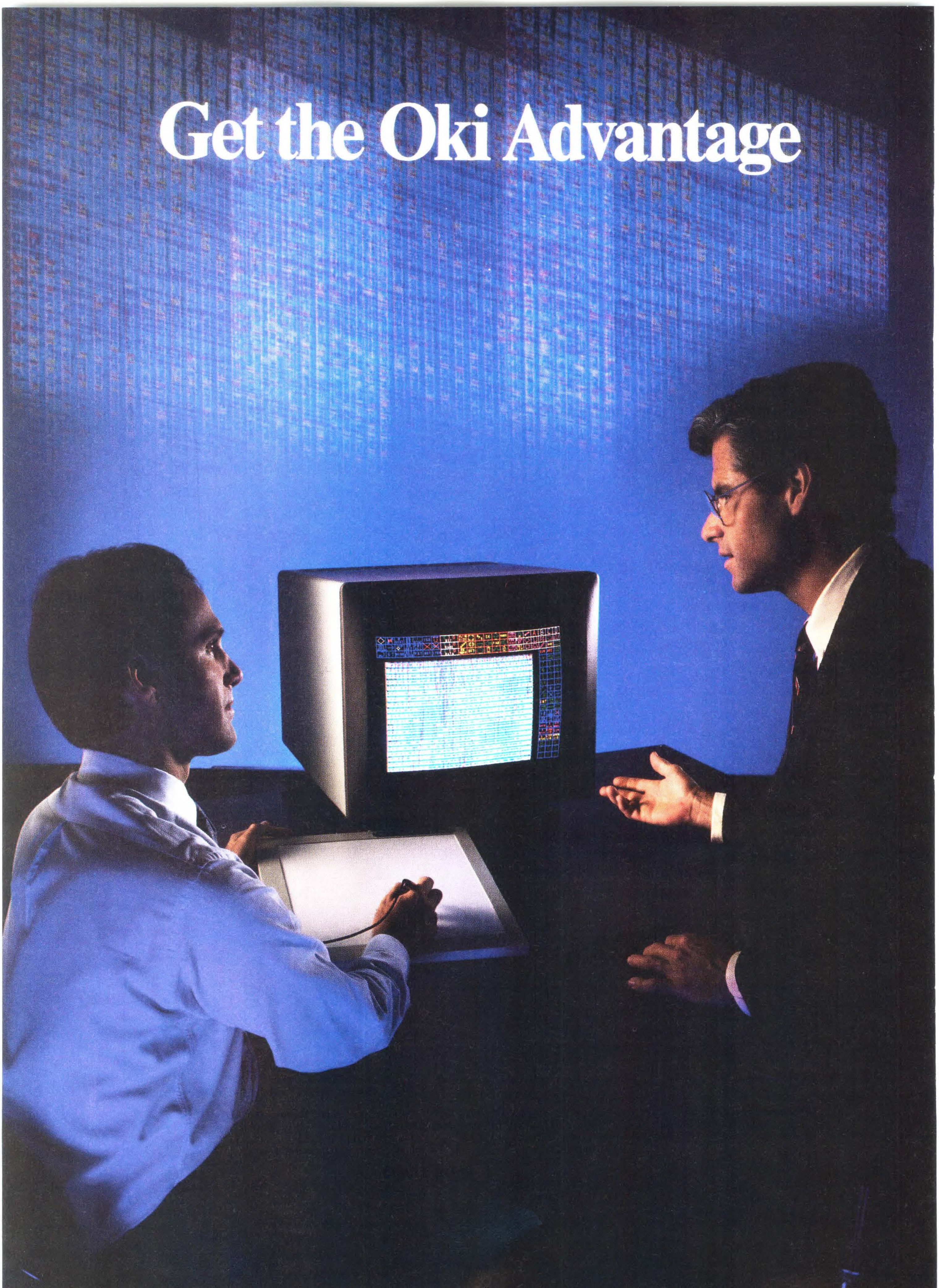
Examples of new high-end embedded-controller chips include Intel's 80960, Harris's RTX2000, and AMD's 29000.

Four-bitters to the bitter end

In terms of units shipped, this year the 8-bit devices may surpass their 4-bit cousins. Keep in mind it has taken *17 years* for this development to come about.

Go Forth and multiply

Instead of cryptic assembly-language commands, the Harris RTX2000's commands look like Forth-language statements. In fact, Forth programs compile directly into RTX2000 operations: Each Forth statement compiles into an RTX2000 instruction.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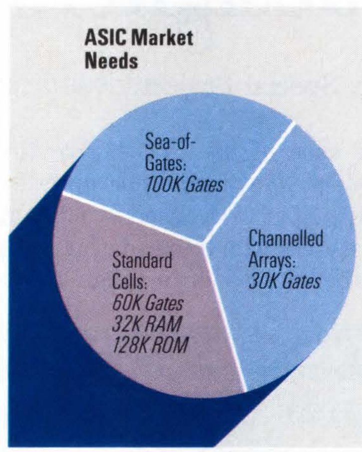

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THE SPECIAL REPORT MICROPROCESSOR

MICROPROCESSORS: What designers want from them

Gary Legg, Special Projects Editor, and Nancy Gaygan, Director of Research

Speed, power, and ease of use. Those are the main things designers want in the microprocessors they use. That's what we learned in a recent survey of EDN's readers who either design with microprocessors themselves or manage other designers. We sent out 2500 detailed questionnaires and received 637 replies. The survey respondents represent a broad spectrum of companies and end-user applications.

The fact that designers want speed, power, and ease of use isn't surprising, of course, but it does lend credibility to the notion that applications for microprocessors are becoming more sophisticated. No longer limited to simple control tasks or the "brain" functions of desktop computers, microprocessors are finding increasing use in embedded applications where intensive processing or control, or both, are required.

It certainly is no surprise that designers are turning to microprocessors with longer data words; 32-bit processors have been available for several years now. Although 8-bit devices have been on the market for almost 17 years, they're just now overtaking 4-bit microprocessors and microcontrollers in the number of devices sold. Our survey seems

TABLE 1—MICROPROCESSOR WORD-LENGTH REQUIREMENTS

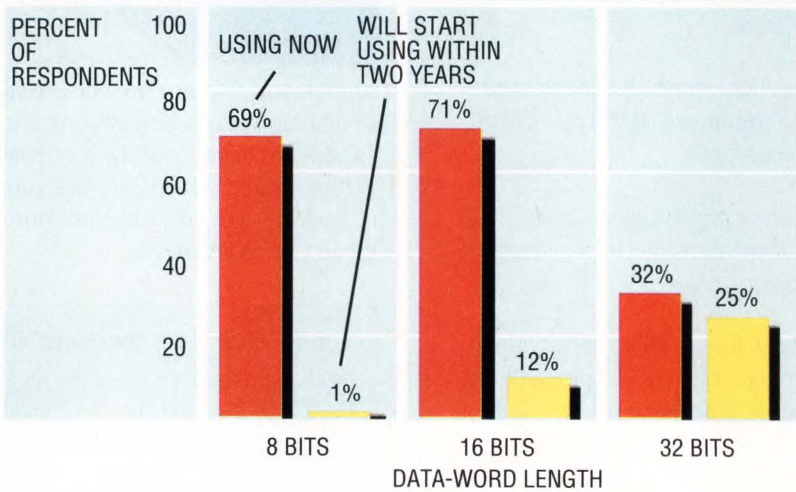
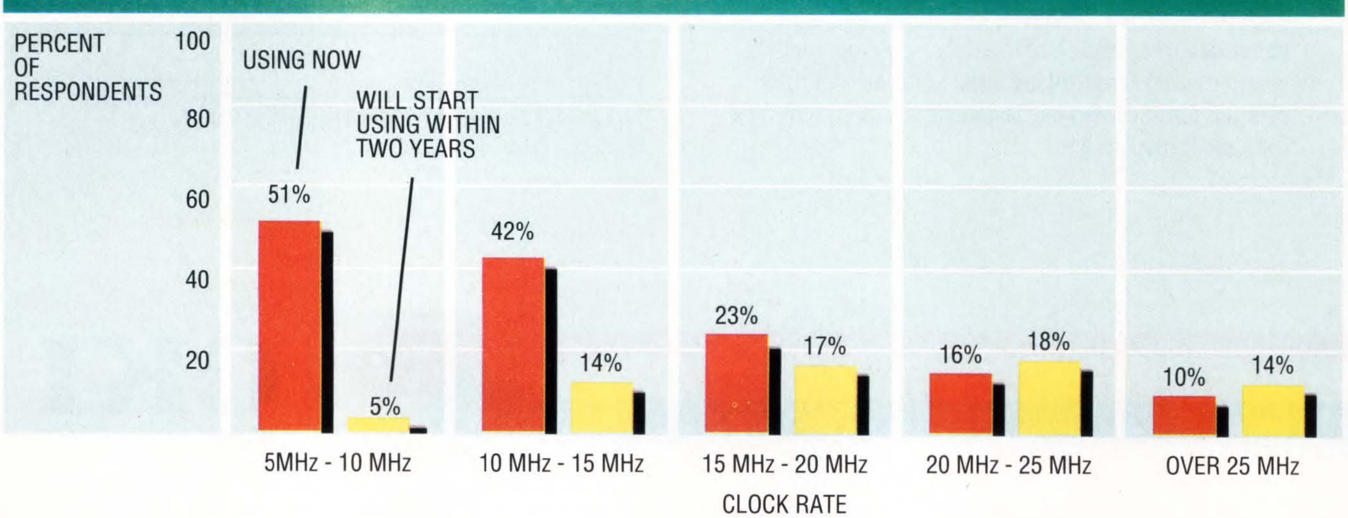


TABLE 2—MICROPROCESSOR CLOCK-RATE REQUIREMENTS



to indicate, however, that 16-bit and 32-bit chips will take over from their 8-bit relatives much faster than 8-bit chips succeeded 4-bit units.

Table 1 illustrates the point. About the same number of survey respondents now use 8-bit and 16-bit processors (69% and 71%, respectively), but there will be many more first-time users of 16-bit devices in the next two years (12% of respondents) than there will be new users of 8-bit chips (only 1%).

The trend toward 32-bit devices is even more impressive. Although only 32% of our survey respondents now apply these top-of-the-line processors, 25% say they will begin applying them within the next two years, thus almost doubling the number of users. When you consider that many current users of 8-bit chips, and possibly 16-bit chips, will soon *stop* using them, and that users of 32-bit devices are more likely to continue using such devices, the trend toward longer word lengths seems even stronger.

Faster and faster

Designers who use microprocessors expect to turn to higher clock rates in the near future, too (**Table 2**). Rates below 15 MHz are by far the most common now, but over the next two years designers will turn increasingly to rates above 15 MHz. Of our survey respondents, 17% expect to make first-time use of rates between 15 MHz and 20 MHz, and 18% expect to use clocks with 20-

TABLE 3(A)—USE OF 8-BIT DEVICES

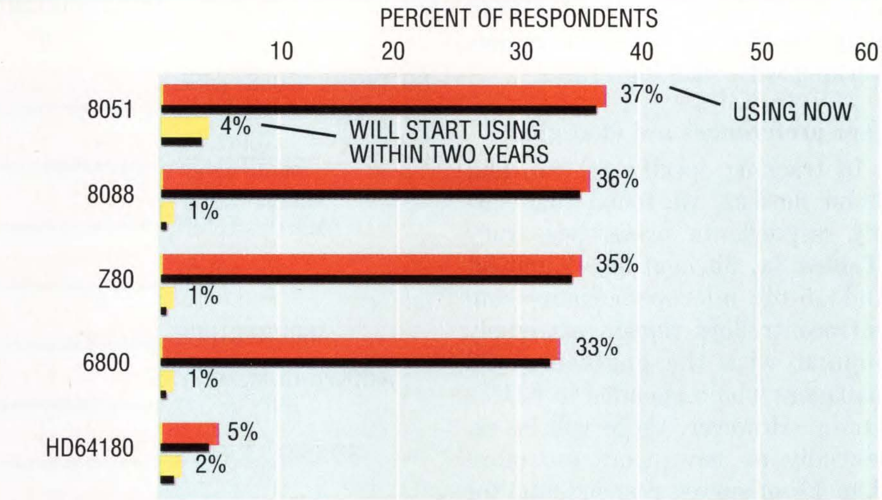


TABLE 3(B)—USE OF 16-BIT DEVICES

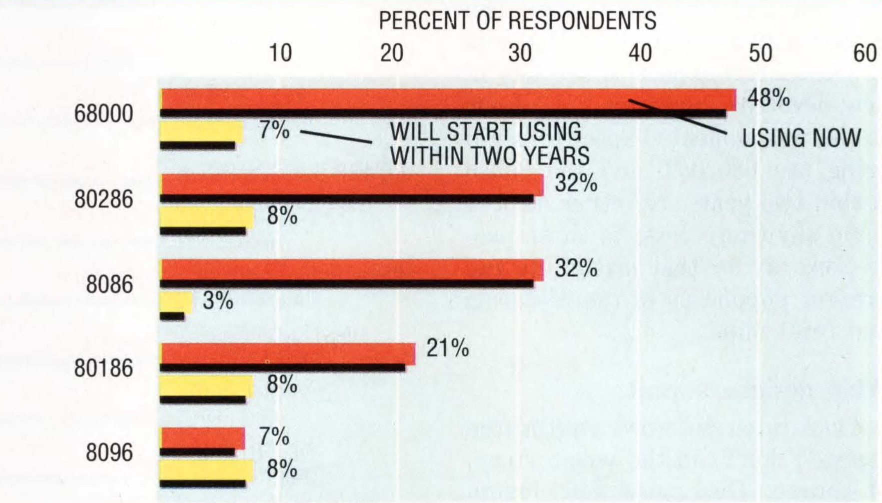
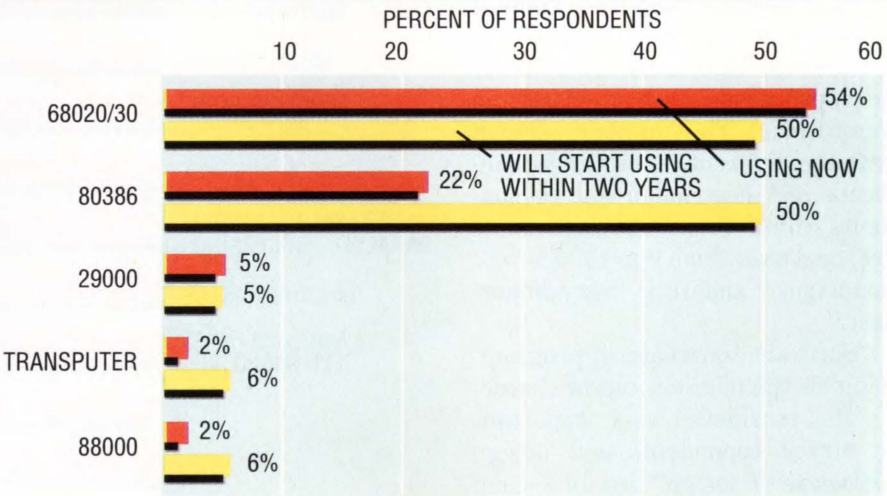


TABLE 3(C)—USE OF 32-BIT DEVICES



MHz to 25-MHz rates for the first time. Almost as many, 14%, will go beyond 25 MHz, more than doubling the number of designers now working with such high rates.

User preferences are changing

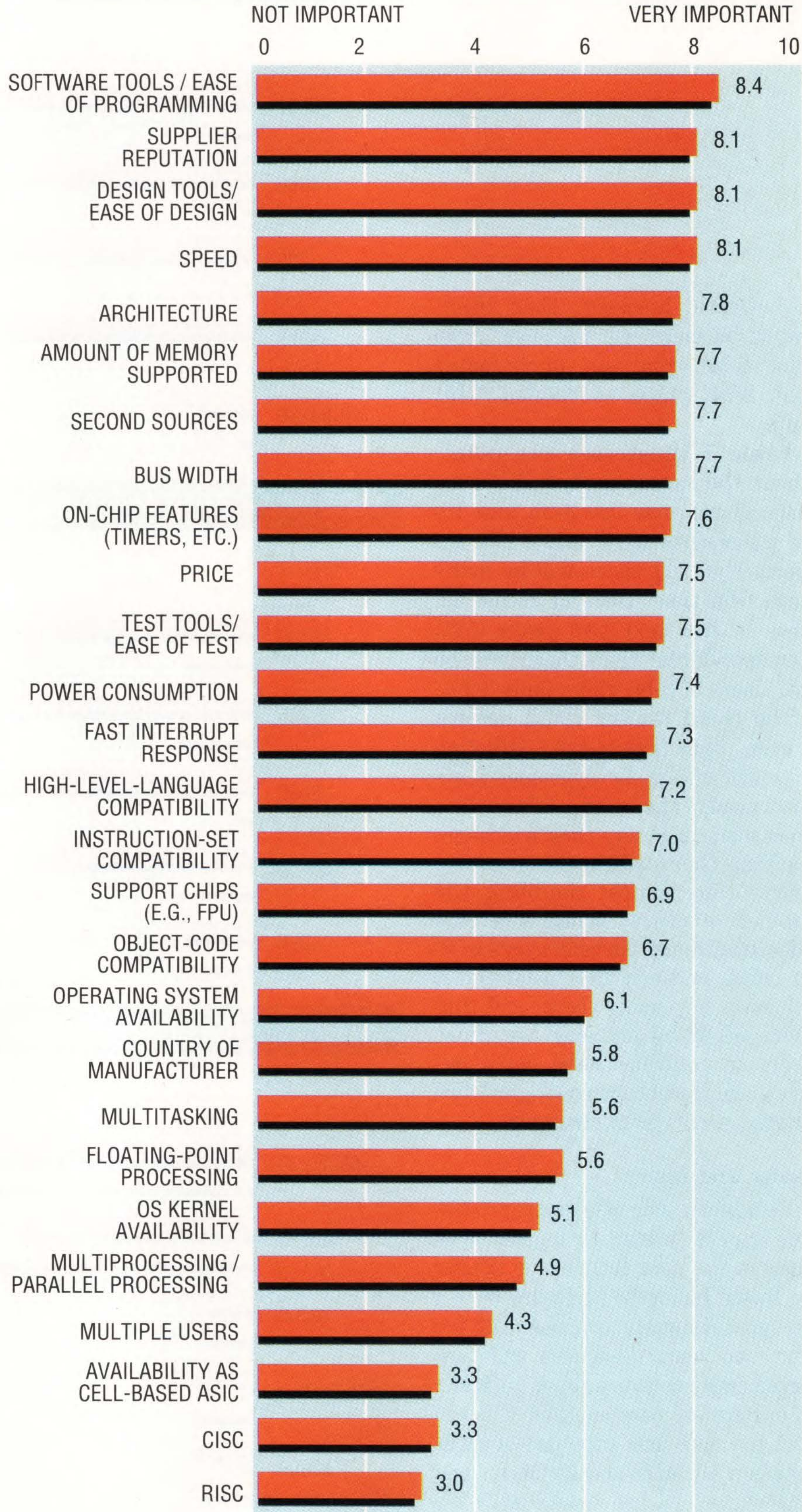
In tracking specific 8-, 16-, and 32-bit devices, we found that survey respondents' preferences vary (**Tables 3a, 3b,** and **3c**). Eight-bit and 16-bit microprocessors and microcontrollers remain extremely popular with the engineers and managers who responded to EDN's survey. However, there will be essentially no new users (no more than 4% of survey respondents) for any one 8-bit device, and only a few new users (8% of respondents or less) for any one 16-bit chip. The powerful 32-bit chips from Motorola and Intel can expect to see lots of new devotees, however; half of our survey respondents expect to begin using the 68020/30 and the 80386 within two years. No other devices come anywhere close to those projections or, for that matter, to the present popularity of the Motorola and Intel chips.

What designers want

Clock rates and word lengths (the "specs") don't tell the whole story, of course. Designers and design managers have qualitative, as well as quantitative, concerns about the microprocessors they use. **Table 4** shows how the people who responded to EDN's survey rank 27 microprocessor characteristics in importance. The numbers shown with the different characteristics indicate just how important respondents think those characteristics are; on a scale from 0 to 10, 0 is "not important," and 10 is "very important."

"Software tools/ease of programming" is the microprocessor characteristic considered most important by survey respondents, and "design tools/ease of design" ties for second

TABLE 4—IMPORTANCE OF MICROPROCESSOR CHARACTERISTICS



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place. Obviously, then, designers and managers are concerned with getting their applications up and running and on the market as quickly and as easily as possible. The reputation of a microprocessor's supplier is also important to our respondents, a fact that correlates with two well-known and long-established companies, Intel and Motorola, topping the list in preferred sources for new 32-bit chips.

Of all the microprocessor characteristics listed in our survey questionnaire, CISC (complex-instruction-set computer) and RISC (reduced-instruction-set computer) architectures are apparently not, in themselves, important to designers and managers. These two characteristics ended up at the very bottom of the rankings. EDN's editors predicted this outcome when they wrote the questionnaire, however; readers and industry sources consistently say that performance is the real issue, not RISC versus CISC.

As you can see by looking at **Table 4**, though, "architecture" *is* important to the survey respondents, so you might wonder why the RISC-versus-CISC architecture question isn't. Our survey didn't address that question specifically, but we can speculate on it and make some intelligent guesses at the answer. Our guess is that the things which our survey shows *are* important to designers—available software tools, available design tools, familiarity and ease of use, speed, and so forth—are closely tied to architecture. In other words, designers are looking for ease of use and high performance, and they'll go for whatever architecture can provide that for them; RISC and CISC are merely factors that contribute to the bottom line.

And the bottom line, of course, is effectiveness; that's what microprocessors are all about.

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8	12.0	320	0.5	0.12	0.12	16	0.12
5	7.5	200	0.8	0.20	0.20	10	0.20
1	1.5	40	4.0	1.00	1.00	2	1.00

*Instruction Rate Measured In Millions Of Instructions Per Second.

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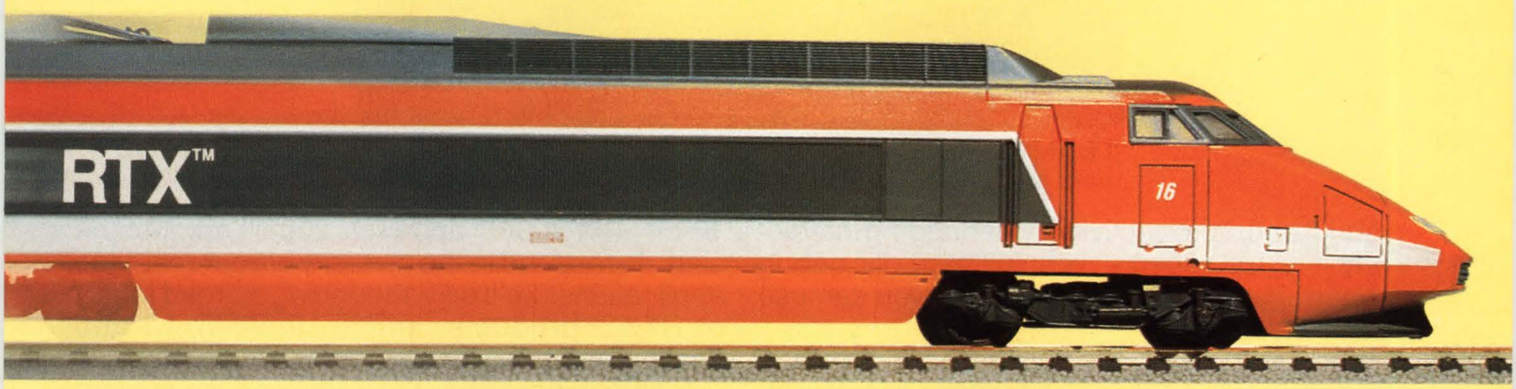

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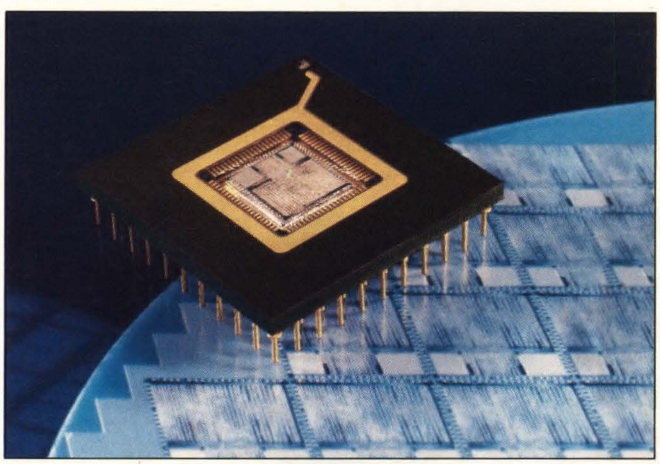

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Memory (on-chip)	256 x 16 Parameter Stack 256 x 21 Return Stack	64 x 16 Parameter Stack 64 x 21 Return Stack
Wait State Controller (on-chip)	Yes	Yes
ASIC Bus™	16 bit	16 bit
16 x 16 Multiply	Single Cycle	20 Cycle
32/16 Divide	21 Cycle	21 Cycle
32/16 Square Root	25 Cycle	25 Cycle
Address Range	1 Mbyte	1 Mbyte
Data Bus	16 bit	16 bit
Byte Operations	Yes	Yes
Package	84 pins	84 pins
883C Compliant	1Q CY89	Not Planned
Semicustom Migration Path	Yes	Yes
Rad-Hard Migration Path	Yes	Not Planned
32 bit Migration Path	Yes	Yes
Development System	Yes	Yes
Forth Compiler	Now	Now
C Compiler	4Q CY88	4Q CY88
Prolog Compiler	1Q CY89	1Q CY89

