FOCUS on Microprocessors

Digital designers faced with the many performance claims for new LSI microprocessors might conclude that one of these little, low-cost marvels could solve all their system problems. After all, if a small IC offers the processing of a computer, replaces scores of standard logic circuits and has a seemingly endless list of applications, who needs to design with anything else?

Closer examination of the burgeoning application literature for a "computer on a chip" reveals a different picture. A large-scale integration processor, for example, does perform many of the functions of the central processing unit in conventional computers. But to use the circuit, many more ICs may be needed to interface with peripheral devices, data-communication lines and even its own memory.

And that low price tag on the LSI processor—typically, well under $100 for 4-bit word-length units and under $400 for 8-bit units—is low compared with the thousands of dollars needed for a general-purpose minicomputer. However, to build a full-fledged microcomputer, you need memory, and the cost of that can easily exceed the price of the processor.

Moreover, if you add up the cost of all the necessary hardware components, you may find the total exceeding the less-than-$1000 level of "stripped down" minicomputers available on PC boards.

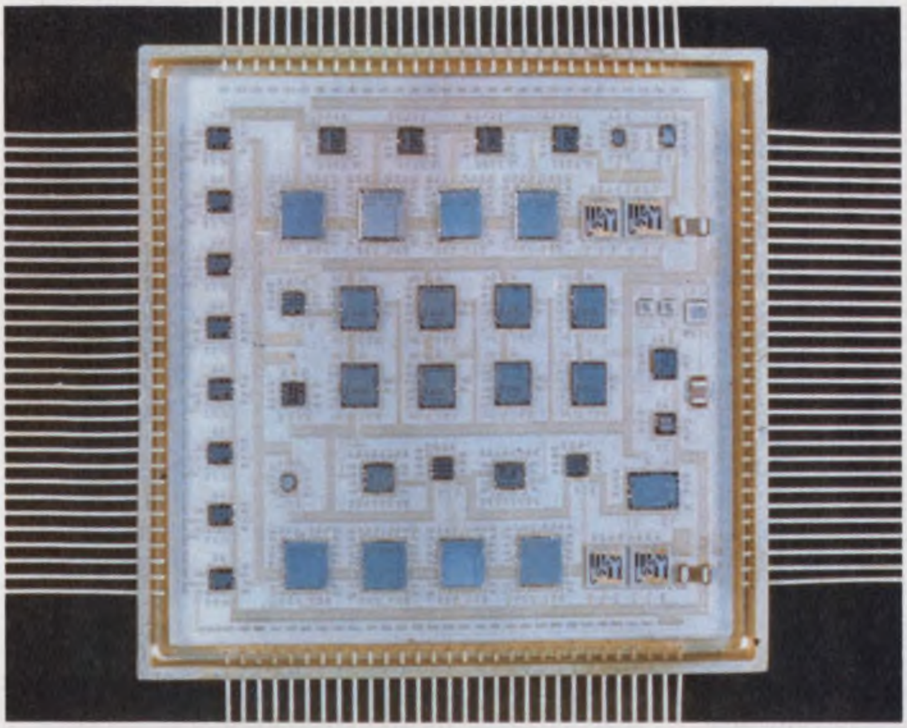
Combine an LSI microprocessor with associated circuitry and memory, and you obtain a microcomputer. In the foreground are LSI circuits and prototype systems offered by Rockwell International. The manufacturer's line includes 4 and 8-bit microprocessor chip sets.

Programming—unfamiliar demands

A decision to use an LSI processor opens up a whole new design ball game. Not only must a digital designer contend with the relatively familiar requirements of any logic system. The designer must also grapple with the relatively unfamiliar demands of programming. And software development, usually involving assembly language (only one step up from a computer's inherent machine language of ONEs and ZEROs), represents by far the major design effort and cost.

In addition microprocessors don't lend themselves to the traditional "learning curve" for new

Edward A. Torrero
Associate Editor



Dice mounted on a substrate form a microprocessor system. This unique packaging approach is used by Teledyne Semiconductor. Other vendors typically mount DIPs on PC boards.

components. Previously the experience gained in the use of one component could be transferred to a similar component from another manufacturer. But different microprocessors generally don't have alternate sources. And the chips come with different software capabilities, hardware requirements and design aids. Hence a completed design, using one LSI processor, might have to be scrapped totally if you decide to turn to another vendor's unit.

Still, there are major benefits. Microprocessors are unique among ICs in that they can be programmed like computers. As a result, they permit a tradeoff of software for hardware to achieve a dazzling increase in system capability and versatility.

They can be used economically to replace or upgrade random-logic designs, involving scores of standard ICs, when many functions must be performed. And they use less circuitry than hardwired logic in applications emphasizing random collection and routing of data.

Of course, for some applications microprocessors are not the sole LSI alternative. Complex logic decisions might be handled just as well with circuitry using programmable logic arrays. And arithmetic computations are performed by arithmetic logic units or by calculator chips—from which a number of microprocessors have evolved. Custom LSI chips provide yet another alternative.

Nevertheless microprocessors are filling the gap between special-purpose LSI circuits and conventional minicomputers. They are currently finding their greatest use as decentralized, cheaper minis in remote, programmable controllers.

There's a wide product range

The many advantages of microprocessors are creating a demand that manufacturers are meeting in a variety of ways. Designers can choose from among single or multichip processors, chip sets or PC-board assemblies, and from among a wide range of technologies.

The most common technology is silicon-gate, p-channel MOS (PMOS). But manufacturers are also using n-channel MOS (NMOS) and silicon-on-sapphire MOS (SOS/MOS) to achieve speeds that are higher than those possible with PMOS. Bipolar processes are employed for the highest speeds—about 200-ns cycle vs 2 μs for NMOS types. Complementary MOS (CMOS) is used for the lowest power dissipations—microwatt-range chip dissipation vs milliwatt range for other types.

Standard LSI-processor products in various configurations handle data in 4, 8 and 16-bit word lengths, and modular multichip microprocessors can be used to achieve even longer word-length processing. The available configurations, with their major features, consist of the following:

- Microprocessor chip sets, including special interface ICs and sometimes special memories, to simplify designs of minimum-hardware systems for specific applications.
- Microprocessor-based logic boards to eliminate the need to test, assemble and interconnect

processor chips, peripheral circuits and memory for a variety of applications.

- General-purpose—nondedicated—microcomputers, on cards or in boxes, to permit system design, development and testing. These are offered by component manufacturers, as well as, a growing number of other vendors.
- Microprocessor-based minicomputers offering, as a result of their traditional mini features, maximum flexibility and capability when compared with MOS microcomputers. Offered by minicomputer manufacturers, these units generally use custom MOS processors.

The cost of each configuration increases with a unit's complexity. At the minicomputer level, hardware cost might be the highest. But available software support is the most extensive. Designers tend to feel that the number of units determines the major tradeoff in a choice between a micro and minicomputer. A small number of units—as for an end-user application—can best be served by a mini, which can minimize software development costs. But for large quantities—as for an OEM application—a microcomputer can minimize hardware costs.

Chip sets improve early versions

Due to increasing availability of special interface circuits and improvements in processor-chip architecture, fewer additional circuits are needed for the newest microprocessors than for earlier versions. First-generation 8-bit processors, for example, typically needed about 20 additional standard-TTL circuits to make them work.

The extra ICs include the following: registers to address memory, either ROM or RAM; decoders to interface with memories; other ICs to handle processor information and to synchronize the operation of the processor and circuits; clock circuits, and a variable amount of interface ICs, depending on the application. For example, in a multichannel data-communications application each channel requires an asynchronous receiver/transmitter and associated interface ICs.

But even with newer processors, applications still can require additional circuitry to obtain one or more of the following: clock generation and timing, memory and I/O control, data and address buffering, multiplexed inputs, interrupt control, refresh for dynamic memories and additional supply voltages.

And some microprocessors are offered only as part of complete chip sets or with the purchase of the associated memory from the same IC manufacturer. This may not be a problem if you plan to buy all your components from the same source, but it does stop you from shopping around for the lowest price and precludes the use of core memory—which most processors can accept just as well as semiconductor types. Also, if you purchase a chip set, you must design around the circuits offered.

Specs don't tell all

Unlike the less-complicated ICs, microprocessors cannot be completely characterized on a simple data sheet. Moreover different vendors use different parameters to measure a processor's capabilities. This makes any comparison of processors—not to mention selection of the best one—a difficult task. And there's no trend in sight toward standardization.

A microprocessor's computing speed is a case in point. Frequently manufacturers use a basic cycle time, or period—sometimes called a microcycle—to denote speed. But many microcomputer operations require several such cycles to be performed. This applies especially to the execution of the more powerful instructions. Hence a critical instruction may require more time than that indicated by the basic cycle.

In addition a microprocessor's maximum clock rate can be misleading, if taken for a measure of speed. It's possible for one microprocessor to perform basic operations—like register-to-register add—faster than a unit using a higher clock rate. Differences in microprocessor architecture and chip design tend to minimize the importance of the clock-rate spec.

Other specs given to indicate speed include minimum instruction time, interrupt response time, and time to add two numbers—which may already reside in the processor. Like cycle time and clock rate, these numbers don't measure such critical times as the over-all time needed to perform important routines. Excluded are additional delays, such as those needed to obtain data from memory. The solution is to use benchmark programs tailored to your application as a basis for selection of one microprocessor over another.

Use of benchmark programs can determine the power of the instruction set, thus circumventing one of the most abused specs—the number of instructions. Microprocessor comparisons based on this number abound, although such comparisons have serious flaws.

