the sine interpolator allowed Tektronix to claim a 10-MHz bandwidth for single-shot signals, even though at 25 Msamples/s only 2½ samples were taken on each cycle.

Schumann, who left Nicolet in 1983 and recently started up Dane Scientific Co., also in Madison, maintains interpolation works only if the operator knows the input is a sine wave or a pulse wave. "If you were measuring a triangular signal, you'd have a nice beautiful sine wave on the screen," he says. "That is worse than having a mess on the screen because you believe you have a sine wave when you don't." Current products from Tektronix, which now has 35 percent of the digital scope market, and from other companies, including Nicolet, use complex interpolation algorithms, such as sin x/x, to depict more accurately the measured signal.

HP, which first came out with a digital scope in 1981 and now has 20 percent of the market, stresses that there is no simple formula for relating bandwidth to sampling rate: the number of samples per cycle actually varies with each signal. The company has compromised at four samples per cycle in specifying bandwidth, and offers interpolation, which can be turned off, only on its single-shot scopes.

While most oscilloscope manufacturers, including Nicolet, Tektronix, and HP, still employ flash conversion, Tektronix also uses a technique incorporating charge-coupled devices (CCDs). A CCD converter quickly samples the signal in analog form, picking up its high frequencies, and sends it slowly to the analog-to-digital converter, which takes its time digitizing the signal. CCD technology allows high sample rates at low cost: the Tektronix 2440, introduced in 1988, digitizes at 500 Msamples/s and costs less than $12 000.

Digital scope manufacturers still strive for easier use and higher bandwidth. HP now offers a 20-GHz sampling scope for repetitive signals, and with the help of superconducting electronics, Hypres Inc., Elmsford, N.Y., has introduced a mini-refrigerator-size scope with a 70-GHz bandwidth. There is also a trend toward complexity, converting PCs to scopes with plug-in cards that serve as analog-to-digital converters.

But Schumann believes that such devices cannot be classed as oscilloscopes. "Designers are making oscilloscopes more complex and computer-like by including computations such as integration, Fourier analysis, smoothing, and correlations," he said. "Many people need to make their own interpretation. All the computers put together with all the software ever devised by the [artificial intelligence] people can't anticipate what the observer is going to want to know." ◆

1965

THE PDP-8

The first 'personal' computer for engineers and scientists ushered in the minicomputer era

"Your computer killed 14 000 of my chickens!" squawked the voice on the telephone. A power outage had scrambled part of the core memory in a DEC PDP-8 minicomputer that controlled heat lamps in a henhouse. Unable to restart, the machine failed to turn on the lights, and thousands of day-old chicks died.

From chicken farms to stress analysis for the Concorde, the PDP-8 went where computers had never been before. No customer use was too outrageous, no application unthinkable. And that was by design. "I never got surprised" by the uses people found for PDP-8s, said C. Gordon Bell, who collaborated on the instruction set design. "If your vision of computing is broad enough, you build a machine to control anything, whether it's nuclear reactors, cigarette machines, or cookie factories."

Digital Equipment Corp. (DEC) was founded in Maynard, Mass., in 1957, but made its name in 1965 with the debut of the PDP-8 scientific computer. At a time when the average computer required an air-conditioned room, the PDP-8 (dubbed a minicomputer by the industry, after the miniskirt of the day) could sit next to or even on a laboratory bench. It could not do everything the mainframe could, but at $16 000, it was cheap enough for each lab technician to have one.

John Voelcker Associate Editor

In contrast, the IBM System/360 series of mainframe computers introduced just a few months before cost hundreds of thousands of dollars and up. The 360 would become the mainframe standard for commercial data processing over the same period that the PDP-8 became the laboratory computer standard.

The goal for the design, Bell said, was quite simple: "Maximum computing power at minimum cost." That made the PDP-8 the spiritual forerunner of the personal computers (PCs) of the 1970s.

Controller or computer?

Like many successful industrial designs, the PDP-8 was actually a redesign. Much of its architecture had been laid down in late 1962 for the PDP-5, DEC's first 12-bit machine. (PDP stood for Programmed Data Processor, a title still in use on DEC computers today.)

The PDP-5 was developed, Bell said, essentially because its designers had the opportunity. Atomic Energy of Canada Ltd. had ordered an 18-bit PDP-4 for a control system to monitor an atomic reactor at Chalk River, Ont. The application required a front-end monitor with an elaborate set of equations wired into it.

After visiting Chalk River late in 1962, Bell and DEC president Kenneth H. Olsen decided they could design an entire computer for the money allocated to build the analog front-end system. "We didn't have anyone with that much patience" to wire the logic, Olsen recalled. Moreover, Bell added, both men believed that a general-purpose computer was "simply better than fixed logic."

The two decided to base this new machine, the PDP-5, on a 12-bit digital controller (the DC-12) that DEC had designed in 1961 but never built. Bell, with DEC since 1960, specified the PDP-5's instruction set in autumn 1962. The "charismatic, enthusiastic, exciting, fun" designer—in Olsen's words—was joined by Alan Kotok, then just three months out of college.

