PDP-8/I: bigger on the inside yet smaller on the outside

Updating a proven computer design with integrated circuits made room for many options inside the machine and paid extra dividends in increased capability

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Redesigning a small scientific computer to replace its discrete components with integrated circuits will, obviously, reduce size and costs. But IC's also make possible the inclusion of many optional circuit assemblies that had to be packaged outside the main frame of the original machine.

The principles of redesigning for IC's that the Digital Equipment Corp. used for the computer can also be used for any kind of IC system for process control, data acquisition, or instrumentation. And the test procedure DEC established for the IC's and their modules, which was vital to the redesigning, could also find widespread applications.

Even though DEC's PDP-8/I (I for integrated circuits) is smaller and has more circuitry than the PDP-8 and PDP-5, it's hardware- and software-compatible with them.

Father and son

Both the PDP-8 and its offspring are single-address parallel computers. Each has a 1.5-microsecond memory containing 4,096 words of 12 bits each. The same programs can run on either machine, and the same input and output equipment can be connected to either. The diagram on page 97, bottom left, compares the vital statistics of the two machines.

The PDP-8/I has much more internal space for optional logic than the PDP-8. But in both computers, major options, such as extended memory control or extended arithmetic, require many modules.

Extended memory in both expands the basic 4,096 words to as many as 32,768; extended memory control consists of several three-bit registers that extend addresses from the basic 12 bits to 15 ($2^{12} = 4{,}096$; $2^{15} = 32{,}768$). Adding the first increment of extended memory requires installation of the control circuits for all increments and one 4,096-word stack—the ferrite-core storage elements and their associated drivers and sense amplifiers. The first stack goes outside the main frame of the 8 but inside the 8/I. Successive increments require only additional stacks, which go outside both machines.

Extended arithmetic permits both computers to multiply and divide directly, making step-by-step programing unecessary for these operations. Parity-checking circuits are a third option, and circuits to protect an operating program if the power fails are also available.

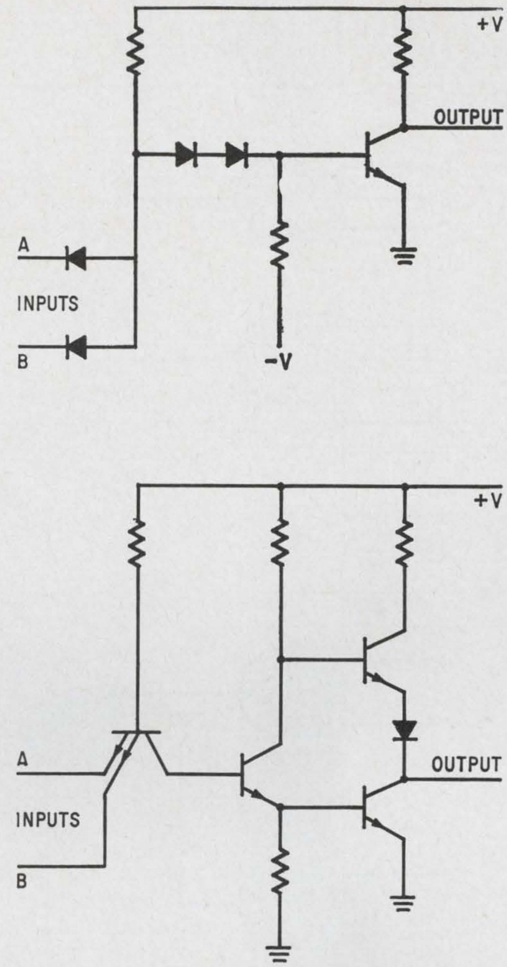
These four options take up all the available space in the PDP-8, but in the PDP-8/I there is still space for control logic for a high-speed paper-tape reader and punch, a card reader, a plotter, one of two display units, a light pen or vector capability for the displays, and a real-time clock. And even with all these installed, space is still left for further expansion.

Yet the basic price of the 8/I is 29% less than that of the 8. The major options are also priced proportionately lower for the 8/I.

Two changes

The transition to monolithic IC's required two major changes: shifting from diode-transistor logic (DTL) to transistor-transistor logic (TTL), and expanding an already extensive testing procedure to ensure IC reliability.

Little giant. This computer, the all-IC PDP-8/I, can be more powerful than the discrete version because it has room inside for several optional features. It's small enough for a desk top.