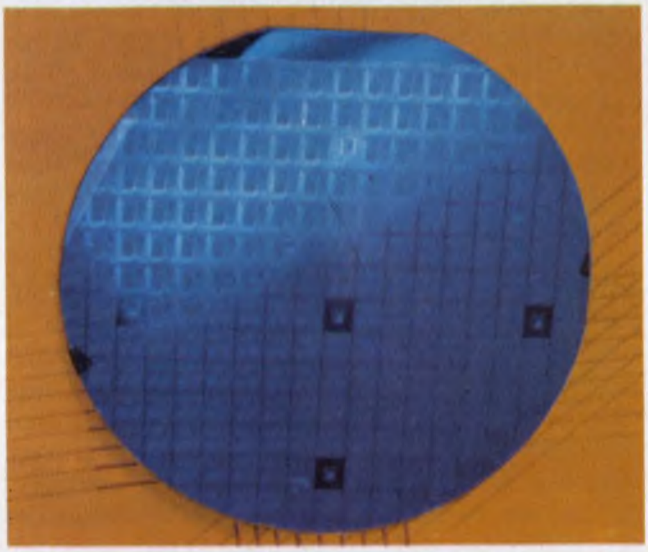
For example, a simple number doesn't reveal what instructions are available for data movement and manipulation, for decision and control and for input/output operations. Some microprocessors have far more I/O instructions than others; they are tailored for a specific class of applications. And missing instructions can always be performed by routines, although with a sacrifice in speed.

Also, the number of instructions claimed for the same microprocessor can increase from one page of a reference manual to another. One reason is that instructions that move data have been multiplied by the number of addressing modes.

Common addressing modes include direct, immediate and indirect. In the immediate mode, the instruction includes data, while in the indirect mode, an address preloaded into a register increases the address bits in an instruction. Variations and extensions of these modes are also available, so a basic instruction can be multiplied several times.

Other factors that inflate the number of instructions may be the number of registers—in, say, a load-to-register operation—or the number of conditions—for example, those on which a branch may occur.

Of course, improved instruction sets are obtained with longer word-length microprocessors and advanced versions of smaller units. For example, 16-bit microprocessors have instructions for multiply and divide—functions that require



They're not "computers on a chip"—yet. But LSI microprocessors, symbolized by this wafer from Intel, perform many of the functions of central-processing units in conventional computers.

software routines in 8-bit models.

And advanced microprocessors feature more powerful instructions as well as the original set of a predecessor. However, this "software compatibility" doesn't allow routine upgrading of systems by chip replacement. In general, expect to redesign to employ the new hardware/software tradeoffs efficiently.

For virtually all models, data sheets claim TTL compatibility. But don't expect many MOS processors to drive TTL loads; most don't. The term primarily refers to the fact that both microprocessor and TTL circuit can use a common 5-V supply. Newer models list a maximum TTL-drive capability of only one standard load, and many models require external components to achieve the interface levels needed for logic compatibility.

Watch architectural claims, too

Many computer-like features of microprocessors are frequently cited, including the number and function of registers, the type and depth of stack, interrupt capability and direct-memory access (DMA). However, there isn't as much architectural diversity as there is with minicomputers. IC manufacturers are constrained by technology limitations, so that comparable microprocessors tend to perform similarly. For example, preliminary benchmark programs run by several manufacturers for their 8-bit, single-chip NMOS processors often show comparable execution times.

Data sheets frequently boast several working registers. But only a single register, the accumulator, is essential. An accumulator, however, must have access to memory, and available instructions should permit immediate addressing and data manipulation between the accumulator and memory. If indirect addressing is available, even the function of special index registers can be accomplished with memory.

The major significance of additional registers lies in access time and the bit efficiency of instruction words. It takes far fewer bits to specify one of several previously defined working registers than a memory location. And a faster execution time can be obtained with registers that are separate from memory. They can be accessed without excessive memory-cycle delays. Otherwise it doesn't matter whether these registers are in an external memory or in the processor, so long as they can be referenced efficiently.

Some data sheets might seem to imply that the quantity of registers is more significant than their quality. It isn't. Not all registers can be incremented and tested for zero, even though they are described as "general-purpose." Those that can may be used for counting and program-loop control. In general, not all registers can be used for indexed addressing. Nor can they be loaded directly from memory—rather than only from the accumulator—or used as a source or destination for arithmetic logic operations.

Microprocessors employ stack-oriented registers that can be accessed only in a last-in-first-out basis—the so-called LIFO, or push-down, stack. These are used for subroutine nesting, interrupts and for temporary storage of data. They can be either on the chip (a hardware stack) or external to the processor in memory (a software, or pointer, stack). The hardware stack permits higher-speed operation, but it has limited size. The size of the software stack may be as large as available memory space permits, but the stack must be maintained by the program.

An interrupt capability is an absolute must for applications that involve asynchronous or unpredictable events. All microprocessors claim some type of interrupt handling ability, but the extent can vary from one unit to another. With older processors, you have to design the means to save the contents of the processor just prior to the interrupt, and then restore the information after the interrupt is serviced.

Those means may involve reservation of registers on the chip, use of external registers or use of another microprocessor. Any of these methods can store the essential contents of the processing unit. Software control, involving special routines, must also be provided to complete the design. The complexity of these techniques tends to discourage designers from attempting to handle even a single interrupt.

Newer microprocessors can accommodate single-line, multilevel and vectored interrupts, and they save essential registers automatically. A complete saving must be programmed. In one single-line interrupt system, device-interrupt requests are ORed together to form one request line. The program identifies the device and resolves priority. A multilevel scheme employs several single-level sense lines to handle additional interrupts. For very fast response, the vectored interrupt directly branches to a memory location that corresponds to a specific interrupt.

Another feature that depends on the unit is DMA capability. For some units, a "direct" access of memory must be performed indirectly through the microprocessor's usual word-by-word transfer procedure. This may not be a problem if you don't mind the processor's idle time, but it does limit data-transfer efficiency.

And don't expect I/O data throughput rates always to include the time needed to sense for a device or to respond to an interrupt. When these times are included, the actual throughput can be significantly less than expected.

Fixed instruction vs microprogram

Most microprocessors come with fixed instruction sets, around which software must be developed for an application. For some units, however, the option exists for microprogramming, the ability to alter or totally change the original instruction set. In essence, you program the microprocessor's internal microinstructions to obtain a macroinstruction set that is tailored to the application.

The advantages of microprogramming include increased speed, since microinstructions are executed considerably faster than macroinstructions are. Also, the technique allows a more detailed level of control that can be used to reduce hardware; the program controls more functions.

Because of the hardware savings, vendors expect microprogramming to find its greatest use in large-volume applications—in excess of tens of thousands of units. Alternatively, microprogramming represents the logical choice for an emulation of another computing system or for the speedy execution of critical, short routines.

The exceptional skills required for microprogramming constitute its major disadvantage. A microprogrammer must deal with the specific timing relationships of the internal architecture. And since each application requires a separate microprogram, each has its own instruction set that can't be transferred easily to another application. Nor can software design aids, geared toward the fixed instruction set, be applied to the changed set.

Design aids speed development

Much of the start-up, or development, effort in the design of a microcomputer system is linked to the coding phase. Coding converts system programs into instructions that can be loaded directly into the memory. However, the basic design-aid tools themselves are programs that generally require the use of time-sharing services or other computer facilities. And like the LSI processors they support, design-aid features can differ from vendor to vendor.

Assemblers are a case in point. All assemblers convert a program into the basic machine language in a process that usually involves several steps. Essentially the assembler reads a so-called source tape—with statements written in the mnemonic, or symbolic, assembly language—and produces a so-called object tape, with binary numbers suitable for the processor's memory. Errors due to misuse of the assembly language can be detected and pointed out by the assembler.

But some manufacturers offer single-pass assemblers, thereby reducing the steps needed to obtain the binary instructions for memory. Or they may provide the option of loading the assembler into ROMs and pROMs so that the microcomputer itself, rather than a host computer, executes the program. These are called hardware assemblers.

Another type, called a macro-assembler, simplifies coding when similar sections of code are used repeatedly, but variations preclude the use of conventional subroutine techniques. With a macro-assembler, a single instruction yields the necessary expansion.

Editors, available on time-sharing services, allow designers to prepare the original assembly-language programs and to change or correct them with simple commands. They can add documentation and store, combine and retrieve programs. And they can readily output programs onto paper