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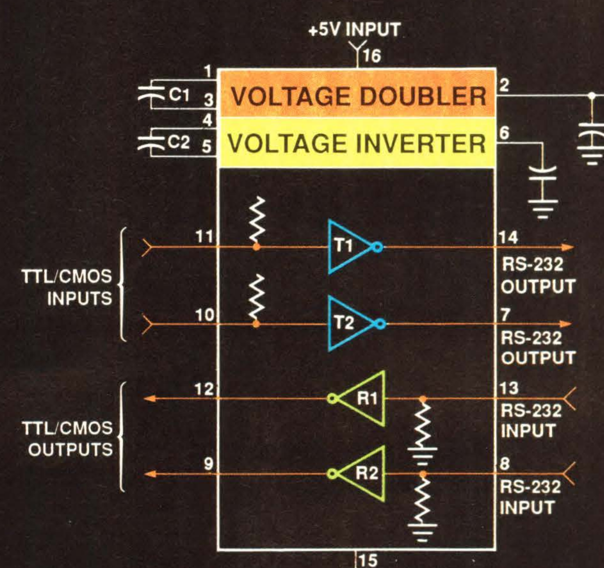

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Alden M. Hayashi

A young boy dabbles with his electronic Etch A Sketch. Using a stylus and touchpad, he begins drawing a fish, which instantaneously appears on the toy's LCD screen. The "erase" function helps him redraw the fish's

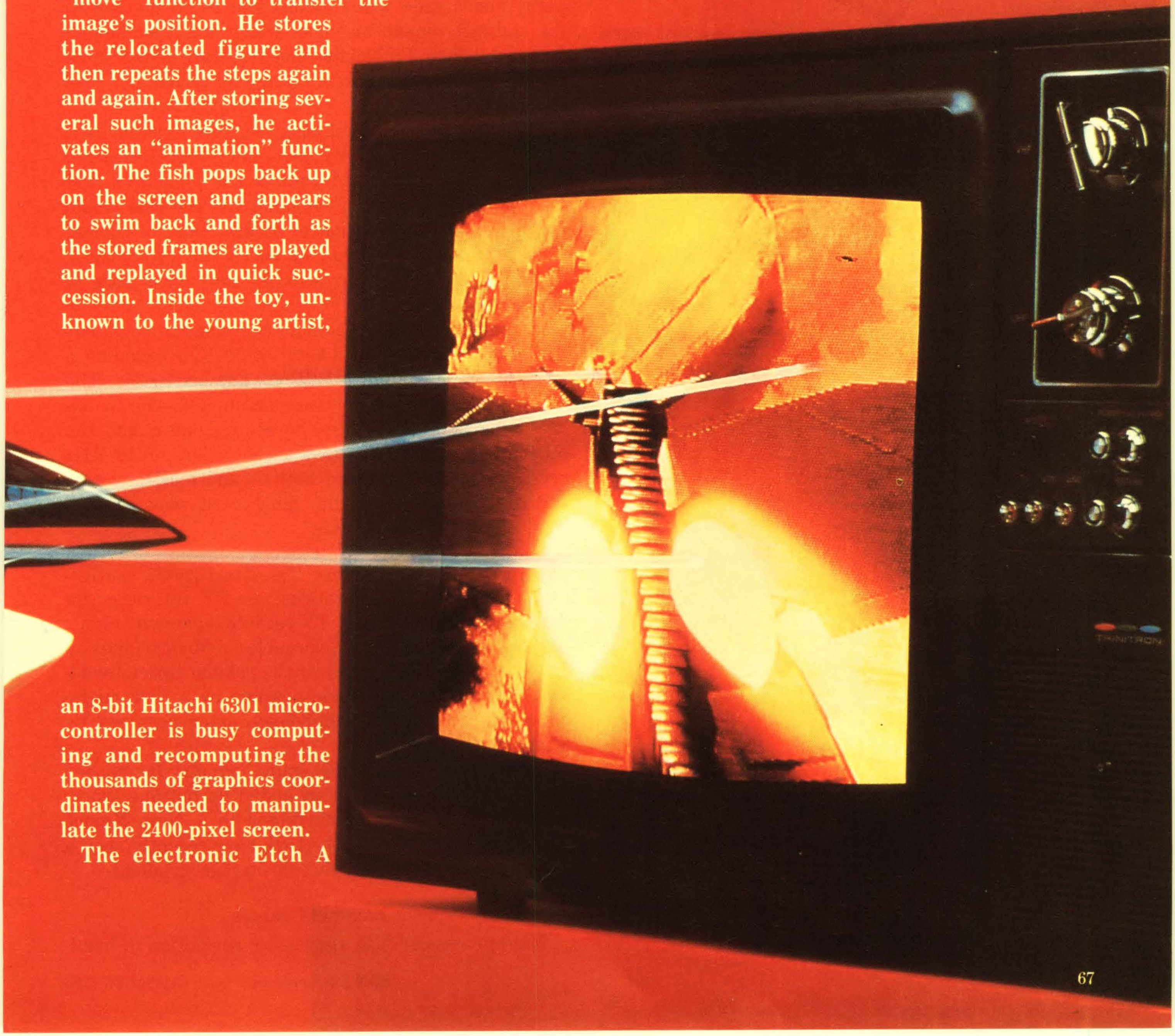
Blasting evil enemy robots on the telecast "Captain Power and the Soldiers of the Future" is easy, thanks to microcontroller-driven ray guns.

MICROPROCESSORS:

tail, which was too small at first. After several corrections, he's satisfied and stores the sketch in the toy's memory.

He then starts a fresh screen by retrieving the fish he just drew. This time, however, he uses the "move" function to transfer the image's position. He stores the relocated figure and then repeats the steps again and again. After storing several such images, he activates an "animation" function. The fish pops back up on the screen and appears to swim back and forth as the stored frames are played and replayed in quick succession. Inside the toy, unknown to the young artist, an 8-bit Hitachi 6301 microcontroller is busy computing and recomputing the thousands of graphics coordinates needed to manipulate the 2400-pixel screen.

The electronic Etch A Sketch—a far cry from the mechanical version so familiar to the boy's parents—is yet another toy that owes its existence to a microprocessor. More than a decade has passed since microprocessor-based toys first appeared, and it's now difficult to believe that many of today's electronic Etch A Sketch aficionados weren't even born when high-tech playthings first began to engage the attention and imagination of children and grown-ups alike.



Electronic Etch A Sketch, powered by a Hitachi 6301 microcontroller, allows young (and young-at-heart) artists to create animation sequences.

Texas Instruments' Speak & Spell

Indeed, few youngsters today have ever played Pong by Atari, a tennis video game with two electronic paddles and a ricocheting ball. Arguably the first video game for the masses, Pong debuted in a Sunnyvale bar in 1972 and caught on instantly. After two days, it ceased to work—its money box was jammed with coins.

Pong, implemented without a microprocessor, whetted the public's appetite. The game's runaway success also spurred its creator, Nolan Bushnell, the founder of Atari. The 6-foot 4-inch Bushnell, his physical stature at odds with his childlike creativity, realized that Pong's simplicity would soon result in boredom after players inevitably mastered the game. But adding more complexity could easily balloon manufacturing costs, and arcade video games had to compete with the stalwart pinball machine, which was then selling for around $600. Pinball machines had already survived assaults by such faddish amusements as bumper pool and Foosball.

What better way to cut costs, but not functionality, thought Bushnell, than by using microprocessors? So, in 1976, Atari introduced Tank 8, the company's first microprocessor-driven video game and one that would spawn a whole generation of others. One, of course, was the famous Pac-Man, in which the protagonist, controlled by the player, scurries through a maze of hungry monsters.

Introduced in 1980, Pac-Man contained a single circuit board that housed a total of 90 ICs, including a Z80 microprocessor, five PROMs, and six RAMs. The board was also home to two custom ICs—one to address the video RAM for the color monitor and the other to operate as the Z80 bus controller. An 18-MHz crystal oscillator provided both 3- and 6-MHz clocks, and the Z80 created audio signals that were boosted by dual audio-amplifier ICs.

Atari was first, in 1977, with a microprocessor-based video system for the home. The Atari 2600's control-console deck housed joysticks, an RF interface (for transforming an ordinary TV set into a game monitor), and a microprocessor. Replaceable ROM cartridges allowed access to games such as the popular Space Invaders. The system was made possible by a 6502 microprocessor from MOS Technology, later acquired by Commodore.

Although the home video-game industry languished during the mid-1980s—Atari ended up burying truckloads of unsold game cartridges in a New Mexico landfill four years ago—the toys have recently seen a renewed interest, partly due to snazzier graphics.

Microchips spawn handheld games

Microprocessors also spawned a revolution in handheld electronic games. Perhaps the first such toy, introduced by Milton Bradley in 1976, was Comp IV, a guessing game in which players try to deduce a sequence of numbers. The toy contained a single circuit board with a Texas Instruments TMS 970, a customized 4-bit calculator chip that was the forerunner of the company's TMS 1000 family of 4-bit general-purpose microcontrollers.

After Comp IV, the market was literally flooded with handheld microprocessor-based games from companies such as Coleco, Mattel, and Tandy. The games—some of which were takeoffs of sports like baseball, football, and hockey—could usually be played either by two participants battling each other or by one person challenging the machine. One such game left many chess players reeling.

Chess Challenger, made by Fidelity Electronics with 28 transistors and 14 ICs, pitted its 8080 microprocessor against chess players of varying skill levels. The game's transistors drove an LED display that, in conjunction with 512 bytes of RAM, tracked the chess pieces being moved. Rules stored in 2 kilobytes of ROM (the advanced version uses 4 kilobytes) allowed the 8080 to determine if a player had just made an illegal move and, if not, to issue forth its best countermove. Before microprocessors became widespread, computerized chess games were limited to the elite few who had access to mainframe hardware.

The same was true for voice synthesis. Implementing the linear predictive coding (LPC) technique for artificial speech was a costly proposition before microprocessors arrived on the scene. According to Larry Brantingham, Texas Instruments' manager of speech technology, LPC then required at least a dozen 6×9-inch cards and a huge power supply, all of which cost around $10,000.

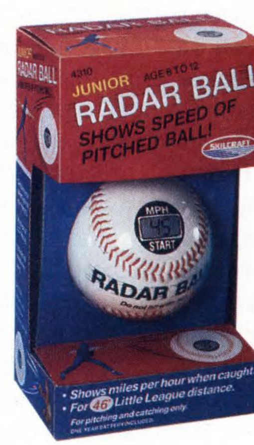
Electronics costs tumble

So Brantingham and a small team engineered a custom 4-bit microcontroller, the TMC 0270, which utilized the LPC technique and could be manufactured for $2 to $3. Thus was born TI's Speak & Spell, an educational toy that was developed in 18 months. Brantingham and his team finished a prototype barely three days before the toy's debut at the Consumer Electronics Show of 1978. Speak & Spell, perhaps the first microprocessor-based application of speech synthesis, became the hit of that year's Christmas season.

With its digital voice, Speak & Spell asks children to spell certain words, particularly difficult ones that do not follow phonetic rules. The child then spells the word using a touchpad keyboard, and the toy gives vocal praise for correct answers. In addition to digitally synthesizing speech, the TMC 0270 also handles the keyboard input and drives the toy's speaker and LED display, where the child can view a word as it is being spelled. The toy's 150-word vocabulary is stored in a separate 128-kilobit ROM chip, and the TMC's on-chip ROM contains the procedure for checking if the words are spelled correctly.

An Intel 80C51 microcontroller enables Coleco's talking dog, Wrinkles, to interact with children. Tickle his tummy, and Wrinkles giggles; put a bone in his mouth, and he makes chewing sounds.

TI's latest educational toy takes speech technology one step further. Using a full-custom 8-bit microcontroller, Voyager incorporates both speech synthesis *and* recognition. Children communicate with the toy solely by talking and listening. In a typical conversation, Voyager might play a game similar to Twenty Questions:



Monogram/Kidstar's Radar Ball uses a pressure sensor and a custom microcontroller to determine the speed of a pitcher's fastball.

Voyager: Do you want to pick a dinosaur and have me guess which one it is?

Child: Yes.

Voyager: Have you picked a dinosaur?

Child: Yes.

Voyager: Does it eat meat?

Child: Yes.

Voyager: Is it the size of a cat?

Child: No.

Voyager: Does it have two crests?

Child: No.

Voyager: Is it Tyrannosaurus Rex?

Child: Yes!

> Pong debuted in a Sunnyvale bar in 1972 and caught on instantly. After two days, it ceased to work—its money box was jammed with coins.

Microprocessor speech synthesis and recognition have not been limited to educational toys. Coleco's dog, Wrinkles, was one of the first stuffed animals to depend on a chip for its vocal chords. (The older talking bear, Teddy Ruxpin from Worlds of Wonder, uses cassette tapes.) Engineered by Beck-Tech, a contract design firm, Wrinkles uses various sensors to interact with children. Tickle his tummy, and Wrinkles giggles. Place a bone in his mouth, and he emits chewing sounds.

Wrinkles' five sensors are controlled by an analog circuit board within the dog's plush body. A digital board containing an Intel 80C51 manages the analog board's functions and also synthesizes the voice and other sounds. A 256-kilobit ROM stores the more than one thousand phrases and sound effects, as well as the software routines, that make Wrinkles interactive. According to Bob Steele, Beck-Tech vice president, Intel's 8-bit CMOS microprocessor was chosen because of its low price (less than $3 in volume), extensive I/O capability, and nominal power consumption. "You've got to watch your current drain," says Steele, "or four batteries go pretty quickly."

For more extensive speech synthesis and recognition, some toy companies use digital signal processors. Worlds of Wonder's Julie doll can recognize 12 different words and respond with over 200 unique sentences. For example, if she hears the word "hungry," she might respond with, "Let's have some cookies and milk." Because Julie must pick out the 12 prompting words from random conversation, a DSP with fast processing was necessary. Worlds of Wonder picked the TMS 320 from TI.

Zap! You're dead!

Microprocessors also made possible the use of infrared light in toys. With Lazer Tag, from Worlds of Wonder, children play the traditional game of tag, but with guns that shoot infrared light beams. To detect hits and for scorekeeping, players wear target sensors on their chests. The game uses two TI 1730 4-bit microcontrollers. One, in the gun, generates a coded infrared pulse train and an accompanying shooting noise when the gun is fired; another, in the target sensor, decodes the pulse train, figures out if it's the right code, and determines if the burst was long enough to count as a "hit."

In another application of electronic weaponry, children can actually interact with a broadcast TV program. Watching "Captain Power and the Soldiers of the Future," they use special guns, made by Mattel, to help the good guys battle evil enemy robots.

The guns contain light sensors connected to microcontrollers that are programmed to detect narrow ranges of color; the TV show broadcasts shimmering square targets of these selected colors. Players at home lock onto the targets (which is indicated by a flashing LED on the gun) and then shoot to register points on the gun's scorekeeper. The robots, in turn, hurl back yellow fireballs, which players can neutralize by shooting them when they reach maximum brightness. If a player fails to shoot a fireball, the gun's scorekeeper deducts points.

Another creative application of microprocessors is Simon, a takeoff of the vintage Simon Says game. The idea for the electronic Simon, introduced in 1978, was first proposed to Milton Bradley by Marvin Glass & Associates, a Chicago firm that brainstorms game concepts. The proposed toy required players to repeat a long sequence of commands; if a player repeated the sequence correctly, the toy would add more commands until the string became so long that mistakes were inevitable.

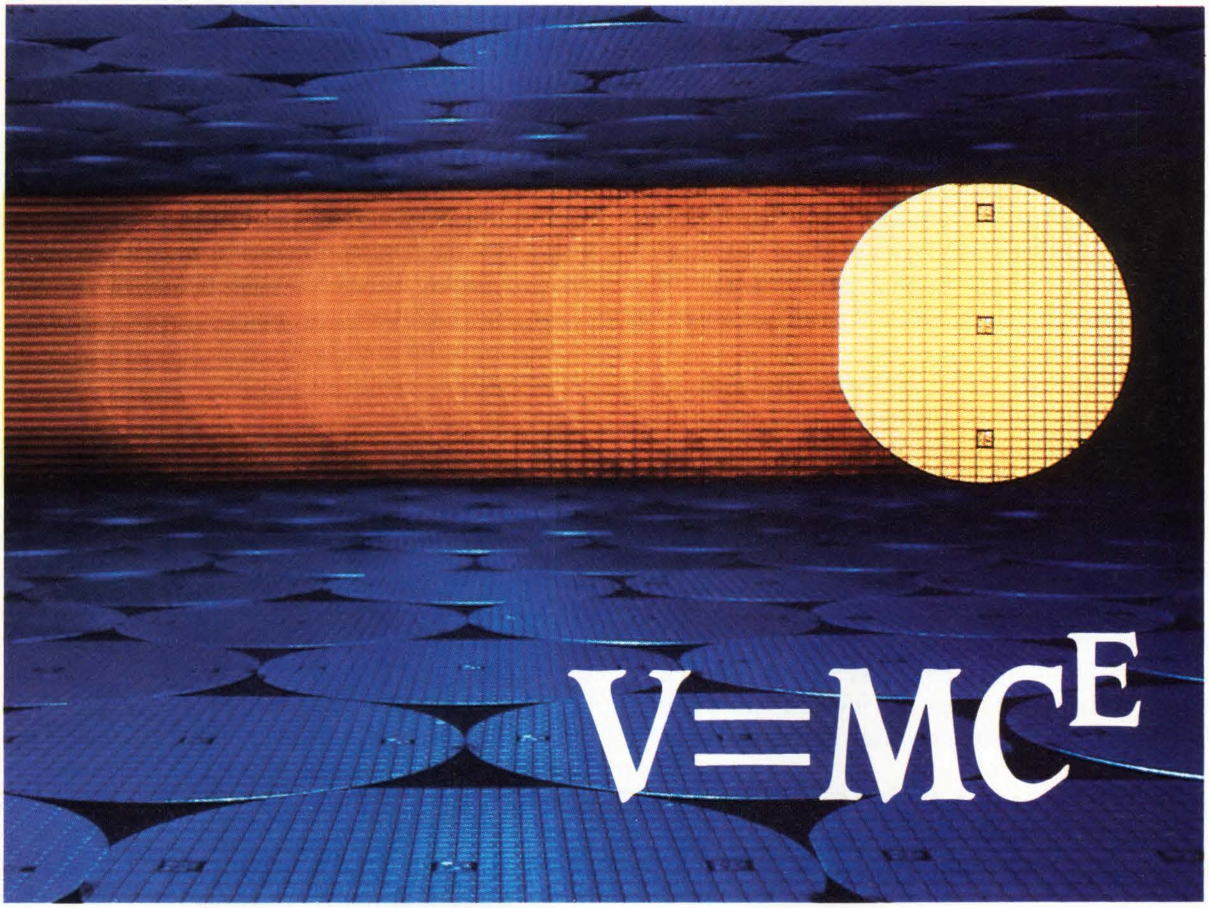
The concept was ingenious, but the Chicago firm had no idea how to develop it. As Gary Bergnann, Milton Bradley's director of marketing, recalls, "They just had a man-behind-the-curtain type of prototype." So Milton Bradley engineers set to work. They discovered that the concept could be handily implemented by using the TMS 1000 MP 3201 4-bit microcontroller from Texas Instruments.

Chip against brain

Simon's sequence, which players must reproduce, is indicated by different colored buttons that light up in random order. The various buttons—red, green, blue, and yellow in the original version—all elicit an accompanying monotone of a different pitch, thus providing players with two different types of stimuli for remembering the sequence. After the fifth, ninth and 13th signals in a sequence, the toy automatically speeds up the tempo, generating as many as 31 random signals in one sequence.

Practically all of Simon's work is done by the TI microcontroller. The chip's processor generates the random sequence, which the player is required to replicate, and stores it in on-chip RAM. Using a procedure programmed into the on-chip ROM, it then compares that sequence with a player's input sequence. The microcontroller also handles the external transistor drivers for the lights and speaker.

The TMS 1000 was the ideal chip for Simon. It had just the right amount of on-chip RAM and ROM. It could run off a 9-volt transistor battery. (The power-



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Parker Brothers learned the painful lesson that electronics for electronics' sake is not necessarily wise.

consuming lights depend on a separate pair of D-size batteries.) And the chip was inexpensive. "At the time," says Milton Bradley's Bergnann, "board games were selling for $10 to $15, so we knew we had to come out with something in that price range." TI's TMS 1000 microcontrollers currently sell for about 60 cents in volume quantities.

Simon celebrates its tenth birthday this year, and more than 10 million of the toys have been sold worldwide. In an interesting aside, at least two hospitals use Simon to treat people with short-term memory disabilities.

A pitch for microchips

Another ingenious use of microprocessors is Monogram/Kidstar's Radar Ball, a baseball with an LCD readout that tells pitchers how fast they're throwing. In a curious exchange of roles, the idea for this product actually came from Japan and was improved upon in the United States.

Dwain Dials, Kidstar's director of product development, saw an early product three years ago in Japan—a ball that displayed how long it flew in the air after being thrown. When a pressure sensor in the ball was released, i.e. when the ball left a pitcher's hand, the ball's internal timer started. When the sensor was activated again, i.e. when the ball reached the catcher's mitt, the timer stopped.

Dials liked the product, but thought it would be better if the ball gave a reading in miles per hour instead of elapsed time. So Kidstar developed two different baseballs: one for the 46-foot distance from a Little League pitching mound to home plate, and another version for the greater distance of 60 feet 6 inches used in professional baseball.

From the outset, Radar Ball presented some interesting design problems. For starters, the ball had to be of regulation size and weight, a restriction that forced Kidstar engineers to use just one chip, a custom microcontroller. The microcontroller does virtually everything: It interacts with the pressure sensor, times the ball's flight, converts the tenth-of-a-second readings to miles per hour based on the appropriate distance, and drives the LCD display.

Electrical power was also at a premium, because the ball's non-removable leather casing makes battery replacement impossible. Dials asserts, however, that a power-stingy design allows the ball to be pitched four hours a day for two years before its two watch batteries expire. At a retail price of $15, the technically misnamed Radar Ball has been doing well. Kidstar should sell its millionth ball soon, according to Dials.

Of course, not all toys have used microprocessors judiciously. In fact, after electronic games caught on like wildfire during the late 1970s, many companies began plopping microprocessors into toys just for the sake of calling them "computerized" or "electronic." When the high-tech toy market soured in the early 1980s, not a few companies were left gasping. Mattel's electronics division nearly drove the company to bankruptcy four years ago.

Parker Brothers also learned the painful lesson that electronics for electronics' sake is not necessarily wise. Several years ago, the company introduced Monopoly Playmaster, an electronic version of the classic board game. In the updated version, a custom microprocessor sped the game's pace by electronically "rolling the dice" and by tending to the various banking duties such as the auctioning of unowned property. The game was literally crammed with bells and whistles. When someone landed on a railroad property, the song "I've Been Working on the Railroad" played. When someone went bankrupt, the opening notes to Beethoven's Fifth Symphony chimed.

Unfortunately for Parker Brothers, the public prefered classic Monopoly, which has sold more than 100 million units since its introduction in 1935. Monopoly Playmaster was discontinued before reaching its second birthday. "There's a place for electronics, but you can't overdo it," chides Charles Brixey, a senior member on TI's technical staff. "There's got to be a very good reason for having a microprocessor in a toy."

Not *too* real, okay?

Although some in the industry claim that toys have already become too sophisticated, others disagree. "We need more computing power," asserts Pong creator Bushnell, "because certain toys need to simulate real life better." Bushnell's new company, Axlon, sells pet robots that do "80 percent of what a real cat or dog does."

So, what will the future hold as 16-bit, 32-bit, and—perhaps one day—64-bit microprocessores are incorporated into toys? According to *Omni* magazine, anti-gravity bicycles, superconductivity-powered train sets, holographic dolls, and robots that play catch could well become the staples of every child's toy chest during the 21st century. And, regarding the classic Etch A Sketch, could a 3D version in color be right around the corner? EDN

Alden Hayashi is a Senior Editor for Electronic Business.

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III. Application Examples
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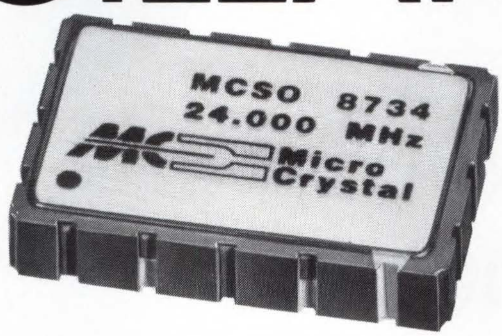

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THE SPECIAL REPORT MICROPROCESSOR

Microprocessors go to the movies

Douglas Eidsmore

Hollywood seems to have an "attitude," as they say on the cop shows, about computers. After all, a HAL 9000 tried to kill off the crew in *2001*, a hacker almost started World War III in *War Games*, and the hero of *TRON* got digitized and downloaded into a CPU.

But on the other side of the screen, the business side, the entertainment industry has gladly embraced high tech. Microprocessor-based motion controllers, optical printers, and computer-animation workstations are routinely used today to create striking images that were impossibly laborious only a decade ago.

2001: the odyssey begins

Although many of the special effects in *2001* were shot almost a decade before the introduction of the microprocessor, the film defined how outer-space epics would look and be shot for years to come. Not only were the space ship models and interiors more realistic than ever before, the film's optical effects and precise motion control laid the groundwork and created a need for the microprocessor-based controllers of the future.

The psychedelic "Star Gate" sequence in *2001*, in which astronaut Bowman is transported over a space-time warp, was created using slit-scan or streak photography. Douglas Trumbull, one of four special-effects supervisors on the film, constructed a slit-scan machine consisting of a 65-millimeter camera mounted on a 15-foot track. A powerful light source shining through glass panels was at one end of the track, and a screen with a long narrow slit in it was between the camera and the light. Film exposure, from the powerful light shining through the slit, occurred one frame at at time as the camera moved down the track. This laborious process was repeated, producing streak after streak, until the entire sequence was shot.