Bell and Kotok had first sketched instructions for a simple 10-bit general-purpose computer. By the start of 1963, however, the bit count had risen to 12. Not only did this increase addressable memory, it also gave two additional bits of precision for analog-to-digital (A/D) conversion (for the machine's role as an analog I/O controller) and fitted more neatly into the general-purpose computing world of 6-bit peripherals.

"There was nothing to the instruction set, really," said Bell. He called it a minimal-instruction-set computer, similar to the reduced-instruction-set computer (RISC) concepts used in workstations and minicomputers of the 1980s. Kotok, now a corporate consulting engineer at DEC, who headed the architecture design team for the timesharing PDP-10, spent just two months on the PDP-5 before moving to another design. But he recalled with amusement that at the same time the PDP-5 was changing from 10 to 12 bits, Bell got interested in timesharing and embarked with Kotok on the project that became the 36-bit PDP-6, introduced in 1964.

The PDP-5's logic design was completed by Edson D. deCastro, the applications engineer responsible for Chalk River's now minimal analog front end. Oddly enough, deCastro never worked in the engineering department at DEC: he was first a member of the special projects department, then moved into sales—a "great opportunity" to spend time with customers and

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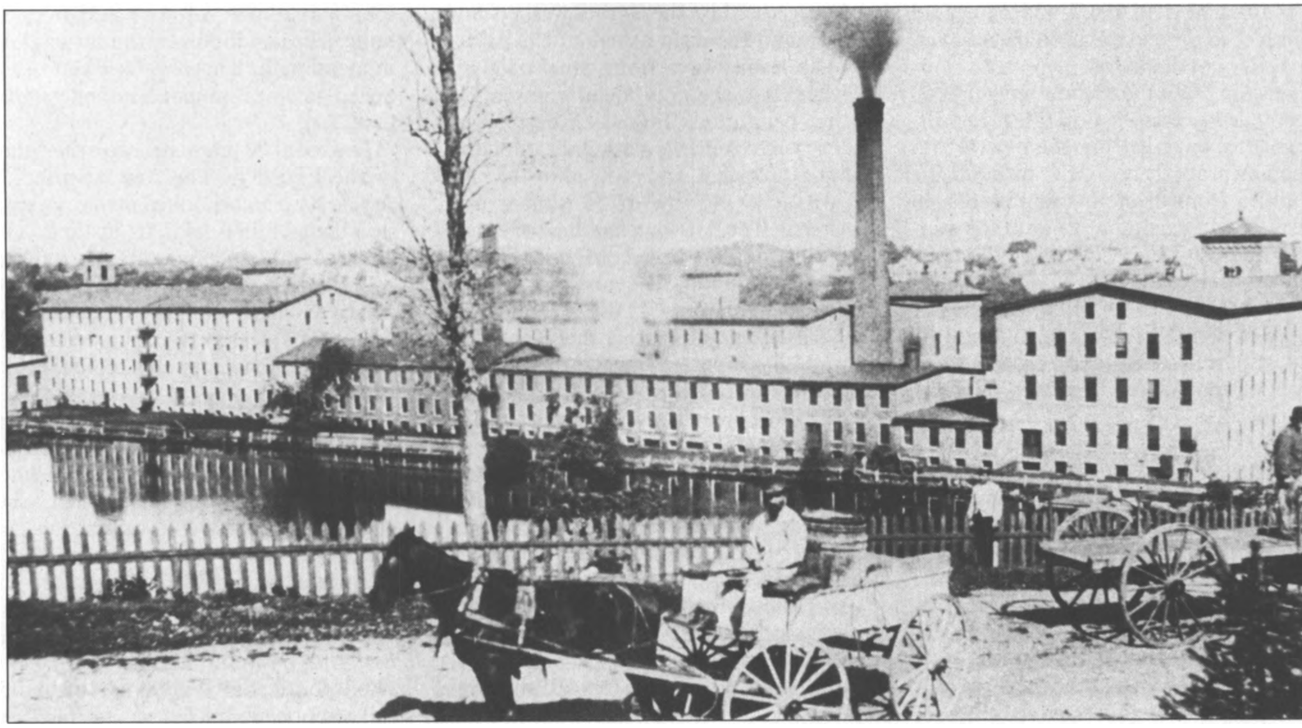


Digital Equipment Corp.

The old woolen mill in Maynard, Mass., that is now the headquarters of Digital Equipment Corp. as it was about the turn of the century; the company also uses the plant's more than 1 000 000 square feet for engineering and prototyping operations.

"see what they did and didn't like," he told *IEEE Spectrum*.

(In 1968, with much acrimony, deCastro and two other engineers would leave DEC to found Data General Corp., which introduced the Nova, a 16-bit minicomputer that competed with the PDP-8.)

The PDP-5 used standard PDP-4 modules, with bit-slice construction for the accumulator, which had a built-in A/D converter, and for the memory address and buffer registers. Equipment options were easily added on the I/O bus, doing away with the cost and space needs of the wiring and cable drivers used in previous machines and simplifying reconfiguration in the field.

The machine was designed for 4K words of memory, and an extension unit for 32K words was later offered. Multiply and divide functions were later built in, too, in the form of an arithmetic extension element.

