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Editorial Director .... *Lothar Stern*
Art Director .... *William A. Preiss*
Photographers .... *Leonard J. Zbiegien*
Edwin J. Rittershaus
Editorial Assistant .... *Janice Harmon*

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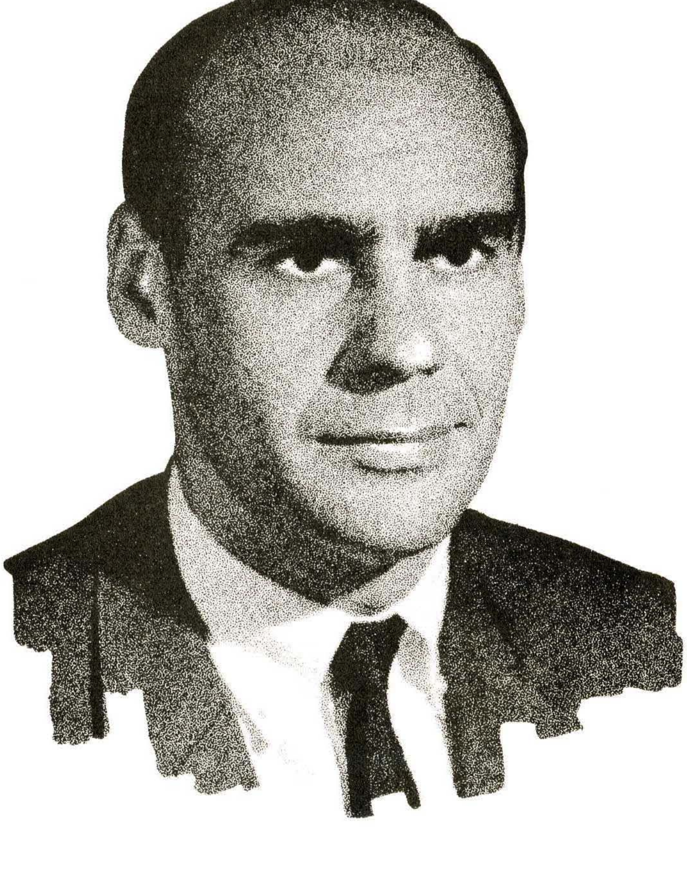
The Vanguard of Semiconductor Technology

By RICHARD ABRAHAM
Operations Manager
Discrete Semiconductor Products



The drum rolls and bugle calls that accompany every innovation and introduction in the field of integrated electronics tend to obscure realities about the future of electronics technology. Concern that discrete semiconductors are gradually fading away is being fostered by announcements that more and more manufacturers, including some old-line semiconductor houses, are phasing out of the discrete-device business. Anxiety about pricing and progress is clouding the perspective of designers whose products are tied to the capabilities of discretes with no suitable or advantageous alternatives. It is time, therefore, to take stock, and to look at the situation as it really is.

In more than a decade of feverish activity, integrated circuits have succeeded in capturing nearly 40 percent of the total semiconductor market. This is truly a remarkable achievement, but the figures alone exaggerate the inroads that have actually been made. A more detailed investigation leads to some interesting insights. The most pertinent of these is that virtually all of the gains made by integrated circuits have been at the expense of lead-mounted transistors and diodes. Of all discrete semiconductors only these small-signal devices have taken a nose dive in the past four years. Other discrete sales, including chassis-mounted (power) transistors and rectifiers have actually increased.

Complementing this statistic is the fact that 85 percent of all integrated circuits sold in 1971 fall into two very narrow categories: Logic circuits and operational amplifiers. Removing these circuit classifications from the $450 million IC market leaves a mere $63 million worth of ICs to infiltrate markets other than those involving data processing and instrumentation. That represents only about 10 percent of the dollar value of the discrete semiconductors now serving these same markets. Clearly, the unrivaled capabilities of discrete semiconductors show no inclination to succumbing to the glamour of integrated circuits.

The statistics presented here are subject to change. A sudden awakening of a vast new IC mass-market, as for example in the electronic watch market, can immediately and drastically effect the relative ratios of IC-to-discrete sales. The development and acceptance of consumer product ICs can have a similar effect. But one thing remains predictably certain: ICs are, and will continue to be, relegated primarily to tasks that can be accomplished with small-signal transistors and diodes operating at moderate frequencies. Their principle attributes are their ability to reduce the cost, size, and weight of electronic equipment and, in the case of very complex equipment, to improve reliability. The task of overcoming performance barriers will continue to fall mainly to discrete components.

This is clearly demonstrable by comparative evaluations which show that virtually every IC advance was pioneered with discrete components.

The advantages of MOS techniques which are just now being emphasized in integrated circuits have been available for years with discrete MOS FETs.

Achievable power levels in integrated switching and amplifiers are totally eclipsed by power transistors with several hundred watts dissipation capabilities.

Flip-flop frequencies up to 300 MHz are achievable with high-speed MECL circuits, but discrete oscillator devices tested at several gigahertz are commonplace.

At small-signal levels, amplifier ICs go up to perhaps 40 to 50 MHz. But one can obtain up to 10 watts at 400 MHz and as much as 2.5 watts at 1000 MHz with discrete components.

To achieve the significant performance superiority, discrete-component processing technology treads well ahead of IC practices.

Tolerances as tight as half a micron are rigidly and routinely enforced in some RF device groups, compared with 1 micron tolerances for the more critical IC production lots.

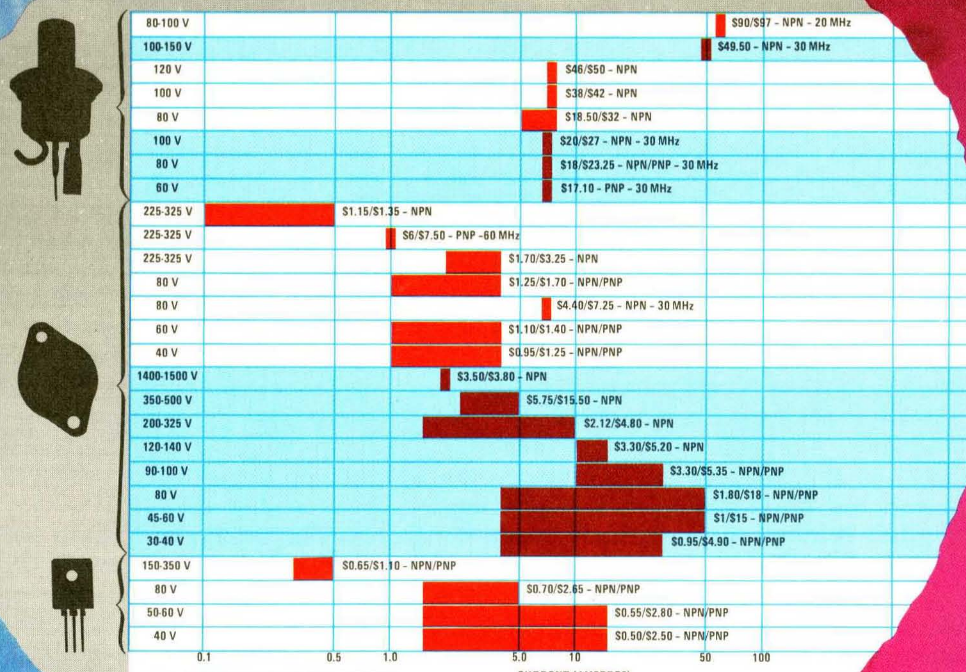
Transistor chips as large as 275 mils per side are employed in some high-power transistors, while 150 mils per side is still considered advanced for IC processing.

Production control of diffusion profiles can be made much tighter and the permissible range of material resistivities is much broader for the simpler discrete devices, thereby permitting designs that result in tighter limits and substantially better specifications.

It is a way of life in electronics today that integrated circuit limits will be pushed as far as process limitations permit, and as fast as high-volume usage demands. It is also true, however, that every performance specification of an integrated circuit can be matched with a discrete component design (albeit at greater cost), while many of the capabilities of discrete circuits are totally beyond the projections of today's IC planners.

The future of discrete semiconductor components, therefore, is not dimmed by the proliferation of ICs. On the contrary, as the low-cost aspects of integrated circuits technology opens new markets to the penetration of electronic principles, discrete components will be used in increasing numbers to supplement and extend IC capabilities. At Motorola, we are strongly devoted to continuing the advancement of discrete semiconductors in all phases of the technology, and our vast financial and technical commitments in this field give assurance of our continuing sensitivity and response to the industry's needs.

PRICE/PERFORMANCE CHART
Low-Frequency Power Transistors



NOTE: PRICES SHOWN ARE FOR 100-UP QUANTITIES.
PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

Price ranges of Motorola off-the-shelf silicon power amplifier and switching transistors as functions of current, voltage, and package. Cutoff frequency is normally less than 10 MHz except where specifically called out. The wide selection satisfies most applications and price requirements.

SEMICONDUCTORS WITH MUSCLE

By LOTHAR STERN, Manager, Technical Information Center

It began in 1955. It sprang from a brand-new idea in transistor packaging and an underlying desire to get rid of the troublesome mechanical vibrator that had plagued automobile radio owners ever since Paul Galvin* first put radio entertainment on wheels. And today, *power transistor technology* still remains one of the more dynamic growth areas in a field where other discrete semiconductor components are rapidly succumbing to the inroads of integrated circuits.

Over the past 15 years, progress in power semiconductors has been impressive. From the modest 2-watt (output) 2N176 power transistor that first replaced output tubes in car radios, audio power output capabilities have now been expanded to well over a hundred watts with a pair of inexpensive complementary devices. From the very restricted frequency range of less than 10 kHz of the late '50s, today's power capabilities have pushed well into the microwave region. From the single-minded applications category of the early power transistors, solid-state power devices have today invaded every field of electronic amplification, switching and power control.

**Paul V. Galvin, 1895-1959, founder of the Galvin Manufacturing Co., later known as Motorola Inc. Generally credited with introducing first automobile radio.*

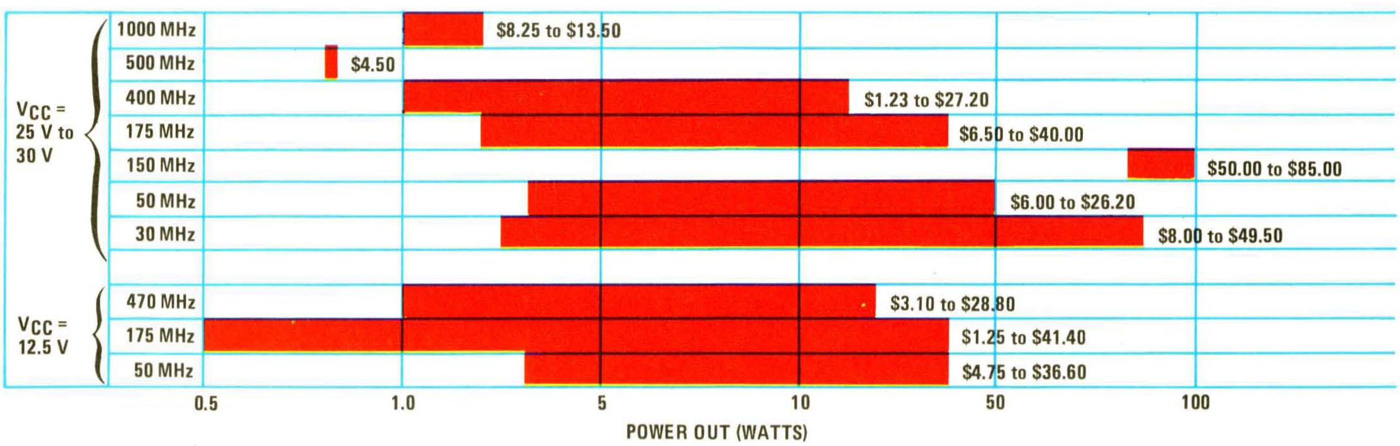
Yet, despite this progress, plans for future power device improvements at Motorola still occupy a high priority rating. Each "milestone" to date has served merely as a stepping stone for subsequent advances, and the end is nowhere in sight.