In several scenes in *2001*, as the space ship Jupiter passes by, you can see astronauts inside the ship through a window. To create this effect, movie technicians first moved a 54-foot model of the space ship on a 150-foot track, photographing it with its window blacked out. Then they rewound the film and repeated

To "stretch" this Renault, R/ Greenberg Associates used an 8086-based optical printer.

the sequence, with everything *except* the window blacked out; the window itself was covered with a white card. During this second sequence, a projector moved with the space ship and cast action footage of the astronauts onto the window, exposing that part of the film that was left blank in the first sequence. Each sequence required over four hours and had to be repeated exactly for proper alignment of the images.

The animation stand Trumbull used in *2001* moved along a single axis and required a 20-foot worm gear for control. It was cumbersome to use and prone to devastating errors. (You shoot, move the camera a sixteenth of a inch, and shoot again. If you miss or repeat a step, the entire sequence is ruined.) Trumbull saw the need for automating such equipment, and soon after *2001* he began experimenting with motion controllers. In a controller used for shooting commercials in 1969, Trumbull and his partner, Jamie Shourt, used an ordinary stereo tape recorder to record square-wave pulses that drove synchronous

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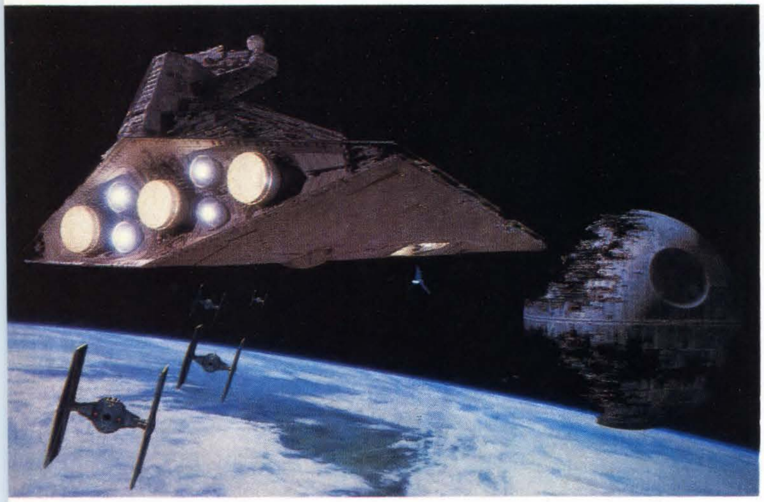


In Lucasfilm's *The Return of the Jedi*, a 68000-based Hewlett-Packard 200 computer directed the motion-control system that moved space ship models for filming.

motors. It was a significant improvement.

Stanley Kubrick took HAL on a long, tortuous journey in *2001*; in *Star Wars*, George Lucas put R2D2 into hyperdrive. *Star Wars* required over 350 special effects that demanded the technical detail of *2001* combined with complex combat scenes showing several rapidly moving space ships on the screen at the same time. John Dykstra, the visual effects supervisor on *Star Wars*, saw the need for an electronic control system that would allow a camera to fly around a stationary space ship model and create the illusion that the model itself was in flight. The system had to record these complex moves so they could be precisely repeated.

Dykstra hired Alvah Miller, who had experimented with computer-controlled cameras in the late 1960s, to design the electronic motion-control system. Miller and Jerry Jeffress designed a control system driven by a custom processor that was implemented with over a thousand ICs on 24 printed-circuit boards. Miller and Jeffress received Academy Awards for Scientific Achievement for this system, as did Dykstra for development of the Dykstraflex Camera.

A number of motion-control systems were developed after *Star Wars*. Jeffress developed a system that was used on *Close Encounters of the Third Kind*, and Dykstra started his own company, Apogee Inc., where Miller is now chief electronics design engineer.

The next feature Miller worked on was *Star Trek, The Motion Picture*. *Star Trek* not only put Spock's ears in a feature film for the first time, it was one of the first films to use a microprocessor-based system for special effects. Miller and Apogee software engineer Paul Johnson opened up Johnson's Apple II, cut the cables between the control system and the individual motor controllers, and patched in the Apple so it could access control-system RAM. The Apple II and its ubiquitous 6502 microprocessor thus controlled Apogee's boom cameras.

In *Invaders From Mars*, special-effects company Apogee used an 80286-based AT to create a ray gun effect in which a pulsating, undulating ray of light blasts from a moving gun to a moving target.

By the early 1980s, motion controllers used Apples, Commodore PETs, and computers based on the S-100 and STD Buses. A Z80-based system developed at Interactive Motion Control was used to shoot the titles for the movie *The Untouchables*. IMC now markets controllers based on the Hitachi 61480 microprocessor.

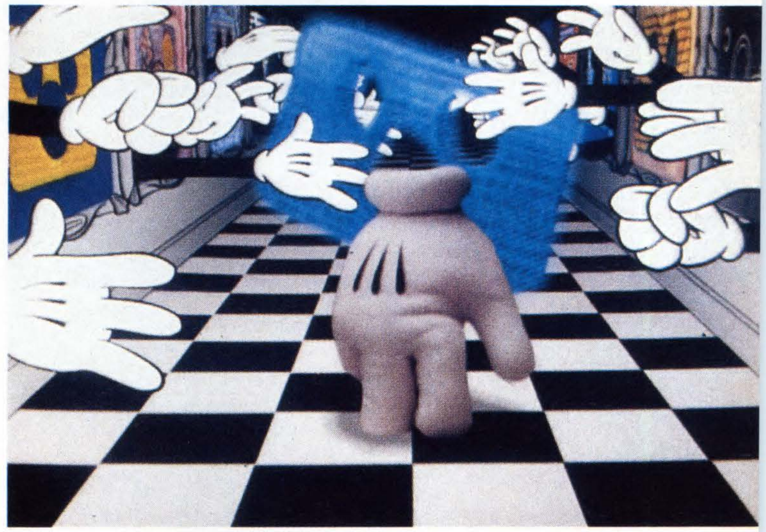
The IBM PC gave special-effects engineers a stable and expandable hardware base with software migration extending from the Intel 8088 to the 80386. In *Invaders From Mars*, Apogee used a 286-based AT with a math coprocessor to create a ray gun effect in which a pulsating, undulating ray of light blasts from a moving gun to a moving target. To create the effect, a laser beam was projected onto a screen that moved on a track. The mathematics for controlling the movement were quite complex—defining an undulating cylinder with both ends moving to match live action with a single laser dot.

After *Star Wars*, Lucasfilm formed an Industrial Light and Magic division to create effects for its own and other companies' productions. ILM's first motion-control system, called Motion Master, was based on a Z80 processor and the STD Bus. Using the Motion Master, camera operators would make initial "moves" for which parameters were recorded on tape, and the tape would then be "Reebok-networked" to a Hewlett-Packard personal computer where the moves got smoothed out. A tape with the smoothed moves would then be used in the controller for actual shooting. This system was used on *The Empire Strikes Back*.

For *The Return of the Jedi*, ILM hooked a 68000-based HP 200 directly into a Motion Master. Space ship models were filmed, by separate real-time motion-control moves against a blue screen, on mounts that

allowed them to pitch and yaw. For movement of the death star or star field (when the camera pans over a model, the star field behind the model has to move as well) motion control was also necessary. According to Scott Squires, ILM's Technical Director, the effects company is now converting to Macintosh II-based motion controllers with custom plug-in interface cards. The Mac's graphics capability and user interface allow moves to be simulated on-screen prior to shooting.

Optical printers can also be used to create special effects. The Oxberry CompuQuad 16-axis, four-projector optical printer has a controller that uses four 8086 microprocessors running under Intel's iRMX real-time operating system in conjunction with four tight OS kernels around each processor for controlling the projector motors. Development of the system began in 1979 when the 8086 was first introduced.



Jonathan Keeton, of Western Images, used a 68000-based video-effects processor to create "Mickey's Nightmare" for The Disney Channel.

Computers learn to draw

Many computer-like images have been created for film without the aid of computers. For example, the computer displays inside the space ships of *2001* were hand drawn, and although *TRON*, Disney's film in which the hero gets digitized and pursued through a computer, used some computer-generated imagery, much of the film was animated by hand.

But computers are playing an increasingly important role. *Star Wars* contains a short computer-generated sequence, and a Cray generated the space ship sequences in *The Last Starfighter*. And in a striking scene in *Young Sherlock Holmes*, ILM used a Pixar image computer to create a moving apparition made up of shards of stained glass.

Why haven't you seen more computer-generated images? Because you can't beat the storage capacity of film. The resolution of 35-millimeter VistaVision film is about 4000 by 3000 pixels, and if you assume 12 bits per color pixel, a single color frame stores 18 million bytes of data. Moreover, generating a 10-second computer-animated sequence can take a 300-MIPS computer center an entire eight-hour shift.

The much lower resolution of television makes that medium much more suited to computer-generated imagery, and a number of hardware and software vendors offer broadcast-quality products. Silicon Graphics' IRIS graphics workstations are the most popular microprocessor-based systems for computer animation; current models include the 16-MHz 68020 systems and 8-MHz MIPS RISC systems. Wavefront Technologies' Dynamic Imaging System is the most popular animation software running on the IRIS. The Wavefront system enables studios and post-production facilities to create broadcast-quality commercials, logos, animated graphics, and special effects.

Wavefront uses the IRIS as a stand-alone graphics workstation or as the front-end processor for a wide range of computers including Cray Research and Ardent Computer Corporation supercomputers and systems from DEC, Hewlett-Packard, Pixar, Ridge Computers and Sun Microsystems.

Bill Kovacs, Wavefront's director of software development, led the team that created Robert Abel and Associates' minicomputer-based custom animation system. Kovacs sees the microprocessor as being the whole economic enabler of an industry that uses raster graphics as a visual medium.

TV winners

Microprocessor-based digital optical effects systems such as Ampex's ADO and Quantel's Harry put incredible real-time effects in the hands of video artists. The ADO uses multiple Z8000 microprocessors, and Harry (a development code name that stuck) uses multiple 68000s. A Harry creates effects for the syndicated television series *Star Trek: The Next Generation.*

What has the microprocessor meant to special effects? Alvah Miller says that "the microprocessor has allowed us to create shots that not only would we not have even attempted before, but would have laughed at." Indeed, the microprocessor does allow complex film effects, but the highly competitive world of special effects is more than wisps and whooshes, sparks and arcs. It is also a business, and the microprocessor works in that business; it allows the creation of effects at costs that are affordable. EDN

Douglas Eidsmore, a freelance writer, lives in Soquel, California.

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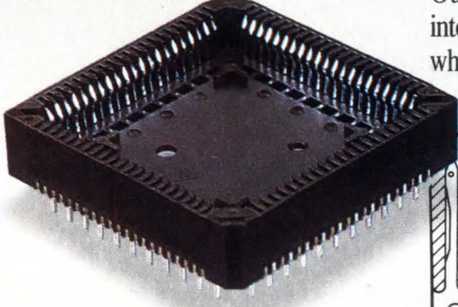

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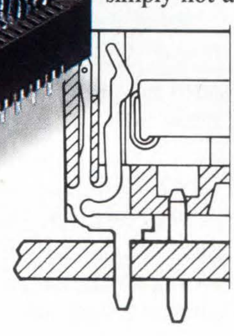

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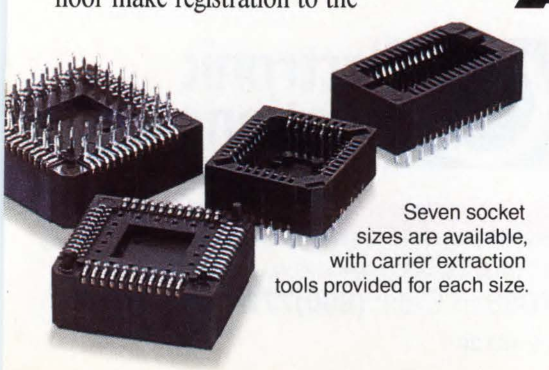

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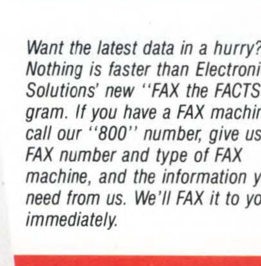

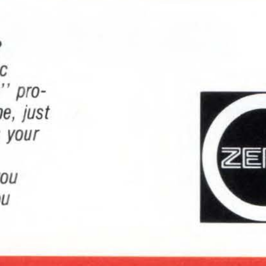

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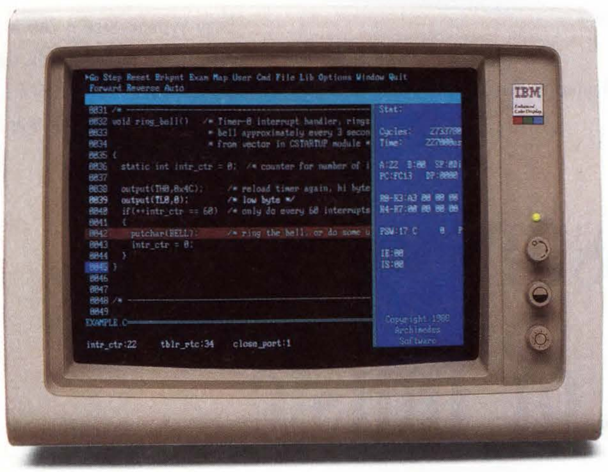

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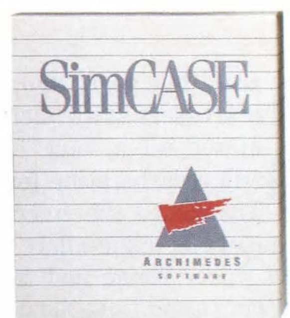

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E-mu Systems used a Z80 in 1977 to make the first microprocessor-controlled matrix scanning keyboard. The company's latest offerings, such as this Emulator II+, combine many electronic-music functions in one instrument.

Microprocessors change the sound of music

Dennis Livingston

Barely ten years ago, the integration of microprocessors with electronic music instruments kicked off a sonic revolution whose impact is still reverberating for music lovers everywhere. Thanks to the microprocessor, musicians can now generate, manipulate, and record a palette of sounds whose range and tonal qualities are virtually unlimited. In addition, the use of the same microprocessors in personal computers has brought the pleasures of playing and composing music to larger numbers of nonprofessionals than ever before.

Microprocessors have also helped to dramatically lower the cost of music. In the mid-1970s, if you wanted to record a piece of pop music, you needed half a dozen musicians, instruments, a bunch of microphones, a mixing console, a multitrack tape recorder, and a recording studio to house all this—all at a capital cost of about $300,000. Today, you can have a recording studio in your home for about $3000.

A prophet with honor

Early electronic music, beginning in the 1960s, was all analog. Notes on synthesizers were set by twisting potentiometer knobs, and there was no memory for storing the settings. The microprocessor changed all this. The first high-volume, commercially successful synthesizer to use a microprocessor (Zilog's Z80) for controlling analog functions was the Prophet-5, introduced in 1978 by Sequential Circuits Inc. (Sequential has since been acquired by Yamaha Music Corp., USA.)

A major microprocessor function in the Prophet-5 was the generation of control voltages for analog synthesis chips. These specialized chips, which handled dedicated oscillator, filter, amplifier, and envelope-generator functions, produced the actual sound and helped reduce the synthesizer's cost. The chips were used in five independent sound modules, with the Z80 serving as orchestrator for this ensemble.

The Prophet-5 could generate as many as 40 sounds, some of which came programmed in memory. This made a big difference in commercial potential, according to Sequential president Dave Smith, because "you just had to press a few buttons to call up the sounds in memory. People didn't have to have a techie level of experience to make music with our machine."

Users could also create their own synthetic sounds by manipulating front-panel knobs. The processor converted the knobs' positions to numbers, which could be stored in battery-backed memory, ready for instant retrieval at the press of a button. Thus, all sounds defined by users were precisely repeatable and could easily be reprogrammed or modified.

Given these advantages, all makers of electronic instruments began using microprocessors within a year. Why didn't they begin earlier? Part of the reason, says Smith, is cost. The Z80 was priced at $300 each when it first appeared; when it dropped to $15, it was more practical to use.

Initially priced at $4500, the Prophet-5 was the most popular electronic instrument with professional musicians for several years. It was used by performers with widely varying styles—Pink Floyd, Genesis, Herbie Hancock, Barry Manilow, and Devo, to name a few—and is still in use.

Keyboards get physical

Another important microprocessor function is to carry out sound-module assignments through keyboard scanning, thus making possible an efficient polyphonic keyboard—one that can sound more than one note at a time.

"In a piano," explains Jim Turner, vice president of engineering at Kurzweil Music Systems, Inc., "every key you press is connected to a specific set of strings. But in a synthesizer, only a limited number of oscillators is available to receive pitch instructions from each of the 88 keys on the keyboard." Thus, if you want to play chords, some system is needed to link pressed keys with available oscillators.

Early synthesizers needed no such system, because they were monophonic to begin with. A dedicated set of patch cables configured each sound, one note at a time. The Polymoog, from Robert Moog and his colleagues at Moog Music, got around this limitation, but in a hardware-intensive way: It allocated a sound-producing circuit card for each key. The microprocessor, however, finally made it possible to dynamically link all key depressions to only a handful of oscillators.

E-mu Systems was first with this approach, turning to the Z80 in 1977 to make the first microprocessor-controlled matrix scanning keyboard. You could play chords or counterpoint with the E-mu keyboard, although you still had to use potentiometers and careful tuning to set up different sounds.

In Sequential's Prophet-5 programmable synthesizer, the same microprocessor that directs the analog chips also scans the keyboard. It monitors the keyboard, end-to-end, several hundred times a second to see if any new key has been depressed or released since the last cycle. Then, using an assignment algorithm, the processor looks for any sound module not in use at the time a key is pressed and assigns the new note to that module. With five such modules, the Prophet-5 can play up to five simultaneous notes.

Chips bring finesse

The microprocessor has also brought more finesse, or what musicians call "expressiveness," to keyboards. "The piano is still considered the most expressive keyboard instrument," says Bob Moog, "because of what it does in turning a person's hand motions into energy that produces sound. That ability to naturally and rapidly change from loud to soft notes, and anywhere in between, is the kind of thing we are recreating in electronic devices."

Sequential's Dave Smith notes that the Prophet-5, like other synthesizers of its time, had a keyboard whose plastic keys operated as little more than on/off switches. Its keyboard had no dynamic feel or response; no matter how hard you pressed a key, you just closed a switch.

The Z80- and Z8000-driven Prophet T-8, introduced by Sequential in 1983 at a price of $5900, was a pioneer in expressive keyboards. "We had a real, tactile, wooden keyboard," says Smith, "with real handles that flew like a piano and optical sensors that detected their motion and converted it into electrical signals." Algorithms in the processors computed sound parameters

New England Digital Corp. president Bradley Naples stands with recording star Sting, who owns and uses several of NED's Synclavier music systems.

The Commodore 64 and its VLSI, three-voice Sound Interface Device (SID) chip were milestones in electronic music for the average consumer.

from these signals.

Among the T-8's features is the ability to sense key velocity and thus precisely determine how hard you hit the keys. In addition, if you continue to put pressure on a key after pressing it down, a microprocessor will route this information to the tone generator to alter pitch, vibrato, and other factors.

Sampling the real world

Synthesizers create an impressive range of sounds from scratch, but they are less successful in simulating the complex timbral nuances of acoustic instruments. For more accurate renditions of such sounds, you need a sampling machine.

Samplers, unlike synthesizers, did not exist before the advent of microprocessors. By changing the rate at which a sampled note is played back, you can alter its pitch. Some machines can perform other manipulations on sampled sounds as well, such as adding vibrato and splicing together parts of different sounds. Most samplers come with floppy-disk drives so that you can not only save the sounds you sample, but gain access to vendor libraries of prerecorded sampled sounds as well.

Linn beats the drum

Roger Linn's work on drum machines illustrates one early application of sampling. Devices that played repetitive, continuous rhythm patterns existed before the creation of Linn Electronics, but the sounds, created by analog synthesizers, were unrealistic. Then, in 1980, Linn marketed the Z80-based LM-1, the first drum machine with presampled sounds. The sounds were stored internally in ROM chips.

The LM-1 allowed musicians to program its sounds to their own drum beats. While listening to a built-in metronome, you could tap buttons marked as snare, bass drum, and other percussion instruments. The processor sensed what buttons were pressed and stored the relationship between metronome beats and button pushings. A current Linn product, the 80186-based MPC60, developed with Akai Corp., enables you to sample sounds of your own creation.

Several thousand of Linn's early machines were sold, altering the sonic feel of popular music. Now, he points out, many popular groups use some kind of electronic drummer. Linn products have also been useful in recording demos. "The steadiness of the timing, compared to human drummers, makes the song feel more steady, and the sounds are exactly what you want them to be, without the trouble of setting up mikes, changing equalizations, and so forth," says Linn.

Mirage was no illusion

Devices with broad sampling capabilities began appearing in the late 1970s, but they were expensive ($8000 to $30,000). The Mirage, from Ensoniq Corp., introduced in 1984 at $1,700, became the first mass-marketed sampler, and over 25,000 have now been sold.

Mirage used a Motorola 6809 for the main processor, because, according to Bob Yannes, senior design engineer at Ensoniq, it "is very fast, like the 6502, and more code-efficient." Ensoniq's ability to lower the cost of samplers, however, was due more to its development of the Q-Chip, or Digital Oscillator Chip (DOC), for sound generation. This custom chip allowed one circuit board to replace four larger ones.

Another advance in sampling occurred in 1984 with

The chip of choice

Zilog's Z80 was most often the chip of choice for synthesizers and other electronic musical instruments from the mid-1970s into the early 1980s. "For these applications," says Roger Linn, whose pioneering drum machine used the chip, "the Z80 was the cheapest, hippest processor of the time."

The Z80 appeared on the market just as electronic instruments were coming along, says Linn. "Everyone went to the Z80 because it had onboard refresh and was faster, cheaper, and easier to implement than the Intel 8080. It also had a better instruction set and required little support circuitry."

the introduction of the $10,000 Kurzweil 250 by Kurzweil Music Systems. Based on Motorola's 68000, it provided users with high quality sampled sounds for 36 instruments. According to Kurzweil's Jim Turner, the piano sample was so accurate that musicians couldn't distinguish it from a real piano in a blind test.

Behind this feat is Kurzweil's approach to a problem faced by all samplers: since the limitations imposed by memory preclude sampling every note of an instrument, how do you capture as much as possible of an instrument's full tonal essence?

One technique is to record only some of an instrument's notes, using pitch changes to approximate the rest. Kurzweil, however, turned to a proprietary algorithm that uses pattern recognition techniques to define the essential characteristics of an instrument's waveforms and frequency spectra. Both algorithmically extracted information and data-compressed sampled portions of a sound are stored on ROM chips in the 250. This approach uses less memory to reproduce the full range of an instrument without degrading sound quality.

Resynthesis is a recent hybrid technique for sound creation based upon the analysis of sampled sounds. With New England Digital's (NED) Synclavier, for example, the resident processor identifies and analyzes significant parts of a sampled sound's digitized waveform, such as the attack and first decay parameters, and recreates them as synthesized sounds. This method is less time consuming than creating from scratch the fundamental harmonic, the overtone series and other performance artifacts; you start with a complex waveform—from a piano, for example—and add to it.

Sequencers move sounds around

Synthesized and sampled sounds give the musician access to a large variety of tonal colors. Making full use of this musical palette, however, depends on your being able to manipulate these sounds through cutting, pasting, and editing, as a writer does with words on a word processor. That is the job of a sequencer.

Sequencing is akin to recording, but what gets stored in sequencers is not the actual music you make or a digital sampling of it, but the keystrokes (or more precisely, the performance information) that make up a tune. Sequencers allow such information to be stored so that the tone colors can be changed at any time in the future.

A modern, microprocesor-controlled sequencer allows you to transpose notes, duplicate and cut sections, change tempos, alter the instrumentation, and carry out a variety of other manipulations on synthesized and sampled material. Multiple sound tracks can thus be created and played back through a synthesizer, which, in effect, acts like the sequencer's player piano.

> In the 68000-powered Kurzweil 250, the piano sample is so accurate that musicians can't distinguish it from a real piano in a blind test.

Sequencers give musicians great editorial flexibility. "With a sequencer," says Craig Sibley, product specialist manager at Roland Corp., "you can examine your work, rearrange it, and get it right before spending valuable time at a recording studio. With a tape recorder, you can't change the sound without wiping out the performance, but all a sequencer is interested in is things like how long and how hard particular keys were held down; you can change the sound by pressing a button." Moreover, a modern sequencer can feed notes into more than one synthesizer to achieve multitimbral, orchestral effects.

The most popular of the early microprocessor-based sequencers was Roland's MC-4, which used the Z80. Entering the market around 1978, this four-channel device made sequenced music a permanent part of pop music and greatly enhanced the versatility of composers and orchestrators in creating music.

By the mid-1980s, microprocessors were once again changing synthesizers, which previously had used the chips primarily for control of analog functions. Now, custom VLSI digital chips are replacing their analog brethren.

Yamaha's DX7, with over 200,000 units sold since 1983, has become the most popular all-digital musical product and is the widest selling synthesizer yet made. Thanks largely to its VLSI technology, it sells for an affordable $2,000. The main processor is a customized, 16-bit chip similar to the Intel 80286, but it has an instruction set designed to be efficient in controlling the sound-generating chips.

The DX7 uses two custom VLSI chips that incorporate mathematical models for analog components. Because these algorithms make it possible to single out individual harmonics within complex sounds with great accuracy, the DX7 can create realistic sounds with the sensitivity of an acoustic instrument. The product even incorporates user-controlled inaccuracies to simulate the sonic quality of acoustic music.