MICROPROCESSOR SCORECARD®

μP Scorecard®	Classification	Technology	Parts Family: Clock Driver	Parts Family: I/O Interface	Parts Family: UART/USRT	Parts Family: RAM	Parts Family: ROM/PROM	Parts Family: Interface	Features: Interrupts	Features: Integrated CPU	Features: Microprogrammed	Features: Accessible Stack	Features: DMA Ability	Features: BCD Arithmetic	Word Size (Data/Program)	Address Capacity (Program Words)	Clock (kHz/Phases)	Register Add Time (μsec per Data Word)	Number of CPU Registers: ALU	Number of CPU Registers: XR	Number of CPU Registers: GP	Return-Stack Size (NR x Bits)	Voltages Required	Power Dissipation (Watts)	Operating Temperature Range (°C)	Package Sizes (DIP Pins)	Price Range (approx.: CPU only; Quantity 100)	Status	Remarks
BURROUGHS MINI-D	One-chip CPU with ROM	PMOS								✓					8/12	256	1000/1	9	3	—	1		−12, +5			16	$ 60	Custom	
FAIRCHILD PPS-25	Calculator-oriented	PMOS		✓		✓	✓							✓	4x25/12		400/2	62.5	1	—	—	4x12	−10, +5	.6	0, +70	16, 18 24, 40	$ 60	Delivered	
INTEL MCS-4/4004	Calculator-oriented	PMOS		✓		✓	✓	✓		✓				✓	4/8	4K	740/2	10.8	1	—	16	4x12	−10, +5	1.0	0, +70	16	$ 30	Stocked	
INTEL 4014	Calculator-oriented	PMOS		✓		✓	✓	✓	✓	✓				✓	4/8	8K	740/2	10.8	1	—	24	8x12	−10, +5	1.0	0, +70	16, 24		Rumored	
INTEL MCS-8/8008	One-chip CPU	PMOS							✓						8/8	16K	500/2	20	1	—	6	8x14	−9, +5	1.0	0, +70	18	$100	Stocked	
INTEL 8008-1	One-chip CPU	PMOS							✓						8/8	16K	800/2	12.5	1	—	6	8x14	−9, +5	1.0	0, +70	18	$130	Stocked	
INTEL 8080	One-chip CPU	NMOS	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	8/8	64K	2083/2	2	1	—	6	(RAM)	−5, +5, +12	1.0	0, +70	40	$200	Delivered	
INTERSIL ISD-8	One-chip CPU	CMOS							✓	✓					12/12	4K	2000/1	6	1	—	—	Modifies Program	5	.002	−55, +125	40		Announced	DEC PDP-8 Code
MOTOROLA 6800	One-chip CPU	NMOS		✓	✓	✓	✓		✓	✓				✓	8/8	64K	1000/2	2	2	1	—	(RAM)	5	.25	0, +70	24, 40	$150	Samples	
NATIONAL GPC/P	4-bit Slice	PMOS									✓	✓	✓		4N/23	100	715/4	1.4	8	—	—	16x4N	−12, +5	.7	0, +70	22, 24	$150	Delivered	1 ≤ N 5 6
NATIONAL IMP-4	3-chip CPU	PMOS						✓	✓		✓	✓		✓	4/4	64K	500/4	12	4	—	—	7x12	−12, +5	1.0	0, +70	22, 24	$150	Samples	16x4 Data Stack
NATIONAL IMP-8	3-chip CPU	PMOS							✓		✓	✓	✓		8/8	64K	715/4	4.6	3	1	—	16x8	−12, +5	1.0	0, +70	22, 24	$230	Delivered	
NATIONAL IMP-16	5-chip CPU	PMOS							✓		✓	✓	✓		16/16	64K	715/4	4.6	2	2	—	16x16	−12, +5	1.4	0, +70	22, 24	$310	Delivered	
RAYTHEON RP-1600	4-bit Slice	Bipolar									✓				4N/48	64K	5000/1	1	j	k	—							Announced	(j + k) ≤ 8
RCA COSMAC	2-chip CPU	CMOS							✓				✓	✓	8/8	64K	667/1	6	p	q	—	r x16	12	.01	−55, +125	40		Announced	(p + r + 2q) ≤ 15
ROCKWELL PPS-4	Calculator-oriented	PMOS	✓	✓		✓	✓			✓		✓	✓	✓	4/8	4K	200/2	5	1	—	1	3x12	17	.225	0, +70	42	$ 40	Delivered	
ROCKWELL PPS-8	One-chip CPU	PMOS	✓	✓		✓	✓		✓	✓		✓	✓	✓	8/8	16K	256/2	12	1	1	2	2x14	17	.3	0, +70	42		Announced	
SIGNETICS 2650	One-chip CPU	NMOS							✓	✓				✓	8/8	32K	1200/1	4.8	s	t	—	8x15	5	.5	0, +70	40	$100	Announced	(s + t) ≤ 6
TOSHIBA TLCS-12	One-chip CPU	NMOS		✓		✓	✓		✓	✓	✓				12/12	4K	1000/3	13	1	—	—	(RAM)	−5, +5	.8	−20, +80	16, 24 26, 42		Announced	Multiply Instruction

July 1, 1974

A tabulation of representative LSI microprocessors reflects the product range: from calculator-oriented, 4-bit units using PMOS technology to newer 16-bit multichip bipolar processors. Note that the table, reprinted from "New Logic Notebook" by Microcomputer Techniques, compares push-down stacks—called return stacks—in terms of number of registers (NR) and the bit size of each. Also processor registers are divided into accumulators (ALU), index registers (XR) and remaining registers (GP) for general use.

tape as well as printers.

A number of loaders are available to complete the coding process. With these, which can be stored in ROMs, assembled programs are loaded into read-only memory. They can also be loaded into RAMs, in which case a bootstrap type is used. A so-called relocating loader automatically adjusts program addresses and loads the resulting instructions. And some loaders have linking capability that lets you use routines with undefined labels. These types supply the missing cross-references between separate routines.

Several manufacturers also offer compilers, which allow programs to be written in a high-level language. The benefits are many: A short readable compiler statement corresponds to many symbolic assembly-language statements. Compilers eliminate the need to write detailed codes to control loops, to access complex data structures or to program formulas and functions. And since programming details are lessened, errors are reduced.

But while high-level language programs are compact, easy to read and much easier to write, the net result could be excessive storage space and slower execution, when compared with an assembly-language program. Generally a choice between the two approaches depends on the degree of optimization required and the design time allowable.

In addition to these design aids, test programs —such as simulators—are virtually mandatory to track down the various subtle errors that may remain. Similarly hardware prototype units are essential to the development of the final product. Prototype units generally involve expanded memory capability, teletypewriter or card-reader interface, power supply, chassis and control panel —in addition to a microcomputer.

Besides boosting initial development costs for the designer, the wide range of hardware/software support requires a major investment by the semiconductor manufacturers. This investment is in addition to that needed to produce the LSI chips. In fact, one indication of a vendor's seriousness in marketing a particular microprocessor is the availability of hardware/software support for the product.

Still, ever more manufacturers are entering the field because of the high potential payoff. Various sources predict that the microcomputer market—valued at under $50-million last year—should reach at least $500-million in four years. In the process, a sizable chunk of the TTL market could be replaced. Major microprocessor-chip vendors—such as Intel, National Semiconductor and Rockwell International—are meeting the challenge in a variety of ways.

The Components

By any standard, the recognized leader in microprocessors is Intel, which introduced the product in 1971. Benefiting from its early, one-to-two-year lead over competitors, Intel reportedly captured as much as three-quarters of last year's microcomputer market. Moreover each of its processor chips has been a first of its kind, beginning with a 4-bit unit, the 4004, and leading to an 8-bit PMOS model, the 8008, and the latest advance, an 8-bit NMOS microprocessor—the 8080.

Among the Intel products, the 8080 sets the pace for increased speed and improved instructions. The silicon-gate processor has a 2-μs instruction cycle and 74 basic instructions, which include the 48 instructions of the earlier 8008. The additional 30 instructions and a 6:1 faster execution rate provide up to a 10:1 speed advantage over the 8008. Moreover the improved performance of the 8080 is obtained with a typical power dissipation of only 600 mW, the same as that of the 8008.

The 8080 can address up to 65-k bytes of memory without need for an external address register. This compares with 16-k bytes of memory and an external register for the 8008. The 8080 requires only six peripheral ICs, as contrasted with the 20 needed with the 8008. The NMOS 8080 comes in a 40-pin package and operates from +12 and ±5-V supplies.

A number of architectural differences account for the improved performance of the 8080. For example, it contains a 16-bit stack pointer (to operate the external LIFO stack) and a 16-bit program counter (to indicate the next instruction), instead of an address storage stack with eight 14-bit locations. A portion of the external memory can be used as a last-in, first-out stack, addressed by the stack pointer upon the execution of a Call, Return or Restart instruction.

Moreover not only the program counter but also the data register, the accumulator and the flags (bits that are set to indicate various conditions) can be saved in the external push-down stack. As a result, multiple interrupts can be handled more easily with the 8080.

The 8080 can perform BCD and binary arithmetic. It also has capability for double-precision arithmetic involving two 16-bit numbers. The NMOS processor can handle up to 256 input ports and a similar range of outputs.

Intel offers several hardware and software design aids for the development of microcomputer systems with its processors. The aids include the Intellec series, consisting of expandable, modular systems that come complete with microprocessor, memory, power supplies and circuitry for teletypewriter interface and clock generation. Each Intellec system is housed in a compact cabinet that features a control and display panel for immediate system monitoring and debugging. All program storage can be accomplished with RAMs, rather than ROMs, for easier program loading and modification. After a program is firm, it can be loaded into ROM.

The standard software package for the Intellec

Most manufacturers offer design aids to simplify development of microcomputer systems. Intel's aids include the Intellec series, which comes complete with memory, supplies and clock and interface circuitry.

series includes a system monitor, contained in pROMs, resident assembler and text editor. A programming module provides the timing and level shifting to program pROMs. Additional support is provided by a cross-assembler and simulator written in Fortran IV and by a PL/M compiler available on time-sharing terminals.

The use of PL/M, derived from IBM's PL/1 language, permits sample programs to be written in a fraction of the time needed to write the same program in assembly language. PL/M offers a far simpler means of programming, compared with assembly language. And the debugging and checkout times of a PL/M program are less, because the structure of the language allows the compiler to detect error conditions that would not be spotted by an assembler.

Recent additions to the Intel product line include several ICs, intended to simplify system design and expansion, and an advanced version of the company's 4-bit microprocessor. The additional circuits include a 4-k-bit dynamic RAM (the 8107), a 2048 × 8-bit ROM (the 8316), a 512 × 8-bit pROM (the 8604), and several peripheral circuits. The latter interface communications lines, handle increased loads and replace IC packages now required.

Intel's new 4-bit microprocessor, the 4014, features software compatibility with the earlier 4004. Additional instructions permit logic operations, such as AND and OR. The 4014 also allows storage capacity of 8-k bytes of memory, increased from the 4-k bytes for the 4004. Other capabilities include improved single-interrupt handling and a single-step mode of operation to simplify testing and debugging.

IMP series—chips, cards and 'boxes'

National Semiconductor offers a broad line of PMOS microprocessor products. They consist of 4, 8 and 16-bit parallel processors that are available in chip form, on card subsystems and in complete microcomputer boxes. Each microprocessor features downward software compatibility—it's compatible with a microprocessor having a shorter word length, but not one with a longer word length. And the fixed instruction set of each can be altered or changed through microprogramming techniques.