The PDP-5 was successful, but it had drawbacks. To lower its cost, the program counter register was not a dedicated hardware register but located in core memory, making programs run more slowly by adding an extra cycle to the execution of each instruction. The machine was also too large to fit into the then-standard 19-inch (48-centimeter) equipment rack width, deterring other manufacturers from building it into their own equipment.

Still, its designers knew they were onto something. Although the PDP-5 was "trivially, naively simple," in Olsen's words, many users were doing general computing on what had been designed as a mere controller. About 100 PDP-5s had been built—"from our point of view, a success," Olsen said—and it was time for a redesign.

When it all came together

Viewed in retrospect, Bell said, the PDP-8's success was due to everything coming together at the right time: a working PDP-5 architecture, new half-size modules that reduced the size of the machine, and—in place of hand assembly—wire-wrapping machines for high-volume, reliable manufacturing.

The design of the PDP-5 was modified slightly, but the basic architecture remained. The main change was to move the program counter from core memory to a separate register, which speeded instruction execution substantially.

Just as important, a new series of printed-circuit board modules packed the machine into less than the full-size cabinet that had been the absolute minimum size for a computer to date. The PDP-8's half-cabinet size not only fit on laboratory benches, but allowed other manufacturers to integrate it into larger systems for resale. The entire circuitry fit onto two frames, hinged to a center support, that swung out of the cabinet for servicing [Fig. 1].

Each frame was laid out as the maximum size that could be accommodated in the new automatic wire-wrapping machine from Gardner-Denver Co., Quincy, Ill. The PDP-8 was actually DEC's second wire-wrapped machine, the first being the PDP-7, which began delivery in December 1964, four months before the PDP-8.

This automated manufacture was the third element in the PDP-8's success. It allowed PDP-8s to be produced fast and accurately in high volumes—replacing, said Bell, "a whole floor full of little ladies wiring computers." These hand-wired machines routinely took hours or days to debug, with thousands of wires and soldered connections that had to be checked with an oscilloscope. Most PDP-8s, in contrast, worked properly from the start.

Flip Chips for zip

The fundamental technologies that contributed to the PDP-8 were new logic modules and faster core memory. Between April and December 1964, Olsen and his engineers developed a new series of modules for DEC's PDP-7 18-bit mainframes. Called the Flip Chip series, these promised better execution speeds than the PDP-4 modules that had served the PDP-5. At 2.5 by 5 in., they were also half the size of the PDP-5 modules and packed in a larger number of smaller germanium transistors [Fig. 2].

The Flip Chips had a color-coded plastic handle on top, and plugged into 144-pin connector blocks that could support eight modules. Each of the PDP-8's two frames held slots for 216 modules.

The connector block, designed by Sylvania Electric Products Inc., Flushing, N.Y., for use by IBM Corp., inspired the Flip Chip package, Olsen said, because blocks could be wired into place with the Gardner-Denver machine. DEC improved on Sylvania's design, however, specifying

18 pins to IBM's 16 and adding a gold "pimple" to the end of the connector wire for better conductivity.

The Flip Chips themselves were originally intended to carry hybrid integrated circuits. Problems getting the new ICs to function properly led DEC to build the modules from discrete components, in order to get the computers onto the market. The PDP-8 Flip Chips used the same circuits—diode gates and diode-capacitor-diodes—as their PDP-7 predecessors, but engineer Donald A. White lowered the values of the load resistors to provide greater noise immunity and hence raise execution speed.

Those were the days

Smaller core memories with lower read voltages and higher switching speeds shortened memory cycle time to 1.6 from 6 microseconds. Total memory was still 4K words, but it could be expanded to 32K words with additional circuit cards, as in the PDP-5. The PDP-8 used two 3-bit registers to select which of the eight 4K-word blocks were addressed as program and as data.

Finally, ongoing reductions in logic cost justified the one major modification to the PDP-5 architecture: a separate hardware register for the program counter. For about $200 more, said Bell, the decision improved execution speed by 30 percent.

In 1964, DEC occupied only about 10 percent of the old woolen mill—its floors permeated with lanolin—that is now its headquarters. Other tenants in "the Mill" ranged from small electronics makers to a label company. From 1960 to 1964, the staff had increased by 900 to about 1000, but DEC was still so small that few considered it part of the computer industry.

Looking back, Bell and Kotok identified one major difference between the process of designing a computer today and the PDP-8 effort: fewer people were involved then. Increasingly complex computers, and the advent of computer-aided design systems, mean that no one project manager can—or needs to—keep an entire design in his head. In 1964, Kotok said, at most half a dozen people were involved in a design at any time. And Olsen, said Don White, would still come down to inspect the design "and beat us up for not using standard parts."

Hours at discount stores

Olsen's biggest role in the PDP-8 design was in the layout and packaging, however. Breaking with the stodgy look of computers then, he deliberately set out to give the PDP-8 the feel and appearance of a consumer product.

"I spent hours at discount stores studying home appliances, how they were made," Olsen recalled. "At the time I could tell you how every single front panel was put together" on the clothes washers and driers and the dishwashers of the day.