The DX7's microprocessor also controls chips in the sequencer and the expressive, polyphonic keyboard. A single oscillator can be multiplexed by the processor to make as many as 16 notes sound like a chord.

Putting it all together

Recent years have seen the emergence of versatile, high-end machines that integrate the capabilities of all-digital synthesizers, samplers, sequencers, and expressive keyboards.

NED's Synclavier may be the most ambitious such product on the market, as well as the most costly, at an average price of $150,000. It combines the above functions with the ability to synchronize sound to film, using time-based standards established by the Society of Motion Picture and Television Engineers (SMPTE). At the Synclavier's heart lies a proprietary 16-bit RISC microprocessor that governs specialized downstream chips linked in a star topology.

At the other end of the financial spectrum from dedicated musical systems are the host of personal computers—including the IBM PC and compatibles, Commodore Amiga, Atari ST, and Apple II and Macintosh—that have metamorphosed into electronic instruments.

One important step in helping desktop machines to sing was the development of the Musical Instrument Digital Interface (MIDI) in the early 1980s from collaboration among researchers at Yamaha, Roland, Sequential Circuits, and other companies.

MIDI standardizes the digital encoding of musical data, thus enabling computers and electronic instruments from different vendors to work with each other. A master keyboard or computer terminal can then be used to control the operation of an array of other instruments over multiple channels. With a pitch-to-MIDI converter, acoustic instruments can also be used to transmit MIDI signals to receiving ports on synthesizers and computers.

Even before the first computer-connected MIDI port appeared in the Atari ST, however, home computers were being widely used for music-making. With the appropriate software and such peripherals as keyboards, interface cards, and digital oscillator boards, personal computers can be used for generating and editing waveforms on screen, sequencing, running vendor sound libraries, storing music, and printing compositions. MIDI attachments extend these capabilities.

Initially marketed in 1982, the Commodore 64 and its VLSI, three-voice Sound Interface Device (SID) chip were milestones in this context. SID, designed by Bob Yannes at Commodore, in effect is a synthesizer on a chip. It works with the 8-bit 6502 main processor as does a traditional analog synthesizer, with programmable envelope generators, filters, waveform selectors and so forth. "Before SID," Yannes says, "personal computers were generally limited to generating square waveforms, with no filtering to change the tone color. SID significantly expanded the musical horizons of home computer users." EDN

Dennis Livingston is a senior editor for Mini-Micro Systems.

Inside an electronic music studio

Packed into a third-floor room of Robert Ceely's home in Brookline, Massachusetts, is the array of electronic music instruments and recording devices that comprise BEEP Studio. Ceely, director of electronic music at the New England Conservatory of Music in Boston, uses this facility to write and record his own music and to give workshops.

A Synclavier, a multifunction, $150,000 machine, holds the place of honor at BEEP, surrounded by a number of other products. Running up one wall is a set of Moog analog synthesizer modules. A Yamaha TX802 FM tone generator, a Roland linear synthesizer, and a Roland Super JX (a microprocessor-controlled analog synthesizer) all sit mounted on a rack in the middle of the room.

"I want to show you how easy it is to tap the capabilities of this system," says Ceely, loading a floppy disk. He calls up a timbre directory at his computer terminal and pecks out instructions to create several harmonic structures, including their partial timbres. A harmonic display rapidly graphs the amplitude of all harmonics indicated. "Imagine what it took to do basic synthesizing," he says, "when you had to play with dozens of knobs, one note at a time."

"Let's make a tune," Ceely says. He improvises a catchy line on the keyboard, using the synthesized sound he just created. "You can record up to 200 tracks from the built-in sequencer and view 32 of them at a time on the comparative track display." He records the tune on an empty track, sets it to loop indefinitely, and pushes a button to create a steady "click" track behind the beat that he would use if the results were eventually to be synchronized with film. Ceely then adds a simple melody on top of the basic tune and experiments with changing its timbre and pitch.

Four MIDI channels enable him to control the rack-mounted synthesizers and other equipment from the Synclavier. He calls up a sample of a shakuhachi, adding the breathy sound of this Japanese bamboo flute to another track. Finally, he plays back the whole piece and stores it on a floppy disk. His composition is complete.

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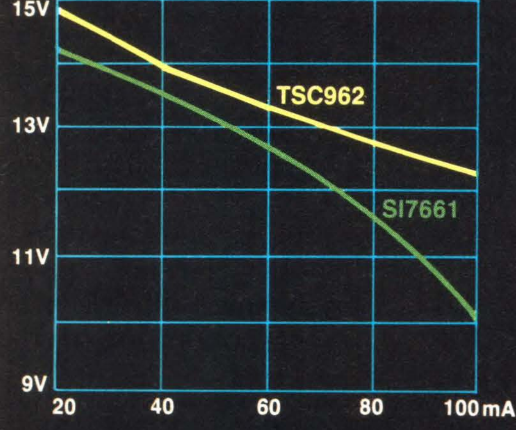

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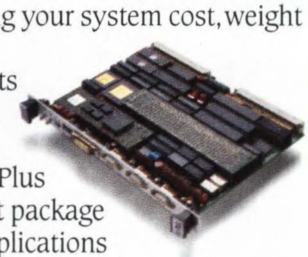

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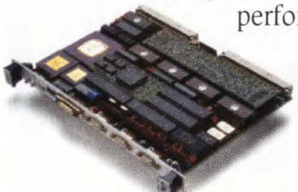

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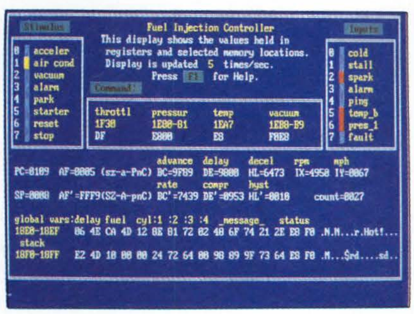

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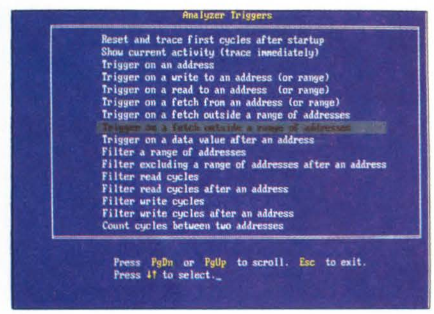

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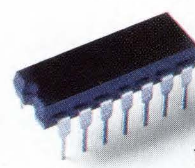

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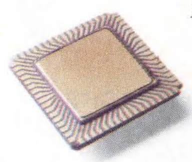

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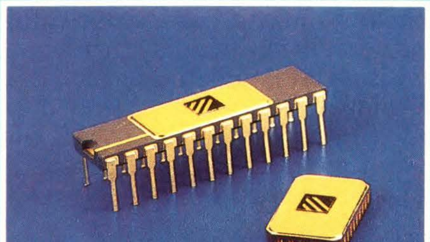

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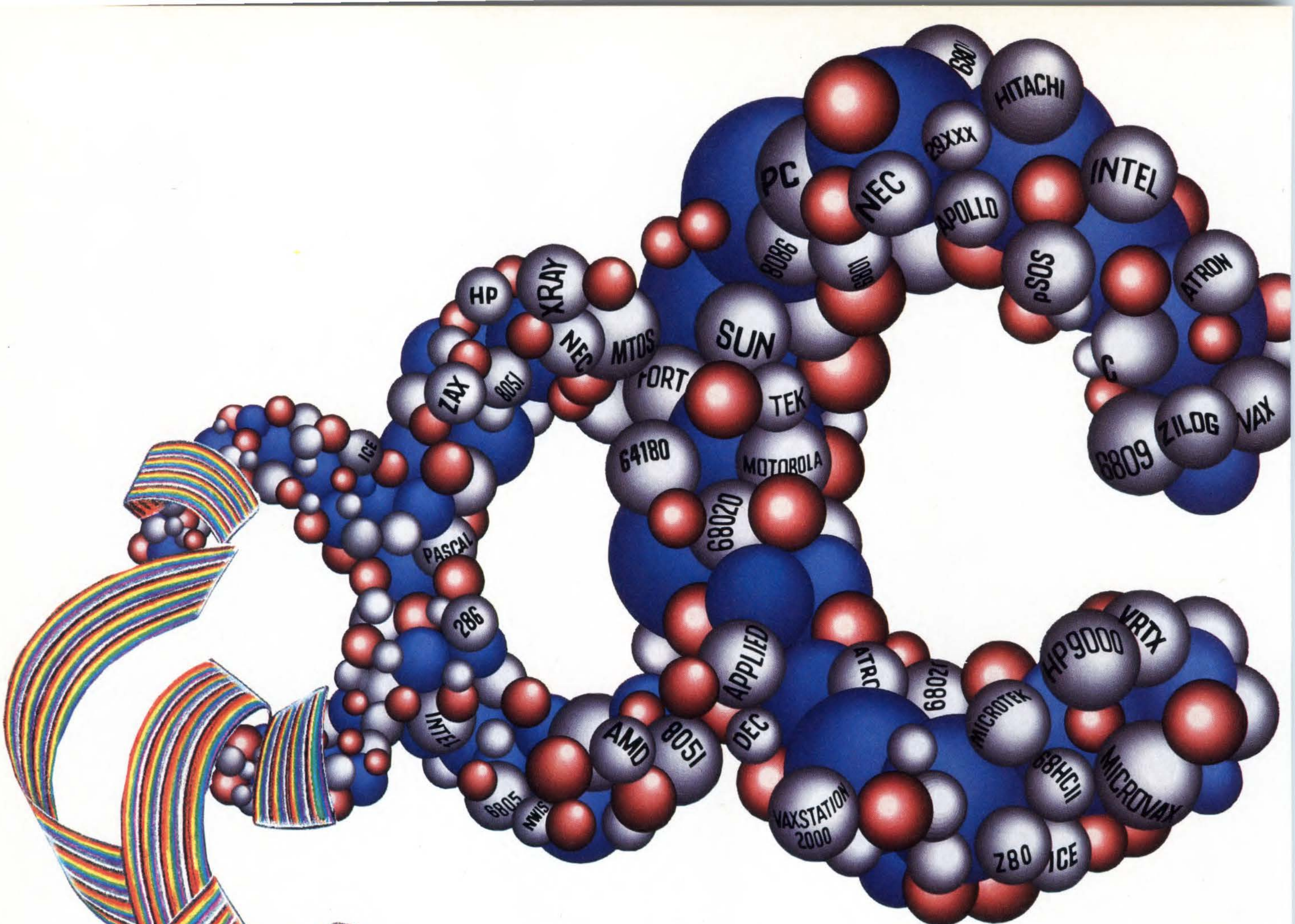

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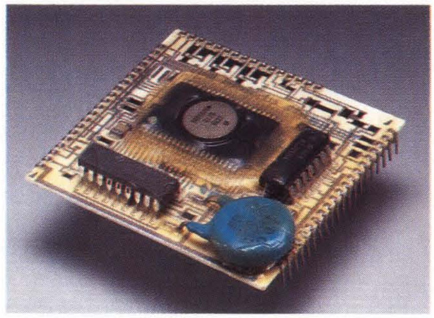
CIRCLE NO 41

Microprocessors: The brains in cars' central nervous systems

Norman Alster

There is more to life than making inferences. While much attention has focused on the efforts of computer designers to emulate human intelligence, it is automotive electronics that has most closely tracked human system functions. From the start, the objective of microprocessor-based vehicle controls was to make the car a more efficient organism.

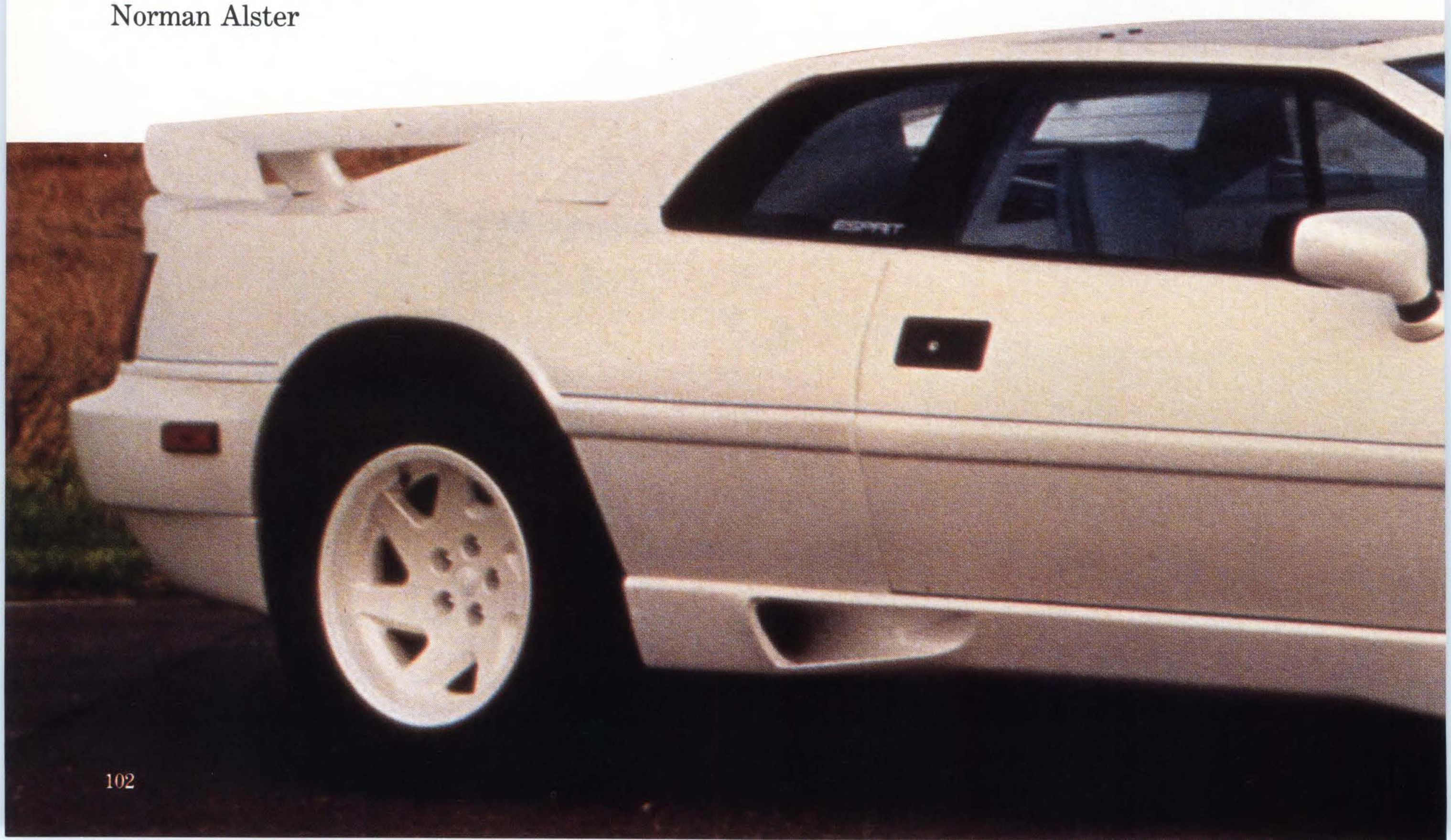


The spark timing module on the 1977 Oldsmobile Toronado was the first application of the microprocessor to engine control. The MISAR (Microprocessed Sensing and Automatic Regulation) system used a two-chip set from Rockwell Semiconductor.

Like living things, cars consume and process fuel and expel waste. They are, by definition, mobile. They react to external conditions. Microprocessors have allowed vehicles to master the mechanics of nutrition, metabolism, and motion. Now, little more than ten years after the first automotive microprocessor, vehicle electronics is bringing the car closer to a central nervous system and an ever more sophisticated sensory apparatus.

It was environmental crisis that hastened the pace of automotive evolution. In response to air pollution and energy shortages, the U.S. government required auto makers to reduce exhaust emissions and improve fuel economy. Each of these goals was independently daunting, and the task was complicated by the fact that improvements in controlling emissions generally came at the expense of fuel economy. Only precision microprocessor-based control of engine functions allowed simultaneous progress toward both goals.

The spark timing module on the 1977 Oldsmobile



Little more than ten years after the first automotive microprocessor, electronics is bringing the car closer to a central nervous system and an ever more sophisticated sensory apparatus.

Toronado was the first application of the microprocessor to engine control. The MISAR system (Microprocessed Sensing and Automatic Regulation) was based on a two-chip set from Rockwell Semiconductor. The 10-bit microprocessor housed I/O ports, scratchpad registers, I/O registers and analog-to-digital conversion circuitry. A second chip contained 10,240 bits of read-only memory. The PMOS (for its high immunity to noise) processor gathered information from sensors on engine vacuum, engine speed, coolant temperature, and crankshaft position. The Rockwell processor compared the gathered data with 350 preprogrammed data points to specify the optimal moment for the distributor to fire each cylinder. With MISAR, the auto industry had taken its first step towards fuel efficiency—coaxing the Toronado from a neolithic 13.8 to a slightly less barbaric 15 miles per gallon.

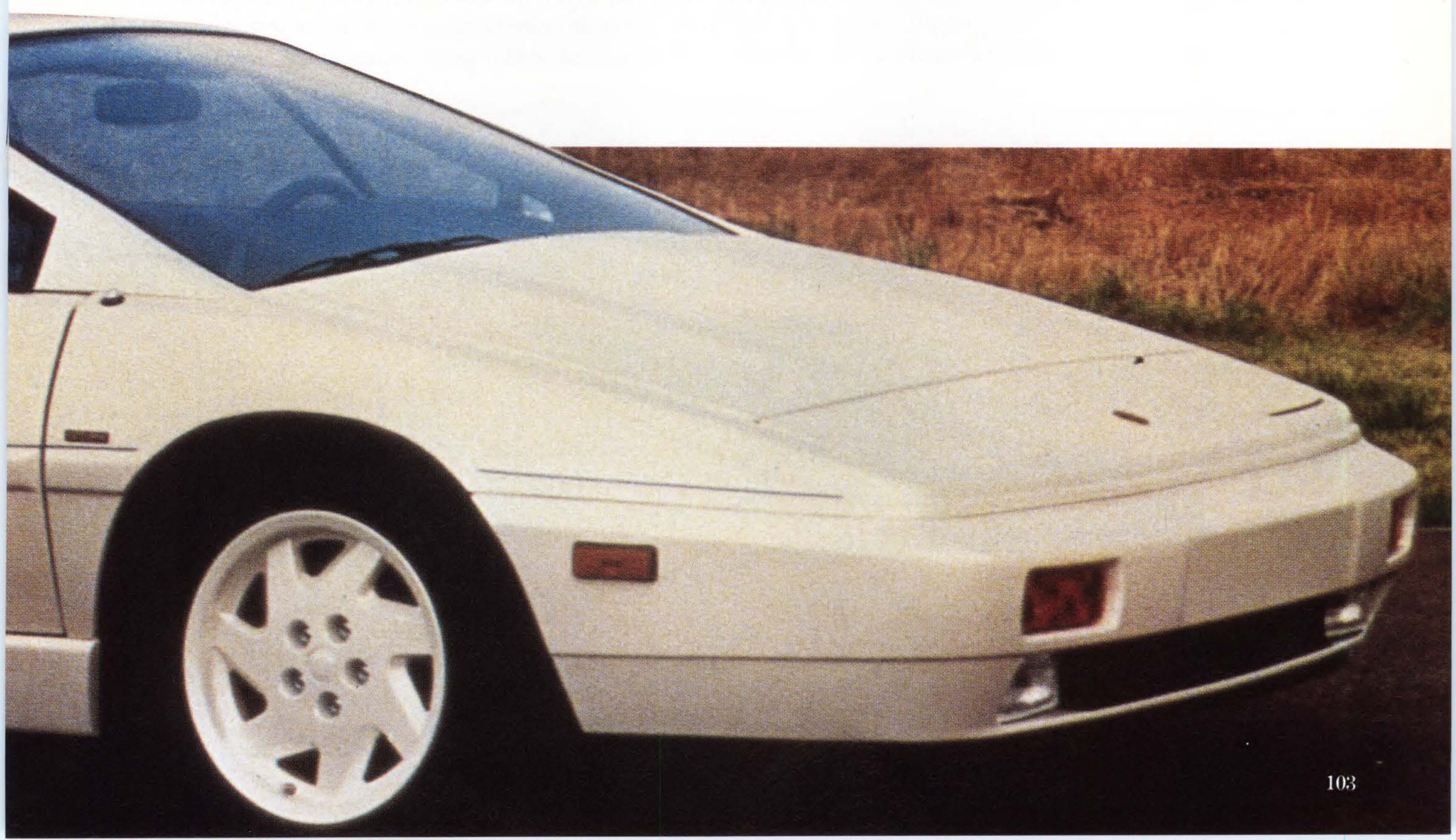
Exhaust emissions mandated for reduction by the federal government were of three different types: carbon monoxide, hydrocarbons, and nitrogen oxides. The best way to reduce them, it turned out, was by hewing to a balanced diet—more precisely, by achieving an optimal air-fuel ratio of 14.6 to 1. This stoichiometric ideal became the Holy Grail of microprocessor-based fuel injection.

The evolution of Ford's electronic fuel injection shows how auto makers learned to achieve ever finer control through ever more powerful microprocessors. Ford's first engine controls, based on a Toshiba microprocessor, governed spark timing and firing, along with exhaust gas recirculation, but did not have the processing power to also handle carburetion. By 1980, however, a customized version of Motorola's 6800 was able to provide central fuel injection: all cylinders were nourished through the engine manifold by a single microprocessor-controlled fuel mist.

In 1984, Ford went to a 16-bit microcontroller that was custom designed by Intel. With the speed and precision of 16-bit multiply and divide capabilities, the new microprocessor-based controls (known as EEC IV) were able to deliver fuel independently to each cylinder. Instead of hosing imprecise blasts into the engine manifold, EEC IV calculated air volume in each cylinder before directing the appropriate portion of fuel. An eight-cylinder engine operating at 6000 RPM required a decision cycle—including input, calculation, and actuation—of just 2.5 milliseconds, notes Frederick Phail, Intel's automotive strategic marketing manager. "That was the rule of thumb. We had to get everything done within that time period."

Microcontrollers—consisting of processor, memory, and I/O—are the devices normally used for engine con-

The 1988 Lotus Esprit Turbo features some of the most advanced electronic suspension technology. Performance and luxury vehicles are generally test beds for new electronics.



Braking, suspension, and transmission have all begun to come under microprocessor control.

trol. The 68HC11, designed jointly by Motorola and Delco, was the first single-chip microcontroller for automotive use. The first 16-bit automotive microcontroller was, as noted, the Intel-designed device at the heart of Ford's EEC IV module. A 32-bit microcontroller, developed jointly by Motorola and GM's Delco Electronics, will be introduced late next year. The first CMOS microcontroller was RCA's 1802, the brains of Chrysler's early controls. Unlike Ford and GM, Chrysler wanted its engine controls under the hood. Operating temperatures exceeding 100°C eliminated both bipolar and NMOS as viable options.

Handling improves

As auto makers learned to bring the basic alimentary, or fuel-related, functions under control, they began to examine the potential of microprocessors for mastering the mechanics of motion. Now, braking, suspension, and transmission have all begun to come under microprocessor control.

Anti-skid brakes, for example, use microprocessors to sift through sensor inputs on wheel speed. If the processor detects rapid deceleration, it orders solenoid switches to modulate hydraulic pressure to the wheels. Newer systems can pump and release the brakes 12 or more times per second in order to slow down a skidding vehicle and at the same time prevent the brakes from locking up. The processing power required by anti-skid brakes is comparable to that required by engine controls, notes Jack Morgan, vice president and director of the auto segment of Motorola's Semiconductor Products division. But the algorithms are much less complex, adds Morgan, and the program memories are accordingly smaller.

As has fuel injection, anti-skid systems have grown ever more sophisticated with advances in processing power. Whereas the simplest systems use 4-bit processors to control only the two rear wheels, advanced systems use 16-bit microcontrollers for independent control of all four. High-end systems, such as Bosch modules built around Intel's 16-bit 8096, even prevent wheel spin during rapid acceleration on slippery surfaces.

Electronically controlled suspension is also evolving rapidly. Britain's Group Lotus Plc (acquired by GM in 1986) has been a leader in this technology, which is now inching down the luxury ladder. The 1988 Lincoln Continental uses an Intel 8096 controller for automatically adjusting air springs at each wheel to provide optimum handling, leveling, and stability. Sensors

The 1988 Lincoln Continental uses an Intel 8096 controller for automatically adjusting air springs at each wheel to provide optimum handling, leveling, and stability.

monitor the turning rate and angle of the steering wheel, the car's height—at front and rear—from the road surface, and other parameters. Sensed data goes to the processor, which varies the amount of air in the springs.

Microprocessor-controlled transmissions have lagged behind other advances in vehicle control, but soon, according to Mark Grant, director of advanced automotive products at National Semiconductor, they will offer the handling advantages of manual transmissions. Grant says such systems, which feature automatic shifting of electronically controlled gears, will be less prone to wear and will offer clutch-avoiding drivers better acceleration and a sporty ride.