Old and new. Diode-transistor-logic circuit (top), used in older PDP-series computers, has been superseded by transistor-transistor logic—faster, less sensitive to noise, and cooler.

Of course, the TTL circuit, at right above, has several advantages over the DTL circuit, such as quicker switching and a propagation delay only about half as long.

The switching time is less because the multiple-emitter transistor at the IC's input has less chip area and capacitance than the diodes. The two output transistors make the waveform's rise time very nearly the same as its fall time, and it's this characteristic, combined with the quicker switching, that cuts the propagation delay to about 12 nanoseconds from about 25 in DTL. The "totem-pole" output also makes TTL less sensitive to capacitively coupled noise. Finally, the TTL circuit requires only one supply voltage, not two, and it draws only 10 milliwatts from the supply, compared to 80 or more for DTL.

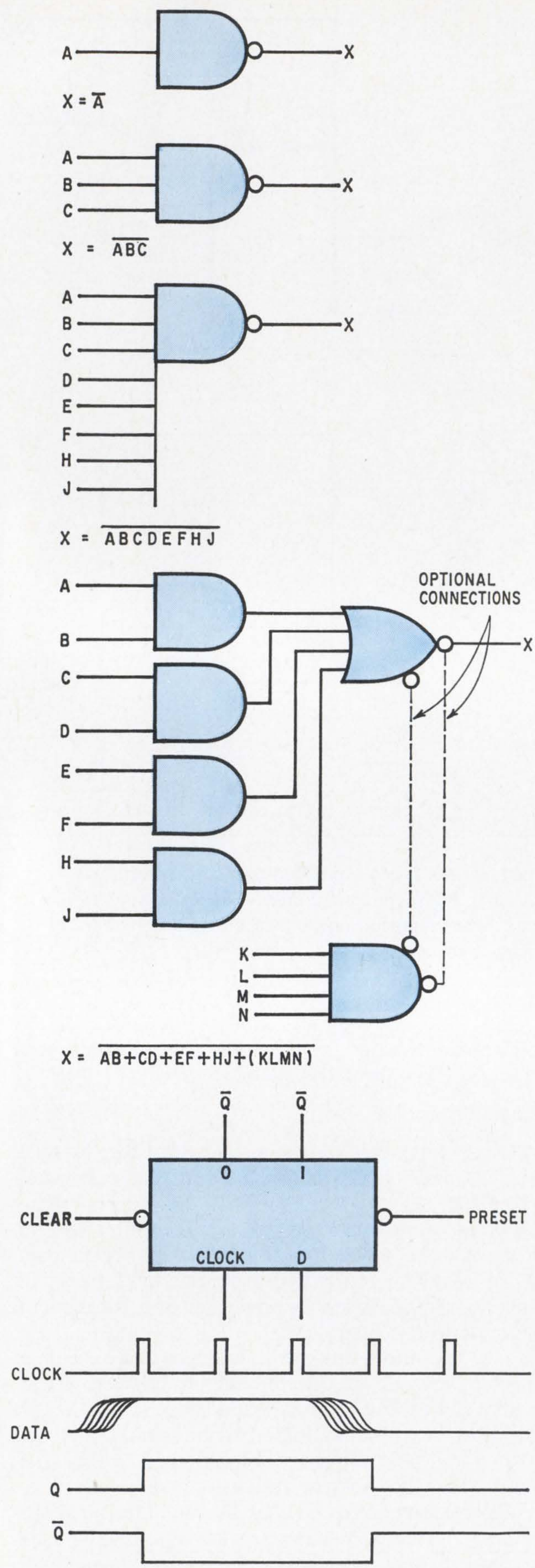
The DTL does have one advantage. DEC's R series DTL gates have a load capability of 18 gates, but the TTL circuits in the PDP-8/I can drive only 10 gates. The TTL driving ability, however, is adequate. Both types of circuits have logic thresholds of about 1.4 volts, and the load-driving ability of both is determined by how much current can pass through the output transistor to ground.

Logic types

Other types of logic are also superior to DTL, but TTL was chosen because it's available in quantity from several IC manufacturers, in the many different logic forms needed for computer design. For example, a NAND-gate family, shown on page 94, must have circuits with from one to eight inputs so they can be used as inverters and for general logic and decoding.