The result was a front panel of glass, rather than the gray metal common to other computers [Fig. 3]. A design was silkscreened onto the glass, indicator lights shone through it, and protruding through it was a single row of 26 "bat-wing" switches. The bat-wing handles were easier to manipulate than conventional slide switches, and they also cost only 6 cents apiece. They became a DEC standard and were used on many other machines. The source? Olsen spotted them on a 1964 Hotpoint clothes drier.

Two key switches were needed at the lower corners to hold the front panel onto the frame of the PDP-8. One was obvious, Olsen said: the power on-off switch. But "we had to invent another," so he came up with a second key switch that enabled and disabled the front panel controls. For years afterward, Olsen said with a grin, minicomputers from all over the world used this two-switch arrangement as if "it came from heaven," never realizing it was just to hold the machine together.

The first PDP-8 had smoked-plastic and rosewood-patterned panels around the upper structure where the boards fitted. He was not fond of the smoked plastic, Olsen said, although he reluctantly allowed an industrial designer also working on the machine to overrule him. But he liked the mock-rosewood material right from the start. Shortly after the introduction of the PDP-8, Olsen said, he ordered a large supply and used it to redo the kitchen of his house. Later DEC machines, including the PDP-8, also used distinctive lower-case typefaces [Fig. 4].

Olsen also guided the adaptation of the Model 33 teleprinter from Teletype Corp., Skokie, Ill., which for only $600 gave both the PDP-5 and PDP-8 a cheap terminal that combined printer, keyboard, and a paper-tape I/O device [Fig. 5]. The Model 33's price made the PDP-8 practical as a machine for a single user, he said, but the original product had been designed only for light use. DEC had to gamble that, with good maintenance, it would hold up under much heavier use. It did, and quickly became a standard for the industry—one that Olsen called a "gamble we won," which became a "key decision in minicomputer history."

Another innovation was the *Small Computer Handbook*, a single volume that reached 700 or so pages and contained "everything we knew about our computer," in Olsen's words. Handed out free at trade shows, the book convinced many engineers that computers were understandable and approachable [Fig. 6]. The discipline of writing the book was also "a big part of finishing the design" of any computer, he said. The handbooks became a DEC tradition, but split into different topics: hardware, software, and programming. The handbook for the current VAX minicomputer line comprises almost two dozen volumes—and it is no longer given away free.

Looked at 20 years later, were there flaws in the PDP-8? "The first architecture should have incorporated memory expansion better," Bell said. "It just didn't acknowledge the upcoming bigger memories. In retrospect, oh my God, how could we not have dealt with that?" Even in 1963, he said, its designers could see that the PDP-8 would not stay a 4K-word machine forever.

Olsen was more reluctant to concede this point, noting that any amount of memory ultimately proves too small as technology evolves. And yet, he said, when he had given his son a PDP-8 for Christmas and then asked him what he wanted for next Christmas, the answer came back: "Another 4K of memory."

Given the PDP-5's 12-bit architecture, Bell said, he would not have switched to 16 bits for the first PDP-8. In 1963, the circuit components for 4 extra bits simply cost too much. The PDP-8 ended up providing a target for every later 16-bit mini, Bell admitted, including deCastro's first Data General machines, which cost even less than the DEC minis of the day and adopted the new IBM convention of 8-bit bytes versus 12-bit words.

128 words at a time

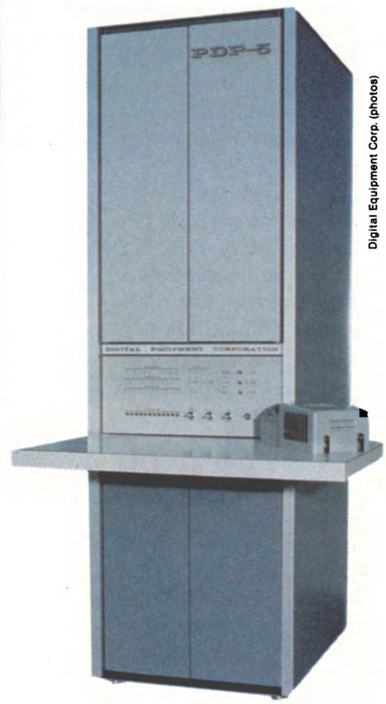
Today, operating systems require hundreds of Kbytes of memory, but early PDP-8s had no operating system. Rather, users received a 4-in.-thick packet of paper tape, including a program editor, an assembler, and a loader. Users added to these building blocks their own programs, written in PDP-8 assembly language.

To run programs, hapless PDP-8 users first had to enter enough information—by toggling the front-panel switches—to enable the machine to read the editor tape. After loading the editor, a user would load the tape of his own program, edit it, usually on a teletypewriter, and have the computer punch out a revised program tape.