No nagging, please

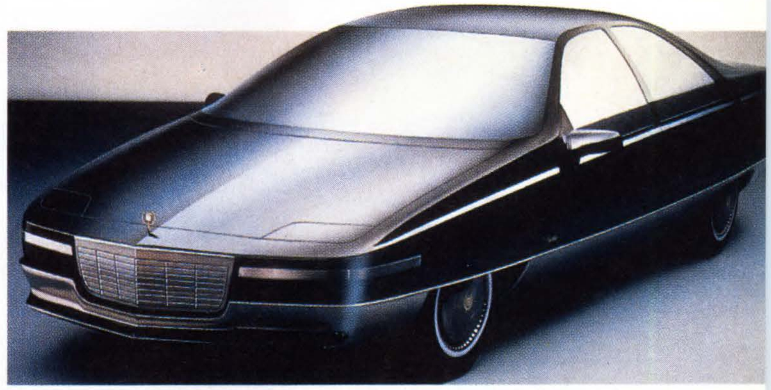
But despite auto electronics' successes, its evolution has not been without some fits and starts. Along the way, drivers gave auto designers some valuable lessons on what they *didn't* want from microprocessors. No nagging, please: That was the clear message recorded at Chrysler when its voice warning systems (based on TI chips) bombed. Chrysler dealers were flooded with complaints, and within months Chrysler offered a switch for silencing the maddening intruders.

The disappointing performance of digital speedometers has also provided a marketing lesson to car makers: Motorists are not impressed with virtuoso electronics that provide no practical benefit. Most drivers now opt for read-at-a-glance analog displays.

Less frivolous new electronics applications extend the sensory capabilities of cars. For example, infrared systems being tested by General Motors cut through darkness, fog, and rain. GM is also experimenting with several types of RF signals, hoping to produce an effective warning system for drivers as they back up or park (a major source of pedestrian accidents). Such systems would signal parkers of objects in their paths. The infrared vision and back-up features represent practical improvements that make the car more responsive to its environment, but they're still too expensive to implement.

Cars need a bus

Microprocessor-based systems have developed a reproductive life of their own within vehicles. Cars today may contain five or more processors, each monitoring sensors and controlling actuators. If there is a factor inhibiting the further application of the microprocessor in cars, it is the wiring required to tie all those chips, motors, and sensors together.



This concept car from Cadillac, the Voyage, would allow computer-controlled switching between rear-wheel and four-wheel drive. Other features on the drawing board include electronic-controlled transmission, anti-skid brakes, and a navigation system with color display.

Wiring harnesses are increasingly heavy, unwieldy, and difficult to service. Some car doors are stuffed with fifty or more cables—hence the incentive for auto makers to implement multiplexing, a kind of centralization of the automotive nervous system. Multiplexing would allow proliferating electronic subsystems to communicate and share sensors along a single electronic bus.

First-generation networking chips such as Intel's 82526, which implements a multiplexing protocol co-developed with Robert Bosch GmbH, have established the feasibility of this automotive central nervous system.

> Microprocessor-controlled transmissions will be less prone to wear and will offer clutch-avoiding drivers better acceleration and a sporty ride.

Elements of multiplexing have already been implemented on gadget-stuffed luxury vehicles like the Cadillac Allante and the Chrysler New Yorker. On sticker-shock specials like these, the benefits of multiplexing are the greatest, as is the potential for passing along added costs to the buyer. The costliness of smart-power integrated circuits is perhaps the key factor inhibiting wider implementation of multiplexing. If the cost per node can be substantially reduced, the evolutionary logic of a centralized nervous system will be abetted by economic logic. EDN

Norman Alster, a freelance writer living in Cambridge, Massachusetts, is a former senior editor of Electronic Business.

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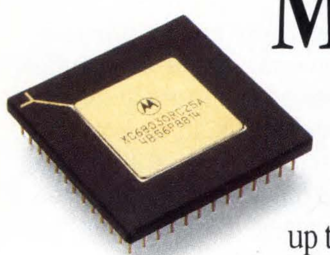

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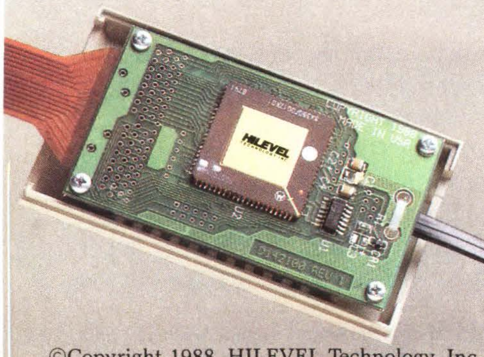

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The microprocessor chips out a new industry

Tim Scannell

The microprocessor has had a tremendous impact on everyone from grade school children to supermarket checkout clerks to corporate CEOs. However, when Intel Corp. released its first influential little chip in 1971, computers and data processing were not exactly what the company had in mind for its future.

Robert Noyce, Intel's head, and engineers Ted Hoff, Stan Mazur, and Federico Faggin, who developed the 4004 microprocessor, initially thought applications for the chip would be limited to hand-held calculators and some other, rather mundane, items.

That first chip, in fact, came out of a project initiated by Busicom, a Japanese calculator manufacturer. The company had asked Intel—a spin-off of Fairchild Semiconductor—to develop an integrated circuit for a new generation of small calculators. Busicom used the resulting chip, but later—seeking a price break—granted Intel the right to market it to other manufacturers. Thus, an industry was born.

Auspicious beginnings

Advertisements for the 4004 first appeared in the fall of 1971. Handling the initial ad campaign was Regis McKenna, who had just established a public relations firm and would go on to play a major role in promoting such companies as Apple Computer. To write the manuals for the 4004, Intel called upon a young engineer it had on the payroll at the time—Adam Osborne—who would later build one of the first luggable personal computers and thereby launch the portable computing industry.

It wasn't until mid-1972, however, that the microprocessor took off as the heart and soul of an infant computer industry. That's when Gary Kildall, a young computer science professor at the U.S. Naval Postgraduate School in Monterey, California, took an interest in the 4004 after seeing one offered for $25 in an ad pinned to the school bulletin board.

In July 1974, *Radio-Electronics* told how to build an Intel 8008-based computer called the Mark-8, designed by electronics hobbyist Jonathan Titus, now editor of EDN.

Kildall didn't have a plan for the cut-rate chip, but he liked to play with computers, and here he had an honest-to-goodness computer-on-a-chip. It wasn't long before he was collaborating with Intel—first as a one-day-per-week free consultant, and then as one of the first software developers for Intel's new 8-bit 8008. Eventually, he produced Control Program/Monitor (CP/M), the operating system for 8080- and Z80-based computers that was his ticket to fame and fortune. CP/M became the first serious operating system for the early microcomputers, and it managed to hold onto this lead until Microsoft and IBM unveiled MS-DOS and PC-DOS in 1981.

Without question, the first machine to have a major impact on the fledgling microcomputer industry was a $397 kit sold by an Albuquerque, New Mexico-based company called Micro Instrumentation Telemetry Systems, or MITS. Called Altair, after a fictional planet on the Star Trek television series, the system actually got its start because of good, old fashioned competitive journalism between two leading electronics magazines at the time: Radio-Electronics and Popular Electronics.

In July, 1974, Radio-Electronics carried an article describing how to build an Intel 8008-based computer called the Mark-8, designed by electronics hobbyist Jonathan Titus, now editor of EDN magazine. The Mark-8 was little more than an engineering trainer that demonstrated functions of the 8008 microprocessor, but it was, nevertheless, a functioning computer.

Titus' article and others published in Radio-Electronics put the magazine clearly ahead of its closest competition, Popular Electronics. PE's editorial director, Arthur Salsberg, and technical editor Les Solomon were furious. Both had been searching for some kind of computer story to ride the growing crest of interest in microprocessors, and here their publishing rival had beat them to the punch. Solomon had received a lot of proposals and design ideas, but none had impressed him as worthy enough to be a cover story. None, that is, until he met Ed Roberts, founder and president of MITS.

Roberts was fascinated with the idea of a computer kit. He was also desperate to revive his small, struggling company with a new product. With encouragement from Solomon, he and the two engineers on his staff immediately set about designing a computer based on Intel's new 8080. Another MITS employee, technical writer David Bunnell—who went on to found Popular Computing and is presently editor-in-chief of PC World—helped with the documentation. Roberts eventually delivered a system to Popular Electronics, but the machine on the magazine's January, 1975, cover was only a mock-up, an empty box with a few flashing lights, since the original system had been lost in the mail.

The MITS Altair was priced at $650 fully assembled or $397 in kit form—an impossible price considering that Intel charged a little less than that for an individual 8080 chip which Roberts had bought in quantity at a discount. It also offered 256 bytes of memory, a mere blip on today's memory scale but state-of-the-art by those early standards. Roberts hoped to sell at least 200 of his computer kits to help pay off his company's debts; in fact, he sold many more than he could supply, building up a backlog of about 4000 orders within the first two months.

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The tiny Altair was a spark that ignited a flame, attracting the attention of the Homebrew Computer Club, a group of early micro enthusiasts in Menlo Park, California, that included Apple Computer founders Steve Wozniak and Steve Jobs. It also piqued the interest of a young Harvard University freshman, William Gates, who was then dabbling in micro software and who would later establish the DOS computing standard. Gates and a friend, Paul Allen, wrote a form of BASIC for the Altair, which they sold to MITS. Allen stayed on as MITS' first software director, and Gates changed the name of the company he and Allen had formed—called Traf-O-Data—to Microsoft. Today, Microsoft is one of the largest micro software companies in the world.

Over the next few years, the number of small computer companies grew by leaps and bounds. The innovative Altair was followed by a computer from Southwest Technical Products that used Motorola's 8-bit 6800 processor. A friend of Gary Kildall, John Torode, formed Digital Systems, which later became known as Digital Microsystems. Other early companies included Vector Graphics, Sphere, Loving Grace Cybernetics, Kentucky Fried Computers, and even the Itty Bitty Machine Co., which based its name on the initials of another, somewhat larger, computer firm. IMSAI Manufacturing, of San Leandro, California, under the marketing direction of head William Millard, was the first of the new companies to target businesses, not hobbyists, as customers, eventually racking up sales of over $1 million.

A lot of people took note of IMSAI's success, among them Charles Tandy, then president and CEO of Tandy Corp., the company behind the chain of Radio Shack stores. Apparently, Tandy was "forced" to become a computer maker when Millard refused to let Tandy invest in IMSAI. Radio Shack buyer and engineer Don French had carefully examined the MITS Altair when it was introduced and had been campaigning to launch a development project of his own. Eventually, he caught the attention of a young vice president of marketing, John Roach, who is now Tandy's president and CEO.

The TRS-80 Model I—Tandy's first microcomputer—was officially unveiled in New York in August 1977. The system was priced at $399, and offered a basic 4k bytes of memory, a Z80 processor, Basic, and slow and awkward cassette tape storage. Radio Shack expected to sell 3000 TRS-80s a year, but after a month it had already pushed 10,000 units through its retail outlets—the same number MITS had managed to sell in a year.

The floodgates open

By 1980, personal computers accounted for 12.7 percent of Radio Shack's total North American sales, a fact that did not go unnoticed in the electronics market. Other companies soon came out of the woodwork, including Nolan Bushnell's Atari and Commodore, with its PET system. Many companies chose to appeal to the non-computing consumer rather than the knowledgeable computer hobbyist. Among these were Texas Instruments, which unveiled its TI-99/4 computer, and Great Britain's Clive Sinclair and his innovative and inexpensive ($99) ZX-80 computer (later marketed by U.S. watchmaker Timex Corp. for $50 under the name ZX-81.)

Tandy itself launched a series of other products—including a pocket computer (a fancy pocket calculator, actually), a color computer, and the TRS-80 Model II. Tandy also unveiled a laptop computer, the Model 100, that was assembled in Japan and featured a liquid crystal display, built-in software, a built-in modem, and a CMOS processor. The system operated on four penlight batteries.

Tinkering with success

In the meantime, a new competitor had suddenly risen in the form of two college classmates who had decided to capitalize on each other's talents and start a computer company. Steve Wozniak ("Woz" to his friends) was the electronics tinkerer, forever working out problems on scraps of paper and devouring circuit diagrams and minicomputer manuals like someone else might eat popcorn. Steve Jobs, on the other hand, was the marketing genius. He had a hobbyist's love for electronics and the early computers, but he also knew how to sell them to the public.

Wozniak had first ventured into computer design when in high school. He and a friend, William Fernandez, constructed a small system out of the discarded and rejected electronics parts that seemed to fill and overflow the trash bins of Silicon Valley. The computer resembled an Altair, replete with blinking lights and switches. They called it the Cream Soda Computer, because that is what they mostly consumed as they worked many a late night building their machine. When it was completed, Wozniak and Fernandez immediately called the local newspapers to tell their story. Both had dreams of riches and fame in their head. However, when the system was plugged in, it ran for a few moments and then began to billow smoke. Wozniak's first computer had failed.

In 1973, having just finished his junior year at college, Wozniak landed a summer job at Hewlett-Packard Co., where Fernandez was already working. Wozniak liked HP so much, he decided to put off college and continue working there. He was assigned to the company's calculator division, and while there, he continued to pursue his greatest love—video games. Wozniak eventually wrote his own game, Breakout, which he and marketer Jobs sold to Atari's Nolan Bushnell for the unprincely sum of $700 (Jobs had spent some time working at Atari and was a friend of Bushnell).

Woz the wiz designs an Apple

Like many electronics aficionados of the time, Wozniak was an avid member of the Homebrew Computer Club, and it was there that he and Jobs introduced their first Apple computer, the Apple I. MOS Technology had just come out with its own processor, the 6502, which it was selling for the then-revolutionary low price of $20. Wozniak bought the chip and designed a board and processor around it, painstakingly installing connections for both keyboard and monitor. The finished Apple I didn't have a power supply, a case, or even a keyboard, but its debut at the Homebrew club was an immediate success. The members went wild; they not only liked the design

Early microcomputer companies included Loving Grace Cybernetics, Kentucky Fried Computers, and even the Itty Bitty Machine Co., which based its name on the initials of another, somewhat larger, computer firm.

(which Wozniak freely circulated), but they wanted to buy a finished product. This was a tall order considering Wozniak had hand-wired the prototype. To raise the $1300 needed to design and manufacture a printed circuit board, Jobs sold his Volkswagen microbus and Wozniak sacrificed his HP programmable calculator.

Wozniak was content to sell the Apple I to Homebrew club members and other hobbyists, but Jobs had been bitten by the entrepreneurial bug. He convinced Paul Terrell, founder of the Byte shops and one of the first retailers of computer products, to place an order for fifty computers. There was a hitch, though—Terrell wanted them completely assembled, not a box of parts or a kit.

With purchase order in hand, Jobs and Wozniak managed to get a 30-day credit from vendors to buy parts. They worked out of Jobs' garage, spending late nights with hot soldering irons. Jobs paid his sister a dollar a board to plug in chips, and, like a high-tech Tom Sawyer, even convinced friends to pitch in. Just one day before deadline, Jobs delivered the fifty fully assembled machines.

The fifty Apples sold almost immediately, and Wozniak and Jobs continued to build and sell more (for $666 each) through local computer storefronts. They only sold about 200 completed computers—not because demand dwindled, but because Woz had already mapped out plans for the next-generation Apple machine—the Apple II. Unlike the Apple I, the II was a fully integrated personal computer that offered the processor, keyboard and connectors all in the same box. You simply plugged it in and it ran. Its official debut took place in early 1977 at Jim Warren's West Coast Computer Faire and sold for $1200. It was a huge success.

Growth and growing pains

Apple was clearly on a roll. In late 1976, Jobs had convinced A.C. (Mike) Markulla—a former executive with Intel and Fairchild who had "retired" at the geriatric age of 34 to do absolutely nothing—to not only join Apple, but invest more than $90,000 in the young company. Jobs had also talked public relations wizard Regis McKenna into representing the young company and had convinced Wozniak to give up his full-time job at HP to devote all his energy to Apple. (As the story goes, Wozniak had originally approached HP with the design for the Apple I and was rejected because HP brass thought his design could not be easily mass produced. HP's own personal computer, the HP-85, was introduced in January 1980.)

Apple's history is not, however, without a few worms; the company did have a few failures. One of these was the Lisa, said to be named after a girlfriend of Steve Jobs. The Lisa was to be a totally different type of computer, using a bit-slice architecture for speed and offering a mouse pointing device—first developed at Xerox's Palo Alto Research Center—as well as built-in integrated software.

Unfortunately, the Lisa project drifted on for many years. Jobs was in charge of the project at first, but later gave up the role to work on another computer he had envisioned after visiting Xerox's PARC. In keeping with the Apple motif, Jobs code-named his

The original TRS-80 microcomputer was unveiled in August 1977. The system cost $399 and offered a basic 4k bytes of memory, a Z80 processor, Basic, and cassette tape storage.

> Adam Osborne was the Cary Grant of the industry. While others traveled to computer shows and clubs with their boards and disk drives slung under one arm and their knapsacks under the other, Osborne wore suits and ties to even the most basic affairs.

new project Macintosh.

One other project that failed, but provided some worthwhile education, was that involving the Apple III. Unfortunately, the project was doomed from the start: The system was developed by a committee of engineers, not a single person, and it was the first Apple project that did not involve Steve Wozniak. Early models of the system would suddenly crash and fail. Soon, what had been dreaded the most began to happen: Apple III systems began returning in droves from the dealerships.

A little help from friends

The Apple II probably would have achieved success on its own, but other products had a lot to do with propelling it to the top. One of these was VisiCalc, a spreadsheet and financial analysis program developed by a thin, bearded Harvard MBA student named Dan Bricklin. VisiCalc was an immediate success, selling at the rate of 500 programs per month at first and quickly rising to 12,000 programs per month in 1981. In its wake, it took the Apple II. Whereas the hardware had established the vehicle, Bricklin's software had mapped out the route.

The success of VisiCalc was like a shiny lure to others who had been carefully watching the rapid growth of the microcomputer. One of these was a young programming consultant, part-time disc jockey, and teacher of transcendental meditation. It was while watching a football game on television on New year's Day, 1979, that Mitchell Kapor supposedly made the decision not to go back to college to pursue his doctorate, and to devote all his time to a relatively new technology called the personal computer. As it turns out, it was a decision that would have a major impact on the microcomputer industry.

The computer community in Boston, where Kapor lived and worked, was relatively small at that time, keeping in touch through such organizations as the then-tiny Boston Computer Society. So, it was not surprising that Kapor was a good friend of both Bricklin and VisiCalc co-developer Robert Frankston. However, Kapor saw some deficiencies in VisiCalc: While it could easily manipulate words and numbers, it had no graphing or plotting capabilities.

Kapor immediately started working on add-on products to VisiCalc, becoming one of the first independent third-party software developers. He spent the entire summer of 1981 working on graphics and plotting software for VisiCalc, and in October of that year he unveiled VisiTrend and VisiPlot. In November, he sold the rights to the programs to Bricklin for the then unprecedented amount of $1.8 million. In April, 1982, he founded Lotus Development Corp. and went on to develop the best-selling 1-2-3.

The first "luggable"

By the summer of 1980 there were more than a dozen hardware and software companies in existence that were all doing fairly well. Apple had the biggest slice of pie, of course, but there was plenty of room for the smaller computer makers. There was also enough room for at least one more—at least that's what popular computer columnist, technical author, and outspoken industry pundit Adam Osborne thought.

Back then, Osborne was the Cary Grant of the industry. While others traveled to computer shows and clubs with their boards and disk drives slung under one arm and their knapsacks under the other, Osborne wore suits and ties to even the most basic affairs. Such was his nature, proper and professional.

As a prolific writer, Osborne recognized the role of the computer as a tool. However, he was unhappy with the fact that someone with such a mobile lifestyle should be tied down to a desktop-bound personal computer. Why couldn't these machines be a little lighter, a little more compact, and durable? Why couldn't they be portable? Thus was borne the idea for the Osborne I. It wasn't the first portable computer; IBM had developed a prototype portable computer in one of its laboratories some years before. However, it was the first commercially available and luggable computer.

In designing the system, Osborne insisted on one thing: It had to fit under a standard airplane seat. This later became the linchpin of his ad campaign for the Osborne I. He also wanted to build a system that offered just enough technology to make it work, but not too much to make it a burden.

Osborne unveiled his machine in April, 1981, at what had quickly become the electronics maternity ward of Silicon Valley, Jim Warren's West Coast Computer Faire. It was based on a Z80 microprocessor, and it had 64k bytes of memory and all the standard interfaces. It also came equipped with software: CP/M developed by Gary Kildall, CBASIC from Gordon Eubanks, Basic from Bill Gates and Microsoft, and WordStar from Seymour Rubinstein's MicroPro. Eve-

ryone except Kildall agreed to take stock swaps and options in lieu of money. Osborne also offered various officer positions to his software SWAT team. Rubinstein was the only one who accepted, becoming chairman of the board.

The small and somewhat militaristic looking system was priced at $1795. It was the star of the computer show, prompting other computer makers to follow with similar products. Kaypro Corp. came out with a system that looked identical to the Osborne, as did Cromemco but at five dollars less. The future seemed bright that summer for the CP/M world.

The winds of change

The strong and steady winds that were blowing for such companies as Apple, Tandy, and a host of others suddenly changed direction on August 12, 1981. That is when mainframe-maker IBM Corp. decided to take a stab at the young but interesting personal computer industry.

IBM had assembled a team of 14 people in its Boca Raton, Florida, facility to totally devote their time to developing a personal computer. The team was headed by Philip (Don) Estridge, an engineer and IBM executive who had been transferred to Boca Raton in the late 1960s. Overseeing the entire operation was William C. Lowe, now an IBM vice president. They were given roughly a year to complete the project, from concept to finished product.

The group functioned as an independent business unit, working outside the normal business restrictions and red tape of IBM. To save time, they decided to acquire computer parts from other vendors—a first for Big Blue, which normally designed and constructed everything itself.

To supply software for the system, IBM turned first to Gary Kildall of Digital Research and then to Bill Gates of Microsoft. Kildall reportedly wasn't interested because he didn't want to get locked into IBM's tough non-disclosure rules that surrounded the new product. Gates didn't mind and quietly worked with a prototype of the PC in the back room of a bank building in downtown Seattle.

The IBM PC—officially dubbed the Model 5150—made its debut on schedule on August 12, 1981. First shipments were scheduled for September. The system featured an Intel 8088 processor running at 4 MHz, two 160k-byte floppy disk drives, 16k bytes of RAM (expandable to 64k bytes), and four expansion slots. It sold for $1,565—a little more than the Apple II.

The IBM PC was an immediate success, not only because it was backed by the formidable marketing muscle of IBM, but because it opened the industry to a variety of players involved in both hardware and software. Before the end of that year, IBM would ship 13,000 PCs from its Boca Raton manufacturing facilities. The small task force has grown from its 14-member beginnings to more than 10,000 employees worldwide, pumping $5 billion annually into IBM's coffers. Almost immediately, companies like Apple Computer took a back seat to IBM in the business computer world.

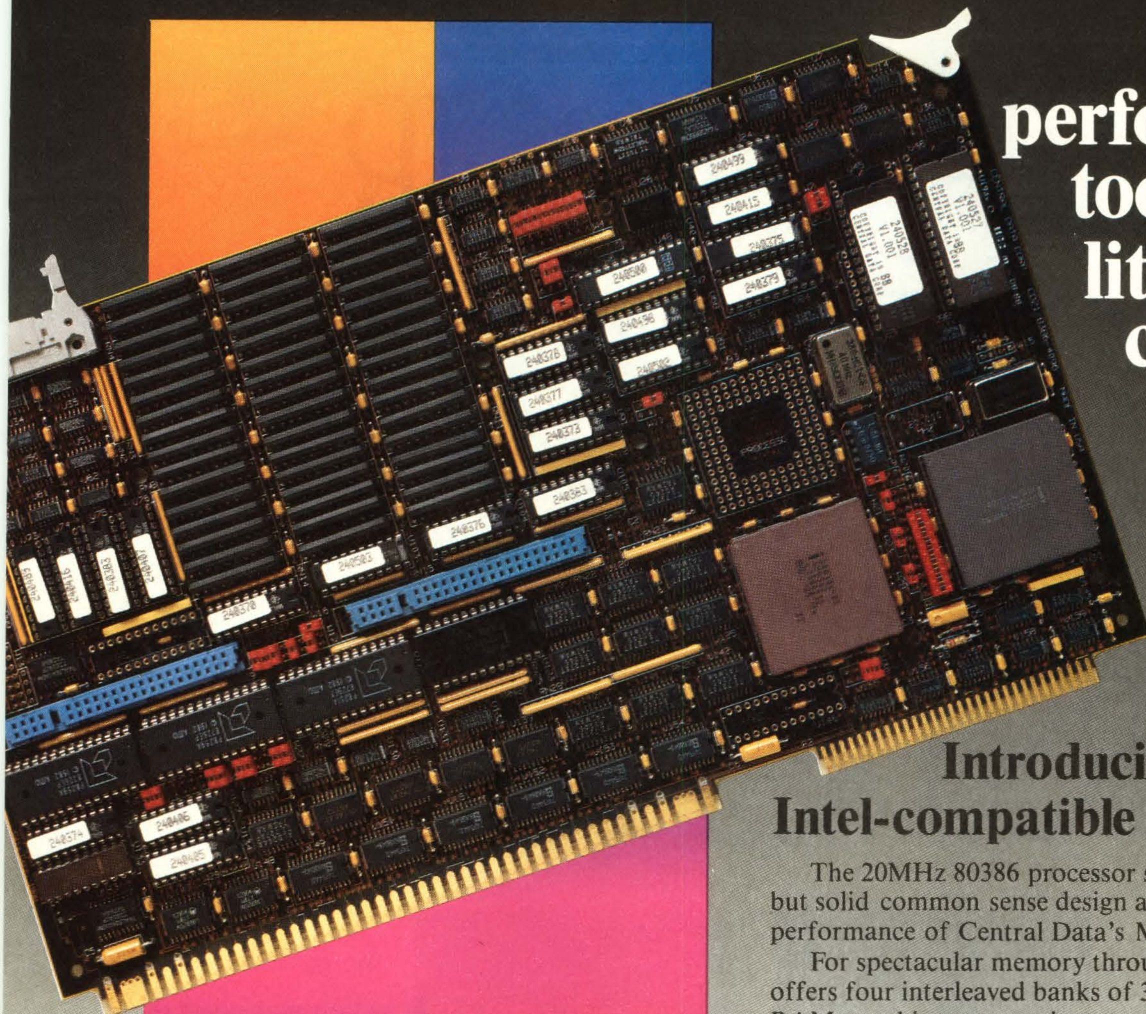
> Steve Wozniak and his friend called their first machine the Cream Soda Computer, because that is what they mostly consumed as they worked many a late night.