Two or more gates can have electrically common outputs, giving an OR function at no cost in circuitry, but all the common gates must share a single collector resistor. In this configuration, the usual TTL totem-pole output can't be used; a variation with only the bottom transistor takes its place. These circuits are somewhat slower than the standard TTL circuits, because, as in DTL, the line capacitance must discharge through the common collector resistor.

Where speed is essential, this "wired OR" can-



Logic configurations. All these gate forms are available in TTL circuits.

not be used. An AND-OR INVERT logic gate is a suitable substitute; it's available with an extender element for additional inputs.

A flip-flop circuit is necessary for single-bit storage functions, both in control applications and as a building block for registers in the data path. In the PDP-8/I, a single-input flip-flop controlled by a clock signal performs this function in both applications.

Where a single signal must drive a great many loads, as is often the case with timing or general reset signals, a power driver is needed. Finally, more complex logic assemblies can be used if their cost and the number of circuits per machine justify them. In the PDP-8/I, for example, two full adders in a single package were chosen over less costly multichip devices because 12 adders are used in each machine. Two single chips, with associated logic, are included on a single module that also contains two bits of each of four registers. On the other hand, a part needed only once in each machine—and then only as an option—would hardly justify the extra cost of single-chip design.

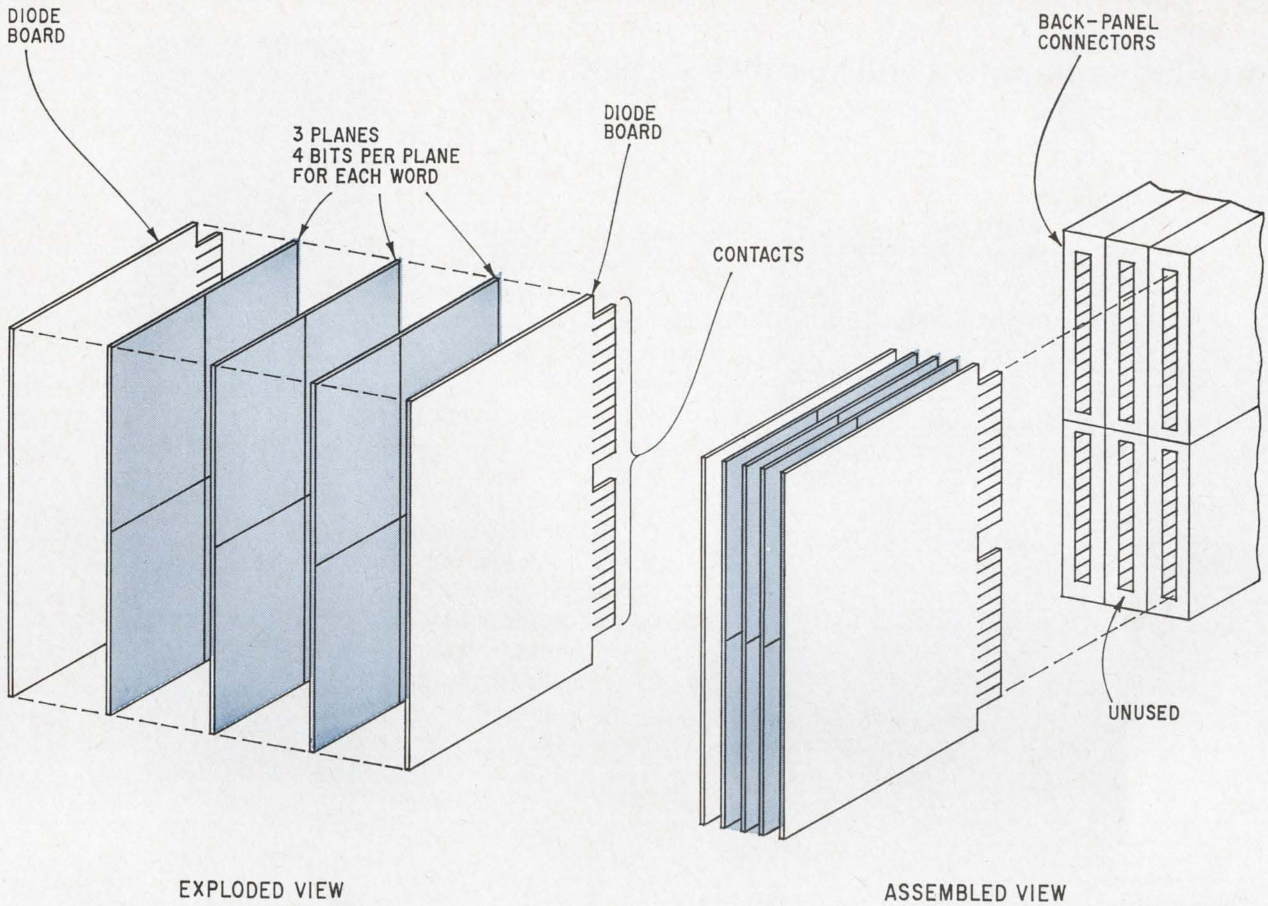
DEC buys its logic circuits for the 8/I in dual in-line packages and mounts them on module boards with contacts on both sides along one edge. These modules plug into connector blocks in the computer panel. The boards are made the same size as those in the 8 to capitalize on existing production facilities, but the older machine uses modules with single-sided contacts.