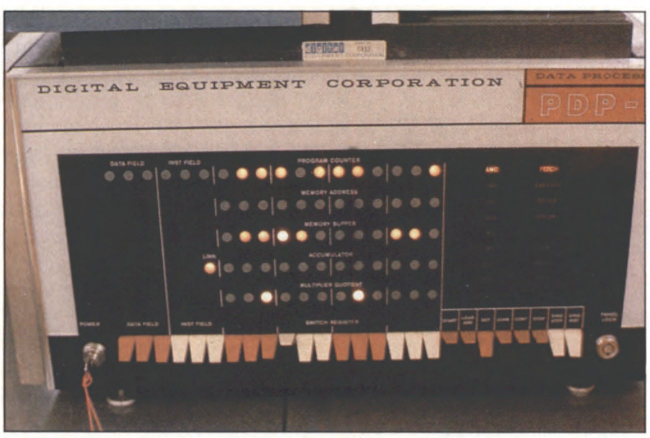
Then the assembler tape had to be read in, the program tape loaded, and an object file tape punched out. Then the loader tape was read in, followed by the object file. Finally the user could execute the program. If there was a bug, of course, and the program did not run, the process began all over again!

So by the 1970s, the idea that a proper operating system could be written for the PDP-8 excited DEC engineers. One was Richard Lary, who joined DEC in 1969 fresh out of what was then Polytechnic Institute of Brooklyn, New York City. At the time, the PDP-8 was migrating from 4K- to 8K-word memories, and the possibilities of doubled memory intrigued him.

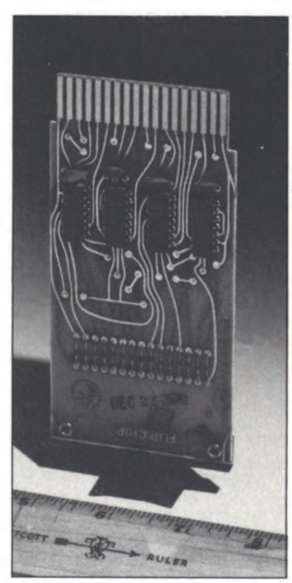
[1] The prototype PDP-8 minicomputer (left) was derived from the architecture of the hand-wired PDP-5 (below). But the PDP-8 was assembled automatically and was small enough to fit on a laboratory bench.



Digital Equipment Corp. (photos)



[3] The front panel of the production PDP-8 had colors and lettering silk-screened onto the inside of the glass, and used batwing switches like those found on the Hotpoint clothes driers of the day.



[2] The Flip Chip circuit cards were designed for both the PDP-8 and the larger PDP-7 18-bit mainframes. Each of the PDP-8's two circuit-card frames had slots for 216 Flip Chip modules.

[4] A later front panel shows the lower-case lettering and distinctive graphics that gave DEC's computers a unified corporate identity throughout the 1970s.

At DEC, Lary had developed PDP-8 software on the 36-bit timesharing PDP-10 operating system, "fallen in love" with it, and wanted to have the same abilities on the PDP-8. But a first attempt at PDP-8 system software, from outside DEC, had "lots of internal problems," Lary said, and really "wasn't a product."

So Lary decided to write his own. He started with the user interface of the PDP-10 system, with the idea of producing a seemingly identical system. For six months, Lary said he and his supervisor "lied to management" about his project, while ostensibly he worked on modifications to the outside system.

Once that deception ended, Lary's project had another problem as well. He had deliberately chosen the title of First Upward Compatible Keyboard Monitor for his PDP-8 operating system. (There was also a Second Upward Compatible Keyboard Monitor project, for the PDP-9, but it was never finished.) The program library had to censor their acronym listings for a long time, said Lary cheerfully.

Regardless of the name, Lary's project had tough constraints. The PDP-8 architecture divided code and data into blocks of 256 words, split into two pages of 128 words each. With only the original 4K words plus the newly added 4K, an operating system could easily occupy most of the available main memory, leading to immense amounts of swapping in and out of magnetic-tape storage. Lary's system ultimately occupied only 256 words, with two 1024-word sections that were swapped in and out of memory as needed.

In the final product, called OS/8, Lary included a date format method that extended out eight years and then expired in 1978. After all, he said, at age 21 he hardly expected that his work would still be used 10 years hence. Besides, the date formats of several other DEC operating systems expired in 1975, and he assumed that even though changing date formats was "a major pain," someone would have found a convenient way to do it before his system expired as well. (He was right.)

OS/8 was still extremely limited, Lary admitted, compared with modern operating systems. It did not use the PDP-8's interrupt system at all, for instance; the system either computed or did I/O, but never both. The simple reason: the interrupt routines were too large for the 256-word limit. The sequential access required for DECtape magnetic-tape storage was better suited to long read and write operations anyway, he pointed out, than to many short, interrupt-driven reads and writes.

Lary, now a senior consulting engineer for DEC's storage systems group in Colorado Springs, Colo., is proud of OS/8. And he has had the chance to see his work propagated as few other engineers have. The popular CP/M microcomputer operating system is much like OS/8 and in turn served as a model for the designers of MS-DOS, the system used by IBM PC and compatible machines. So in some sense, Lary fathered the world's most popular operating system: more than 10 million copies of MS-DOS have been sold so far. He has no regrets, Lary says, but reflecting on the profits that have accrued to MS-DOS publishers Microsoft Corp., Redmond, Wash., he mused that perhaps "I wrote it for the wrong machine!"

Timesharing and Burger King

One of the PDP-8's greatest strengths was its ruggedness. Stephen Kallis Jr., now a public relations officer at DEC, recalled a field service engineer's visit to a university laboratory after a disastrous fire. One of the lab's PDP-8s, installed without its cover, had been dug out of the mess.