A Major Milestone

In common with other transistor types, power technology began and flourished in the germanium era. For over a dozen years of evolution, the germanium specifications expanded to encompass ever widening applications categories. Current ratings increased from 3 amps to 60 amps, breakdown voltages from 40 volts to 400, and frequency response increased by about an order of magnitude. But the first major breakthrough came not from an evolutionary process, but in the transition from germanium to silicon as the basic semiconductor material.

Silicon power transistors had been available since around 1957. Their cost, however, had been prohibitive. Attempts to make them with the familiar alloy process used for germanium resulted in price tags ranging from $25 to over $100. Current gain was low and saturation voltage high. It wasn't until 1960, with the development of a

PRICE/PERFORMANCE CHART RF POWER TRANSISTORS



Price ranges of Motorola off-the-shelf silicon RF power transistors as functions of power output and frequency. RF transistors are normally grouped into specific voltage ranges that determine their ultimate applications. The voltages specified are power supply voltages at which the transistors are tested for the indicated power at the rated frequency.

single-diffused system, that silicon power transistors became practical for high volume applications.

The switch to silicon had two immediate benefits of significant proportions. First, it instantly increased the maximum junction temperature of power transistors from 110°C to 200°C, thereby increasing the permissible operating ambient, reducing heat sink requirements, and enhancing safe operating area (SOA). Secondly, it facilitated the development of both NPN and PNP power transistors (germanium yielded principally PNP devices), resulting in the development of true complementary circuitry with greatly improved circuit performance, simplicity, and cost. And, where germanium transistors had never been able to generate significant power levels at the higher frequencies, silicon, over the years, has overcome this limitation.*

Paradoxically, the rapid expansion of silicon technology, so far, has failed to affect germanium power devices as strongly as had been predicted. In certain high volume applications, as in car radio output stages, germanium has proven itself technically adequate, and the long production history has reduced device costs to the point where silicon is still non-competitive. Similar cost advantages accrue to applications requiring high current flow; cost differentials ranging as high as 10 to 1 favor germanium as the current limits of both technologies are approached. Germanium even holds certain technical advantages. Its threshold voltage being lower than that of silicon (0.2 V compared with 0.6 V), it follows that the internal voltage drop is lower in germanium transistors. For high-current, low-voltage applications, therefore, germanium power transistors can provide enough of an increase in efficiency to make them the logical choice. These considerations, plus the many years of experience accumulated by circuit designers with germanium power transistors, virtually assure a continuing existence for these devices, though the shifting of research activity to the more growth-oriented silicon lines will diminish the influence of germanium on new-equipment designs.

The How and the Why

The exploitation of silicon technology for power devices is taking many different directions. In contrast with the early days of the transistor art, when engineers were diligently looking for the one structure and the one process that would yield an ideal "universal" transistor, today it is recognized that such a phenomenon does not, and cannot, exist. On the contrary, there are many ways of making transistors, and each method offers some improvements while suffering some limitations. In its ultimate form, a particular application requiring extremely tight specification of one type or another could demand a special device in which process, geometry and structure are all carefully matched to optimize a specific series of parameters. In general, however, power transistor technology has already progressed far enough to satisfy the vast majority of applications with readily available, off-the-shelf devices utilizing the gamut of proven process techniques.

To achieve a meaningful insight into power semiconductors, the field must be initially divided into two groups: low-frequency power transistors and high-frequency devices. The division occurs at approximately 30 MHz and represents a transition from process-dependent specifications to geometry-dependent parameters. At the lower frequencies, transistor specifications depend to some extent on the manufacturing process. At the highs, the processes do not change much, but geometric designs can cause significant performance variations.

Low Frequency Processes

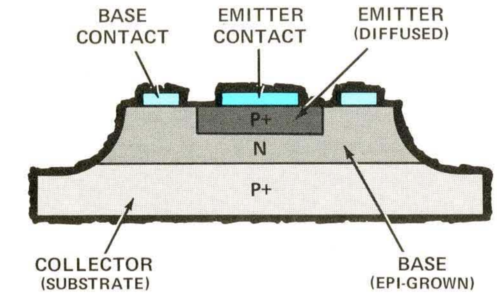
There are four basic processes by which today's silicon power transistors are manufactured.* Each of these is outstanding in certain device characteristics but has compensating weaknesses in others. The tradeoffs are between ruggedness (SOA), frequency response, voltage rating, versatility, and cost.

The processes and structures of the low-frequency devices are illustrated and described on page 7. Of these, the *Epitaxial Base* (Epi-Base®) structure is by far the most popular, and probably accounts for better than 45% of total industry sales. The reason for this is a unique combination of characteristics that best satisfies the large majority of low-frequency applications. The Epi-Base process results in one of the more rugged transistors, making it suitable for the large power-amplifier and series-pass regulator markets. It is moderately fast (f_T — 10 MHz) making it useful for medium-speed power switching. Current handling capability, up to 50 A, is as high, or higher, than that of any other process, and voltage ratings (BV_{CEO} up to 140 V) spans most common application requirements. Moreover, process versatility made this the first power structure suitable for both NPN and PNP devices, adding immeasurably to its applicability due to complementary-symmetry circuit possibilities. Finally, the process is relatively non-critical, producing

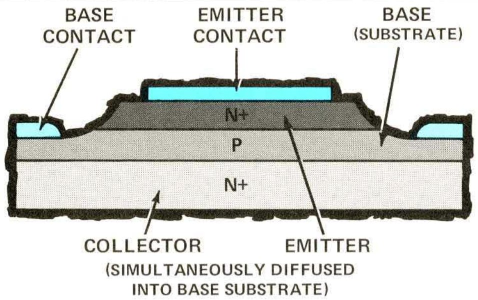
**Actually, most of the improvements credited to the use of silicon are not caused by the differences in the materials, but by the vastly superior process technology that can be employed with silicon.*

**Germanium transistors are made by alloying or by a combination of diffusion and alloying. Since little processing progress has been made in this product line in recent years, these devices will not be discussed here.*

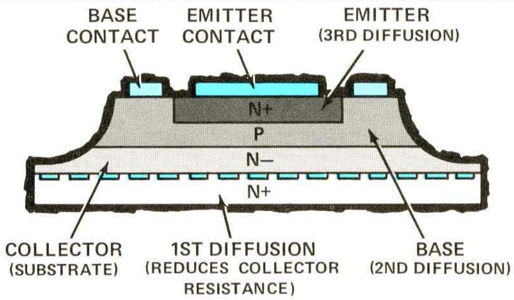
LOW FREQUENCY SILICON POWER PROCESSES



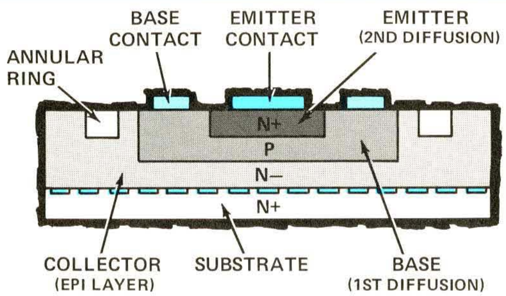
EPI-BASE



SINGLE-DIFFUSED



TRIPLE-DIFFUSED MESA



DOUBLE-DIFFUSED

PROCESS	CHARACTERISTICS	POLARITY	OUTSTANDING FEATURE	PREFERRED APPLICATIONS
EPI-BASE	I_C = to 50 A BV_{CEO} = to 140 V SOA = EXCELLENT f_T = to 10 MHz	NPN/PNP	VERSATILITY	ALL
SINGLE-DIFFUSED	I_C = to 30 A BV_{CEO} = to 140 V SOA = EXCELLENT f_T = to 2 MHz	NPN ONLY	RUGGEDNESS	POWER SUPPLY REGULATORS
TRIPLE-DIFFUSED MESA	I_C = to 10 A BV_{CEO} = to 1500 V SOA = GOOD f_T = to 10 MHz	NPN ONLY	HIGH VOLTAGE PERFORMANCE	TV DEFLECTION CIRCUITS
DOUBLE-DIFFUSED	I_C = to 30 A BV_{CEO} = to 200 V SOA = LOW f_T = 150 MHz	NPN/PNP	HIGH SPEED	HIGH SPEED SWITCHING

Four basic processes, each with its own particular advantages and limitations, form the nucleus of today's low-frequency silicon power technology. Proper utilization of these processes permits tailoring of devices to fit virtually any specific application.

high manufacturing yields and associated low cost. Small wonder that the development of this process, in 1965, represented a second major milestone in the power transistor development calendar.

The Epi-Base process doesn't entirely supplant the earlier *single-diffused process*, however. For one thing, single-diffused devices have been around for a long, long time and prices for some of the more popular devices are low. For another, they are extremely rugged and provide better SOA in the region of BV_{CEO} than do the equivalent Epi-Base devices. However, their frequency response is a limiting factor, restricting them to slow-speed power switching applications and series-pass power regulators. Indeed, for special power supply circuits, where the transistor must work into an unclamped inductor and must absorb the stored energy, the single-diffused device is still the best choice. The process yields only NPN transistors.

Whereas most power transistors are used in applications requiring little more than 100-V or 200-V breakdown ratings, the number of uses for higher voltage devices is increasing. Moreover, high-voltage applications are becoming more important because of the large number of devices associated with these potential markets, as in TV deflection circuits and automotive ignition systems.

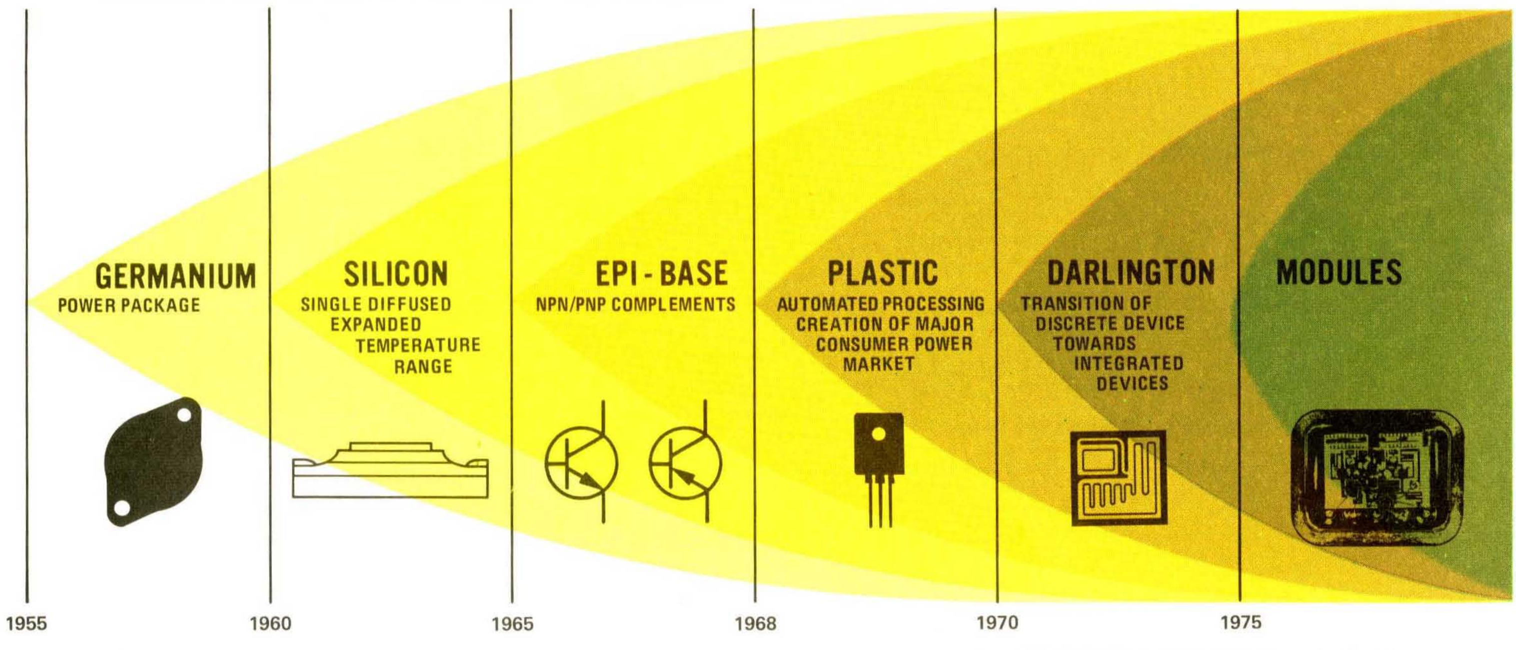
Most power devices are voltage limited by the reach-through (punch-through) phenomenon resulting from the spread of the collector-junction depletion region into a high-resistivity base region. To overcome this, a *triple-diffused* structure has been developed in which the collector region has much higher resistivity than the base. As a result, the depletion region spreads into the collector and the reach-through limitation is avoided.