The microcomputer industry has come a long way since IBM decided to jump with both feet into the pool. There have been a number of advances in microprocessor technology, with chips getting faster and more flexible. Today, chips such as Intel's 80286 and 80386 are the standards for most business applications, while Motorola's 68000 series takes aim at graphics-intensive applications. Apple's Macintosh systems are based on the Motorola chips, the most recent entry being a Mac that sports a fast 68030 chip that can easily be coaxed into operating at a clock speed of up to 25 MHz. Workstations also use multiple-processor architectures, with individual chips dedicated to specific functions.

One recent trend in the industry is toward reduced instruction set computing (RISC) chip architectures. Basically, RISC speeds up processor functions by reducing the number of instructions built into a chip and relying on much simpler steps that are repeated at faster speeds. RISC research was originally conducted in the mid-1970s by IBM computer scientist John Cocke. In fact, IBM developed a prototype RISC processor as early as 1980, and it holds many of the patents on RISC architectures.

Today, nearly every major computer manufacturer is either experimenting with RISC designs or has unveiled a RISC processor. Among these are IBM with its RT PC, Sun Microsystems, Inc. and its Scalable Processor Architecture (SPARC) systems, and Mips Computer Systems, Inc. While most RISC chips are proprietary in nature, Motorola has developed and released a RISC chip, the 88000, that is being used by workstation builders as a platform for the UNIX operating environment. In fact, a consortium of vendors has even banded together to promote the chip as a standard. Called 88Open, the group includes such members as IBM, Data General Corp., and Apollo Computer, Inc. **EDN**

Tim Scannell is editor of Mini-Micro Systems.



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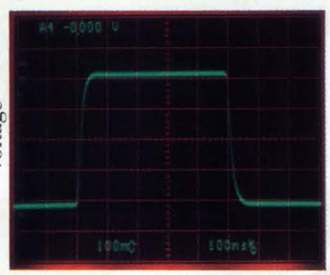

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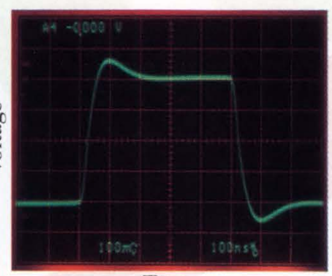

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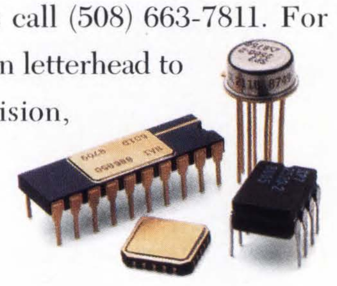

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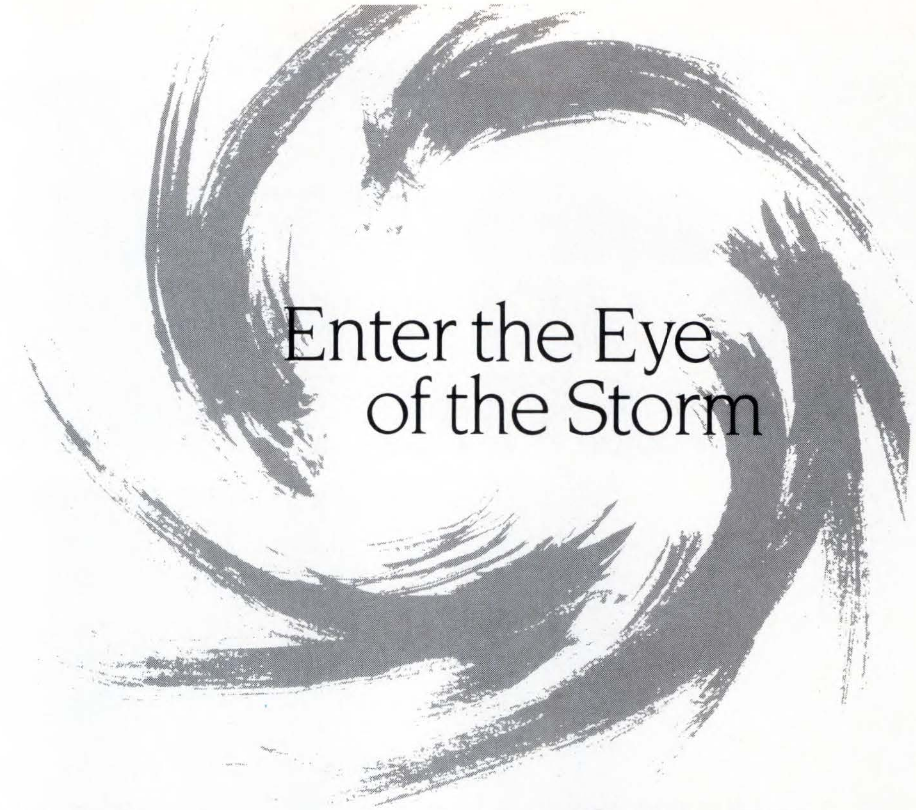

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THE SPECIAL REPORT MICROPROCESSOR

MICROPROCESSORS move slowly, but confidently, into space

Paul Kinnucan

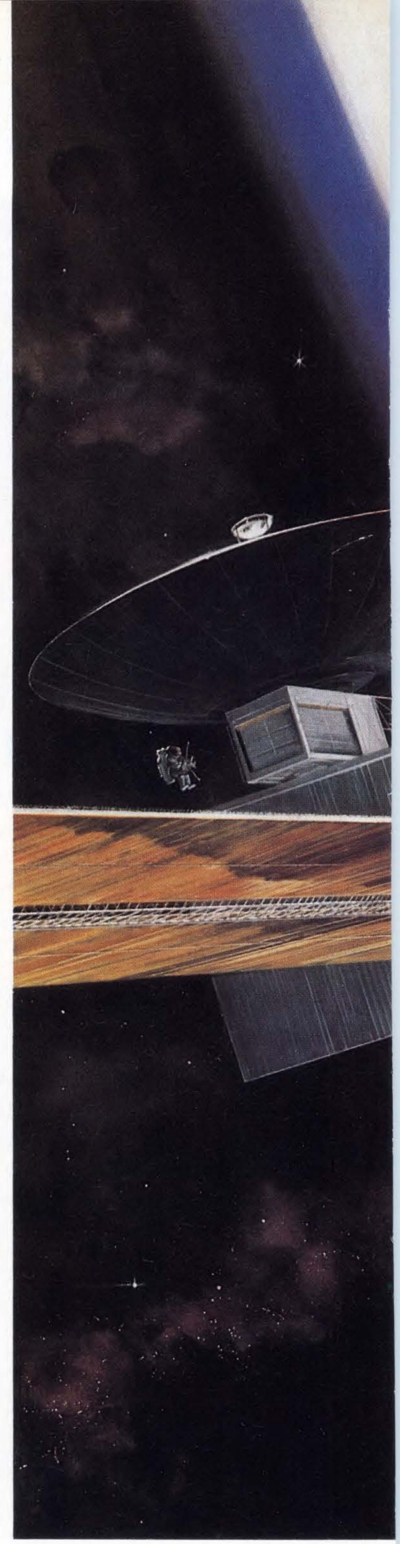
On-board spacecraft systems mean weight and intolerable launch costs, so most spacecraft control is from the ground. Microprocessors are making lighter systems ever possible, however.

For years pundits have been predicting that microprocessors will revolutionize space applications by enabling development of a new breed of automated satellites and spacecraft. Such automated space systems can be far less expensive to operate than current satellites, which require elaborate and costly ground-based monitoring and control facilities. Automated satellites can also reduce the vulnerability of space-based military intelligence and communications systems, which can be rendered inoperable by attacks on ground control facilities.

Microprocessors can benefit space systems in another way, many experts say. They can speed the flow of weather and earth resource satellite imagery to users by processing images in space, at the time of collection, rather than on the ground as now. In this way, microprocessors eliminate the time-consuming intermediate steps of transmitting raw images to the ground for processing and then relaying them to end users, such as TV stations, via satellite communications links.

Such benefits are still in the future, however. The reason? Automated control and data processing systems, even those based on microprocessors, exact a significant weight penalty. With launch costs running \$5000 to \$30,000 a pound, space-systems designers prefer to put into space only those components of a system—radio transponders, antennas, and TV cameras, for example—that are absolutely necessary there.

Moreover, putting automated control and data-processing systems into space increases the complexity of on-board electronics and hence the risk of a mission-

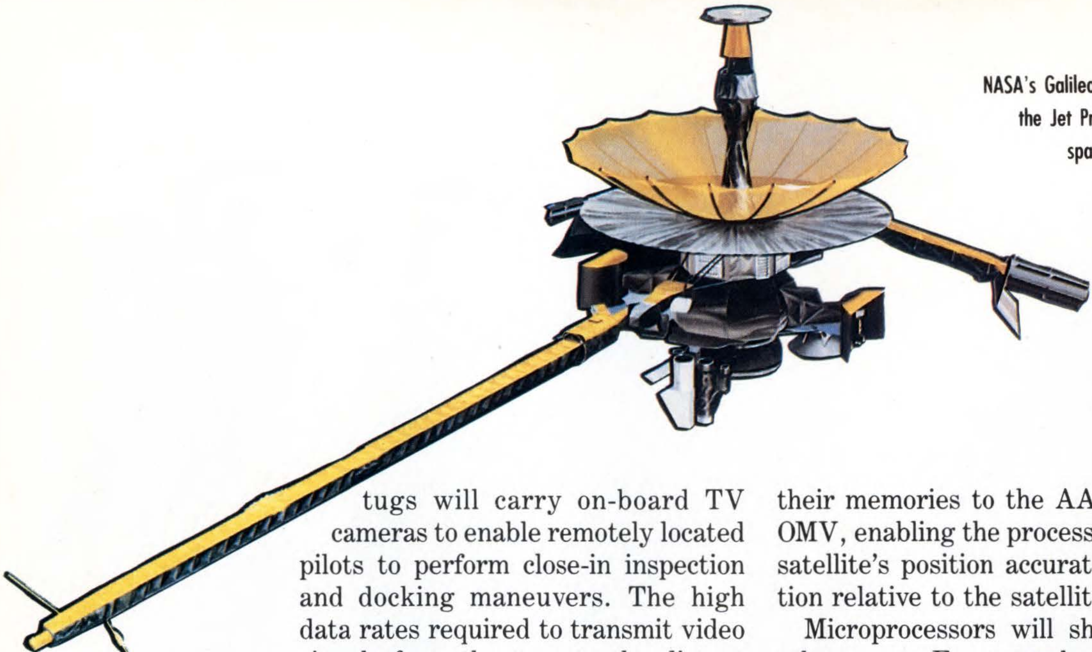


NASA's Orbital Maneuvering Vehicle, built by TRW and appearing here as a hovering disk-shaped craft near a docked Space Shuttle, can aid in the construction of the future Space Station by moving large structures into place. Microprocessors will play an extensive role in the OMV because of their low weight and power consumption.

endangering component failure. Since even in the Space Shuttle era, most satellites cannot be recovered—or, if they can, only at extreme cost and risk to astronauts—satellite designers again prefer to avoid the additional complexity and chances of failure that on-board data processing and automated control systems can entail.

Recent developments, however, could change this bias against on-board data processing and mission control. NASA intends to deploy, beginning in the next decade, remotely piloted space tugs that will enable the retrieval of satellites from orbits beyond the Shuttle's reach and without risk to human pilots. The satellites could then be repaired on the Shuttle or the Space Station or on the ground and reboosted into orbit by a space tug. Space tugs will greatly expand the number of satellites that can be repaired and hence reduce the design penalty entailed in moving mission-control and data-processing functions into space.

Interestingly, space tugs themselves illustrate a benefit of moving automated systems into space. Because they will be remotely piloted from ground locations or from the Space Station or Space Shuttle, they will put a heavy load on NASA's already overburdened spacecraft-to-spacecraft and spacecraft-to-ground communications system. This is especially so since space



NASA's Galileo Jupiter mission spacecraft (developed by the Jet Propulsion Laboratory), was one of the first spacecraft to employ a microprocessor-based data-management system. Galileo was developed in the late 1970s by the Jet Propulsion Laboratory and originally scheduled to be launched in the early 1980s by the Space Shuttle. A series of problems with the Shuttle, most recently the Challenger disaster, has delayed the scheduled launch until late next year.

tugs will carry on-board TV cameras to enable remotely located pilots to perform close-in inspection and docking maneuvers. The high data rates required to transmit video signals from the tugs to the distant pilots will consume valuable bandwidth on NASA's spacecraft-tracking-and-control communications system, which will also have to support the Space Station, Shuttle, and other NASA spacecraft.

To reduce this load, NASA's first space tug, the Orbital Maneuvering Vehicle (OMV), now being developed by TRW Inc., will be equipped with a sophisticated autopilot that will enable it to find and rendezvous with satellites and other spacecraft without the need for human piloting. This, in turn, will eliminate the need for spacecraft-to-pilot communications for all phases of the mission except the final and critical inspection and docking maneuvers.

Not surprisingly, microprocessors will play an extensive role in the OMV because of their low weight and power consumption. For example, a Harris Corp. 80C86 microprocessor will perform signal processing and control functions in the OMV's rendezvous radar being developed by Motorola Inc. The radar will enable the tug to acquire and track spacecraft located up to 35 miles away.

Similarly, an AAMP microprocessor made by Rockwell International Corp. will be used in an on-board navigation system being developed for the OMV by Rockwell. The Rockwell microprocessor will compute the OMV's position, using information from radio navigation satellites to be launched in the next few years as part of the U.S. Navy's Global Positioning System (GPS). In addition to supplying position updates once a second to the OMV's autopilot and remote human pilots, the AAMP processor will also be responsible for locating navigation satellites as they rise over the OMV's horizon. At least four such satellites must always be in view for the navigation system to obtain an accurate radio fix.

Texas Instruments 9080 microprocessors in the GPS satellites themselves will also play a critical role in OMV navigation. The TI microprocessors will transmit ephemeris data (predicted satellite position) stored in their memories to the AAMP processor on board the OMV, enabling the processor to determine a navigation satellite's position accurately and hence its own position relative to the satellite.

Microprocessors will show up in the OMV in yet other ways. For example, a processor will be used to compress the video signal from the OMV's on-board TV cameras, thereby reducing communications traffic during the final inspection and docking manuevers to be handled by remote pilots.

In all these applications, the OMV's microprocessors are replacing functions once handled by dedicated logic or computers. The resulting weight savings—significant because each of the OMV's systems are replicated to assure reliable operation—translate into greater on-board fuel capacity and hence range. The OMV will be able to retrieve satellites orbiting some 1300 miles above the Earth's surface—more than 1000 miles above the Shuttle's maximum altitude.

When the OMVs, two of which are being developed, are deployed early in the next decade, they will not be the first spacecraft to use on-board microprocessors. Indeed, because of their low weight and power consumption, microprocessors have been replacing dedicated logic and computers in a variety of spacecraft systems since the late 1970s.

An application where microprocessors have become especially popular is spacecraft attitude-control systems (ACSs). Here, the microprocessor computes the spacecraft's current orientation vis-a-vis some celestial object, typically the sun, stars, or earth, using on-board sensors. If the orientation differs from one assigned by mission controllers, the microprocessor computes the degree and direction of force required to re-orient the spacecraft. This information is then communicated to on-board thrusters or momentum wheels that supply the required forces.

One of the first spacecraft to employ a microprocessor-based ACS was the Indian government's Insat-1 multimission satellite developed by Ford Aerospace in the late 1970s and launched into orbit in 1983. (Such long lead times between satellite development and launch are typical because of the scarcity of launch facilities). The Insat-1's ACS employed an 8-bit microprocessor built out of 4-bit 2901 slices. The Insat-1 satellite was notable in another way. It was the first satellite to simultaneously support voice communications, direct broadcast TV, and weather-data collection functions.

Other spacecraft that have, or will, deploy microprocessor-based ACSs include the Arabsat and Superbird multimission satellites and the U.S.'s GOES V geostationary weather satellite (all developed by Ford Aerospace), NASA's Galileo Jupiter mission spacecraft (developed by the Jet Propulsion Laboratory), NASA's Tracking and Data Relay Satellite System and its Gamma Ray Observatory (both built by TRW), and the Space Shuttle. The Space Shuttle will soon carry a so-called Two-Axis Pointing System (TAPS) that is being developed by NASA to enable the Shuttle to serve as a space platform for telescopes and other scientific instruments. According to John Azzolino, who heads the development of TAPS at NASA's Goddard Space Flight Center in Greenbelt, Maryland, TAPS will increase the Shuttle's pointing accuracy from 15 arc minutes to 4 arc minutes.

In all of these spacecraft, microprocessors are replacing a function once handled largely by discrete-circuit-based dedicated control logic. The resulting weight savings enable more fuel to be carried on the satellite, resulting in longer on-orbit lifetimes.

In some instances, the use of microprocessors in ACS systems to replace dedicated logic has resulted in decreased design costs. For example, Ford Aerospace has used the ACS developed for the INSAT 1 satellite in many follow-on satellites, adapting the system to varying mission requirements via software modifications. By reusing the same basic hardware, the company has been able to cut ACS design time—and hence costs—from 18 months to six months.

Such benefits will increase with the growing power of microprocessors. For example, most ACSs to date have used power-hungry TTL-based bit slice processors. The reason? The ACSs in these spacecraft are used to stabilize the spacecraft by counteracting the minute disturbances caused by solar winds, the Earth's magnetic field, and other environmental forces that buffet satellites in space. Initially, only TTL-based devices were fast enough to react to these disturbances and keep a spacecraft steady for clear images. With the advent of fast CMOS devices, it is now possible to reduce the power consumption of microprocessor-based ACSs—a significant benefit in spacecraft where on-board power systems typically generate no more than a kilowatt of power. As a result, current ACSs are turning to these devices. For example, NASA's TAPS system will employ an 80C86 CMOS processor from Harris Corp.

The National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satelites (GOES), under construction by Ford Aerospace & Communications Corporation, will provide improved capabilities for weather forecasting. GOES will have a microprocessor-based altitude-control system.

On-board data-management systems are another area where microprocessors have come to the fore in space applications. Here, microprocessors perform two functions. On the one hand, they unpack commands and data uplinked from the ground via telemetry systems and distribute them to other on-board systems such as communications repeaters or scientific instruments. On the other hand, the microprocessor takes data such as status information or sensor data from on-board systems and packs this information into a serial telemetry data stream for transmission to ground-based mission control facilities.

One of the first spacecraft to employ a microprocessor-based data-management system was the Galileo Jupiter mission spacecraft, developed in the late 1970s by JPL and originally scheduled to be launched in the early 1980s by the Space Shuttle. A series of problems with the Shuttle, most recently the Challenger disaster, has delayed the scheduled launch until late next year.

Spacecraft data-management systems typically require significant processing power because of the high data rates involved, especially in imaging missions such as Galileo. For this reason, spacecraft designers have resorted to distributed processing to overcome the limited processing power of microprocessors. For example, the Galileo spacecraft will employ four 1802 8-bit processors built by Sandia Laboratories. (Sandia licensed the 1802 technology from RCA and built radiation-hardened versions.) Two 1802s will handle command processing and distribution, and two others will control on-board data storage and transmission.

The U.S. Space Station, to be built, if all goes according to plan, in the mid-1990s, will take this distributed processing approach a step further. According to Clarence Pitman, Space Station Data Management System project manager at NASA's Langley Research Center, it will employ a high-speed fiber-optic local-area network, instead of serial point-to-point I/O links, to distribute the data-management load among multiple 32-bit microprocessors. Such a powerful system is needed, because the Space Station will play host to a far larger number of on-board systems than any previous spacecraft and will be constantly updated, creating a need for the expandability and flexibility only a local network can efficiently provide.

Although still in the preliminary design stages and subject to change, the Space Station's DMS will probably employ Intel 80386 microprocessors, according to Pitman, in order to take advantage of the huge body of applications software and powerful development tools available for Intel's popular microprocessor family. In addition, the fiber-optic network will probably be based on the Fiber Optic Distributed Data Interface (FDDI) standard to reduce interface costs for on-board instruments and systems. This will enable such devices to take advantage of the commercial interfaces expected to emerge around FDDI.

The growing use of microprocessors in space has not escaped the attention of semiconductor vendors. Until recently, most semiconductor makers have steered clear of space applications, in part because the market was minuscule compared to terrestrial applications. Also, space applications demand elaborate inspection techniques to assure reliability, plus special circuit design and manufacturing techniques to assure reliable operation in the face of the intense radiation encountered in space. Few vendors were willing to make the investment required to produce and inspect radiation-hardened microprocessors for such a small market.

Now, however, with the growth of the space market—and the military market, which always requires radiation-hardened parts—more microprocessor makers are entering the fray. Among those currently pursuing this market are Intel, Texas Instruments, TRW Inc., and Inmos Corp. This is in addition to Harris Corp. and General Electric (formerly RCA and now, recently acquired by Harris), traditionally the leaders in this field.

Such competition will foster the use of microprocessors in space not only by reducing parts prices but also by making available leading edge processors, such as the Intel 80386, in radiation-hardened versions.

Although microprocessors to date have played a fairly minor role in space applications, this will certainly change in the future. As the cost of launching and maintaining space systems decreases, as it is expected to do with the growing competition in launch services, users will be more willing to move mission-control and data-processing functions from the ground into space. Microprocessors will accelerate this trend by reducing the weight and power consumption penalties associated with adding on-board automatic control and data processing. Ultimately, users of weather, communications, earth resource, and scientific satellites will benefit by the reduction in operating costs and the speeding of information flow that will result from the migration of microprocessors into space.

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Paul Kinnucan, a freelance writer, lives in Milton, Massachusetts.