Because it was uninsured, the university begged the engineer to see whether he could rescue it. He scraped as much debris as possible off the circuit boards and sawed apart the plastic front-panel switches, which had melted and fused in the inferno. To everyone's surprise, the machine booted and ran perfectly. It was later retired with honors; the owner swapped it for a new model.

Olsen recalled an equally dramatic demonstration: one of DEC's manufacturing engineers, trying to persuade a reluctant customer of a later PDP-8's strength, kicked it down a flight of iron fire stairs. It came through with flying colors, Olsen said, and the customer was convinced. But the engineer was lucky, he added, since he'd never done it before—and "he never did it again, either."

The uses of the PDP-8 were many and varied. It thrived in hostile environments and unusual sites. Its construction was sturdy, based on square-section steel tubing—Olsen had rejected an early proposal, framed in extruded aluminum, as too flimsy.

Burger King used PDP-8s for some of its first point-of-sale terminals. Two PDP-8s and a PDP-10 were linked with fail-safe hardware, designed by John Kirk, to perform nondestructive testing on the prototype Concorde supersonic transport, built by British Aerospace and France's Aérospatiale. Many PDP-8s were sold to telecommunications companies for message switching; they assembled characters by bit-sampling, checking teleprinter lines at five times the transmission rate to recover data if necessary.

DEC always specified that PDP-8s should be sited in air-conditioned rooms and treated well, Olsen said, but "people just used them in mysterious ways." The U.S. military experimented with PDP-8s in airplanes, and they went on many ships—some of the first oceanographic computing work and the first satellite navigation was done with PDP-8s, Olsen noted.

A cache-based PDP-8 was designed in 1971 at Carnegie Mellon University, Pittsburgh. The goal was to explore the use of emitter-coupled logic (ECL) for computer design; the need for a cache memory quickly surfaced, but in ECL the cost was so great that it would have made the PDP-8 project uneconomical.

Characteristics of the PDP-8 family of computers

Model	Date of first shipment	Innovations and improvements	Cost of processor and 4K words of memory, dollars
PDP-5	9-63	12-bit architecture	25 800
PDP-8	4-65	Automatic wire-wrapping production; low-cost bit-sampling communications controller	16 200
PDP-8/S	9-66	Serial instruction implementation	8790
PDP-8/I	4-68	Medium-scale integrated circuits	11 600
PDP-8/L	11-68	Smaller cabinet	7000
PDP-8/E	3-71	Omnibus I/O bus	4990
PDP-8/M	6-72	Half-size cabinet with fewer slots than PDP-8/E	3690
PDP-8/A	1-75	Semiconductor memory; floating-point processor	2600
VT/78	6-77	CMOS implementation of architecture; VT/52 terminal components	7800*
DECmate	6-81	Revised CMOS implementation; VT/100 terminal components	6795*
DECmate II	5-82	Similar to DEC Rainbow personal computer; optional Z80 and 8086 coprocessor cards	3745*
DECmate III	10-84	Increased integration for cost reduction	2695*
DECmate III+	12-86	Hard-disk drive	4695*

*Terminals and word processors based on the PDP-8 architecture were equipped with more than 4K words of memory, up to a maximum of 64K words in the DECmate III and III+.

Another unusual PDP-8 application was the TSS/8 timesharing operating system, also developed at Carnegie Mellon (where Gordon Bell taught from 1966 to 1972). Bell is inordinately proud of the TSS/8 machines; "as much as anything," he said, "we did it to ridicule IBM's timesharing system."

It worked, he said: students got the same access and response time on $100 000 worth of timesharing PDP-8 that they did on $5 000 000 of IBM System/360-67 mainframe, also timesharing. The PDP-8 users were limited to "honest little Fortran jobs," Bell said, but when the TSS/8 system was finally decommissioned by Carnegie Mellon, it turned out to have logged more student hours than the IBM mainframe. The authors of the TSS/8 system went on to design the PDP-11's RSTS timesharing system for the Basic language.

The PDP-8 was popular for educational uses in general. Students loved the immediate access it offered and its small scale. A new generation of what would come to be called hackers grew up around the PDP-8, among them Apple II designer Stephen Wozniak, who has called the machine the first he ever fell in love with.

Getting smaller and faster

Any design that has a life of more than 20 years will reflect the technological changes of its times, and the PDP-8 is no exception. From the first PDP-8 introduced in 1965 to the DECmates still in production today, PDP-8 models got cheaper, smaller, and faster—sometimes all three at once.

The PDP-8 family can be classed into four groups: the original PDP-8s, machines built with medium-scale integrated (MSI) logic, machines that incorporated the Omnibus I/O bus, and machines that used the "CMOS/8" single-chip microprocessor. Within each group are minor variations.

Three years after the initial PDP-8, the advent of MSI circuitry allowed DEC to introduce the PDP-8/I and PDP-8/L, which had better performance at two-thirds the price. These machines also used positive bus logic, compared to the negative logic of the previous PDP-8 and -8/S. The design staff changed too, as deCastro left to form Data General and "Uncle Don" White became DEC's "general PDP-8 guru," Bell having moved on to other systems.