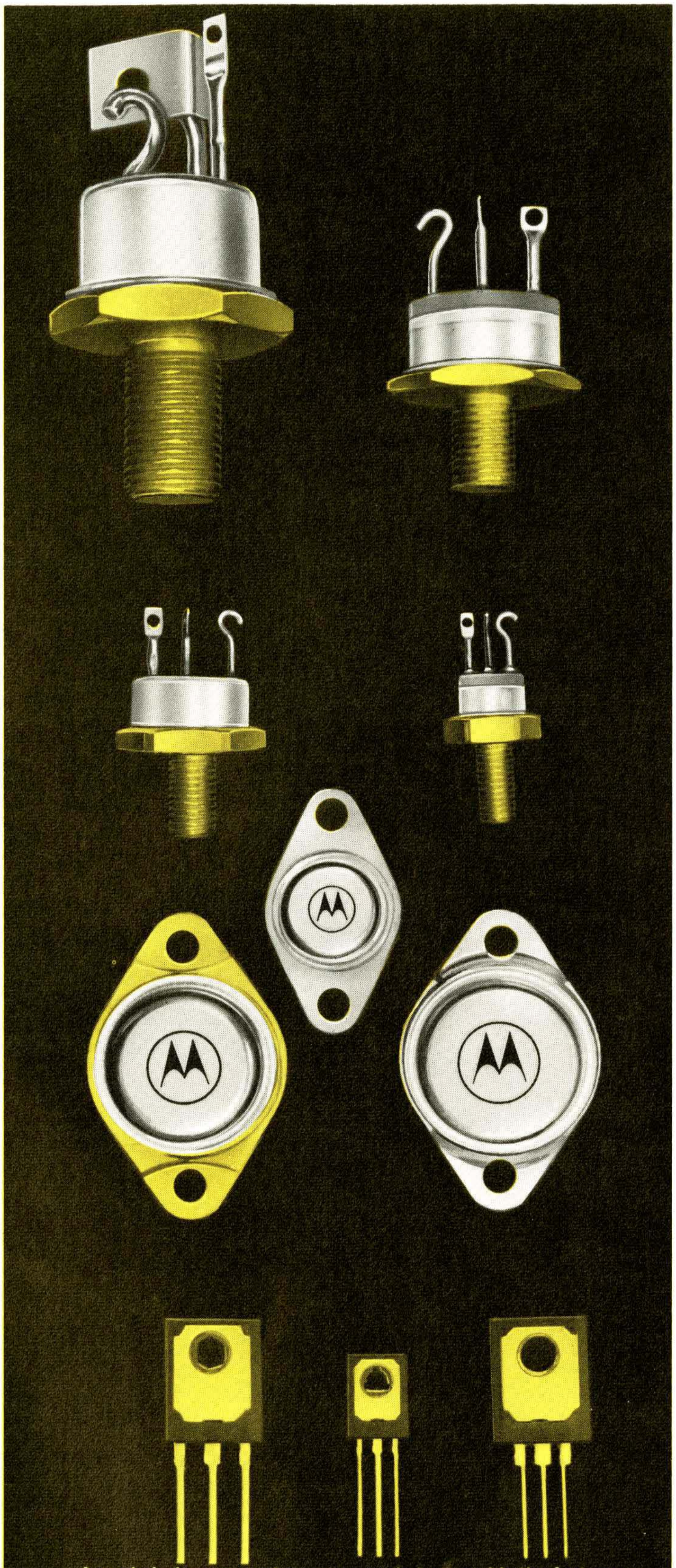
With the triple-diffused process, transistors with voltage ratings up to 1500 volts have been fabricated on a production basis and even 2000 V is under active discussion — and at prices compatible with low-cost requirements of the mass markets.

There's still one more process employed for silicon power transistors. It's a *double-diffused* process similar to that used in ICs, and it yields devices of relatively high frequencies — up to 150 MHz f_T. And they have excellent gain characteristics. Generally, these are used in high-frequency switching circuits. Their high-frequency characteristics are a result of very narrow base widths which limit the dc safe-operating area. But, since such devices are used principally in the pulse mode where junction heating is minimal, this is not a major detriment. The double diffused process can yield both NPN and PNP devices.

It is quite conceivable that devices suitable for a given application can be made by any one of a number of processes. The ultimate device selection is normally based on electrical specifications and cost, rather than on processing. Nevertheless, since each process has a preferred area of technical emphasis, it is evident that only a manufacturer with expertise in each process category can provide devices for across-the-board applications needs.

MILESTONE CALENDAR FOR THE POWER TRANSISTOR INDUSTRY





A myriad of power packages are needed to provide the features associated with today's broad transistor line; plastic for low cost, metal for high power, stud mounts for highest reliability and best heat dissipation.

Low Frequency Power Packaging

A major, undesirable by-product of power is heat. Under high-power operating conditions, if the heat is not conducted away from a transistor junction, the junction could become hot enough to break down, and even to melt the solder that holds the die to the package. Since the package serves as the first heat sink for the die, the amount of power that can be dissipated by the transistor is directly related to the ability of the package to carry the heat away from the junction. Hence, the package becomes an important part of the power system.

Like the dice themselves, transistor power packages have proliferated with a myriad of variations and improvements. From the first diamond-shaped TO-3, a variety of designs have evolved; always with two purposes in mind: improving power dissipation and reliability, and reducing cost. The former led to the development of a number of stud packages, while the search for the latter resulted in the use of a number of different case materials, leading from copper, to steel, to aluminum, and finally to what must be considered another milestone in power transistors — plastic.

Plastic-packaged power transistors don't have the higher power dissipation capacity of the various metal packaged devices, but they're perfectly adequate for a large number of applications, and they literally blasted power transistor prices. From an average selling price of about $2.00 for metal-can transistors, the ASP for plastic devices has dropped to approximately $0.50. That's because of automation in die assembly (through stripline assembly) and one-step, multi-unit encapsulation. Whereas a typical TO-3 metal package takes 4 individual assembly steps of relatively expensive package parts, a few cents' worth of plastic material can encapsulate dozens of plastic transistors in one fell swoop. The resulting lower prices have caused plastic devices to create a market for power devices in the entertainment and other consumer fields,* and to make strong inroads into the industrial market as well.

**This does not include the auto-radio power stages which are still heavily committed to metal-packaged germanium transistors.*

Start of a New Era

The available discrete power transistor types already number in the thousands. They dissipate up to 300 watts and operate at currents up to 60 A and voltages as high as 1500 V. At a first evaluation, it is difficult to see where there is room for much improvement other than a continuing advance of the parameter frontiers — but there is!

A strong hint as to a new direction came late in 1970, when Motorola introduced the industry's first commercially practical power Darlingtons.

A Darlington device actually consists of two independent transistors and a couple of resistors, all hooked up in a powerful amplifier circuit with current gain on the order of 1000 or greater. In essence, such devices consist of a driver-output stage combination which reduces the component count in a circuit significantly.

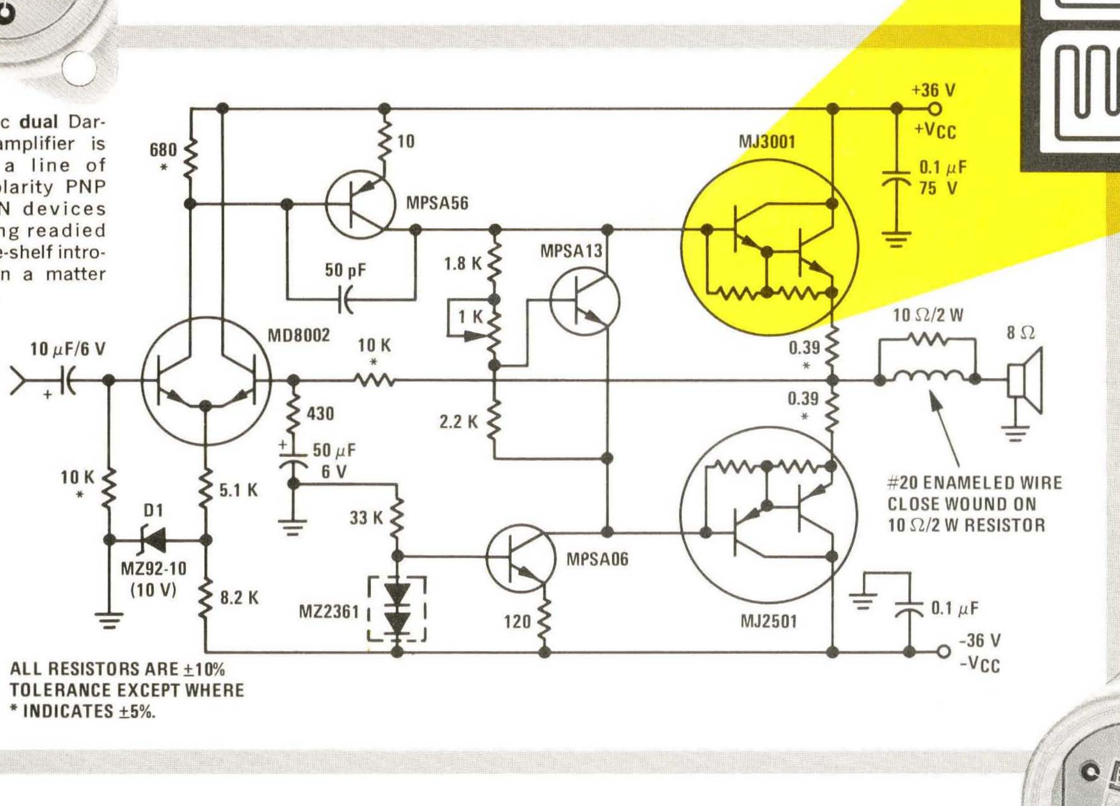
By today's standards, a couple of active devices in conjunction with two resistors hardly constitute an "integrated circuit," but the implication is clear — power devices aren't *succumbing* to integrated circuits; with the advent of Darlingtons, *they are starting to head in that direction themselves.*

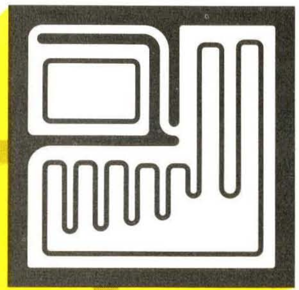
Power Darlingtons are being made today in volume with both single-diffused and Epi-Base processing, with double-diffused and triple-diffused units already in the prototype stage. The single-diffused technology, as with individual transistors, yields only NPN devices while Epi-Base processing provides complementary pairs. The other processes will lend their individual benefits to the upcoming Darlingtons. The almost incredible simplicity of a high-power amplifier obtainable with such a system is illustrated below.

The practical step up in multi-component power chip is, of course, the natural evolution from

Monolithic **dual** Darlington amplifier is one of a line of single-polarity PNP and NPN devices now being readied for off-the-shelf introduction in a matter of weeks.