Shrunken memory

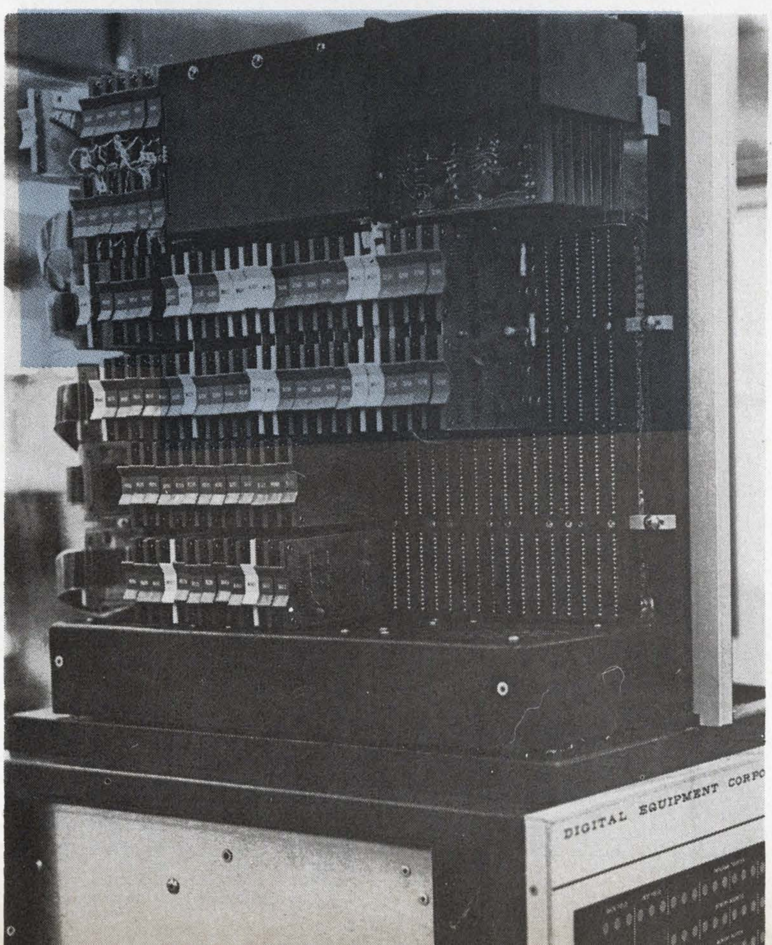
Although IC's were primarily responsible for the reduced size of the PDP-8/I, its memory is an excellent example of how careful design can pay dividends without extensive use of IC's. The memory's capacity and functional design are the same as in the PDP-8, but the packaging drastically reduced the size.