A more fundamental change, however, was the introduction of a new I/O bus to allow customers more flexibility in expanding their systems' peripherals, as well as reducing packaging and cabling requirements. The new bus was designed by a team led by White, who remains a consulting engineer at DEC's Maynard facility. A contest to name the new bus generated entries such as Blunderbus, but in the end, the name Omnibus was chosen. Adapters for older peripherals allowed existing customers to upgrade to the new PDP-8/E without buying new tape drives or monitors.

The PDP-8/E processor itself, introduced in March 1971, took up just three 8-by-10-in. boards. Three others contained 4K words of core memory, and the rest of the system required four more boards, for a total of 10. In less than eight years, processor size had been reduced to the 8E's 240 square inches (1500 square centimeters) on three boards, from the PDP-5's 2100 in.^{2} on 100 boards. The price, meanwhile, had fallen to $4990 from $25 800 over the same period.

But further reductions were on the way. By the mid-1970s, the microprocessor was making waves in the computer design world. A DEC project to implement the PDP-8 in a single p-channel metal oxide semiconductor (MOS) chip, known as the PDP-8/B, began in the fall of 1972. The goal was to ship production systems by the autumn of 1974. But the project was abruptly ended in the summer of 1973, as effort instead shifted to a PDP-11 processor in the newer and faster n-channel MOS process.

The PDP-8's Omnibus, Bell pointed out, was too large and complex to implement on a single chip, whereas processors that multiplexed addresses and data on the same leads at different times could be put on one chip. Against the more complex PDP-11, the savings that could be gained from a single-chip PDP-8 did not justify a "microprocessorized PDP-8."

DEC also made an effort, Bell said, to interest the fledgling Intel Corp., now of Santa Clara, Calif., in building a PDP-8 microprocessor in 1972. But Intel's own 4004 and 8008 chips were doing well, and the company "didn't want to have anything to do" with DEC, he said.

Instead, by January 1975, DEC had re-engineered the PDP-8 to fit onto the 8-by-15-in. circuit boards already used for two years in the larger PDP-11. Fifty percent larger than the 8E's boards, the boards had six sets of 36 contacts, as against the 8E's total of four.

Moreover, semiconductor memory chips were at last economical, and the new PDP-8/A model used 48 1K-bit chips to provide 4K words of memory. Two years later, twice as many 16K-bit memories offered 128K words. Larger boards allowed the entire PDP-8 processor to reside on one board, and several of the 8E's peripheral controller options were condensed onto another board.

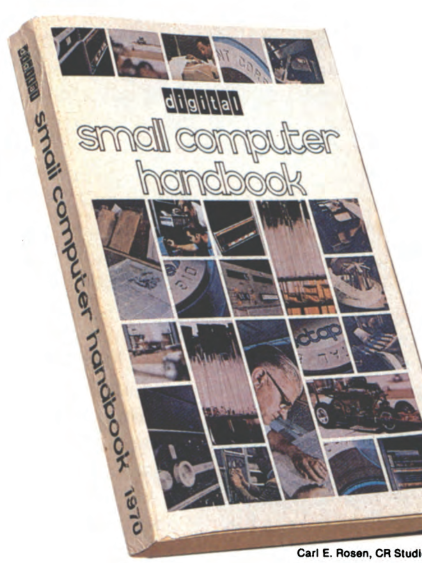
Defying death

By this time, however, the PDP-8 was getting old. "Lots of people tried to kill the PDP-8 for years," said John Kirk. "There is always more glamour in new instruction sets." But the PDP-8 architecture seems to be a survivor. Kirk, now a senior consulting engineer at the Mill in Maynard, was one member of the DECmate design team: the DECmate, which used a very large-scale CMOS chip, the 6100, to implement the PDP-8 architecture, is still built today.

Bell said that he always tried to think of the architecture as something that could be provided in even the least costly terminal. Since fewer than 64K bytes were needed for word processing, why not "just throw it in as part of the terminal?" he

Digital Equipment Corp.

[5] A promotional photo of a typical PDP-8 user from the late 1960s shows the Model 33 teletypewriter from Teletype Corp., on which thousands of engineers, scientists, and students first interacted with a computer.



Carl E. Rosen, CR Studio

[6] The Small Computer Handbook, *another Digital innovation, originally contained complete descriptions of the PDP-8's entire architecture, logic, and software. It was given away free at trade shows. The 1970 edition is shown here.*

asked rhetorically.

The result was the VT/78, a video data processor introduced early in 1977. It was essentially a VT/52 video terminal with an added module that contained the 6100 CPU and controllers for such peripherals as floppy-disk drives and serial lines. The VT/78 sold into the 1980s, as did its DECmate successors, but they were never identified as PCs—which they were—and so never exploited that booming market.

Total production volume of the PDP-8 is 190 000 to date. Of these, roughly 40 000 are older PDP-8s, while the rest are VT/78s or DECmates.

Two DECades later

All the designers associated with the PDP-8 are not only proud of their work, but fond of the machine itself. "You didn't have to air-condition a room just to have one," engineer White said. "Real people used it."