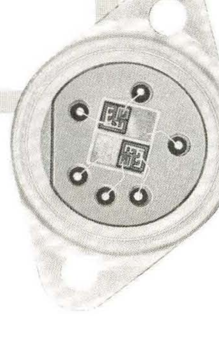
Schematic diagram of 60-watt power amplifier with dc-coupled, complementary Darlington output devices demonstrates circuit simplifications resulting from this latest technology. For greater details regarding this circuit (and others) send for AN-483B.





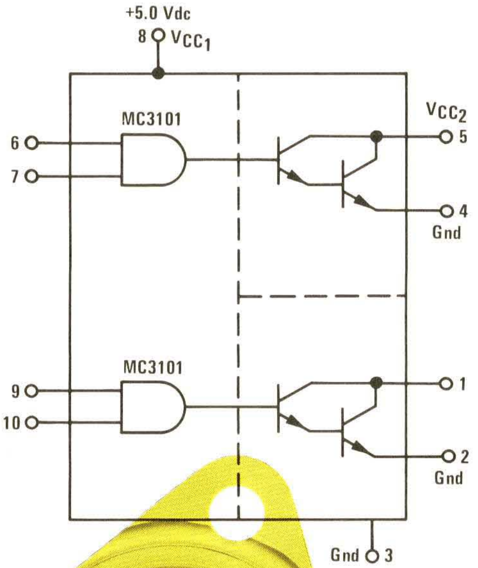
Motorola's silicon power Darlington "transistor" incorporates both driver and output transistor plus necessary resistors in one monolithic structure.

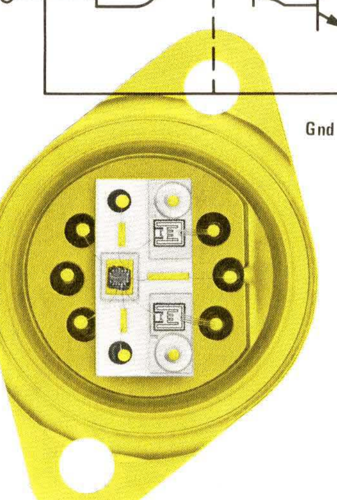
Hybrid **dual** Darlington amplifier incorporates PNP and NPN devices in a single package. This prototype device illustrates feasibility but is not yet ready for standard introduction.



a single power Darlington to dual Darlingtons and, indeed, this has already been achieved. Dual Darlingtons further reduce package count and manufacturing costs, but the devices available so far suggest that some progress is still in the offing. For example, today's dual Darlingtons contain either two PNP or two NPN devices. None yet contains a complementary pair in a single monolithic structure. This means that single-channel complementary amplifiers with a single-package output are still over the horizon. For stereo or quadra-sonic amplifier systems, however, the single-polarity dual Darlingtons again cut the number of needed packages in half.

It isn't that single-package complementary Darlingtons can't be produced. They can and have been made, both monolithically and by putting two complementary chips in a single housing. Both methods, however, involve extra processing steps which, so far, have raised the projected selling price to a level beyond what the expected market will bear. Until such manufacturing costs are reduced, complementary single-package Darlingtons probably won't go into mass-production. For those with applications in this category, one can predict with reasonable certainty that it's only a matter of time.



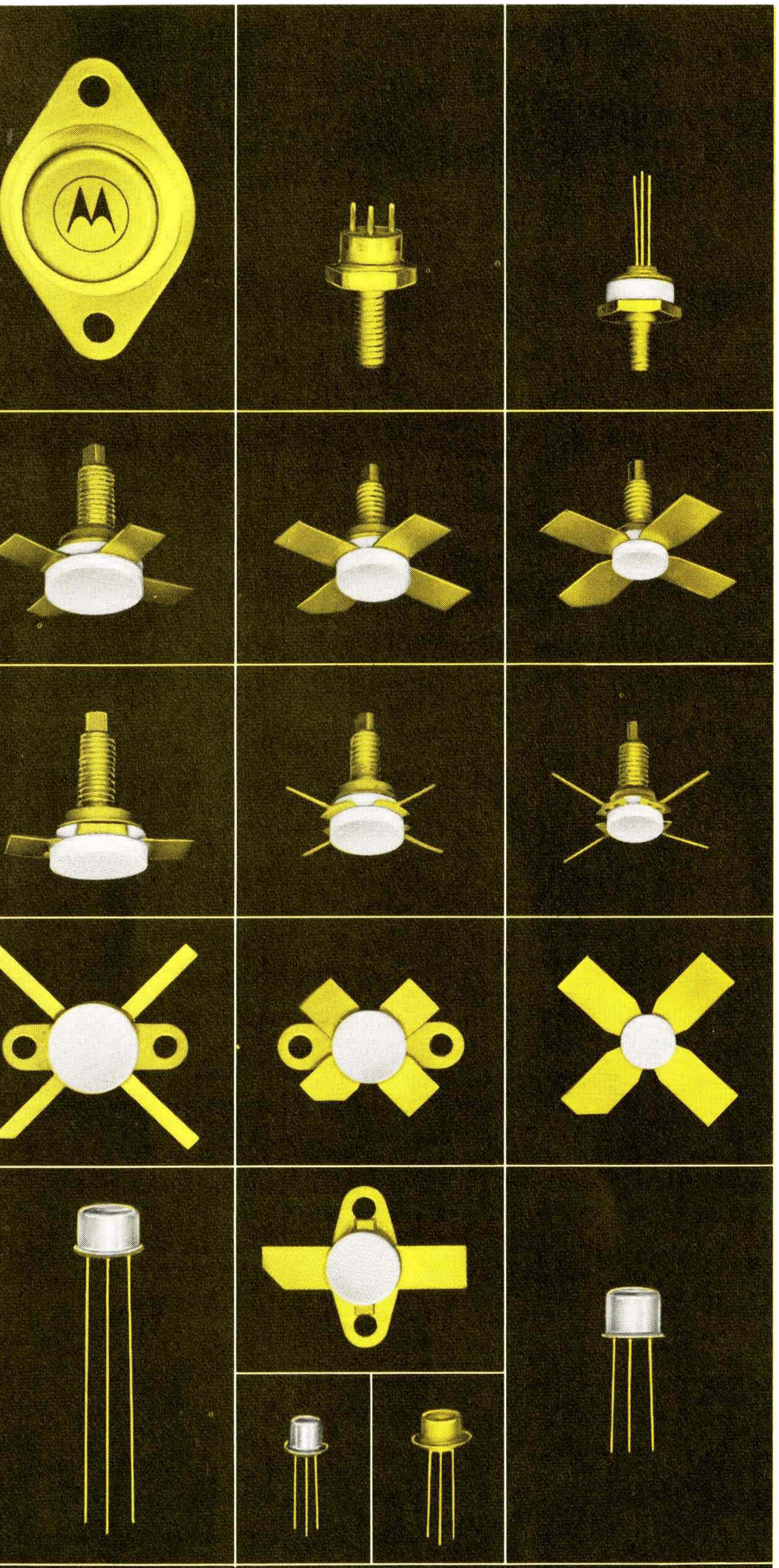


Dual power driver demonstrates hybrid device capability. This off-the-shelf device, type MCH2890R, provides a 6-ampere output for driving mechanical loads.

That single-package power circuits of greater complexity are not beyond the realm of feasibility is indicated by the MCH2890R dual power hybrid circuit shown. Here, in a 10-pin TO-3 package, are a multi-gate chip and two Darlington amplifier chips. The drivers are capable of providing up to six amperes of current for driving digital printers, relays, lamps, punches, etc. In the near future, one can anticipate a proliferation of circuits of this kind. But they won't be inexpensive. Hybrid technology involves substantially more labor than monolithic technology, and it isn't easy to combine power devices and small signal devices in a single package. The latter cannot tolerate the high temperature at which power devices are often operated to achieve maximum ratings. This means that the power devices, when operated in the same package with low power circuits, can't be made to function at their maximum ratings. And if this is true for hybrid circuits, it's emphasized even more strongly in monolithic designs. Though one can predict an increase in power hybrids on a specialty basis, mass-produced, complex, monolithic circuits with substantial power output capability still are relegated to the R&D phase.

In review, low-frequency power semiconductors have already successfully replaced vacuum tubes in every major application involving high-volume production. Technically they have entrenched themselves solidly in all markets. But there are still barriers to be overcome. Of most immediate importance is the proliferation of multi-component, single-package monolithic and hybrid devices, with the attending cost-reduction potential.

A potential also exists for such power transistors to penetrate the very high power control field, i.e., greater than 2 kW. This category is now being served principally by gas tubes and thyristors. Power transistors offer the distinct advantages of *continuous* control. There is little doubt that the technical capability already exists. The big question is a marketing one — whether the available volume is great enough to justify the development effort. But even if the profit motive cannot be satisfied, it's still a safe bet that very high power transistor barriers will be broken — if for no other reason than — "the mountain is there to be climbed."



High frequency power devices utilize the widest variety of package styles and sizes of any semiconductor line. Package designs minimize parasitic inductances and capacitances to achieve significant power at frequencies up to a gigahertz.

Power At High Frequencies

It wasn't very long ago that a frequency of 30 MHz was in the area of wishful thinking for semiconductors *at any power level.* Today a whopping 100 W of CW power can be wrung from a single transistor at five times that frequency, and in excess of 10 W is possible at the new frontier of 1 GHz (1000 MHz).

High-frequency power transistors are similar to their low-frequency counterparts in name only. That, and in the fact that they generally employ the double-diffused epitaxial structure that is sometimes used at the lower frequencies. But, whereas low-frequency devices utilize large, simple geometries, high-frequency geometries are more like high-density integrated circuits that demand the ultimate in state-of-the-art processing.

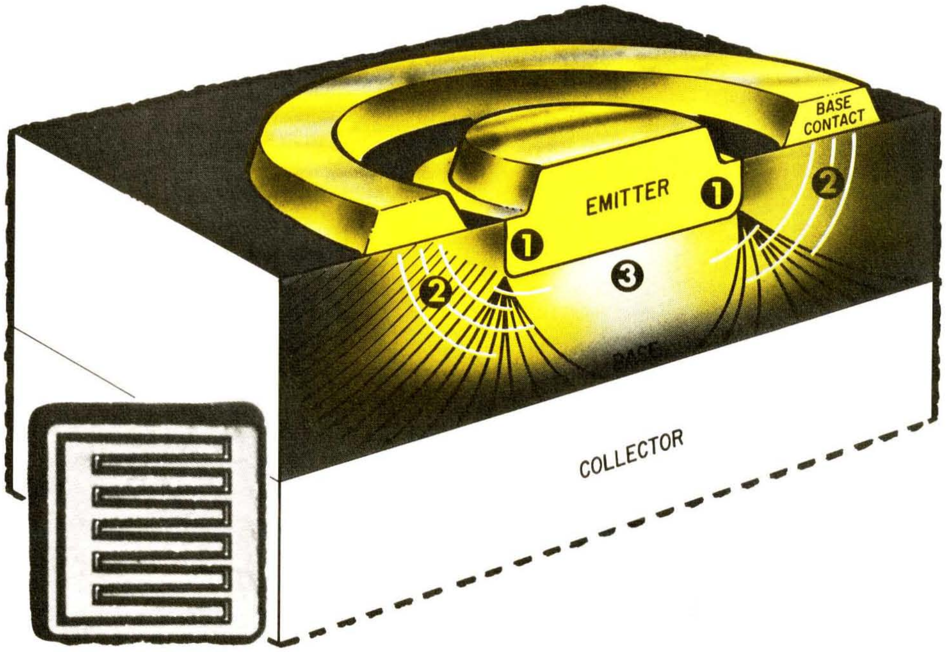
All of the problems of low-frequency power transistors are accentuated and multiplied in the VHF/UHF region. For example, there's the problem of current crowding. It is well known that when a heavy emitter current is injected into the base region, the base current that traverses the base region to the base contacts can be quite large. Since the base region has a certain amount of resistance, this base current sets up a lateral voltage drop and establishes an internal bias potential. The effect of this potential is such that it tends to reduce the external bias in the center area of the emitter, *thereby crowding emitter current emission to the edges, or periphery, of the emitter structure.*

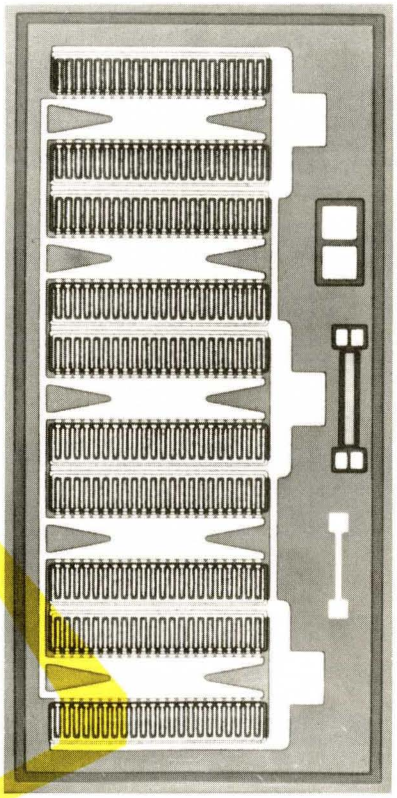
Obviously, this impairs the efficiency of the emitter, and reduces the amount of current that can be injected. Also obviously, to compensate for this effect, one could increase the emitter area, thereby increasing the emitter periphery. But this expedient not only calls for a bigger and more expensive chip, it adds parasitic emitter capacitance that literally makes the device useless at high frequencies.