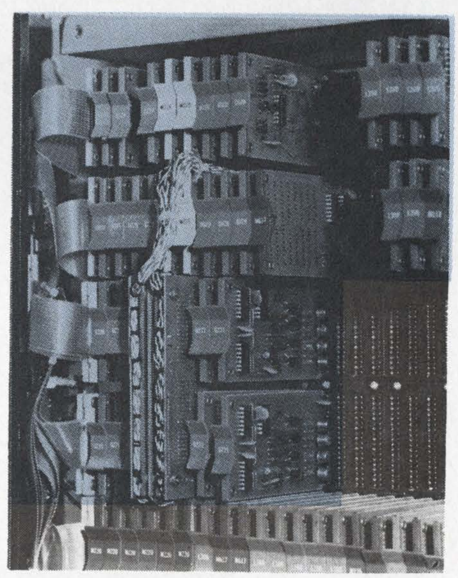
The new memory has only three core planes, each containing four bits of the 4,096 words. These planes are sandwiched between two end boards carrying selection diodes, shown at right, top. The boards are the same size as double-height modules, and each plugs into a pair of back-panel connectors. The entire sandwich assembly covers three pairs of back-panel connectors; the memory planes, between the end boards, cover one pair but don't plug into it. Short cables connect the assembly with related circuitry packaged on modules that plug into nearby connectors. The reduction in size is illustrated in the photos directly opposite.

Another design technique that saved space was a new type of switch that does away with the need for baluns (pulse transformers that are necessarily discrete components). All 3-D or 2½-D memories require circuitry to drive current in either direction through the memory windings—one way for reading, the other for writing. This current is routed through a configuration that resembles a balanced transmission line. Because the read-write current controls usually drive an unbalanced line, most



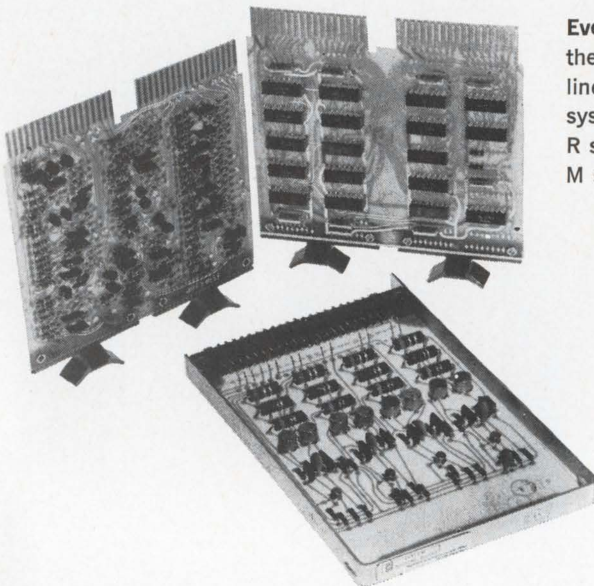
Midget memory. Only three core planes, sandwiched between two diode boards, make up a memory that holds as much as one requiring 12 planes and several cards full of other components.



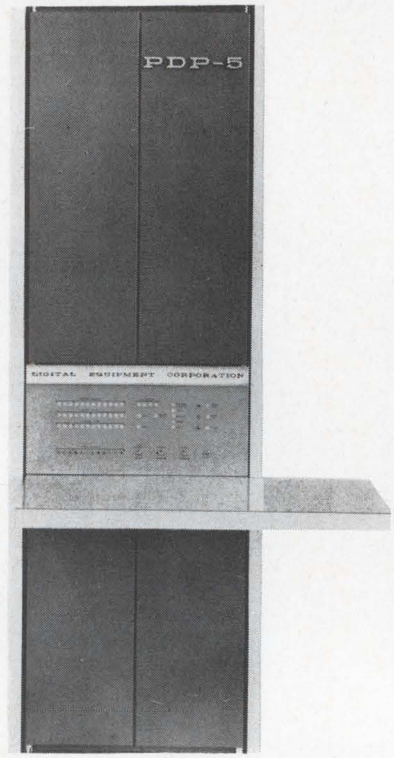


Before and after. The big black box is the memory assembly for the old PDP-8. The small assembly above stores just as much data and makes it accessible just as fast.

Three little computers and how they shrank



Evolution. Three stages in the development of DEC's line of circuit modules; the system modules at bottom, R series at left, and new M series at right.



Granddaddy. Digital Equipment's first small computer, the PDP-5, was introduced in 1963. It was built with system modules.