The National microprocessors are built around two building-block chips: a Register and Arithmetic Logic Unit (RALU) and a Control Read-Only Memory (CROM). The RALU is a 4-bit "slice"; four are used with one or two CROMs to obtain the 16-bit system, and eight RALUs with two CROMs can be used to form a 32-bit system. The CROM provides storage for the manufacturer's fixed instruction set and the control logic for up to eight RALUs.

The IMP-16C, National Semiconductor's 16-bit microprocessor system, comes on an 8-1/2 × 11-in. PC board. It consists of the processor, clock system, I/O bus drivers, 256 words of RAM and provisions for 512 words of ROM or pROM memory.

The IMP-16C uses a basic 43-instruction set and an expanded 17-instruction set provided by a second CROM. The additional 17 speed processing with instructions that include divide, multiply and double-precision add and subtract. The basic microcycle, or machine cycle, is 1.4 μs. Several microcycles are needed to execute a typical instruction. Two 16-bit numbers can be multiplied for a 32-bit result in a speedy 150 μs.

Each RALU supplies the IMP-16C with an accumulator and a push-down stack. A total of four accumulators improve the bit efficiency of instruction words by cutting down memory-cycle delays. The hardware stack permits rapid nesting of subroutines and interrupts, and its limited depth can be extended—for, say, overflow conditions—by use of main memory.

The microprocessor also features vectored as well as slower, single-line interrupts. With a single-line interrupt, the total overhead time to get to the service routine can be as high as 34.85 μs, since it depends on the number of peripheral devices, and these might number 16. But with a vectored interrupt, the total overhead is only 4.55 μs, a figure that doesn't change with the number of devices.

Several software design aids are offered with each microprocessor. Programs are available for cross and self-assembling, source editing, debugging, and absolute and relocate loading. Also, driver/utility and diagnostic aids are offered. Hardware design aids using assembly language come as complete microcomputers and prototype systems. For the 16-bit system, these are the IMP-16L and 16P boxes. Both units contain a 16-bit microprocessor card.

The IMP-16L has a front-panel display, which provides access to memory and microprocessor registers. The box comes with 4-k, 16-bit words, expandable to 65-k words. Also, a high-speed asynchronous bus permits direct-memory access by peripheral devices without the need to go through the RALUs.

The IMP-16P can interface with a teletypewriter for application software development. This prototyping tool comes complete with chassis, control panel, power supplies and one or more 4-k, 16-bit-word read/write memory modules. National Semiconductor says the IMP-16P is the box to start with to begin a 16-bit design.

Recent additions to National Semiconductor's line are an advanced 4-bit microprocessor system and a microprogramming tool to help designers alter or change the fixed instruction set. The 4-bit system performs BCD arithmetic and uses one CROM, one RALU and a Four-bit Interface Logic Unit, called FILU. The interface unit combines the functions of a number of standard-TTL peripheral circuits.

The microprogramming tool, called Field-Alterable Control Element (FACE), makes use of the fact that a change of CROMs changes the fixed instruction set. FACE, which comes on a card, replaces the CROM on a microprocessor board to form what mainframe designers call writable-control store. Microprocessor control logic now becomes accessible to external ROM or RAM for development of a tailored microprogram. The final result can be stored in a custom-masked CROM or a bipolar pROM. The increased speed of the bipolar memory can reduce delays incurred through connection of external, off-the-board circuitry.

PPS family provides chip sets

Aiming to reduce the number of additional components often needed with single-chip microprocessors, the Microelectronics Div. of Rockwell International offers chip sets for both 4 and 8-bit systems. The sets come complete with processor, clock circuit, memory and input/output ICs. For additional flexibility, you can get a combination ROM and RAM chip or you can select from a growing number of interface and peripheral circuits.

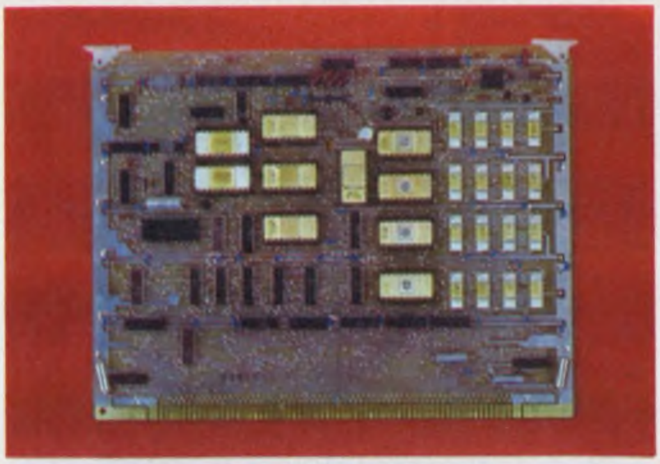
Rockwell estimates that up to 30 peripheral circuits can be eliminated by use of the PPS-4 or PPS-8 chip sets. These are 4 and 8-bit parallel processing systems, respectively. Moreover some of the special circuits in the Rockwell chip sets are not generally available with competing processors. For example, a nonvolatile RAM is being developed for the PPS-4 set. And a controller circuit, in an advanced development stage, for the PPS-8 will permit direct memory access. Rockwell is also developing other circuits for use with peripherals such as CRTs, printers and floppy discs.

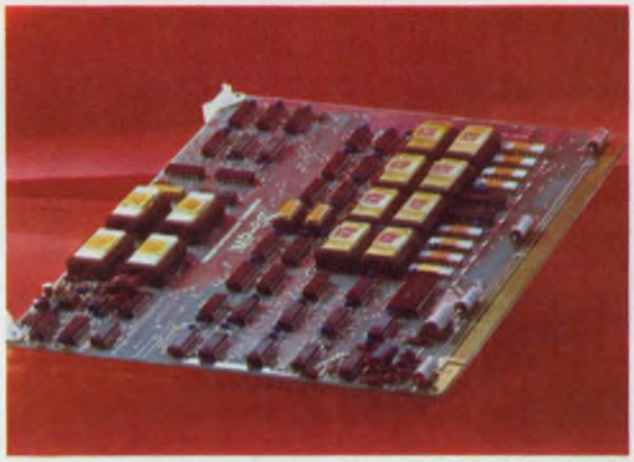
The PPS-8 features over 90 instructions, with capabilities for decimal and binary arithmetic single-byte subroutine call and digit/byte manipulation. A complete instruction cycle can be executed in 4 μs, and decimal addition or subtraction is performed at 12 μs per digit. Among 4-bit microprocessors, the PPS-4 sets the pace for speed, with an instruction cycle of 5 μs and a register-to-register add time of 2.5 μs. The 50 instructions for the PPS-4 contain logic and conditional and unconditional data-transfer operations.

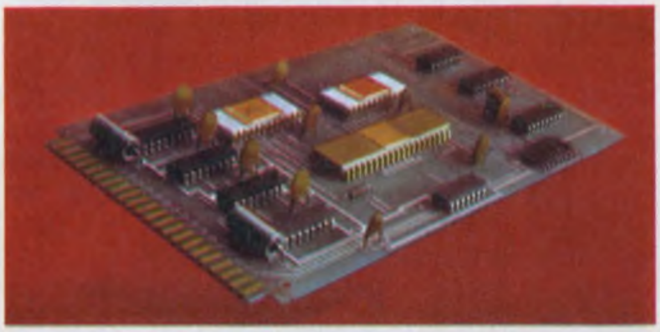
The PPS chip sets use a relatively slow clock, typically 200 kHz. However, signals internal to the system are handled at four times that rate. The clock generator provides the processor with two synchronized signals, which are then divided logically into four phases, thus boosting the speed.

Bus lines transfer data during the second and fourth time intervals. In the alternate intervals, address and data-bus lines are automatically cleared to zero. This interface timing scheme permits direct connection of an extensive number of circuits. For the PPS-4, up to 30 circuits can share the bus without need for additional buffering or drive circuitry.

Also, the control logic within the processor allows arithmetic or logic instructions to be carried out in one cycle time. Addition of two decimal digits requires six instructions, or six cycle times. Hence for the 5-μs cycle of the PPS-4, two decimal







Processor cards provide an assembled and tested microprocessor system, complete with memory. Clockwise from the top left are National Semiconductor's 16, 8 and 4-bit models (the IMP-16C/300, 8C/200 and IMP-4, respectively). National units also feature a microprogramming option that can be used to alter or change the fixed instruction set.

digits can be added or subtracted in 30 μs.

Software aids consist of cross-assemblers and simulators available on time-shared services. The aids may also be purchased for use on in-house computers. Hardware aids range from Assemulators (developed by Applied Computing Technology) to evaluation boards, containing microprocessors, RAMs, I/O circuits and clocks.

Micro Systems

Aiming to shorten the usual development time for a microcomputer design, some manufacturers are offering systems that constitute full-fledged microcomputers and complete prototype units. These vendors use chips supplied by Intel, National Semiconductor or Rockwell International.

Product forms range from consoles with circuitry on conventional PC boards to LSI dice mounted on a single substrate. Besides providing the necessary components for a host of applications, these products also feature additional circuitry that helps extend the capabilities of the internal LSI microprocessor.

An early microcomputer entry is the Micral series from R2E (Realisations Etudes Electroniques, based in France). Micral systems, built around Intel's 8-bit microprocessors, come in three processing speeds: 12 μs (basic model), 6 μs (Micral G) and 2 μs (Micral S).