A practical solution to this problem is simply to make the emitter in the form of long, narrow fingers, interspersing these with base-contact metalization. This gives each emitter finger two emitting edges, eliminating much of the useless, parasitic-producing, center portion of a square or round emitter. And, the slimmer the fingers, the greater the periphery-to-area ratio, hence the greater the emitter efficiency.

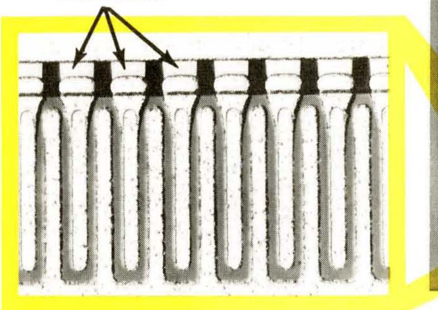
This periphery-to-area (P/A) ratio represents a figure of merit for high-frequency power transistors.

The interdigitated geometry just described does a great deal for power transistors by considerably reducing the size of the chip required for a desired power output. But as frequencies go higher and higher, the requirements become increasingly critical. To hold parasitics to an abso-





Current Crowding. In power transistors, base currents are not always negligible. This current sets up internal voltage drops that bias the center of the emitter region to cut off, thus crowding emission of emitter current toward the edges of the emitter. Left: Multifingered emitter structure provides more "edge" for less bulk, and greatly increases emitter efficiency.

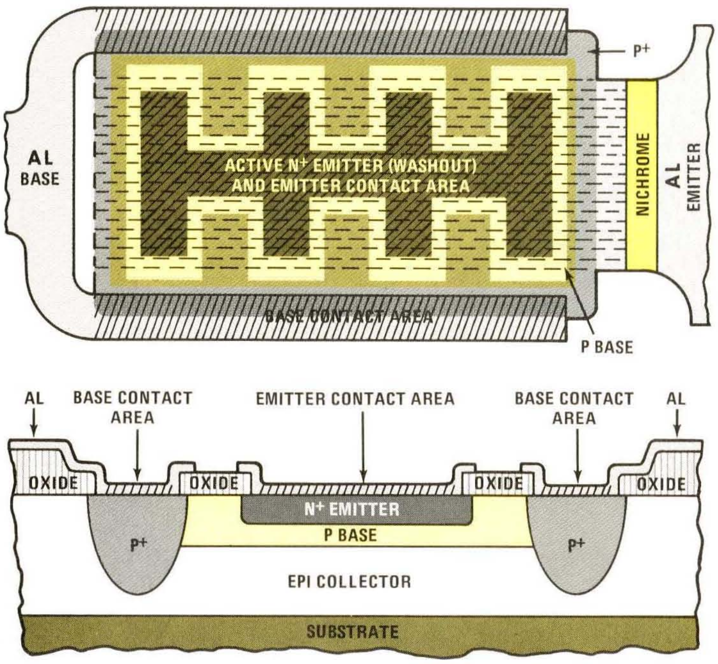


In high frequency structures, non-emissive emitter area must be minimized to reduce parasitic capacitance. Hence, many slender "fingers" that maximize periphery-to-area ratio. Enlargement of this "interdigitated" geometry shows emitter resistors that have been added to balance the current throughout the chip.

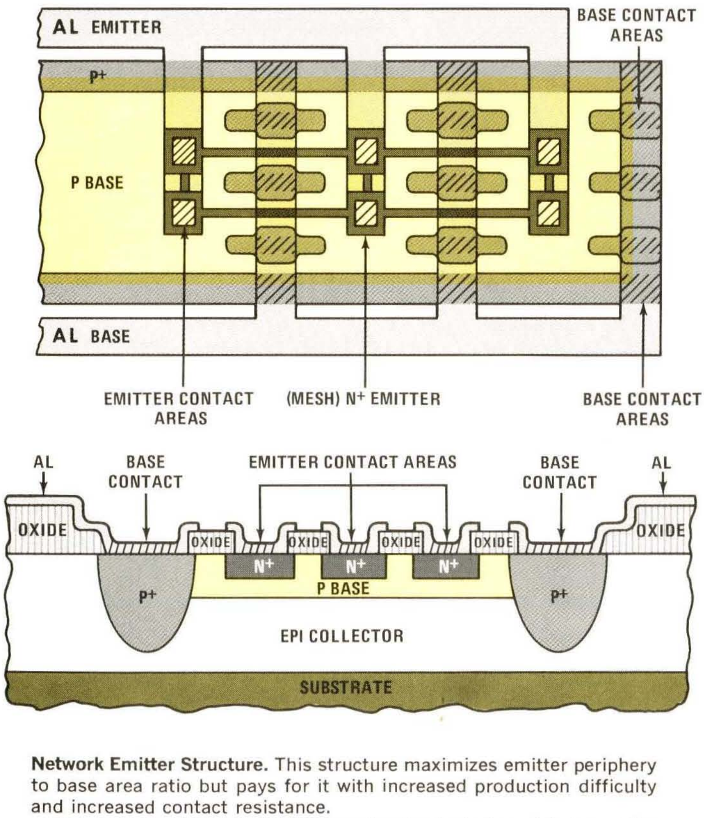
lute minimum, the emitter area must be very small compared with that of low-frequency units. Therefore, if power is to be held to a high level, the width of the fingers (and the resulting metalization) must also be reduced, permitting a greater number of fingers, to maintain the higher power capabilities at the reduced area. In the final structure, the emitter consists of long, narrow diffused fingers, all interconnected by a metalization pattern.

Of course, there's a limit to how thin the fingers can be made. The limit is set both by processing capability and by the minimum amount of metal required to handle a given current without introducing a failure mode called metal migration. This causes the metal to squirm, buckle, or otherwise disfigure itself under extremely high current densities, finally causing metalization failure. Practically, by pushing the limits of the technology, interdigitated structures can be built with a periphery-to-area ratio of about 5 to 1, and with 0.1 mil lines and spaces. Because of this line-width limitation, devices with about 5 W at 3 GHz appear to represent today's best capabilities.

The splitting of the emitter into a geometry with a lot of edges for a given area provides the basic RF transistor structure, but for higher power applications there are numerous improvements and variations. One of the most important improvements is the so-called BET (balanced emitter transistor) configuration that involves the deposition of a small, thin-film resistor at the end of each emitter finger, just ahead of the interconnecting metalization. The purpose of



Overlay Structure. Individual emitter cell blocks are diffused into a common base region. Emitter interconnection runs are made over a passivating silicon dioxide layer, reducing the need for critically thin interdigitated metal fingers.



Network Emitter Structure. This structure maximizes emitter periphery to base area ratio but pays for it with increased production difficulty and increased contact resistance.

Motorola employs a thin nichrome barrier (not shown) between the silicon and the aluminum metalization in most network emitter and overlay devices to prevent aluminum metal migration thus improving long-term reliability.

RELATIVE CHARACTERISTICS OF RF STRUCTURES

GEOMETRY	ADVANTAGES	LIMITATIONS
Interdigitated	High emitter periphery to base-area ratio. (≈7.0). Low r_b'. Adequate manufacturing experience. Easily balanced with emitter resistors.	Processing critical due to narrow interdigitated fingers. Limited to relatively low currents due to narrow metal stripes.
Overlay	Wider fingers for higher current capability. Reduced manufacturing difficulty.	Higher r_b' and considerable emitter-base parasitic capacitance limits high-frequency response. Relatively low P/A ratio, (≈4.0). Emitter balancing difficult.
Network Emitter	Wide metal fingers. Highest P/A ratio, (7.0 to 8.0).	High contact resistance. Emitter balancing difficult. Processing critical.

TABLE I

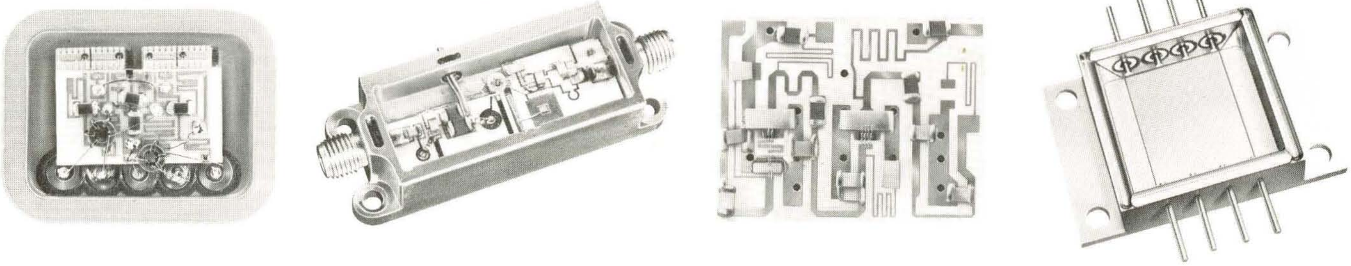
these resistors is to make sure that the total emitter current is essentially balanced between all emitter stripes. Should a chip develop a "hot spot," thereby causing some emitter stripes to conduct more heavily than others, the increased current flow through the emitter resistors so affected would set up a negative feedback, thus reducing the current through those emitters. As a result, the damaging phenomenon of "thermal runaway" can be prevented, and the safe-operating area of the transistor is greatly extended.

There are two additional high-frequency geometries coming into favor. Both of these are outcroppings of the interdigitated structure in that they utilize many small interconnected emitter segments to make up the total emitter. Their principal advantages over the interdigitated geometry are that they reduce manufacturing difficulties and improve current-handling capability by permitting increased metalization thickness and width. Typical specifications of devices made with these processes are listed in Table I. Performance wise, it should be emphasized that the available process can yield very similar electrical specifications. The choice, therefore, is up to the device designer, and depends on his evaluation of the best price/performance ratio for a given application.

The last words in high-power, high-frequency chip design have not yet been spoken. Already, the state-of-the-art structures shown here are being modified and improved. The result is that the frequency and power specifications which represent the present limits can be expected to be moved ahead as the need arises. Yet, from the standpoint of need, it is not clear that further significant chip processing improvements will be needed in the near future.