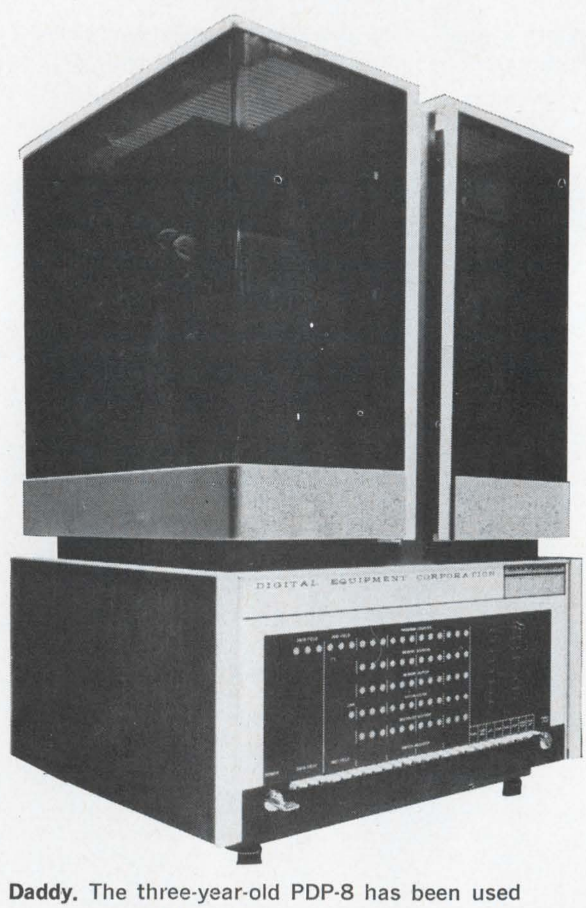
The evolution of modules from the earliest discrete solid state circuits to monolithic integrated circuits is illustrated by those shown above, used by Digital Equipment in its machines.

At the bottom of the photo is a typical system module, made with germanium transistors. These modules are large and rigidly supported so they can withstand extended experimentation. They were also used in DEC's PDP-5 computer, introduced in 1963. The computer is no longer in production, but the modules are; they're still being sold as replacement parts and for experiments and instruction.

The smaller R- and S-series modules, carrying DEC's trade name "Flip-Chip," are made with silicon transistors. The typical double-height module at the left has 36 pins on its connector edge; a single-height module would have only 18. The double-height modules are less rigidly built because most of them are used either by DEC in its own computers—such as PDP-8—or by customers in their own systems; the modules, once plugged into the systems, aren't very likely to be changed.

The M-series modules, with monolithic IC's, are used in the PDP-8/I. They have more logic and more kinds of logic than the earlier versions.

The three computers are program-compatible, so they illustrate the size reductions and increased capability made possible by module evolution. The PDP-5, above right, occupies a whole rack; it stands on the floor and is as tall as a man. The PDP-8, at the right, is a tabletop machine, but most people would have to stand on tiptoe to see over it. The PDP-8/I is also a tabletop computer, but the operator can see over it while sitting down. The 8/I is also available in a rack-mounted version that has plenty of extra space for external options or associated instruments.



Daddy. The three-year-old PDP-8 has been used as a subassembly in many instrumentation and process-control systems.

memory systems use baluns to connect the two lines.

But in the PDP-8/I, a switch consisting of four diodes and one discrete transistor, shown at right, replaces the bulky and expensive balun. What's more, two of the diodes are "free" because they would be required even with baluns. Thirty-two of these switches are used; they select one of two sets of 64 wires threading the cores in the memory. Each wire passes through 64 cores—each threaded by a different wire in the other set—in a single plane, and passes through all 12 planes, for a total of 768 cores.