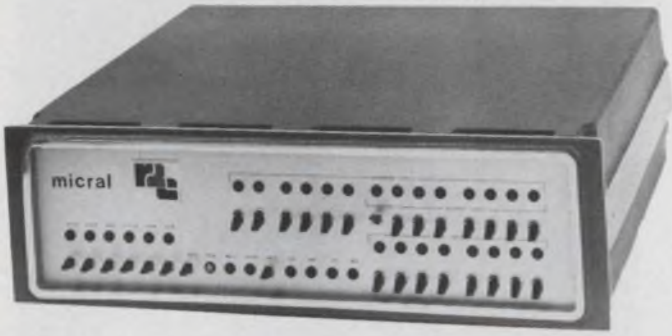
Although Micral uses the 8008, it has several instructions beyond those available with the 8008. The additional instructions permit improved handling of interrupts and allow register saves. Interrupt-driven I/O channels can be operated at a maximum throughput of 56-Mbyte/sec. Also, the Micral G (and S) includes five added instructions for data manipulation.

Software support includes a two-pass assembler, keyboard editor and diagnostics for peripherals and I/O interfaces supplied with the microcomputer. In addition R2E offers a high-level control language to simplify prototype development.

Micral units have a memory capacity of 16-k bytes, and this can be increased to 64 k. The direct addressing capacity of peripherals is a hefty 1792 bytes at the input and 23 at the output. Up to seven I/O channels can be operated.

Applied Computing Technology provides a series of Assemulators—short for assemblers/simulators—for the Intel and Rockwell 4-bit processors. Assemulators, which can interface directly with a teletypewriter, reduce the development phase of microcomputer designs.

In a typical development phase, a designer specifies and interconnects the I/O circuitry, which is then interfaced to the Assemulator. Programs are written and assembled in the Assemulator, which holds the utility system in ROM



Complete microcomputers extend the capabilities of the basic microprocessor used. R2E's Micral system, for example, provides additional instructions for interrupt handling and data manipulation. R2E uses Intel chips.

and the assembled program in a special emulation ROM. As a result, testing of programs involves simple manipulation of Assemulator console switches or the teletypewriter, so that program debugging can be reduced to a fraction of that normally required. And because the unit contains a resident assembler, costly time-sharing changes can be eliminated.

Both the CBC-4, the Assemulator for the Intel chip, and the PPS-4MP, which is used for Rockwell's model, are similar. However, the CBC-4 features a single-pass assembler for simplified assembly. For both units, the corrected program can be recorded in pROMs, which are then inserted into the microcomputer to complete the design.

Pro-Log features the PLS-400 family of microcomputers on 4-1/2 × 6-1/2-in. PC cards. Built around Intel's 4-bit processor, the 4004, the PLS-400 also contains Intel's 4002 RAMs and 1702A erasable pROMS. A minimum system consists of a single card with 1024 bytes of memory and 32 TTL I/O lines. For expanded capability, a three-card system contains 4096 bytes of memory and 128 TTL I/O lines.

Also available from Pro-Log is the MPS-800 family of 8-bit microcomputers for data processing. The family consists of three-card and five-card systems. Both units come with 256 words of pROM and 1024 words of RAM data/instruction memory. The memory can be expanded to 16-k words.

Process Computer Systems offers a microcomputer built around Intel's 8080 microprocessor. Called the Series 2000 Micro CPU, the system aims for such industrial applications as torque monitoring and control and also engine testing.

Plug-in modules allow the Series 2000 to control a variety of processes. The I/O modules include a 12-bit a/d converter, 16-bit digital input interface and modules for relay outputs. These units communicate with the system's memory and microprocessor through a common back-plane data bus. Moreover the microprocessor sees all I/O devices as memory locations, precluding the need for special—and possibly less efficient—I/O instructions.

Process Computer Systems also offers plug-in breadboard cards, which allow the development of special analog and digital I/O modules. In addition assembler, compiler, debugging and other programs are available.

Teledyne Systems takes a unique packaging approach for its microcomputers. Rather than mount DIPs on PC boards, it mounts IC dice on ceramic substrates. The hybrid approach results in reduced size and improved reliability at prices that are comparable with PC-board equivalents. A single package measures only 2 × 2 × 0.2-in.

Teledyne's microcomputers are the TDY-52A, which uses Intel's 4004 microprocessor, and the TDY-52B, which uses National Semiconductor's dice to form a 16-bit unit. Instructions for the TDY-52A can be tailored to an application by alteration of the control microprogram in ROMs mounted on the substrate.

The TDY-52A requires external power supplies and some I/O circuitry, as does the 16-bit unit. In addition the TDY-52B requires an external clock (5.7 MHz square wave) and memory (ROM, RAM or combinations of both). Memory configurations are available in hybrid packages identical to those of the microcomputers.

New LSI Processors

At various stages of introduction—from chip development to some product delivery—are a multitude of LSI processors, all of which are expected to be available in quantity by about the middle of next year. The great majority use NMOS technology, handle 8-bit word lengths and have a basic cycle of about 2 μs, as does Intel's 8080. And most of these are being offered with special peripheral circuits and memories to minimize the circuitry otherwise needed.

In addition to these circuits, manufacturers are developing 12-bit processors that employ CMOS technology and emulate popular minis. And bipolar/LSI processors, featuring high-density techniques, promise to close the speed gap between microcomputers and conventional minis.

Five ICs comprise the basic microcomputer chip set promised by Motorola in its M6800 family. The heart of the set is the microprocessing unit, or MPU—an 8-bit parallel processor. The MPU lists 72 instructions and seven addressing modes, with one mode reserved for two 8-bit accumulators on the chip. It also uses 16-bit memory addressing, allowing memory size up to 65-k addresses.

The MPU shares data and address buses with special byte-organized memories—1024 × 8-bit ROMs and static 128 × 8-bit RAMs—and two programmable I/O circuits, the Peripheral Interface Adapter (PIA) and the Asynchronous Communications Interface Adapter (ACIA). The special I/O circuits permit reduced interface circuitry.

All five silicon-gate NMOS chips operate from a single 5-V supply. A total of 10 circuits of the M6800 family can be interconnected on the bus without reduction of the maximum clock rate of 1 MHz, which must be supplied by an external clock.

The interface circuits look like memory locations to the MPU. Hence the MPU can use the same instructions for, say, peripherals, connected to the PIA that it uses with RAM; special I/O instructions are not needed. The PIA controls and transfers data and status information to and from peripheral devices or, possibly, other microprocessors.

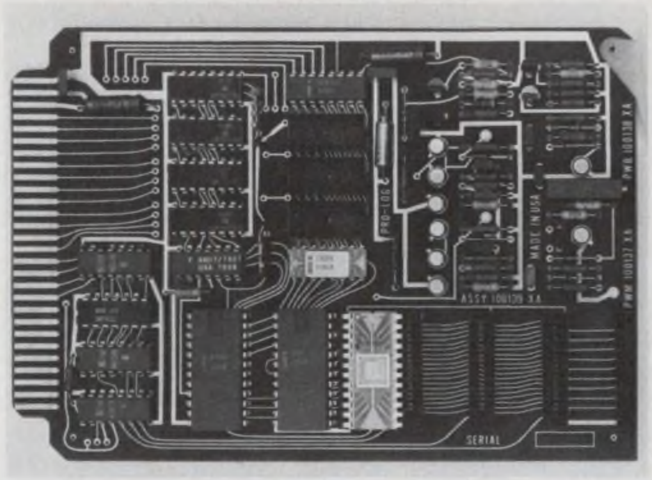
Much of the control logic for peripherals can be handled by the PIA. In an application described by Motorola, for example, a PIA replaces the 16 to 20 standard MSI logic circuits usually required to control popular OEM printers. The complete interface consists of the PIA, peripheral drivers and comparators. The latter provide TTL-compatible logic levels in the face of inductive surges from the printer.

Similarly the ACIA performs all the functions of a standard universal asynchronous receiver/transmitter. It relieves the MPU of many of the timing and control functions of asynchronous data communications. And it can interface directly with standard modems, including a special modem IC planned for the M6800 family.

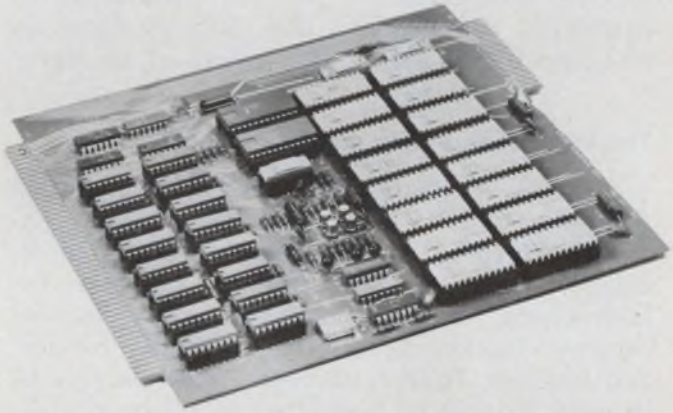
The MPU features decimal and binary arithmetic capabilities, variable-length instructions and double-byte operations. Addressing modes include extended, indexed, implied and relative, as well as immediate and direct. The minimum execution time, as for the Add instruction, is 2 μs. The maximum time reaches 12 μs in the case of a Software Interrupt instruction.

A special feature of Electronic Arrays' 8-bit NMOS parallel processor is string or series capability. Up to 16 bytes of data can be entered from memory or from an I/O device, and stored in the chip's multiregister accumulator for processing. And the 16-byte data transfer can be accomplished with a single instruction.

Moreover the chip contains a 24-byte RAM, called the Program-Address Storage (PAS). It can be used as a push-down stack, for interrupt vectors, for program-call storage, or for a combination of these functions. For expanded capability, the PAS can be extended into external RAM.



Microcomputers on PC boards are offered by Pro-Log. Models available include a 4-bit system for dedicated-controller applications and an 8-bit model for data processing. Both systems use Intel chips.



Prototype systems help cut development time. Applied Computing Technology calls its systems Assemulators, or combination assemblers/simulators. The vendor supplies prototype units for microprocessors offered by Intel and Rockwell International.