Typical of the trend toward modules is (a) this CATV amplifier being readied for imminent introduction, and the two custom power amplifier modules (b and c) operating in the UHF region. Hybrid technology, combining standard semiconductor processes with thin- and thick-film techniques, provide a high degree of flexibility. Except for a few high-volume categories, like CATV, modular technology is expected to become principally a custom business. A new 8-pin experimental power package for hybrid circuits (d) is indicative of a wide interest in this exploding technology.

(a) (b) (c) (d)



A Trend Toward Modules

If the previous statement seems contradictory to the philosophy of technological progress, consider the following:

Already, today's chips possess a power-frequency capability that satisfies the requirements of most high-volume applications, even in the UHF and microwave spectrums. And, the technology is pressing the theoretical limits of silicon. There is, therefore, no clear-cut mandate to push the state of the art much beyond what can already be achieved by nailing down and perfecting present capabilities — particularly at the high cost levels to be encountered as we approach the ultimate limit. But there is a strong mandate to take much of the "art" out of state-of-the-art, and to replace it with more predictable technology.

This is not surprising at frequencies where a wavelength is measured in inches and where the repositioning of a component by a few millimeters can spell the difference between success or failure of a circuit. Nor is it surprising, that, as frequencies increase, the difficulties and cost involved in developing a suitable chip housing, a package, are at least as high as those for improving the chip itself. That's why there's a trend today toward the development of hybrid modules that eliminate the deleterious effects of individual transistor packages and take full advantage of the chip's maximum capability.

The modular concept, by utilizing unencapsulated high-frequency transistors, eliminates the parasitic capacitance and inductance associated with the package and permits significantly better performance than can be achieved with the same transistor used in the conventional way.

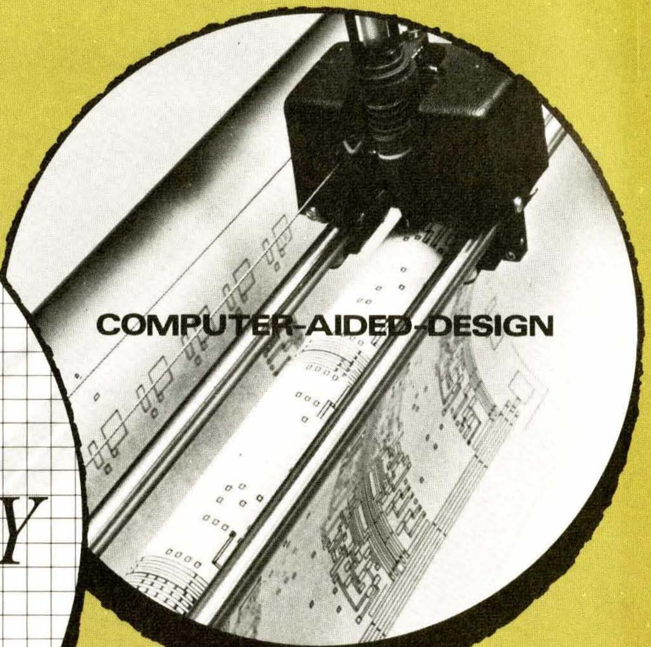
Periodically, in every age, men of vision have pondered the various situations and proclaimed that "Everything that can be invented, has already been invented." Invariably, to prove them wrong, such pronouncements have heralded a raft of new inventions which have dramatically advanced both technology and civilization. With regard to semiconductors for RF and microwave applications, while it is tempting to predict that there will be no startling breakthrough in the years ahead, history and a projected doubling of the potential market over the next five years just don't bear out such a contention. Nevertheless, the industry is faced with the everpresent question of whether there should first be a demonstrated need for greatly improved products, or whether the products should be developed first, in the hopes that the need for them would then materialize.

In the region beyond a gigahertz, that question is perhaps a bit easier to answer than for other categories — and for logical reasons:

1. Despite the fact that microwave components other than semiconductors are readily available, the use of microwaves has not expanded significantly over the years.
2. As frequency and power increase, the device cost increases as well, so that there appears to be little hope for creating large new markets through low-cost components.
3. The potential volume at these frequencies does not appear to be high enough at the projected device cost to predict process breakthroughs toward lower costs through a rapid traversal of the learning curve.

While there is little doubt that the need for improved reliability in special projects will continue to push the development of semiconductors into the microwave power region, it is not likely that technical advances into these new frontiers will be as rapid as they have in the past. It is far more likely that the efforts in the immediate future will be concentrated on getting the most out of already existing techniques. This will generate further performance improvements, to be sure, but it is likely that these improvements will come in the form of *high-performance modules*, rather than in any dramatic advance in discrete component capabilities.

A Strong Commitment to COMPLEMENTARY MOS



As digital equipment needs are studied, and logic lines are evaluated to meet these needs, an early commitment to Complementary MOS is likely to yield substantial rewards to both equipment and components manufacturers.

By *JIM GEORGE* and *BERNARD SCHMIDT*

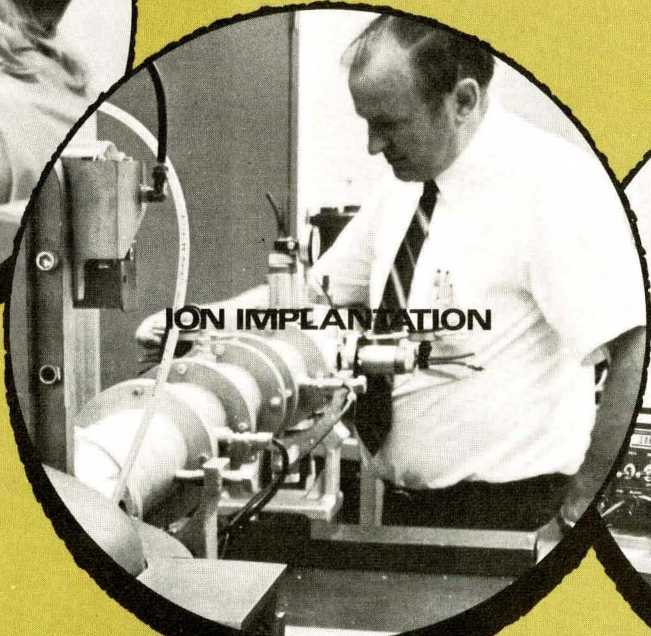


FIGURE 1 — The strength and diversity of Motorola's commitment to the production of complementary MOS is reflected here. The latest techniques of computer-aided design are coupled with completely modern diffusion facilities to produce Motorola CMOS devices. The latest technological breakthroughs, such as the ion-implantation depicted here, allow Motorola to pass along process savings to the customer. Critical in-process testing assures that all CMOS devices measure up to Motorola's high-quality standards.

The bulls and bears are at odds again. The dispute in this instance is not over market trends, it's over technology — Complementary MOS technology, to be specific — and the nature of the disagreement is not as much over direction as it is over magnitude and time. That is, while the wildly enthusiastic CMOS prognosticators predict a world-wide CMOS market of around $220 million by 1975, the far more conservative members of Motorola's market research department have it pared down to about $150 million in the same time frame.

The significant aspect of this controversy is, however, that even the least optimistic sales outlook still predicts a growth rate for complementary MOS technology that eclipses the previous most dynamic new-product lines in the explosive semiconductor industry.

Pragmatically, market analysts reason that:

To be *successful*, a new product line must be able to offer practical benefits that permit it to capture a significant share of an existing market.

To be *spectacularly* successful, it must, in addition, offer capabilities that permit it to tap large new markets that cannot otherwise be served. In both categories, complementary MOS could be cited almost as a textbook example.

History Projected

The winds of change deal devastatingly with products in high-technology areas, but nowhere as emphatically as in the digital logic field. Already, in little more than a decade of IC technology, two types of logic (RTL/DCTL and DTL) have captured the spotlight, and then succumbed to improved performance and lower cost of newer developments. Currently, transistor-transistor logic (TTL) is king of the hill, and though its use rate far exceeds that of previous logic favorites, Figure 2, and its growth is still on the ascent, experts are already predicting its decline in the next few years. Indeed, by 1976 the relatively new CMOS technology is expected to surpass TTL. So say the experts charged with market forecasting and development. Of total MOS technology (PMOS, NMOS, and CMOS), CMOS is expected to capture a third of the market.

The projected CMOS explosion is predicated on its unusual affinity for the twin requirements — existing-market penetration and new-market development.

To gain market penetration, it is aiming its sights directly at TTL, the heart of today's digital component lines. It is doing so with the promise of technical improvements that will result in greater versatility and lower cost.

Like TTL logic, complementary MOS is principally a medium-speed logic form. Though there are still differences in maximum-speed capabilities for the two, in the overlap region (the speed range where TTL usage is most prominent) the power dissipation of CMOS is substantially lower, in some areas by several orders of magnitude. This power reduction opens a number of applications advantages. For one thing, it permits the use of bigger chips, housing far more components, without running into thermal problems that attend bipolar MSI and LSI designs. For another, it simplifies portable equipment design and greatly reduces power source costs. For computer

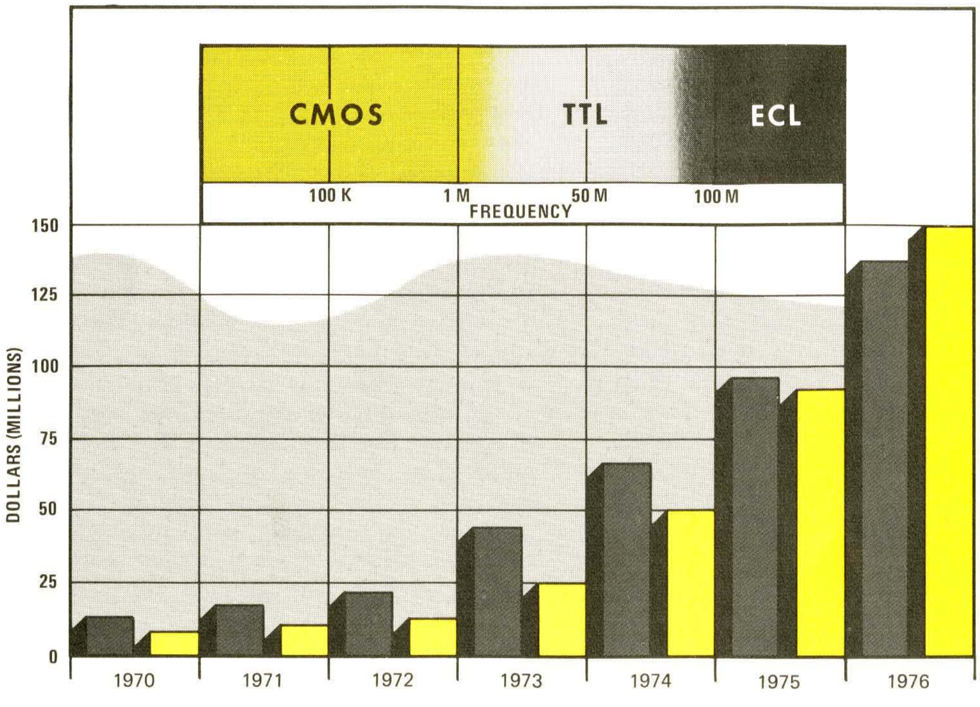


FIGURE 2 — The wide dominance of TTL in the digital logic field is being seriously threatened. As seen in the frequency graph at the top of the figure, both CMOS and ECL are pushing into areas previously covered by TTL. In the bar graph portion of the figure the erosion of TTL's market dominance is depicted. Here, within the half decade, both CMOS and ECL market dollars are projected to bypass TTL.