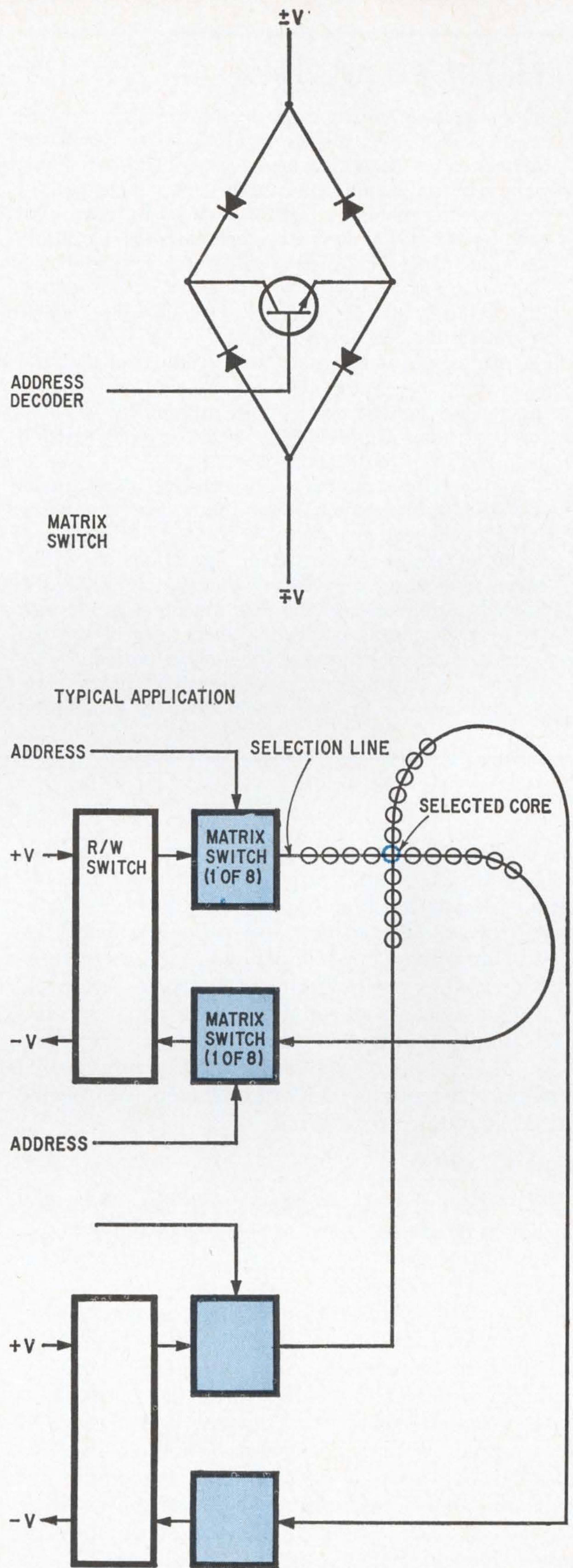
Testing cuts costs

DEC, which regularly tests all the components it buys, developed a special test procedure for IC's as part of the PDP-8/I project. Defects are found and eliminated before assembly is started.

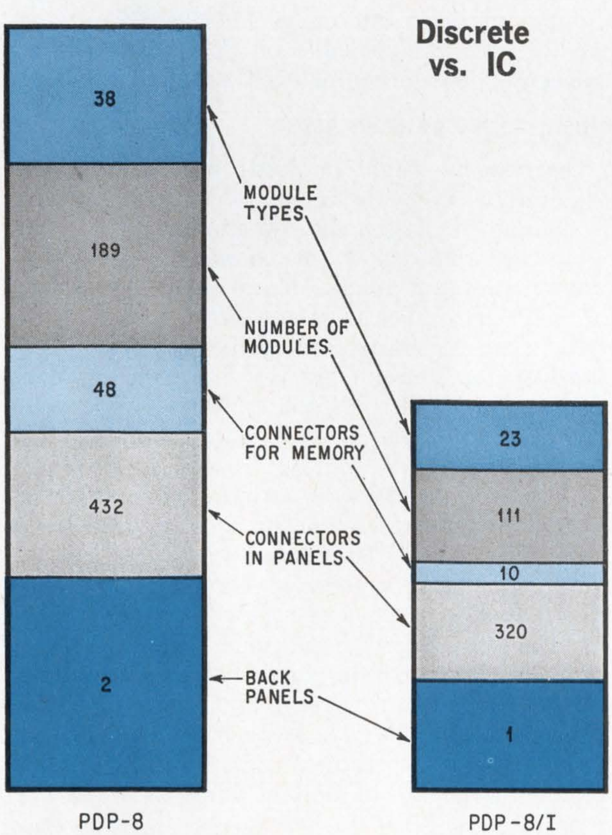
Forty static tests and 16 dynamic tests, performed in slightly more than one second, measure minimum and maximum voltage and current levels at the circuit inputs, propagation times—using worst-case waveforms of minimum amplitude—and, in general, all the manufacturer's specifications.

The more complicated IC's, of course, take longer to test; the gated full adder, for example, has so many specifications that its computer-controlled testing takes 30 seconds.

The modules are tested both before and after the IC's are inserted. The back-panel wiring is tested before the modules are inserted, and the complete computer is also tested. All these checks



Matrix switch. Four diodes and a transistor replace a pulse transformer, helping to reduce the size of the PDP-8/I memory.