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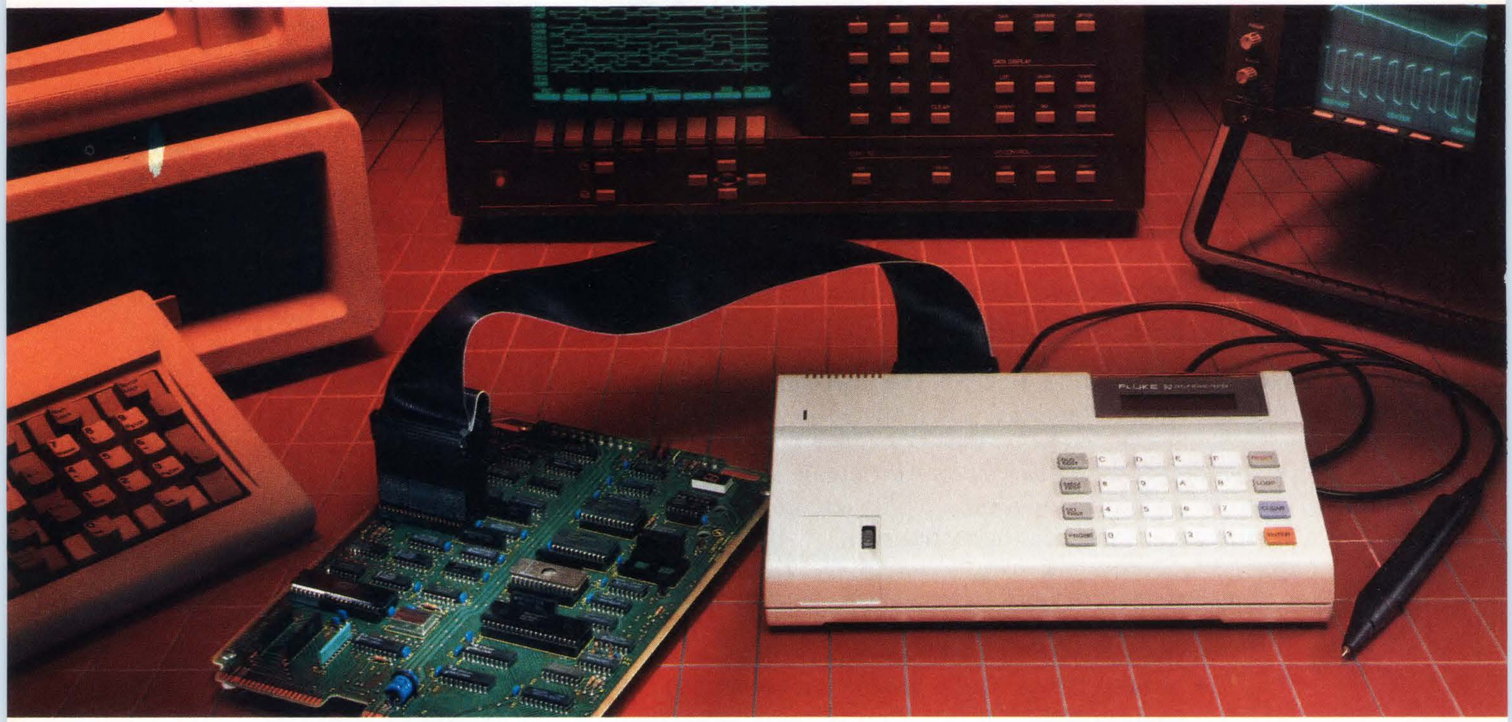

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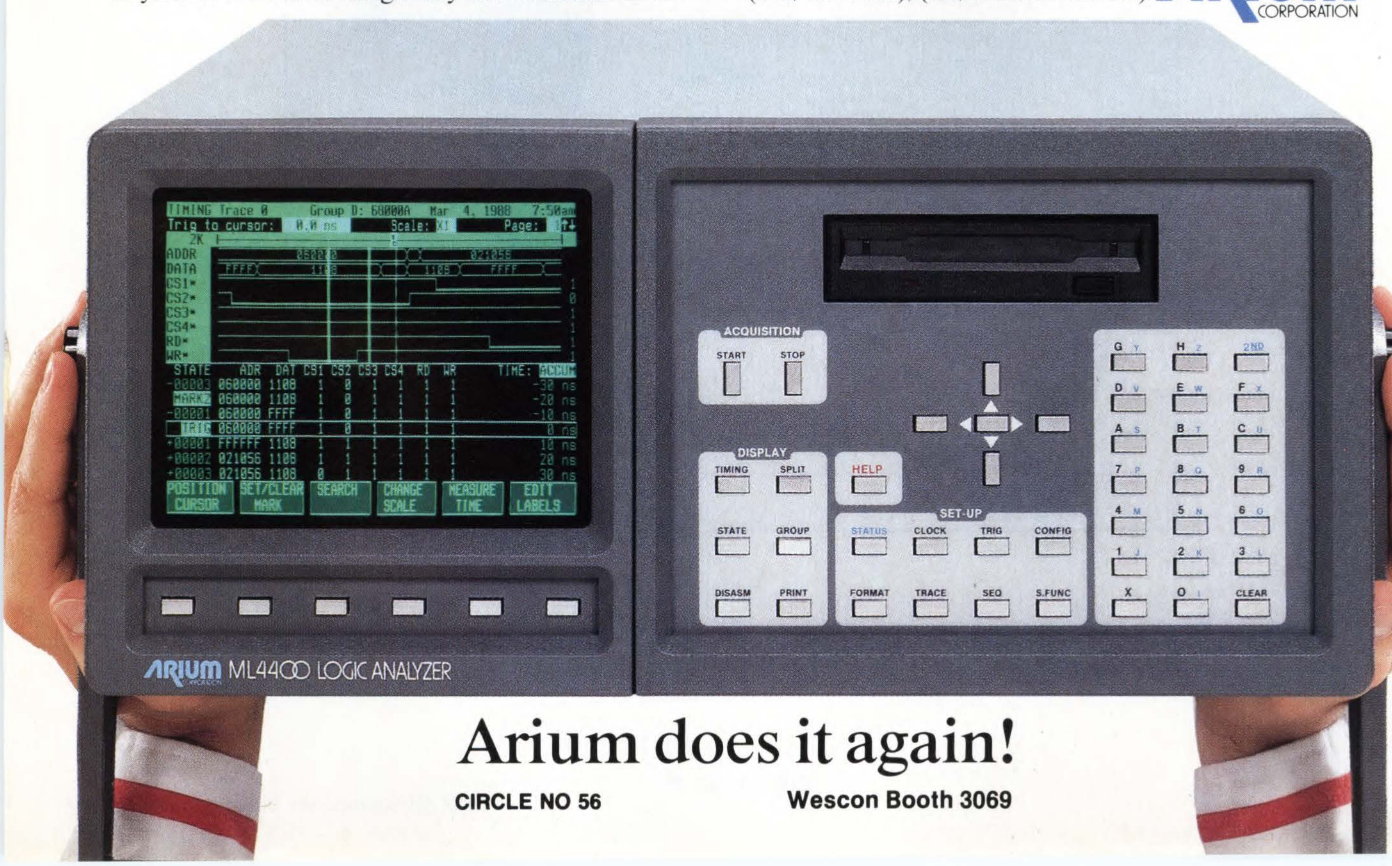

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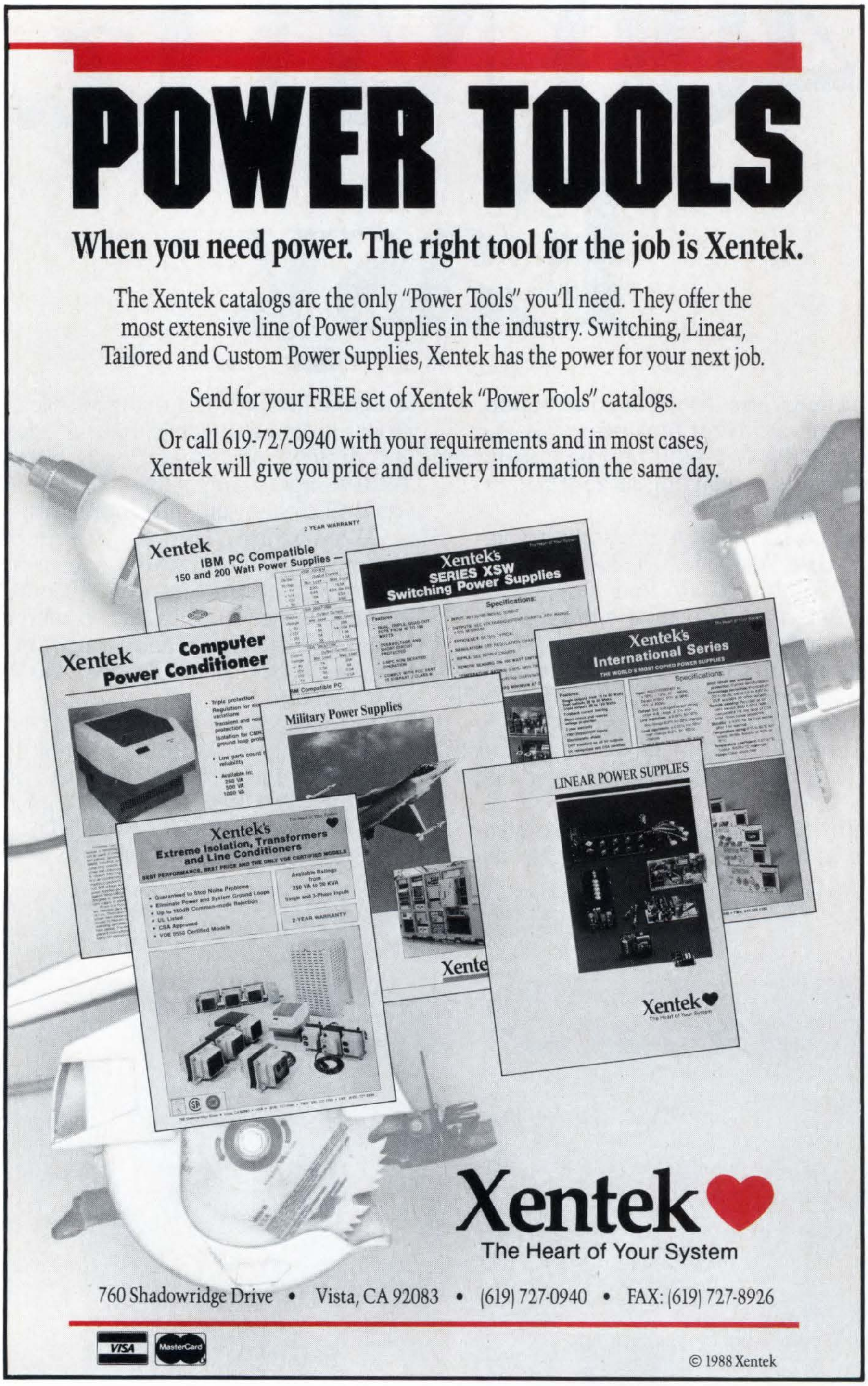
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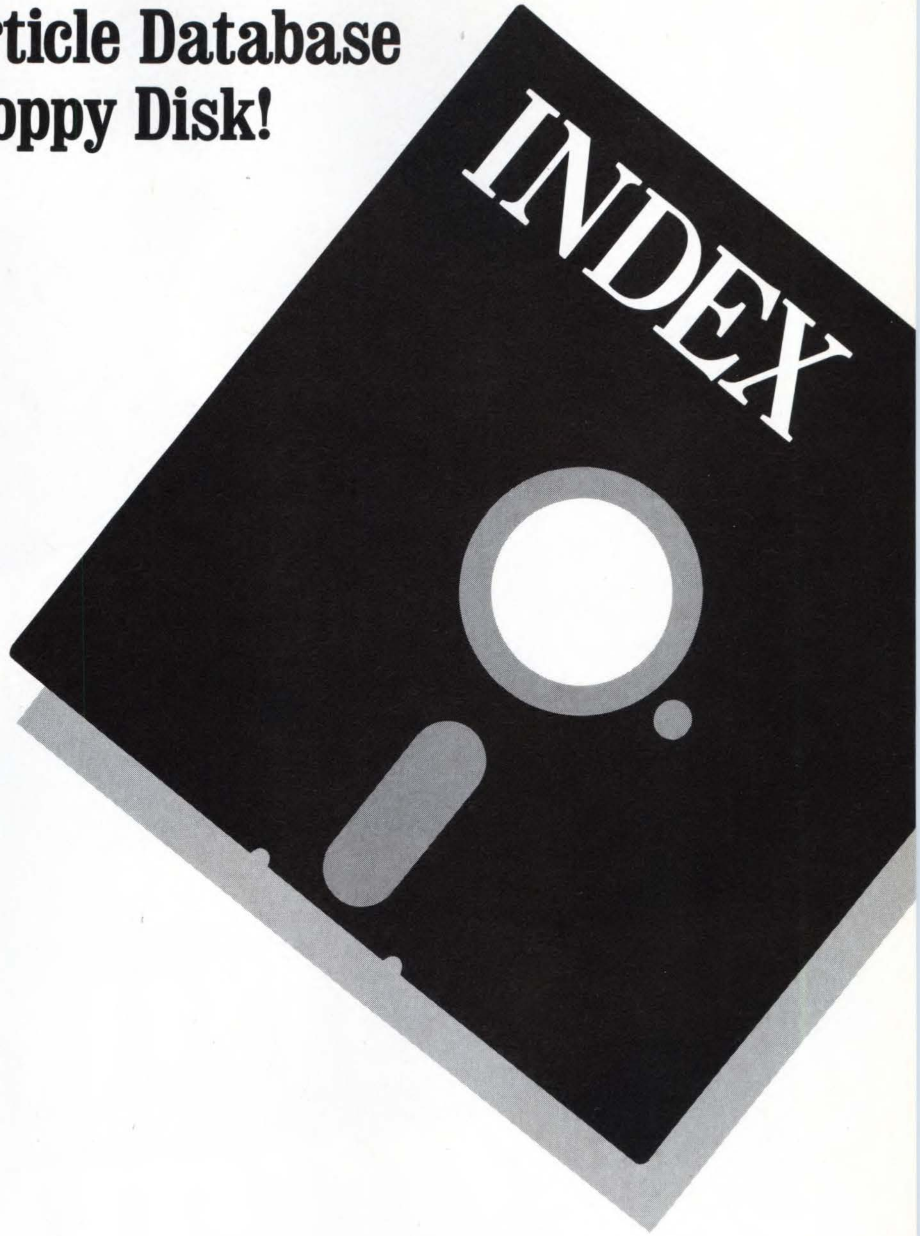

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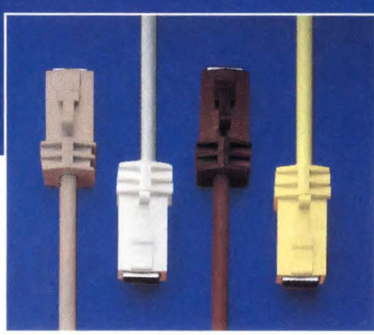

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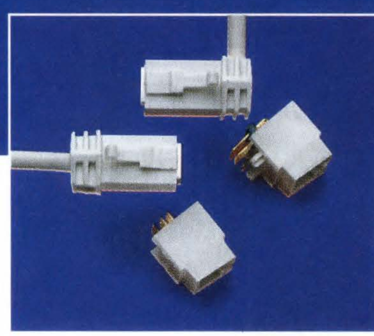

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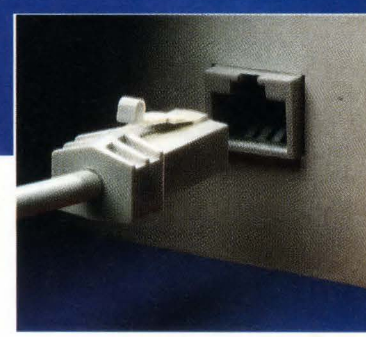

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THE SPECIAL REPORT MICROPROCESSOR

Future microprocessors: Fast & fantastic

Robert E. Peterson Jr.

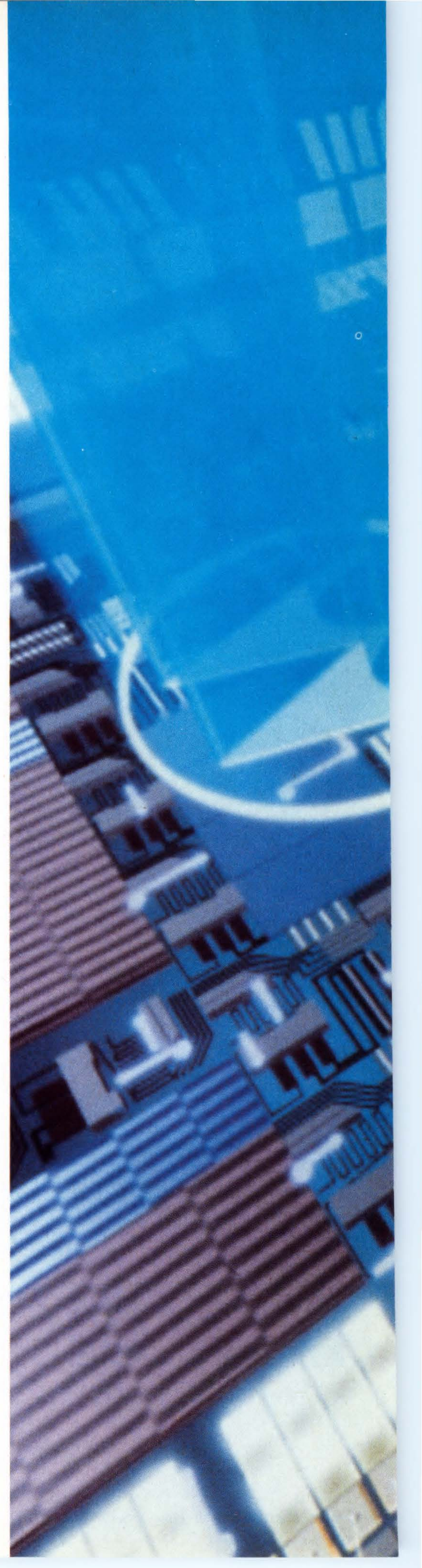
In case you've ever doubted, be reassured that the microprocessors of the next five to ten years will be really, really powerful and you'll like them a lot. Beyond these platitudes, you won't find much agreement about what microprocessors will look like. But the disagreements are fascinating, and they herald major changes in microprocessors.

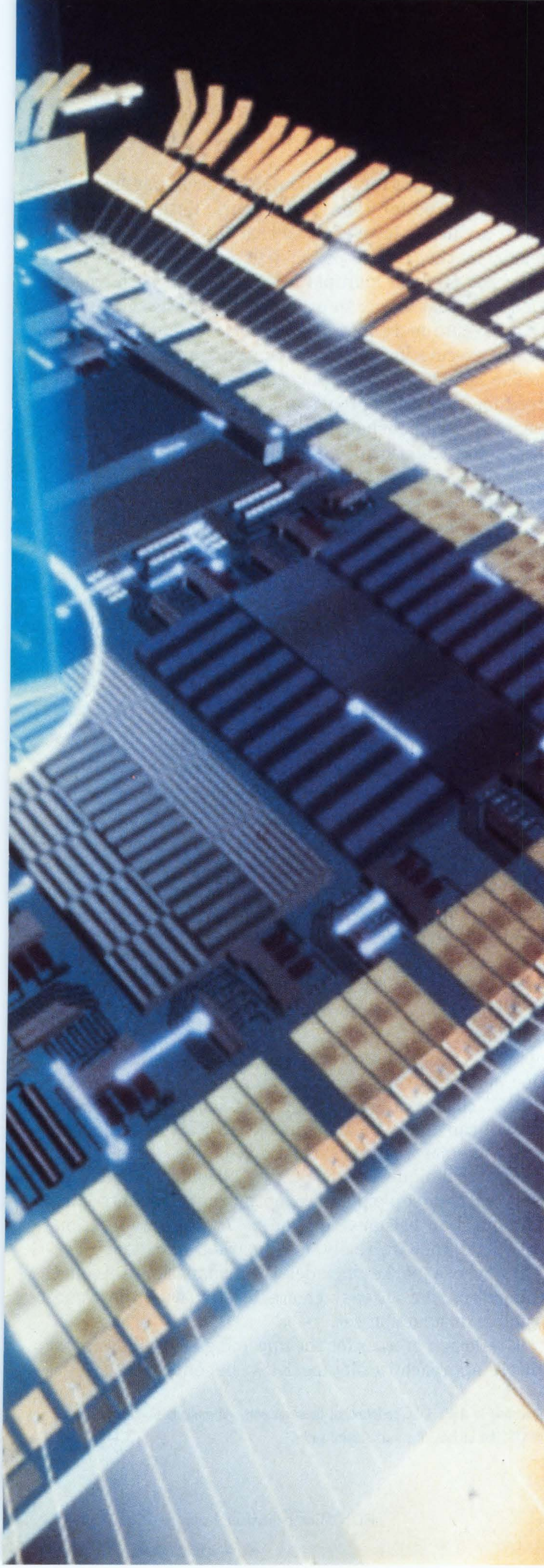
Just how powerful will microprocessors be ten years from now? If you talk with industry movers and shakers, the term "Cray" might pass through your mind again and again—not as a specific prediction, but more as an icon that suggests the power we can expect from the microprocessors of the future.

> RISC is especially well suited to controlling specific applications, where customized instruction sets can provide enormous efficiency advantages.

But the source of that "Cray-power" is elusive. It could be RISC, CISC, or something else. Both RISC and CISC proponents happily predict performance levels of hundreds of MIPS, but they get vague when it comes time to substantiate the claims. Those who make such projections in this industry commonly and implicitly work from existing curves, which indicate how fast performance has been doubling. Soon, though, we will reach a critical juncture in microprocessor development at which the rules will change. They are changing even now.

It is difficult to see the long-range effects of the changes because microprocessor makers only look into the future a maximum of about 2½ generations. The





RISC versus CISC: Which will win? Or will both find acceptance for different applications? Does Motorola's new 88000 RISC processor, shown here, complement or compete with the company's established 68000 CISC family?

current state of microprocessor design at any given company involves the specifics of the next generation, the architecture of the generation after that, and a look at the generation after that in terms of processor technology and performance level. This process, therefore, extends only about five years into the future at best. Forecasting five to ten years out enters uncharted waters.

10 million transistors

Before exploring some differing opinions about the future, consider one projection that chip makers agree on: the number of transistors that will be available to implement a single IC. Both Intel and Motorola project 10 million transistors within the next ten years for high-volume production. For comparison, an 80386 employs about 275,000 transistors.

The increase in the number of available transistors represents an important trend in microprocessor design. In the next five to ten years, the increase in the number of transistors is going to be more dramatic than the increase in clock rate, according to Jeff Nutt, technical marketing manager for both RISC and CISC microprocessor products at Motorola.

Faced with the ability to pour 10 million transistors into one microprocessor, what recipe should manufacturers follow? The biggest argument today centers on RISC versus CISC. The RISC backers say they don't need millions of transistors to deliver more MIPS than do CISC processors. But will anyone turn away the coming transistor bonanza?

For a RISC processor, the goal is simplicity. The original idea behind RISC processors was that they could implement a small instruction set very well. The complexity embodied in a large instruction set was transferred from the hardware to the software—a change that made the software slightly less efficient but made the hardware much more efficient. In the end, for a given technology level, a RISC processor runs faster than a CISC processor.

The real story of RISC success is not a story of reduced instruction sets, however. Opinions differ as to just why RISC is so good. The general picture, though, is that at any given technology level, computer architects can implement specific features and functions more efficiently in either hardware or software. Thus, you design the ideal RISC chip by getting both hardware and software designers together and letting them make tradeoffs. The process results in both a RISC processor and an optimizing compiler. In contrast, a CISC processor is typically designed from a hardware standpoint only, with the instruction set deriving from traditional sources such as mainframes and minicomputers.

Over their short history, RISC microprocessors have exhibited a doubling in performance every 12 to 18 months, compared with CISC's doubling about every two years. The question for the future of RISC is this: How long can the hardware/software tradeoff process continue to produce superior performance? According to Rick Rasmussen, microprocessor group marketing manager for LSI Logic Corp., the trend should continue out to an 80-MIPS performance level. "Beyond that," he says, "it gets pretty fuzzy." That means, at the current rate of performance gains, the picture gets fuzzy at about the five-year mark.

LSI Logic fabricates both the SPARC and MIPS RISC chips. Another chip producer, Advanced Micro Devices, has committed to RISC with the 29000 microprocessor. Paul Chu, AMD's manager of product planning for processor products, predicts that RISC microprocessors will achieve the 100-MIPS level in five years and is certain that the current pace of performance gains will extend over the next ten years.

Ever higher performance

Chu explains that processor improvements revolve around three factors: instructions per task, cycles per instruction, and time per cycle.

The goal for any processor is to minimize the product of these factors. Most planners assume that the number of instructions per task will remain relatively constant and that chip makers can do nothing to change this factor (more on this questionable assumption later).

RISC's initial goal was to execute every instruction in only one cycle. Because of branch latency, RISC chips currently average about 1.3 cycles per instruction—much better than CISC chips. Both RISC and CISC architects have realized that there is no inherent magic in the 1-cycle-per-instruction level, however. Why not perform multiple instructions on each cycle? Chu says that a way to overcome branch latency, and thus execute more instructions per cycle, is to concurrently execute instructions in multiple processors.

The last factor, time per cycle, is minimized by increasing the microprocessor's clock speed. This, in turn, is accomplished by reducing the chip geometries—the traditional speed-up strategy for all types of digital devices—and by making the circuitry more efficient. An example of the latter is the switch from physical to virtual caching. This fairly simple change, promoted by SPARC-chip maker Cypress Semiconductor, eliminates some of the overhead associated with translating each physical address into a virutal one. The virtual approach allows the processor to avoid going through the MMU when the necessary data is in the large cache.

CISC impersonates RISC

As RISC processors improve in these areas, CISC chips will not be resting on their laurels. If Intel has its way, in fact, CISC microprocessors will be riding partially on RISC's laurels. Certainly CISC will benefit from shrinking geometries; but, even more important, Intel asserts that many RISC techniques apply as well to CISC as to RISC. For these reasons, Intel's director of marketing, Claude Leglise, makes disparaging comments about RISC.

For example: "RISC is a big marketing hype," he says. RISC consists of a series of design techniques that speed up execution of operations, and RISC also calls for a new instruction set. However, in Leglise's opinion, the speed-up techniques apply to any instruction set. He drops big names to put dents in RISC: "[DEC chairman] Ken Olson was telling me, 'That's hype. I can do a VAX that runs like a RISC machine.' "

To summarize Intel's position, Leglise says, "The design techniques of RISC we absolutely endorse: large cache, deep pipelining, optimizing compilers, etc. The question becomes, do you need a new instruction set? And then it really is a market question." For Intel, whose market includes IBM-compatible personal computers, it's an easy choice to stay with the same complex instruction set.

The design process for the upcoming 80486 illustrates Intel's approach to tapping RISC benefits. First, says

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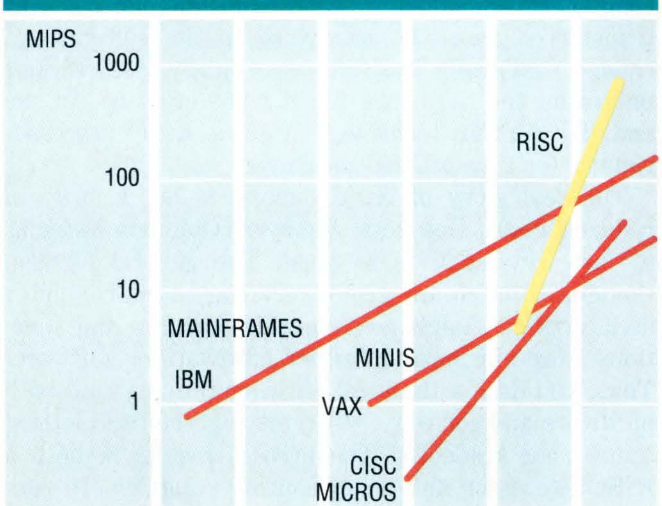
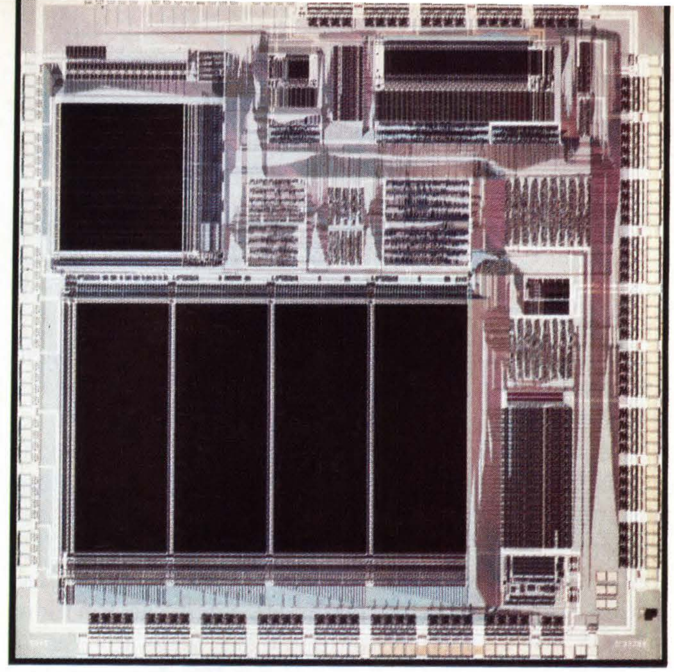


According to AMD, RISC performance improvements will continue to outpace those of CISC for at least the next several years.