The 8-bit processor has about 66 instructions and addresses up to 65-k bytes of memory. The four addressing modes are direct, immediate, indexed and extended. Memory can be ROMs or RAMs of various speeds in any combination.

Other circuits planned by Electronic Arrays for the microprocessor consist of the following: a 1024 × 8-bit ROM, 256 × 4-bit RAM and an I/O controller. The I/O chip is intended to be a general-purpose, programmable logic design for any interface.

Fairchild Semiconductor plans to offer the F8 chip set, consisting of an 8-bit NMOS Isoplanar microprocessor, a memory interface chip, an 8-k bit ROM and a custom RAM. The system features a basic cycle of 2 μs and has internal clock and interface circuitry. Direct-drive capability exists for standard peripherals, such as teletypewriters and printers.

Fairchild estimates that improvements in the F8 family can reduce the amount of peripheral circuits by 10 to 30%, compared with other 8-bit NMOS processors. Also, preliminary benchmark programs indicate speed improvements by a factor of 1-1/2 to 3.

Software support includes a compiler to accept the PL/M language and a special conversational utility system that requires an interface module. The system allows a program to proceed in slow motion, so designers can debug a program with paper tape or cassette. The utility system avoids the need to modify the contents of a pROM each time a correction is required.

An earlier microprocessor from Fairchild is the PPS-25 system, a 4-bit chip set. Intended for scientific calculators and control systems, the PPS-25 uses standard ICs for interfacing of keyboards and displays. The PPS-25 specs an add time of 125 μs for two groups of 16 digits.

The PIP: 8 addressing modes

Signetics' upcoming Programmable Integrated Processor (PIP) allows the use of eight addressing modes, for increased flexibility and efficiency in programming. Operand addresses for instructions can be defined in these modes: register, immediate, relative, absolute, indirect and indexed. Branch addresses may be formed through the use of a relative or absolute mode, and each may be direct or indirect.

The PIP responds to over 64 instructions, the most complex of which are executed in less than 10 μs. Instructions feature variable lengths for improved bit efficiency; they may be 1, 2 or 3 bytes long. Also each of the chip's four general-purpose registers may be used as an accumulator. Hence processing bottlenecks that result from having only a single accumulator are eliminated.

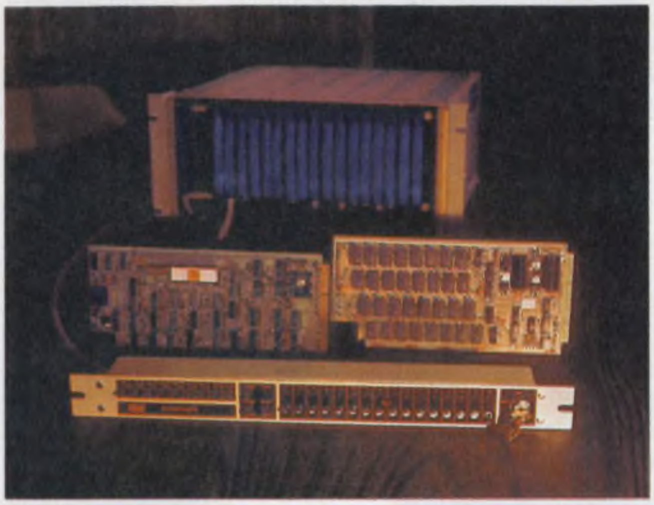
The Signetics' chip operates from a single 5-V supply. Its input clock frequency is variable down to dc; externally the PIP resembles a static IC. The processor's address lines allow direct addressing for up to 32-k bytes of memory. And PIP's vectored-interrupt capability allows indirect branching to any location in memory.

A full range of design aids is planned for the PIP, including a cross-assembler written in Fortran II rather than the more common but advanced Fortran IV. The use of the more basic language permits the assembler program to be run on a wide range of computers, from mainframes to minicomputers.

In a rare example of microprocessor alternate sourcing, Microsystems International Ltd. offers the 8008, the 8-bit PMOS processor introduced by Intel. MIL provides the microprocessor, as well as the various components needed to make an 8-bit microcomputer, on seven basic boards. Each board measures 4-1/2 × 6-in. and uses a standard dual 22-way edge connector.

On the MOD8-1 board, for example, are the microprocessor, clock generators and state-decoding and bus-switching control logic. An I/O board, the MOD8-2, contains teletypewriter interface and reader-control and system-restart logic. Other boards provide ROM, RAM, buffer and I/O circuitry.

MIL's design aids include the Monitor-8 software package, which allows interactive debugging of designers' programs entered in assembly language from a teletypewriter. In addition the company offers a similar applications package for a series of boards that will use a proprietary 4-bit microprocessor expected shortly. The 4-bit system is called the MOD4 series.



Microcomputers aim for industrial applications such as engine testing and torque control. Process Computer System's Series 2000 Micro CPU features a common backplane data bus on which interface modules communicate with the microprocessor and memory.

Proving that PMOS is still around for 8-bit units, Mostek is sampling an 8-bit p-channel, parallel processor called the MK5065. Compared with first-generation units, the MK5065 expands the number of instructions and slashes the number of peripheral circuits. Also, the chip's architecture is three-leveled for rapid handling of interrupts. One or two of the chip's three program counters and three accumulators, for example, can be reserved for immediate servicing of interrupts.

Bipolar processors emerge

The first general-purpose bipolar/LSI microprocessor has just been announced by Raytheon

Semiconductor. A seven-chip processor called the RP16, the 16-bit unit surpasses MOS microprocessors in speed through the use of bipolar technology, increased addressing modes and an improved instruction set. Two versions of the RP16 are slated. Model A emphasizes arithmetic capabilities, while Model B stresses byte handling (see product feature; p. 109 this issue).

While most microprocessor chips are intended for random-logic designers, a Schottky-TTL processor from Monolithic Memories is aimed at the computer architect. The special-purpose microprocessor, dubbed the Model 6701 microcontroller, can be used to emulate conventional computers and replace scores of packages at reduced power. A single 6701 can perform the function of 25 TTL MSI packages while saving about 6 W.

The 6701 consists of four 4-bit controllers and associated ROMs and shift registers. None of the ROMs is used to decode the processor's 36 instructions, which are at the fundamental level of arithmetic logic units. As a result, microprogramming techniques can be employed to apply the IC.

A single cycle takes about 200 ns. But within this period the 6701 can execute such functions as subtract, shift and store. The bipolar speeds assure a precise emulation of conventional machines, which use standard-bipolar circuits. Moreover the 6701 can be expanded in increments of 4 bits, so that other than 16-bit systems can be designed without significant reductions in speed. Other applications foreseen for the 6701 include high-speed peripheral controllers and point-of-sale systems.

12-bit models fill a gap

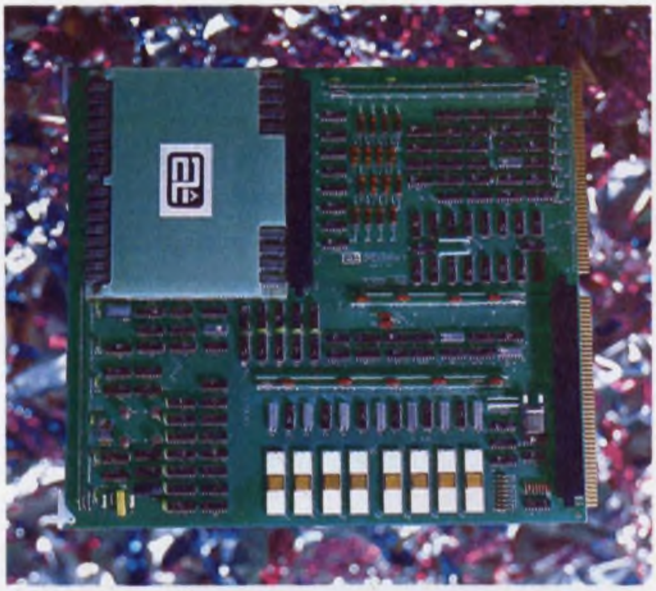
Although much of the current microprocessor activity involves 8 and 16-bit units, two manufacturers—Intersil and Toshiba—are filling the gap with 12-bit models. The Intersil processor is designed to be a CMOS/LSI equivalent of Digital Equipment Corp.'s popular PDP-8 minicomputer. The Toshiba processor (the TLCS-12) is a proprietary PMOS design, with such component-saving features as a timing generator on the chip.

Preliminary data for the Toshiba chip indicate add and subtract times of about 10 μs. And multiply and divide functions reportedly can be executed in 30 to 60 μs. The chip operates from ±5-V supplies and dissipates 0.8 W.

Intersil's CMOS microprocessor benefits from the sizable software support that exists for the PDP-8. And the many designers familiar with the mini should be able to transfer that experience to the CMOS processor. However the unit's repertoire of eight basic memory-reference instructions tends to limit the range of applications.

Still a multitude of applications uses the PDP-8. Noting this fact Intersil plans to develop a full set of circuitry and memory, all using CMOS, to operate with the processor. Conceivably, the end result could be a pocket-sized, portable PDP-8.

RCA, the leading CMOS manufacturer, also has a CMOS microprocessor. Called COSMAC, it is an 8-bit, two-chip set that emphasizes low-power dissipation and I/O interface capabilities in a proprietary design. Each chip dissipates only 100 μW. And the I/O can be controlled with up to 16 commands and a total of 23 lines, including a bidirectional data bus.



A complete mini, except for power supply, comes on this PC board. Computer Automation's Naked Mini/LSI-1 uses four custom LSI chips, each a 4-bit slice, and programmable logic arrays—rather than ROMs—to form the mini's central processing unit.

COSMAC is built around a 16 × 16-bit scratchpad register, from which references to memory are made. The microprocessor can address up to 65-k bytes of memory, and it uses a simple two-step fetch-and-execute sequence.