LEGEND

TTL ECL CMOS

PRODUCT LINE	1972 McMOS NEW PRODUCT CALENDAR			
AS OF END OF 1971	1ST QUARTER	2ND QUARTER	3RD QUARTER	4TH QUARTER
MC14001 Quad 2-Input NOR	**MC14015** Dual 4 Stage Static S/R	**MC14007** Dual Pair And Inverter	**MC14006** 18-Bit Shift Register	**MC14017** Decade Counter/Divider
MC14002 Dual 4-Input NOR	**MC14021** 8-Bit Static S/R	**MC14009** Hex Inverter/Buffer	**MC14008** Four-Bit Full Adder	**MC14034** 8-Bit Static Bus Register
MC14011 Quad 2-Input NAND	**MC14027** Dual J/K F/F	**MC14010** Hex Buffer	**MC14016** Quad Analog Switch	**MC14511** BCD-to-7 Segment Latch/ Decoder/Driver
MC14012 Dual 4-Input NAND	**MC14501** Triple Gate	**MC14023** Triple Three NAND	**MC14028** BCD/Decimal Decoder	**MC14517** Dual 64-Bit Static S/R
MC14013 Dual Type D F/F	**MC14508** Dual 4-Bit Latch	**MC14025** Triple Three NOR	**MC14032** Triple Full Adder (Positive)	**MC14528** Dual Monostable Multivibrator
MC14507 Quad Exclusive OR	**MC14514** 4-Bit Latch, 4/16 Line Decoder (High)	**MC14510** BCD Up/Down Counter	**MC14040** 12-Bit Binary Counter	**MC14529** Dual 4-Channel Analog Data Selector
MCM14505 64-Bit RAM	**MC14515** 4-Bit Latch, 4/16 Line Decoder (Low)	**MC14512** 8-Channel Data Selector	**MC14502** Strobed Hex Inverter	**MC14530** Dual Majority Logic Gate
	MC14518 Dual BCD Up Counter	**MC14516** Binary Up/Down Counter	**MC14506** Expandable A.O.I.	**MC14531** 12-Bit Parity Tree
	MC14519 4-Bit AND/OR Select	**MC14522** Programmable BCD Divide-by-N 4-Bit Counter	**MC14527** BCD Rate Multiplier	**MC14581** ALU (74181 Type)
	MC14520 Dual Binary Up Counter	**MC14526** Programmable Binary Divide-by-N 4-Bit Counter		**MC14582** Look Ahead Carry Block

INTRODUCED

Table I. Available Motorola CMOS devices, as well as the rest of this year's product introductions are given here. Those devices presently available provide the logic designer with the initial logic tools needed for low-power CMOS circuit design. Subsequent devices to be introduced throughout 1972 will add to the range and flexibility of devices for more complex circuit designs.

Denotes proprietary devices

memories it enhances non-volatile designs, and for mobile equipment it significantly increases the proportion of electronics that can be used with a convenient power supply.

And there are other advantages, too, that make CMOS a most desirable logic form. It can operate over a power-supply range from less than 1 volt to 18 volts, with extremely high noise immunity at the higher power-supply voltages. Unlike other MOS lines, it demands only a single-polarity power source; and, in general, it has all the attributes that will make its consideration for new system designs a virtual mandate.

But it's in the area of totally new markets that CMOS has its greatest potential. In fact, CMOS represents the first stepping stone toward the implementation of electronics in the vast consumer market where present penetration is limited primarily to the entertainment field.

The first concrete example of this is the electronic timepiece market which is already well into the production phase. How can electronics help time keeping? It can bring to the ordinary wristwatch or clock an accuracy comparable with that of today's secondary time standards. It can provide reliability and trouble-free performance that comes from replacing the multitude of mechanical gears, springs, and bearings with an all-electronic movement with very few failure or wearout mechanisms. And it can do so, at a cost that can rival that of watches now sold to the mass markets as early as 1975.

The key to this market is low-voltage, low-power electronics. *Electronics that can operate on a single voltage cell. Circuits that will draw so little current that a pea-sized power cell will last a year without replacement. Components with so much built-in stability that changes in environment and operating conditions don't even need to be considered.* And, to date, CMOS circuitry is leading the way into this arena.

Similar considerations are valid for the automotive industry which, in the next few years, must undergo a radical change with respect to performance and safety. Electronics, which hardly participates in today's automotive operation, will become a major battery drain problem in the next few years. Again CMOS represents the logical answer. And it takes only a little imagination to anticipate the phenomenal impact that can be created by a low power, high-complexity, low-cost line of electronic circuits. That's why Motorola has mounted a heretofore unequalled commitment to the development of a single technology — to move the technology from pilot line to production — to provide for unshared development time to assure an ever-increasing flow of McMOS* products for the emerging markets.

Motorola's commitment to McMOS encompasses all aspects of product development, from product planning to volume production.

In the area of product planning, the needs of various market segments are being carefully and rigorously explored. Special McMOS marketing task forces are investigating the industry's needs for the computer, consumer, industrial, and federal markets. Corresponding technical teams are researching and implementing the broadest

**McMOS is Motorola's trademark for its complementary MOS circuit lines.*

McMOS FAMILY ELECTRICAL SPECIFICATIONS

PARAMETER (T = 25°C)		SYMBOL	SERIES AL Typ	AL Min/Max	SERIES CL Typ	CL Min/Max	UNITS
1. Operating Temperature		T_A	-55 to +125		-40 to +85		°C
2. Storage Temperature		T_{stg}	-65 to +150		-65 to +150		°C
3. Power Supply Range		V_{DD}	3 to 18		3 to 16		Vdc
4. Input Capacitance		C_{in}	5.0		5.0		pF
5. Output Voltage							
"1" Level		V_{OH}	V_{DD} -0.01		V_{DD} -0.01		Vdc
"0" Level		V_{OL}	V_{SS} +0.01		V_{SS} +0.01		Vdc
6. Input Current		I_{in}	10		10		pAdc
7. Immunity to External Noise							
"1" Level		V_{NH}	⩾ 30% V_{DD}		⩾ 30% V_{DD}		Vdc
"0" Level		V_{NL}	⩾ 30% V_{DD}		⩾ 30% V_{DD}		Vdc
			Typ	Min/Max	Typ	Min/Max	
8. Output Drive Current		I_{OD}					mAdc
I"Source"	V_{DD} = 5.0 Vdc, V_{out} = 2.5 Vdc		-1.5	-0.5	-1.5	-0.2	
	= 10 Vdc, = 9.5 Vdc		-1.0	-0.5	-1.0	-0.2	
I"Sink"	V_{DD} = 5.0 Vdc, V_{out} = 0.4 Vdc		0.8	0.4	0.8	0.2	
	10 Vdc, = 0.5 Vdc		1.2	0.9	1.2	0.5	
9. Quiescent Power Dissipation		P_D					µW
Gates	V_{DD} = 5.0 Vdc		0.005	0.25	0.025	2.5	
	= 10 Vdc		0.01	1.0	0.05	10.0	
Dual Flip-Flops	V_{DD} = 5.0 Vdc		0.025	5.0	0.05	50	
	= 10 Vdc		0.05	20.0	0.2	200	
SWITCHING PARAMETERS (C_L = 15 pF)							
10. Output Rise Time and Fall Time (10-90%)		t_r, t_f					ns
	V_{DD} = 5.0 Vdc		100	175	100	200	
	= 10 Vdc		35	75	35	110	
11. Propagation Delay Gate (50%)							ns
Turn-Off		t_{PLH}	60	75	60	100	
Turn-On		t_{PHL}	25	50	25	160	
12. Clock Repetition Rates		PRF					MHz
Flip-Flops	V_{DD} = 5.0 Vdc		4.0	3.0	4.0	2.5	
	10 Vdc		10	7.0	10	5.0	
Counters / Registers	V_{DD} = 5.0 Vdc		3.0	1.5	3.0	1.0	
	10 Vdc		5.0	3.0	5.0	2.0	

High noise immunity especially desirable in industrial and commercial system design.

Lower power dissipation opens the door to a wide range of portable and/or remote area applications.

Table II. Electrical parameters show the family concept behind Motorola's CMOS devices. Gates, counters and registers are provided with consistent specifications so that they can be mixed or matched as required. Uniform specification of critical parameters eliminates the usual, lengthy part-by-part referencing to data sheets during system design.

variety of processing innovations. In this way, a product line is being planned with a parts line-up that reflects the existing demand for specific popular devices, as well as for devices that must become available to permit the customer to fill his total system requirements with McMOS. The key point is the major emphasis being placed on defining complex functions which effectively utilize McMOS's ability to pack large numbers of devices on the traditionally limited silicon real estate.

In the design field, a group of well-trained circuit and process specialists has been assembled to convert the marketing plan into a market reality. This team of specialists is exclusively McMOS; with no responsibility for other product lines. Its charter is to marry the circuit requirements with the processing capabilities to create the most efficient designs for optimum performance at the highest yields. One of the industry's largest and most modern computer-aided design and test facilities, supplemented by an experienced team of layout draftsmen give McMOS requirements their highest priorities.

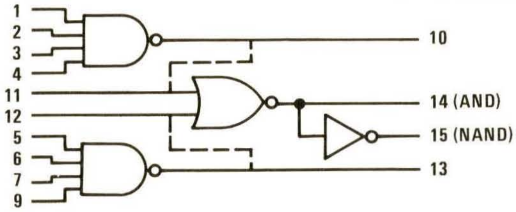
Then there's production. Within a single year, Motorola has expanded its McMOS production capabilities from a trickle to a potential flood. A new wafer processing facility, encompassing the most modern equipment, has been assembled for this purpose. Staffed by personnel devoted to production goals, this multi-shift area has been planned to expand in accordance with the anticipated McMOS growth timetable.

Testing is a key consideration. Motorola's commitment to McMOS includes advanced final-test equipment capable of automatic handling to lower production cost. But more important, the facility performs 100% ac and dc testing to extremely high resolution. In this way, the user is assured that his requirements are satisfied to the highest degree of accuracy.

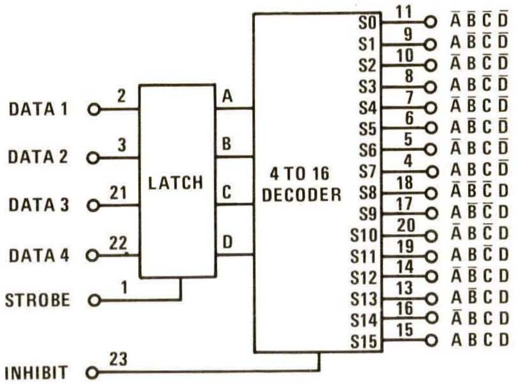
The Trickle . . .

Motorola entered the year 1972 with seven McMOS standard products, Table I, and two production processes. All of the standard products were made with the aluminum-gate process which yields 3-to-18 volt devices, and all but two of these were designed to second-source similar units already on the market. The remaining two standard products, a 64-bit Random Access Memory and a Quad Exclusive OR Gate, had been developed as sole-source items on the basis of customer need. This modest beginning is projected into an ambitious flow of new standard products already being introduced in 1972. For it is fully realized that, to be successful, the device line must be expanded to provide the widest possible choice to the designer who must match his system requirements against available logic functions.

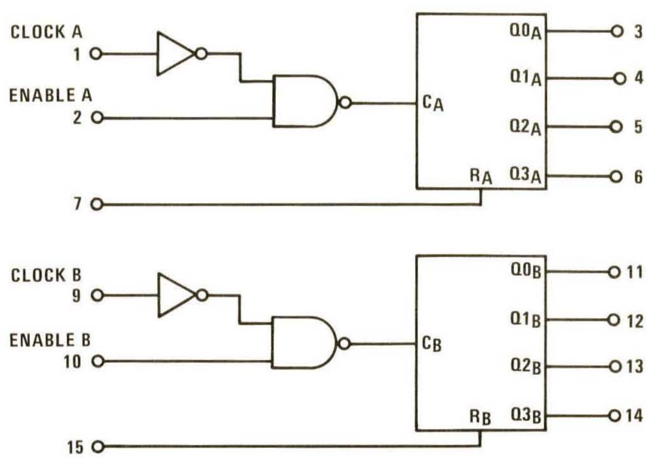
The second McMOS production process is a silicon-gate process which is capable of producing very low device thresholds in the below one volt area. This process, so far, has been adopted principally for the production of electronic watch circuits on a custom basis, in order to achieve the lowest possible power dissipation. But, since silicon-gate processes can also be used to increase circuit speed, it is expected to enter the standard-parts category around the end of the year.