The large amount of memory on this cache controller—Motorola's MC88200, which works with the company's MC88100 RISC microprocessor—suggests what microprocessors might look like in the future as they incorporate more on-chip memory.

Leglise, designers evaluate an 80386 compiler's output, noting the instructions that programs use often. "We take those and optimize the heck out of them," he continues. "Then we put a lot of transistors behind executing those very fast. But we still have enough transistors left to do tasks with chaining, memory management, protection, paging, etc." Intel would be pleased if you view the result as having essentially a RISC core—where some of the most frequently used instructions are extremely fast—yet carrying many additional resources around the core for compatibility reasons and operating system support.

Now Leglise springs his trap: "If you have a RISC machine and all of a sudden you have 10 million transistors, what do you do to speed it up? Well, you start throwing operating system support around it, including memory management, task switching, multitasking, etc. When you're done, what have you got? You've got a RISC core with a whole bunch of other things around it. That looks to me surprisingly like a CISC machine." He concludes that, although the performance curve for RISC machines is steeper than the CISC curve for a given transistor budget, ten years out the two curves will converge.

LSI Logic's Rasmussen wears a patient, faintly amused expression when he hears Leglise's argument. Rasmussen has heard the argument many times. He says that adopting a few techniques that are used in RISC chips will not allow CISC to keep up with RISC. Intel is misrepresenting RISC, as far as Rasmussen is concerned. Even with an enormous transistor budget, he expects compact RISC processors to have the edge because many more of them will fit on a single chip for multiprocessing applications.

Object-oriented microprocessors

Alan Kay, an Apple Computer fellow, thinks that both the RISC and CISC proponents miss the point, although he reserves his greatest derision for the major CISC microprocessor makers. He starts from simple principles: "Most computers are programmed, although this is something that Intel and Motorola haven't gotten around to realizing yet." He argues that the fit between 86- and 68000-type processors and the tasks they perform is poor.

Long a booster of object-oriented languages, Kay observes that languages such as Lisp and Smalltalk are much better suited to the types of tasks performed on personal computers today. For this reason, he says, database management system developers are now becoming very involved with object-oriented languages. The way to maximize microprocessor efficiency, Kay believes, is to design microprocessors that specifically support these languages. The instruction set would be simpler and the computer's overall efficiency much higher. Such processors have already begun to appear on accelerator boards for personal computers.

The object-oriented microprocessor could be thought of as an aspect of the RISC story. Kay notes, however, that RISC processors were originally designed to optimize C and Pascal code. That has continued to be the goal of subsequent RISC processors, leaving a poor fit between hardware and software on these machines in terms of the efficiency of the final task—even though the RISC hardware and software compilers are designed together. The problem, according to Kay, is that the compilers are aimed too low. Pascal is only a fair high-level language, he says, and C is not a high-level language at all. These are the lingering legacies of the mainframe and minicomputer traditions.

Market views dominate designs

The problem of dragging assumptions from one computing context to another arises because of market expectations. If you want a microprocessor to run C code, you're not likely to consider the advantages of a Lisp processor; you won't think to ask whether such a processor could improve your application's overall efficiency.

A similar problem revolves around the types of functions that future microprocessors will include. With 10 million transistors to play with, microprocessor makers will be able to pack in an entire menu of functions, such as enormous caches, floating-point units, LAN controllers, modems, disk controllers, graphics controllers, and encryption/decryption units.

When these types of functions are committed to silicon— especially in a high-volume microprocessor—manufacturers must be sure that each function operates in a widely acceptable manner. Industry standards are the key to ensuring acceptability, note Michael Miller and John Mick, manager and vice president, respectively, for product definition at Integrated Device Technology Inc. (IDT is a partner in developing the coming generations of MIPS RISC microprocessors.) In order for microprocessors to expand their lexicon of features, standards must be in place.

Miller and Mick also question the desirability of packing a lot of peripheral functions into microprocessors. They can see the need for intensive cache support because of the bottleneck in communications between the microprocessor and other system elements. But they do not think the solution is necessarily to bring the system elements onto the microprocessor chip. This reluctance to add many functions is based on the expectation that many users might not want the functions offered. "If a function you don't use takes up 10% of the chip and you take it off and get 10% better yield," says Mick, "at production volumes of millions of units per week, it doesn't take very many weeks to make up the nonrecurring costs of redesigning the device."

Dave Mothersole, design manager for VLSI architecture and system design at Motorola's microprocessor products group, agrees that future microprocessors must suit specific market needs. Formerly, he says, "we could only turn out a design every two to three years, so you targeted as many markets as you could with every general-purpose product. Now, though, it's not really feasible to do that any more. Somebody will go out for one piece of your market and do a very good job of it. It's much more important to identify the market and design the product for that market."

DSP chips promise to assume many of the tasks that microprocessors, microcontrollers, and dedicated devices currently handle.

At the same time, the learning curve that governs yields will still be driven by production volume. As Motorola's Jeff Nutt says, "If the die size only varies by 10%, I'll still come down the learning curve very rapidly, based on volume. If I can add something to the chip that only increases it by 10% but can double my volume, I'll do it in a minute."

The balance between appealing to a big general-purpose market or suiting specific requirements will thus become more critical. Mothersole does not predict the demise of general-purpose microprocessors, but he does think they will not be as general purpose as the microprocessors of today. His comments are echoed at other microprocessor companies.

It might seem that all microprocessors will become ASICs, so that each application gets just the mix of functions it needs. Unfortunately, although ASIC design is becoming ever easier, the test and support issues will act as barriers for many applications into the foreseeable future. Unless these barriers are overcome, only high-volume applications will be able to justify taking advantage of ASICs containing millions of transistors.

Along with a variety of specialized microprocessors, we will probably see an even greater assortment of microcontrollers. RISC is especially well suited to controlling specific applications, where customized instruction sets can provide enormous efficiency advantages. Even Intel's Leglise endorses the use of RISC for this purpose. To illustrate just how specific these microcontrollers will get, Weitek Corp. has already introduced a RISC chip that specializes in processing PostScript page-description code for printing.

In parallel with such introductions, DSP chips promise to assume many of the tasks that microprocessors, microcontrollers, and dedicated devices currently handle. According to Bryant Wilder, Motorola's DSP operations manager, DSP chips represent "cheap MIPS" for applications that do not involve an operating system—an area of computing that he leaves to microprocessors. In addition to extending the realm of conventional signal processing in applications such as hearing aids, says Wilder, future DSP chips will displace specialized controllers in applications such as compact disk players and general-purpose motor control. He asserts that the DSP chips will provide the mix of high performance, low cost, and versatility to suit tomorrow's products to consumers' needs.

In addition to the big architectural questions, several issues involving microprocessor details deserve consideration. These issues include the number of address and data bits, clock frequency, packaging, and standard voltages. For the first of these, the move from 32 to 64 bits is not universally agreed upon. AMD's Paul Chu doesn't expect 64-bit buses in the next ten years, for instance, but others foresee the wider buses in that time—perhaps as wide as 128 bits. IDT's Michael Miller and John Mick point out that 64-bit floating-point standards are in place; it would be nice to have integer data at the same width. Further, notes Intel's Claude Leglise, a wide address bus would allow the microprocessor to do direct addressing across a network. Even if microprocessors' external buses remain at 32 bits for a while, it would not be unprecedented to go to a wider data bus internally.

This same strategy could help microprocessors continue their trend of doubling clock frequency annually. Clock speeds are already just a few orders of magnitude from the infrared region of the spectrum. Dealing with increasing clock frequencies will become a major challenge over the next ten years as rates go to 200 MHz or higher. One way to minimize the need to deal

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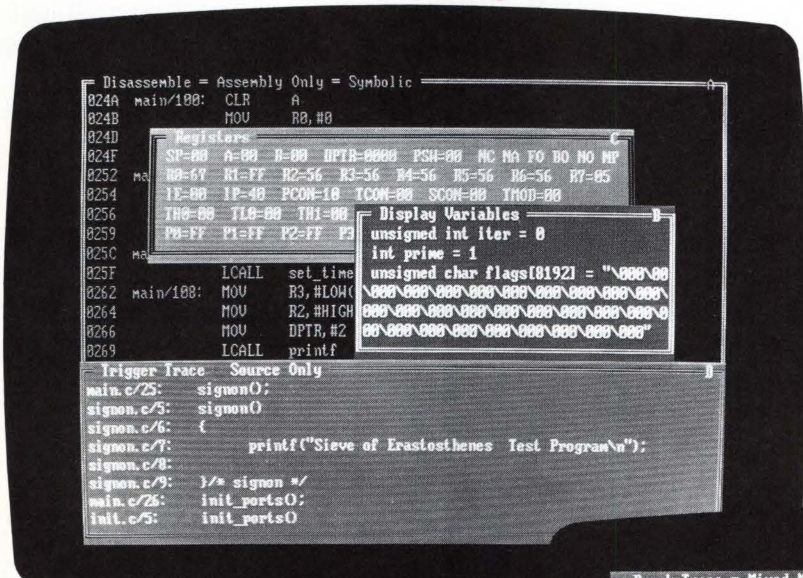

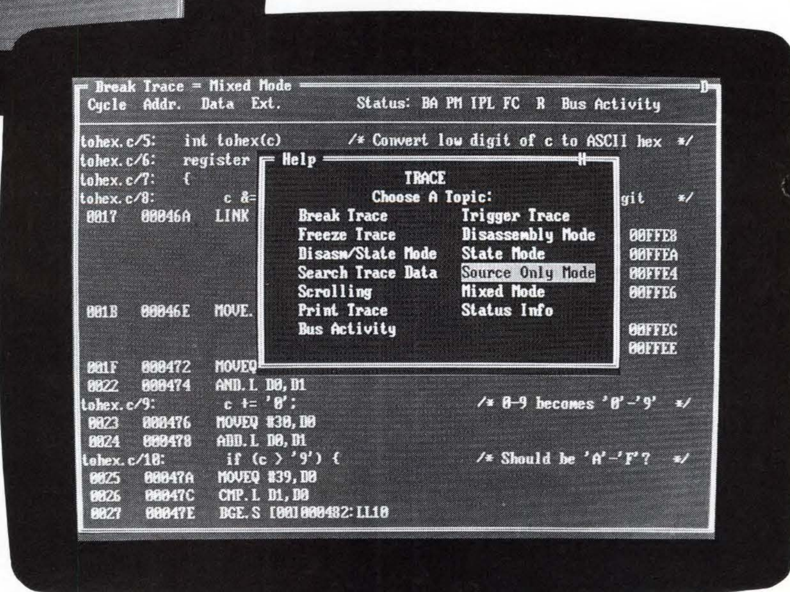

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with transmission line effects is to use an extremely high clock rate inside the chip and run the I/O at a slower rate. Another approach is to use optical I/O for high-speed signals.

The next issue, packaging, is crucial because a microprocessor's package must be able to provide both high pin counts and efficient heat dissipation. The former is not generally viewed as a problem, but heat removal will definitely challenge designers. Motorola's Dave Mothersole feels that it will not be uncommon to see CMOS processors running at 10 watts in the next five years. Even power-efficient CMOS dissipates lots of heat when a chip has millions of transistors switching at 100 MHz with 200 I/O contacts. Neither Intel nor Motorola can currently envision an easy solution to the upcoming heat problem.

Finally, standard voltages must change over the coming years if signal speeds are to continue their upward march. TTL's 5-volt swing is simply excessive for 100-MHz clock rates. Alternatives include a 3.3-volt standard, probably followed by a 1.5-volt standard, which would prove useful for battery-powered applications. ECL-compatible I/O signals have also been proposed as an alternative to TTL voltage levels.

All the evolutionary changes described here will revolutionize applications that currently employ microprocessors and open new applications as well. For example, you would be hard pressed to find anyone who doubts that inexpensive personal computers will routinely provide perfect 3D graphics within the next five years. And Cray-power will find its way into just about everything short of the kitchen blender.

One of the most intriguing applications that will welcome the Cray-power of individual microprocessors is the massively parallel supercomputer. Indeed, Justin Rattner, director of technology for Intel Scientific Computers, asserts that the ultimate destiny of the microprocessor is the supercomputer. As the algorithms for applying massive parallelism to a wide range of tasks become available, he says, such machines will increasingly replace conventional supercomputers as well as many general-purpose computers. Alan Kay notes that massively parallel machines mesh well with object-oriented languages because each object maps neatly to an individual processor.

To achieve the greatest efficiencies, Rattner would like to have microprocessors with on-board floating-point math support, 64-bit or wider buses, and a large amount of on-chip parallelism. This wish list, along with many others, is close to fulfillment. EDN

Robert E. Peterson, Jr. is a freelance writer in Santa Cruz, California, and an EDN contributing editor.

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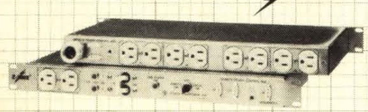

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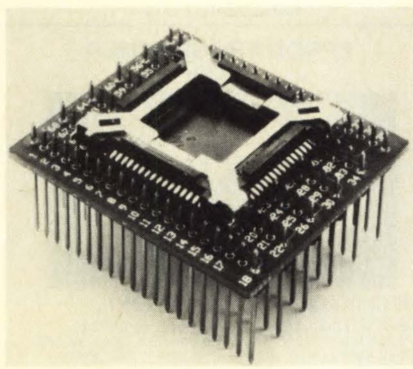

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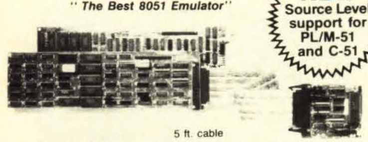

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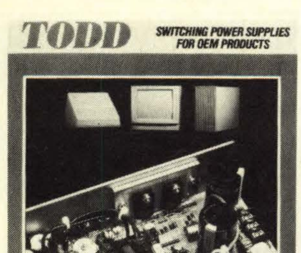

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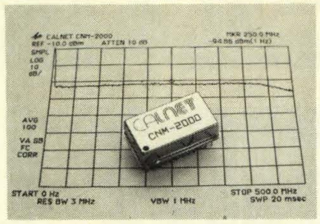

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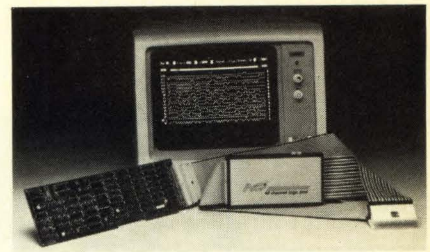

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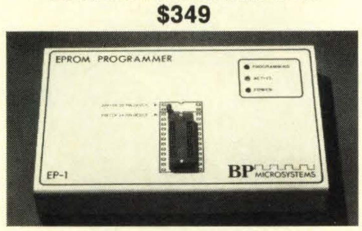

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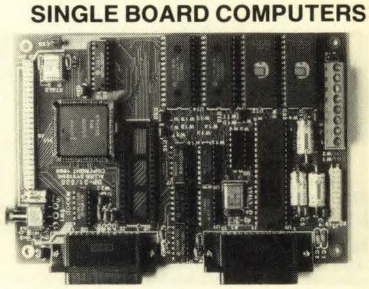

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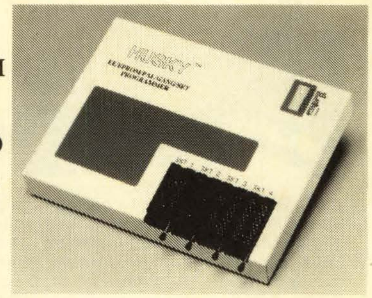

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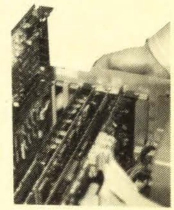

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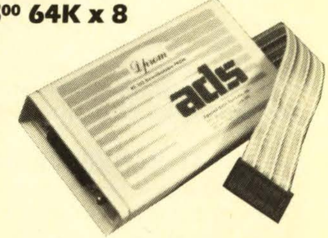

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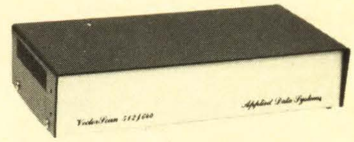

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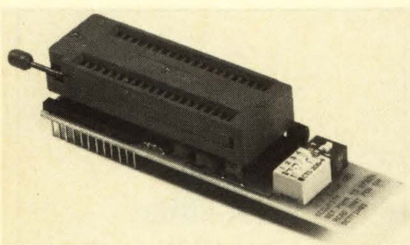

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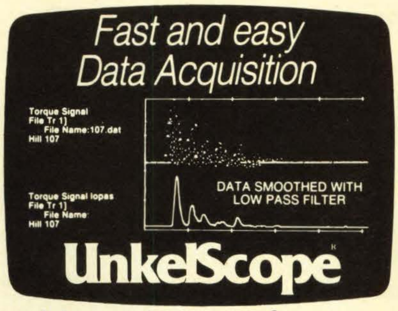

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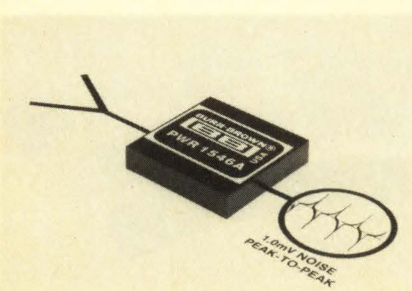

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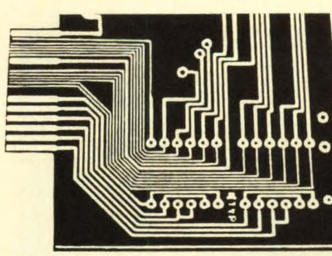

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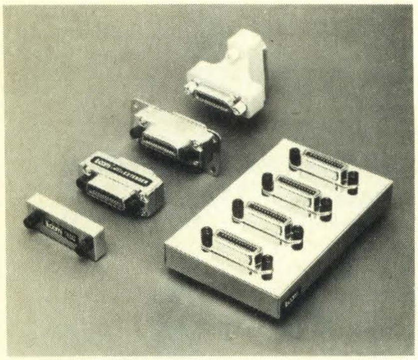

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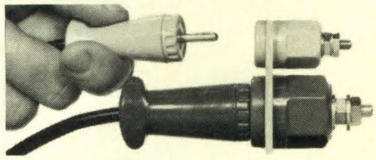

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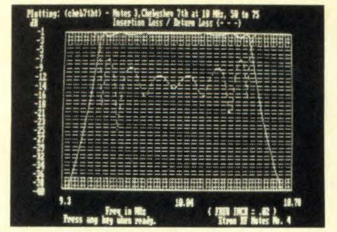

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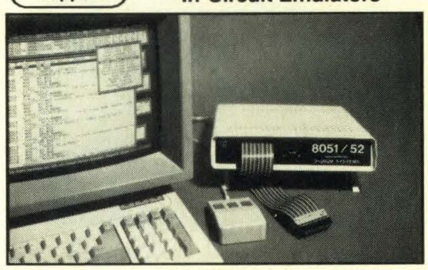

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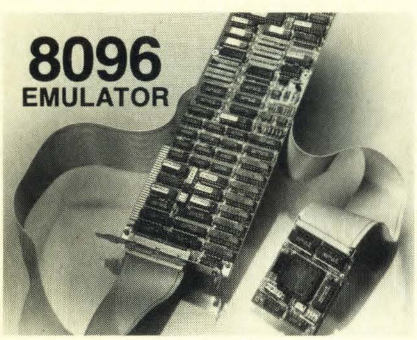

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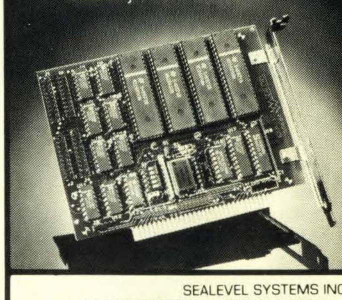

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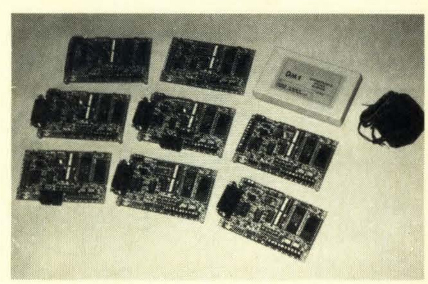

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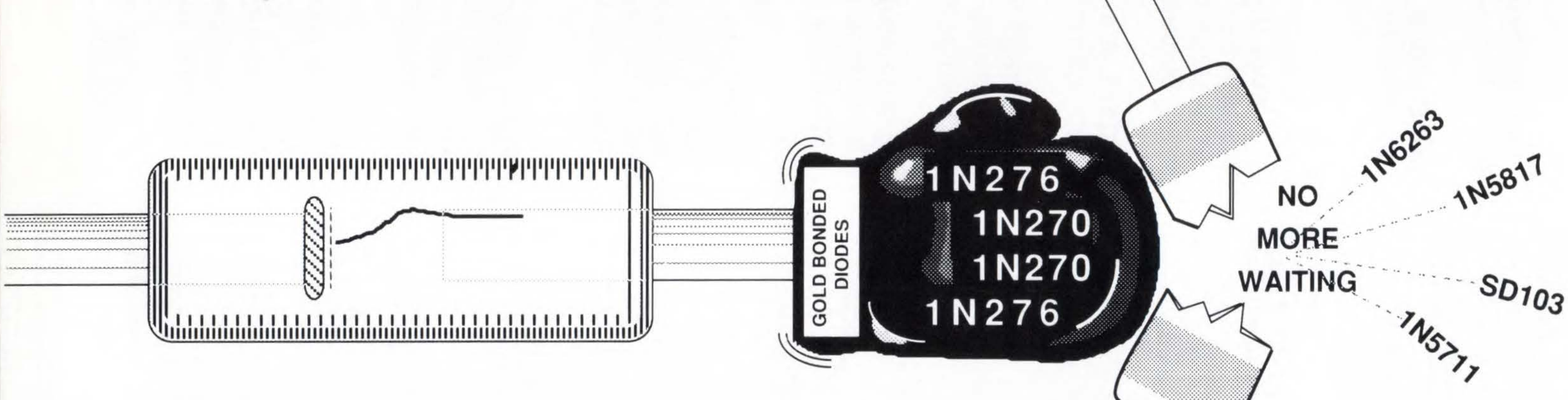

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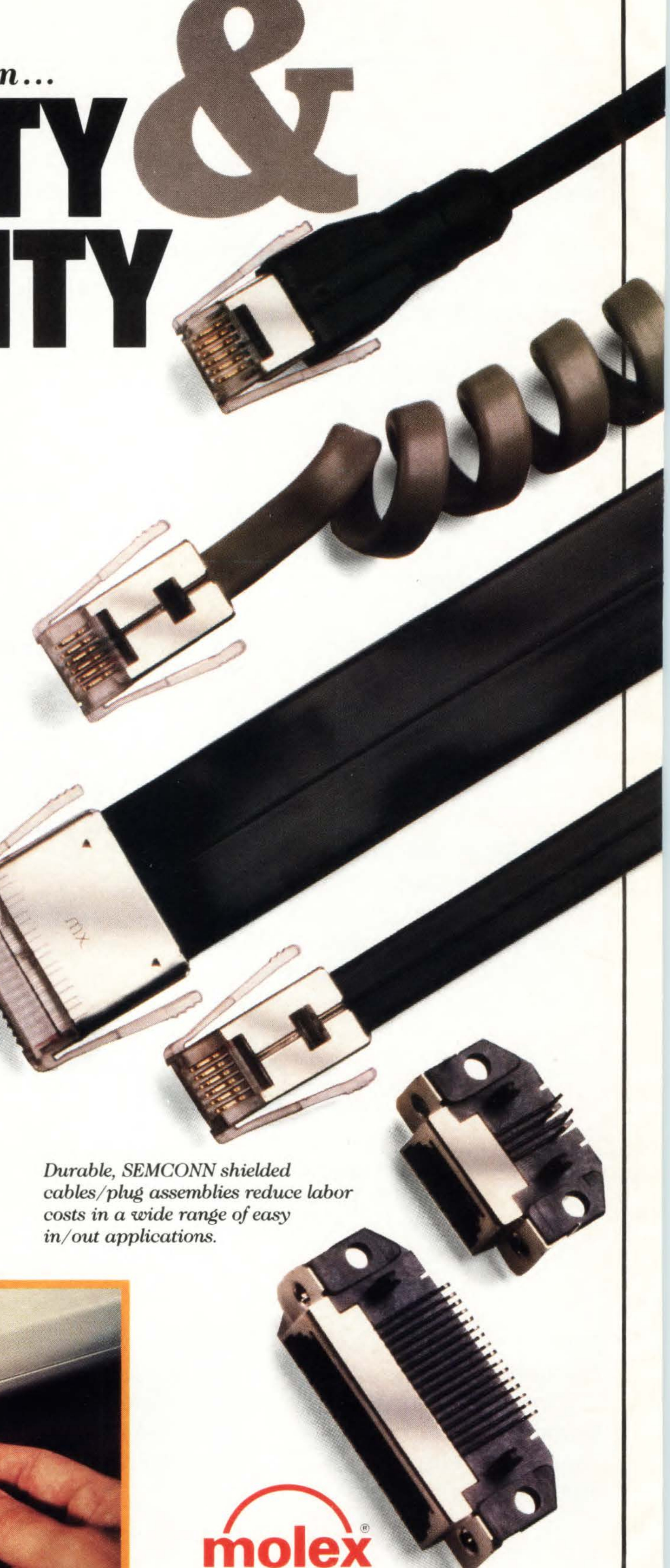

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