The processor cycle, consisting of eight clock pulses, ranges from 3 to 10 μs. With the faster speed, and using a RAM with a 1-μs cycle, a 6-μs fetch-and-execute time can be obtained for any instruction. Response to interrupts, allowed only after complete instruction cycles, ranges from 3 to 9 μs.

In the wings, RCA has a single-chip COSMAC. In addition the company is developing silicon-on-sapphire processors, with multichip units for military applications initially scheduled.

(continued on next page)

Micro-based Minis

Not to be undone by the emergence of component manufacturers into the microcomputer area, minicomputer makers have also embraced LSI microprocessors. Generally using custom MOS chips, they offer models aimed at high-volume applications—as are microcomputers—with large-quantity unit prices hovering about the $500 level. This undercuts the price of many micros.

Micro-based minis are promoted as low-end

Custom silicon-on-sapphire LSI processors are the basis for General Automation's LSI 12/16, an 8-bit system. The mini maker also uses SOS chips for a 16-bit system, the LSI 16, that is a functional equivalent of the company's SPC-16 mini.

models complementing an established line. The new units benefit from the impressive software support—including extensive application programs—available with the rest of the line. Moreover the units offer traditional mini hardware/software features, which results in unique and versatile capability. At present Computer Automation, General Automation and DEC are incorporating microprocessors into their newer models. However, most industry observers expect that list to grow.

Computer Automation calls its microprocessor-based minicomputer the Naked Mini/LSI-1—an allusion to the fact that the mini comes complete, except for power supply, on a 15 × 17-in. PC board. The LSI-1 uses space-saving MOS programmable logic arrays, rather than ROMs, to contain the unit's control logic. Four more MOS/LSI chips, each a 4-bit slice, make up the rest of the central processing unit for the 16-bit machine.

Standard features include direct-memory addressing and four other I/O systems. The unit also has hardware multiply and divide, multilevel indirect addressing, and up to 256 vectored priority interrupts. Memory can range from 1-k to 262-k 16-bit words, and may consist of core or semiconductor types in any combination. The basic processor cycle time is 1.6 μs; an add-memory-to-register operation, involving 16 bits, takes 9.2 μs.

A special feature of the machine's architecture is its ability to organize memory automatically. If memory modules of different size and type are mixed or rearranged on the bus, the computer assigns addresses without any reference to software.

The processor board contains slots for optional hardware functions. These include power-fail/restart, teletypewriter/CRT interface and real-time clock. In addition various plug-in options are available for additional buffers, drivers, interfaces and expanded memory.

Moreover the LSI-1 has an impressive 168 basic instructions. And most of these require only one memory location in contrast with the two or more locations usually needed in other minis.

The instruction set contains 29 memory-reference instructions—which simplify operations involving many pieces of data stored in memory. And conditional jumps can be performed with 63 instructions, each of which causes both the test and the jump. Other features of the instruction set include memory scan, three-way compare, word and byte addressing and full shift capability.

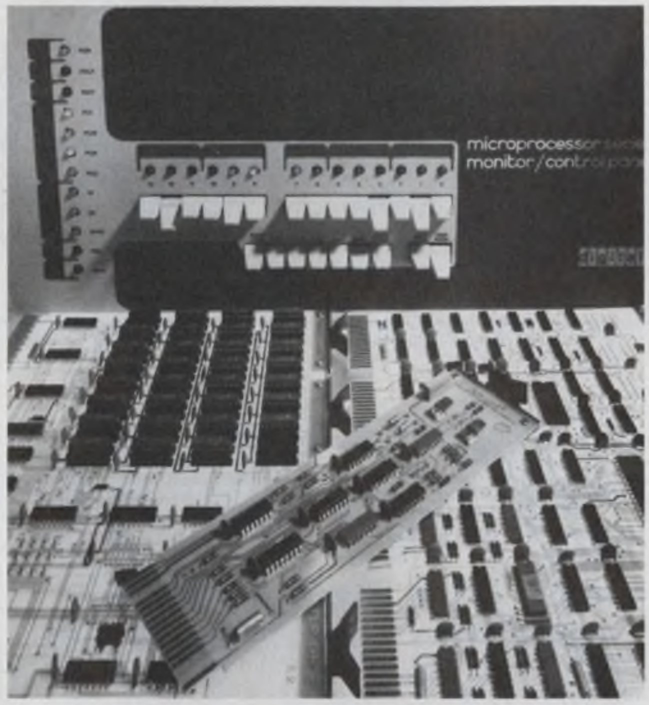
Among the various design aids available, Computer Automation offers several advanced software packages. These include Advanced BASIC, which can run with only 4 k of memory, Extended BASIC, using 8 k of memory, and FORTRAN. Standard packages include assemblers, loaders and debug and utility programs.

Mini turns to SOS

LSI processors employing silicon-on-sapphire techniques are used by General Automation in an 8-bit microcomputer—the LSI-12/16—and an expanded 16-bit model—the LSI 16. The SOS chips, developed for General Automation by Rockwell International, permit operation at speeds comparable with more conventional minis that use bipolar circuits.

The 8-bit unit, featuring 1 to 32-k words of semiconductor memory and an instruction execution cycle of 2.64 μs, comes with a low price tag of \$495 in 1000-unit quantities. It can be obtained on a 7-3/4 × 10-in. PC board and in an enclosed system that contains power supply, battery backup for volatile memory and card slots for additional I/O boards.

For designers who want to retrofit new instructions in a ROM, the 8-bit LSI-12/16 provides a ROM "patch" system in addition to main memory. The patch elminates the need to change ROMs when similar, but not identical, ROM programs are required. In addition the architecture of the LSI-12/16 has a shared-byte feature, allowing a two-byte instruction to be stored in a single-byte of memory. General Automation estimates that this architectural feature could reduce the amount of program memory otherwise required by about a third.



A building-block approach to microcomputer designs is offered by Digital Equipment Corp. The modules, using Intel's 8008 PMOS processor, contain the peripheral circuitry usually needed to operate the microprocessor.

The LSI-12/16 uses 12-bit parallel addressing, which permits direct addressing of 4-k words of memory without paging techniques. It also provides eight 12-bit hardware registers, 52 basic commands, a processor-controlled priority-interrupt system and a teletypewriter interface. Standard control features include a relative time clock, external priority interrupt, 16-bit parallel I/O bus, integral console and a ROM-based console program. Several fail-safe features also protect against power transients and interruptions, component failures and program errors.

Software development can be minimized through the use of a complete cross-program generation system on the company's SPC-16 minicomputer. The disc-based system provides assembly, editing and debugging. Other aids offered include a device-independent, real-time executive program and a conversational assembly system.

While the LSI-12/16 microcomputer can replace the company's somewhat slower SPC-12 minicomputer, General Automation's 16-bit unit is billed as the functional equivalent of the company's slightly faster SPC-16 mini. Furthermore the LSI-16 and expanded memory offers on two small boards the performance of the SPC-16 on six larger boards. The basic LSI-16 unit comes on a 7-3/4 × 11-in. PC board, containing 1-k words of memory and an SOS microprocessor chip set. The two chips consist of an arithmetic logic unit and a control read-only memory, which stores the control logic for the ALU.

A second "micromemory" board of the same size provides a 32-k-word × 18-bit (16 bits plus parity) memory system. The high density is achieved through the use of hybrid packaging. General Automation mounts eight 1103A (1-k bit RAM) memory chips onto a common ceramic substrate and plugs the substrates into vertical connectors on the board. A conventional approach, involving individual DIPs, would have resulted in a maximum board density of 16-k bits. In addition it will be possible to obtain a 120-k micromemory by replacement of the 1-k bit chips with 4-k bit RAMs, when they later become widely available.

Together with the micromemory board, the LSI-16 offers an average cycle time of 1.8 μs. Standard features of the LSI-16 board include power-fail/restart capability, real-time clock, operation-monitor alarm, cold-start capability and an asynchronous memory interface. An additional PC board for options can be obtained with parity and hardware memory protection, teletypewriter controller, operator's console and a piggyback read-only memory board that can accommodate up to 4-k 16-bit words of memory.

MPS modules ease interfacing

A microprocessor module set is the initial entry into the microcomputer field by Digital Equipment Corp. The mini maker expects the modules, which use Intel's 8-bit PMOS processor, to be used as building blocks for dedicated controllers. Called MPS, the series can perform decision-making functions, add intelligence to data terminals and replace hard-wired logic systems. Moreover the units come complete with much of the peripheral circuitry usually needed to operate the microprocessor; hence interface

(continued on next page)

problems are reduced.

Five modules constitute the series. The CPU module contains the processor and complete instruction decode and control circuitry. Other modules provide 1-k to 4-k words of read/write memory and 256 to 4-k words of programmable read-only memory. A detection module can be used to obtain priority interrupts, while a monitor/control-panel unit can serve as a diagnostic checkout.

Software aids needed to program the MPS come in paper-tape format. The aids, offered in a special kit, consist of editors, assemblers, pROM programmer, debug software, duplicator and loader. Programs are prepared in conjunction with a PDP-8 with 4-k words of memory.

TTL/MSI processors are offered, too

Still other microprocessor products use medium-scale-integration (MSI) standard-TTL circuits. These TTL/MSI processors, like their LSI cousins, can be programmed for a host of high-volume applications.

Complete TTL/MSI processors come on PC boards or in compact modules, and they sell for about $1000 in single-unit quantities. They operate at faster speeds than their MOS counterparts, and they are offered by established vendors in the minicomputer business.

For example, 12-bit TTL/MSI units have been introduced by DEC, Fabri-Tek and Microdata The DEC model, called the PDP-8/A Miniprocessor, is a two-module, MSI version of the company's widely used PDP-8 mini.