"They were really exciting times," deCastro said. "We felt like we were really moving the state of the art." Did its designers really expect to sell 190 000 PDP-8s? Probably not, Olsen said, "but we knew we had something good, and our customers loved it." ◆

1970

THE PACIFIC INTERTIE

Swedish technology helped harness hydropower to energize booming southern California

When the king and queen of Sweden arrived in Los Angeles this past April 26, local newspapers carried an advertising supplement that touted Swedish contributions to the United States.

Missing was any mention of the Pacific Intertie, an 846-mile (1350-kilometer) high-voltage dc transmission line. Based on Swedish-pioneered technology, the line supplies more than a third of greater Los Angeles' electrical needs. By linking the city to cheap hydroelectric power in the northwest United States, the intertie has for 16 years been saving southern California consumers some $1 million a day.

Norman Nichols, assistant general manager for power at the Los Angeles Department of Water and Power (LADWP), took the omission in stride. "People take the intertie very much for granted. We just assume it's no big thing to schedule 1000 megawatts out of the Pacific Northwest, and it just magically happens."

But to the intertie's designers and builders, the real magic was that the line was ever built at all. In the early 1960s, when it was planned, there were only two high-voltage dc lines in the world. Both were in Europe, and both were much shorter and at lower voltage than the one envisioned for the U.S. West Coast.

The lack of hard facts about such a large-scale dc project led powerful interests to fight the proposed line on the basis of various perceived threats. Private electric utilities in California said a dc line would disrupt the state's ac networks. Telephone companies argued that the dc converter stations would produce harmonics that would interfere with communication circuits. Operators of underground oil and gas pipelines feared that ground currents from the line would corrode their pipes. And the Northwest's powerful aluminum companies foresaw their cheap hydropower diverted to California.

Glenn Zorpette Associate Editor

Of course, the intertie was not without its own resources. For one thing, it had the support of President Lyndon B. Johnson. Also behind the project were the LADWP, the Bonneville Power Administration, and the giant Asea Co. of Västerås, Sweden. Asea's electrotechnical director, A. Uno Lamm, had done what General Electric Co., Westinghouse Electric Corp., and Soviet laboratories could not: build converter systems to change hundred-thousand–volt currents from ac to dc and back.

Perhaps most important, the nascent intertie had Charles F. Luce, a "real live wire," according to a colleague who knew him well in those days. At 43 Luce had been Bonneville's youngest head when he was appointed in 1961 by Interior Secretary Stewart L. Udall. Bonneville was organized by an act of Congress in 1937 to design, build, and manage the Northwest's hydroelectric supply. Luce had the energy and vision to carry out a project that had been on the agency's drawing boards for more than 25 years.

Early proposals

The first idea for bringing northwestern hydropower to Los Angeles came from Carl Edward Magnusson, a professor of engineering at the University of Washington in Seattle, who in 1920 proposed a 1000-mi (1600-km), 220-kilovolt ac line. But the Pacific Intertie's story really begins in the 1930s with the construction of the Grand Coulee and Bonneville dams on the Columbia River in the Pacific Northwest, where an estimated 40 percent of the potential hydropower of the continental United States is concentrated.

But in the mid-1930s, as the dams were being built, no one had any notion of how their combined 2500-MW output would be used. The chief engineer of a local utility told students at Oregon State College (now University) in Corvallis that none of them would live to see the power from just the first two 48-MW generators at the Bonneville dam put to use.

James D. Ross, Bonneville's first administrator, was also first to conceive dc transmission of Columbia River hydropower to a metropolitan area with high demand. In 1939 Ross, a mathematician and self-taught electrical engineer—and a friend of President Franklin D. Roosevelt—hired Eugene C. Starr to study whether a dc link was feasible between the Bonneville dam and Chicago, where electrical demand was soaring.

Starr, a professor of electrical engineering at Oregon State College, reported two years later that dc technology—at that time used mainly for subways and other transportation applications—was not advanced enough for long-distance transmission. Nonetheless, the report suggested that investigation continue into applying dc to transmission lines more than 325 mi (525 km) long. Over such a distance, impedance would make an ac line difficult, if not impossible, to operate.

World War II brought surging electrical demand among the Northwest's aluminum makers, shipyards, and aircraft plants, and so for a few years there was little talk about using dc to export the region's power. At the same time, however, high-voltage dc technology found a place in the German war machine when Hermann Goering ordered Siemens AG and AEG to develop a plan to bury all of Germany's transmission networks, where they would be less vulnerable to attack and of no use as landmarks for Allied pilots and navigators. After the war, German dc equipment was taken to the Soviet Union, where in the early 1950s German engineers helped build the Moscow-Kashira ±100-kV dc line.

After the war's end diminished industrial demand in the Pacific Northwest, the idea of a dc line to transmit excess power from the region once again took hold. Bonneville chief engineer Sol E. Schultz visited several European companies but found the technology still not sufficiently advanced.

The turning point came in 1954, when Asea built the world's first commercial dc transmission line, a 100-km, 100-kV, 20-MW cable under the Baltic Sea between Västervik on the Swedish mainland and the island of Gotland. Asea was soon producing higher-voltage components suitable for longer lines.

Progress at Gotland was followed closely at Bonneville. When Luce took over in 1961

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