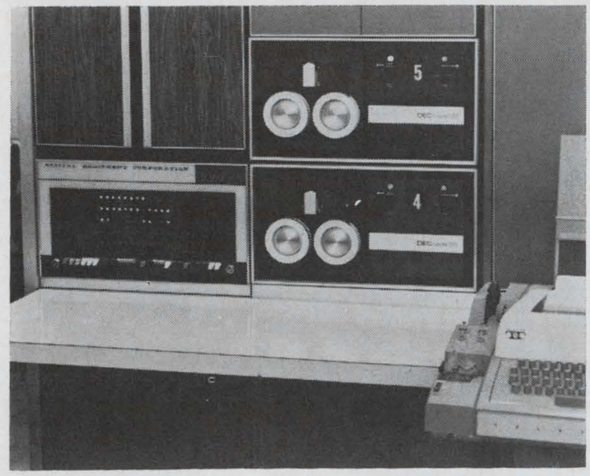
The PDP-8 is still kicking

A new computer that can run any program written for an older model, connect to all the same peripheral devices, fit in much less space, and still cost almost a third less might be expected to wipe out the market for the older machine. But this hasn't happened with the PDP-8 and 8/I, nor with other pairs of compatible machines that Digital Equipment has marketed.

Most of DEC's sales are to makers of equipment that use a small computer as a subassembly. These manufacturers buy the machines in relatively large quantities, and redesigning their products around the new computer would require a major retooling at great expense. It's much more economical—at least for the time being—to stay with the older model, even though it costs more per unit.

Another fountain of youth for the older model is that introduction of a less costly new one often entices prospective customers to start thinking seriously of computerizing their operation; they discover advantages they hadn't thought of previously. But when deliveries of the new machines won't start for several months or even a year, sales of the old machines actually increase for a short period.

The 8/I has been so well received in the few months since its first shipments that its production rate is three to four times that of the 8. However, the latter will never be completely discontinued, although it will probably be phased out of full-scale production before too long.



Going strong. This computerized typesetting system is only one of many current products built around the PDP-8 (left).

are made under worst-case conditions.

Detection is a special problem in modules containing sequential logic instead of purely combinational forms. The outputs of a sequential-logic device at any given time depend on its previous inputs as well as on its inputs at that time; examples of such devices are counters, shift registers, and even simple flip-flops. On these modules, test points permit detection of signals ordinarily not needed outside the module and establishment of specific initial conditions for testing.

Optional extras

The logic for the optional features described earlier may use standard modules like those in the central processor or special modules designed for specific applications.

For example, the extended memory control and the extended arithmetic use modules essentially identical to those in the basic machine. These are complex options and would require several modules even if special ones were designed. But some of the simpler options can have all their controls packaged on a single special-purpose module. For example, an electromechanical device may require an initial delay while the device starts moving; this delay can be incorporated in the control circuitry through the time constant of a capacitor and resistor mounted on a module containing both discrete components and IC's. The PDP-8/I contains several kinds of such hybrid modules as well as the IC variety. These special-purpose modules are simple to install and make it easy to change from one option to another very quickly.

Other special modules include those for the real-time clock option available for the PDP-8/I. The option comprises one double-height module and two single-height modules, all of which are plugged into the machine internally. They provide a capability that was available on the PDP-8 only by connecting an external rack containing 12 modules.

Where do we go from here?

The machine might be made even smaller and less costly through the use of serial techniques or of medium- or large-scale integration. Serial computers are quite slow, of course, because they process one bit at a time. In any event, the outlook for these approaches seems doubtful.

DEC brought out a serial computer, the PDP-8/S, shortly before introducing the 8/I. The existence of the 8/S—the first computer with a price less than $10,000—might at first glance indicate that a serial IC machine would be feasible and economical. However, the PDP-8/L, a kind of stripped-down 8/I that nevertheless remains a fully parallel 12-bit machine, costs only $8,500 and seems to serve the same market that a serial IC computer would be aimed at.

MSI or LSI wouldn't be of much value unless the entire machine were designed that way, especially with a different circuit form, such as metal oxide semiconductor. When LSI is partially used, it generally appears in features, such as scratch-pad memories, that are of limited value in small machines.