Fabri-Tek's MP12 processor includes 4-k words of core memory in a 2 × 15 × 9.5-in. module, and it requires only one 5-V, 40-W supply. And Microdata's Micro-One unit, on a single 8-1/2 × 11-in. board, can be microprogrammed to emulate general or special-purpose computers.

The TTL/MSI processors use circuits that are widely alternate-sourced, in contrast with LSI units, which are virtually sole-sourced. But that picture could change dramatically in the next 12 months. Several manufacturers—Advanced Micro Devices, for example—are reportedly on the verge of following Microsystems International's

Need more information?

Readers may obtain more information on manufacturers' products and services by circling the appropriate information retrieval number. Organizations designated with a dagger (†) offer seminars or provide consultant services on the design or use of microcomputers.

Advanced Micro Devices, 901 Thompson Pl., Sunnyvale, Calif. 94086. (408) 732-2400. **Circle No. 400**

American Microsystems, 3800 Homestead Rd., Santa Clara, Calif. 95051. (408) 246-0330. (David L. Gellatly) **Circle No. 401**

† Andy Hish Associates, 9710 Cozycroft Ave., Chatsworth, Calif. 91311. (213) 998-0222. **Circle No. 402**

Applied Computing Technology, 17961 Sky Park Circle, Irvine, Calif. 92707. (714) 557-9972. (Neil V. Gleason) **Circle No. 403**

† Automata Systems, 592 Maude St., South Hempstead, N.Y. 11550. (516) 483-5185. (Ralph Sienna) **Circle No. 404**

Burroughs, P. O. Box 517, Paoli, Pa. 19301. (215) 648-2000. **Circle No. 405**

† Compata, 1333 Lawrence Expy., Suite 220, Santa Clara, Calif. 95051. (408) 246-7575. **Circle No. 406**

Computer Automation, 895 W. 16th St., Newport Beach, Calif. 92660. (714) 833-8830. (Phil Kaufman) **Circle No. 407**

Datapoint, 9725 Datapoint Dr., San Antonio, Tex. 78284. (512) 696-4520. **Circle No. 408**

Digital Equipment Corp., 146 Main St., Maynard, Mass. 01754. (617) 897-5111. (Larry DeAngelo) **Circle No. 409**

Electronic Arrays, 550 Middlefield Rd., Mountain View, Calif. 94043. (415) 964-4321. (Richard M. Eiler) **Circle No. 410**

Fabri-Tek, 5901 S. County Rd. 18, Minneapolis, Minn. 55436. (612) 935-8811. (Gerald W. Larsen) **Circle No. 411**

Fairchild Semiconductor, 464 Ellis St., Mountain View, Calif. 94040. (415) 962-5011. (David Chung) **Circle No. 412**

General Automation, 1055 S. East St., Anaheim, Calif. 92805. (714) 778-4800. (Stephen D. Bowers) **Circle No. 413**

General Instrument, P.O. Box 600, Hicksville, N.Y. 11802. (516) 733-3000. **Circle No. 414**

† iCOM, 21243 Ventura Blvd., Woodland Hills, Calif. 91364. (213) 340-0611. (David Callan) **Circle No. 415**

Intel, 3065 Bowers Ave., Santa Clara, Calif. 95051. (408) 246-7501 (Hal Feeney) **Circle No. 416**

Intersil, 10900 N. Tantau Ave., Cupertino, Calif. 95014. (408) 257-5450. (John Corser) **Circle No. 417**

† Martin Research Ltd., 1825 S. Halsted St., Chicago, Ill. 60608. (312) 829-6932. (Kerry Berland) **Circle No. 418**

† Microcomputer Associates, P.O. Box 304, Cupertino, Calif. 95014. (408) 226-3191. (Ray Holt) **Circle No. 419**

† Microcomputer Techniques, 11227 Handlebar Rd., Reston, Va. 22091. (703) 620-9676. (Jerry L. Ogdin) **Circle No. 420**

Microdata, 17481 Red Hill Ave., Irvine, Calif. 92705. (714) 540-6730. **Circle No. 421**

Microsystems International Ltd., P.O. Box 3529, Station C., Ottawa, Canada K1Y 4J1. (John Freeman) **Circle No. 422**

Monolithic Memories, 1165 E. Arques Ave., Sunnyvale, Calif. 94086. (408) 739-3535. (Joseph J. McDowell) **Circle No. 423**

Mostek, 1215 W. Crosby Rd., Carrollton, Tex. 75006. (214) 242-0444. (Larry Sullivan) **Circle No. 424**

Motorola Semiconductor, P.O. Box 20912, 5005 E. McDowell Rd., Phoenix, Ariz. 85036. (602) 244-3465. (Link Young) **Circle No. 425**

† National Electronics Conference, Oakbrook Executive Plaza #1, 1301 W. 22nd St., Oak Brook, Ill. 60521. (312) 325-5700. **INQUIRE DIRECT**

National Semiconductor, 2900 Semiconductor Dr., Santa Clara, Calif. 95051. (408) 732-5000. (Philip Roybal) **INQUIRE DIRECT**

Process Computer Systems, 5467 Hill 23 Dr., Flint, Mich. 48507. (313) 744-0225. (Dick Barnich) **Circle No. 426**

† Pro-Log Corp., 852 Airport Rd., Monterey, Calif. 93940. (408) 372-4593. (Ed Lee) **Circle No. 427**

RCA Solid State Div., Route 202, Somerville, N.J. 08876. (201) 722-3200. (Lee Wu) **Circle No. 428**

Raytheon Semiconductor, 350 Ellis St., Mountain View, Calif. 94042. (Bruce G. Wenniger) **Circle No. 429**

Realisations Etudes Electroniques (R2E), 38 Garden Rd., Wellesley, Mass. 02181. (617) 235-3130. (Michael W. Rohrbach) **Circle No. 430**

Rockwell International, Microelectronic Device Div., P.O. Box 3669, Anaheim, Calif. 92803. (714) 632-2321. **Circle No. 431**

Signetics, 811 E. Arques Ave., Sunnyvale, Calif. 94086. (408) 739-7700. (Joe Kroeger) **INQUIRE DIRECT**

Teledyne Systems, 19601 Nordhoff St., Northbridge, Calif. 91324. (213) 886-2211. (Russell E. Lewis) **Circle No. 432**

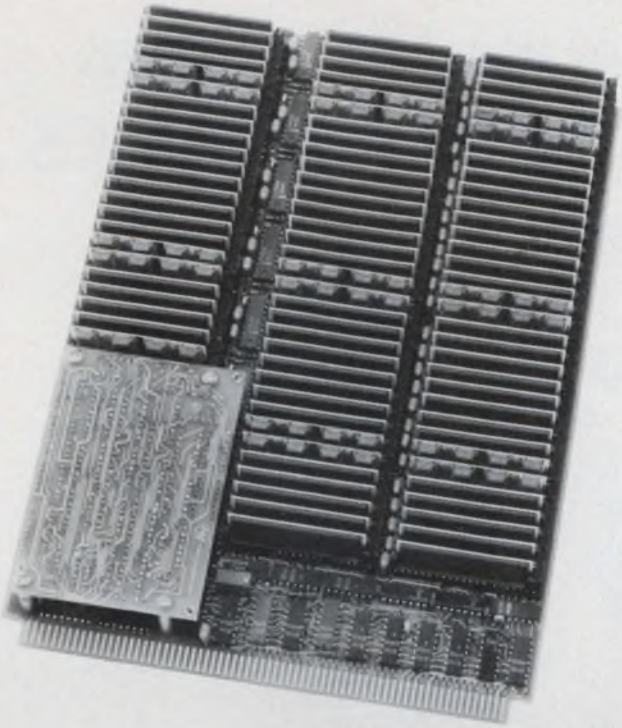
Texas Instruments, P.O. Box 5012, MS/84, Dallas, Tex. 75222. (214) 238-3741. **INQUIRE DIRECT**

Toshiba Transistor Works, 1-Komukai, Toshiba-Cho, Kawasaki-Chi, Japan. **Circle No. 433**

Transitron, 168 Albion St., Wakefield, Mass. 01880. (617) 245-4500. (Martin S. Gordon) **Circle No. 434**

Western Digital, Box 2180, 19242 Red Hill Ave., Newport, Beach, Calif. 92663. (714) 557-3550. (Bill Roberts) **Circle No. 435**

Xerox Corp., Dept. 15-02, 701 S. Aviation Blvd., El Segundo, Calif. 90245. (213) 679-4511. **Circle 436**



Hybrid packaging yields a 32-k × 18-bit 'micromemory' on a single board. General Automation offers the unit for use with the company's LSI-16 system.

lead in alternate-sourcing Intel's 8008 processor, or possibly producing Intel's 8080 chip. Aiming at more recent models, American Microsystems has plans to alternate-source Motorola's microprocessor chips. Furthermore a number of primary processor-chip suppliers are seeking other sources for their proprietary circuits.

Also expected are more bipolar/LSI microprocessors. For example, Texas Instruments—though tight-lipped officially—is said to be developing a biploar unit that uses integrated-injection-logic (I^2L) for increased density. I^2L maintains the high speeds of bipolar circuits while achieving densities comparable with MOS (see "Integrated Injection Logic Shaping Up as Strong Bipolar Challenge to MOS," ED 6, March 15, 1974, p. 28). Most observers consider a high-density process, such as I^2L, absolutely essential to achieve the high functions per chip needed for bipolar/LSI.

The strong emergence of bipolar/LSI microprocessors could have far-reaching effects. At present processor-chip vendors, who are the hardware experts, are increasing their software support, while mini makers, who excel in software, are stripping down to "bare-bones" models.

However, direct competition of products generally is limited because of the speed gap between most micros, which use MOS, and bipolar mini models. Bipolar/LSI processors could bridge the speed gap, thereby sparking a historic confrontation between chip vendors and mini makers. ■■