MC14501 Triple Gate. Versatility is the keyword for this logic device. Both a 2-input NOR/Invert gate and two, 4-input NAND gates are made available in a single package. With an external connection the circuit can provide 2-, 3-, or 4-input AND gating.



MC14514/MC14515 4-Bit Latch/4 to 16 Line Decoder. These devices provide temporary storage of binary weighted input control information. They also provide one-of-sixteen mutually exclusive active outputs. The MC14514 gives a decoded, active high level output while its companion circuit, the MC14515, provides an active low level output.



CLOCK	ENABLE	RESET	ACTION
_/¯	1	0	INCREMENT COUNTER
0	¯_	0	INCREMENT COUNTER
¯_	X	0	NO CHANGE
X	_/¯	0	NO CHANGE
_/¯	0	0	NO CHANGE
1	¯_	0	NO CHANGE
X	X	1	Q0 THRU Q3 = 0

X = DON'T CARE

MC14518/MC14520 Dual Up Counters. Both of these devices provide two identical, independent, internally synchronous counters. The MC14518 provides a dual BCD up counter function and the MC14520, a dual 4-bit binary counter function. A clock inhibit structure allows multistage cascading, or ripple counting. The actual counter stages are Type D flip-flops with interchangeable clock and enable lines for incrementing on either the positive-going or the negative-going transitions of a clock pulse input.

A SAMPLING OF MOTOROLA

The Start of the Flood . . .

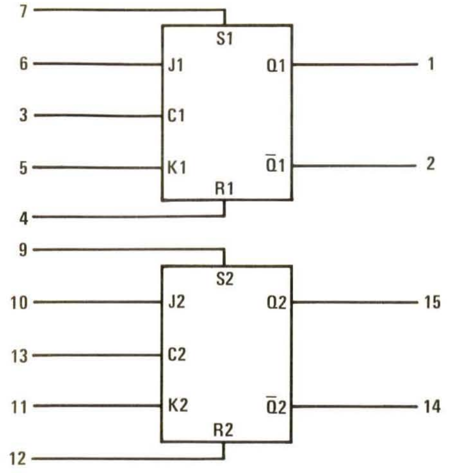
To compete with other forms of standard digital logic in both new and existing markets, a product line must have a critical number of off-the-shelf available items. This year, by coupling a rigorous market survey program with in-house expertise and a full production commitment, Motorola's McMOS product line is expected to achieve "critical mass" status. Already, 40 general-purpose digital building blocks have been defined and scheduled into the 1972 calendar. Some of these, the 14000 series, are intended to expand the availability of functions that have already found wide acceptance on the marketplace. Others, the 14500 series, represent previously unavailable logic functions scheduled as the initial results from market research, and these are expected to be only the stones that start the avalanche toward greater circuit complexity and expanded performance limits in the years ahead.

New for '72

Of the 40 McMOS circuits definitely scheduled for 1972 introduction at the time of this writing, (10 of these circuits have already been introduced) 23 represent new designs. Some of these, like the MC14501 triple-gate, are designed to round out a specific type of function in order to enhance design flexibility. Others, including counters, latches, and special functions, are designed to increase the availability of complex functions to permit the reduction of package count. All are based on inputs from industry and incorporate the most asked-for features.

A case in point is the triple gate. This device brings to the McMOS family both the NOR/NAND and the OR/AND function in a single package — a feature not often found in digital IC lines — and can easily be used for a large variety of gating needs. In its natural form, it provides two 4-input NAND gates and a 2-input positive logic OR/NOR function. By the simple expedient of interconnecting pins 10 and 11 (or 12 and 13), one can obtain a 4-input NAND gate and a 2-, 3-, or 4-input AND gate (by properly biasing some of the inputs of the AND gate). Finally, an up-to-8-input AND/NAND function can be generated by interconnecting pins 10 and 11, and pins 12 and 13.

Other members of the MC14500 series are



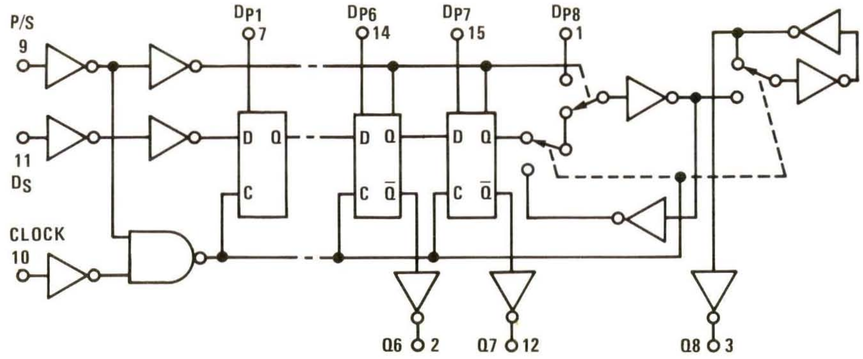
SYNCHRONOUS

J	K	Q	$\bar{Q}_{n+1}$
0	0	Q	Q_n
1	0	0	1
1	0	1	1
0	1	0	0
0	1	1	0
1	1	0	1
1	1	1	0

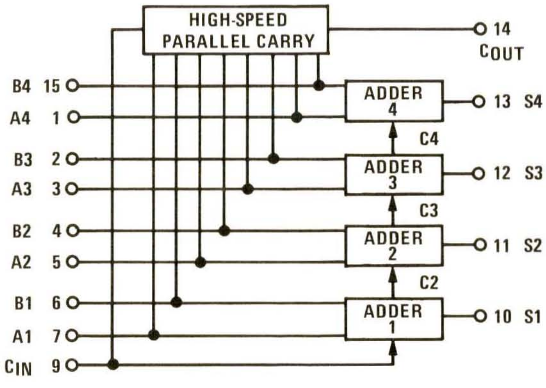
ASYNCHRONOUS

R	S	Q	$\bar{Q}$
1	0	0	1
0	1	1	0
1	1	1	1

MC14027 Dual J-K Flip-Flop. In this dual circuit, each flip-flop has independent J, K, Clock, Set, and Reset inputs. Typical applications for these flip-flops include control, register, or toggle functions where the inherent CMOS low power dissipation offers a system design advantage.



MC14021 8-Bit Static Shift Register. This 8-bit register finds primary use in applications such as parallel to serial data conversion, and asynchronous parallel input/serial output data queueing. The outputs may be fed back through exclusive OR gates to generate a non-linear, or random, sequence.



MC14008 4-Bit Full Adder. This part offers a fast internal look-ahead carry for high speed operation in arithmetic circuitry. Four buffered-sum outputs are provided along with an adder-to-adder ripple carry, and a parallel look-ahead for interchip carry functions. Larger adder structures can be constructed from this basic adder, i.e., if a 16-bit structure is required, four MC14008's can be wired together.

CMOS DEVICES FOR 1972

equally functional*. The silicon gate MC14502 *Strobed Hex Inverter* features 3-State output for direct interface with standard TTL functions over the full −55°C to +125°C operating range when using a single 5-Volt power supply. A set of six dual 4-bit counters offers both binary-coded-decimal and hexidecimal coding UP counters, UP/DOWN counters, and Programmable Divide-by-N counters. There are even some very unique functions, like the MC15427 BCD Rate Multiplier which multiplies an input frequency by a fractional number determined by four control inputs.

Electrical Characteristics

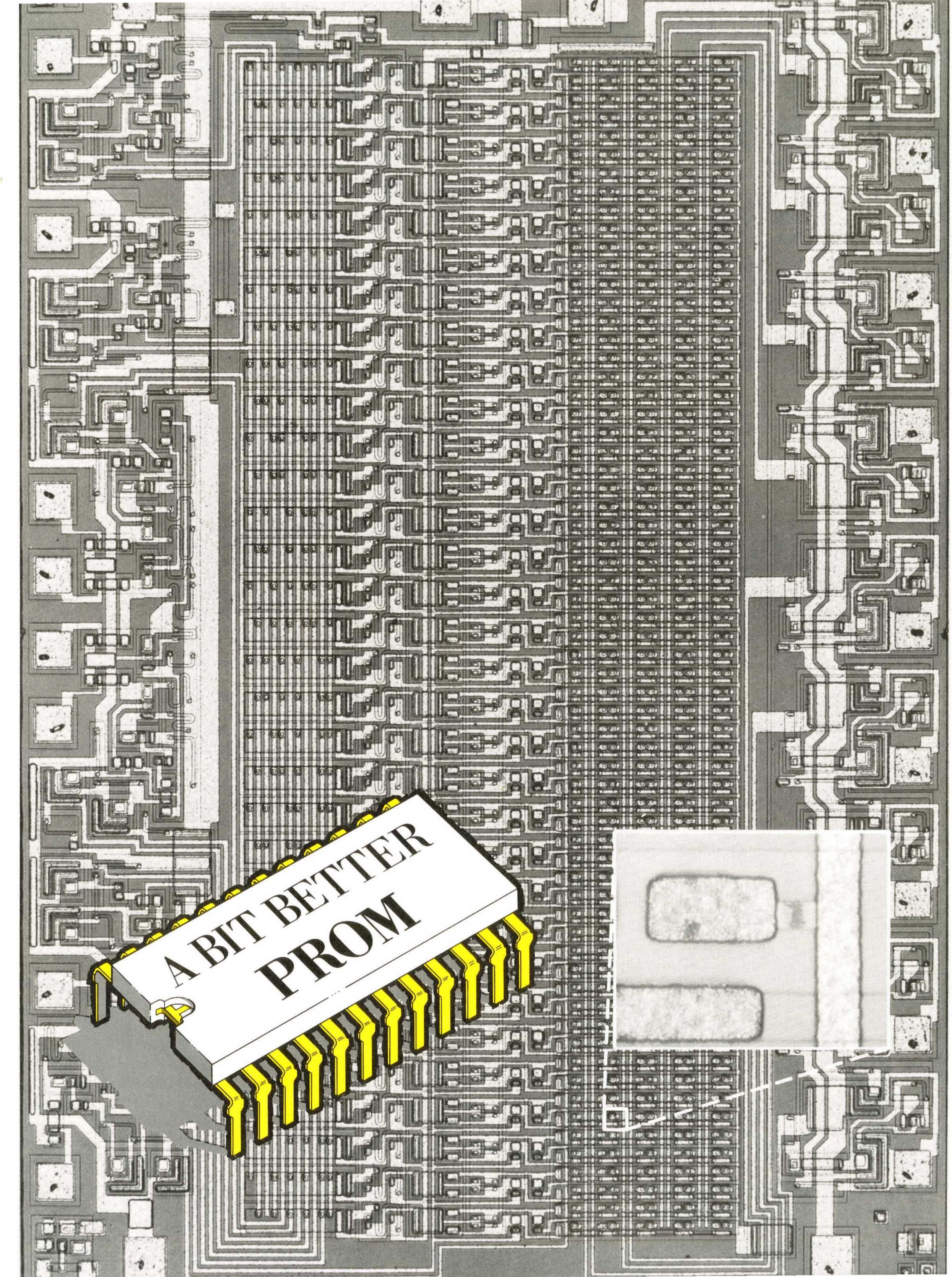
In the design and development of all McMOS devices, particular attention is given to achieving unified, family-oriented electrical specifications. Unlike other available CMOS logic families, where device characteristics such as output drive currents and propagation delays may vary from one device to another (even for the same kinds of functions, i.e., gates, flip-flops, counters, etc.) all similar McMOS functions have common performance characteristics, see Table II. That is, the driving capability and speed for one type of gate are the same as for all other gates at a specific voltage and temperature. This greatly simplifies system design calculations.

Moreover, McMOS system building blocks have consistent input-out specifications, thereby simplifying interfacing with other logic forms. For example, the typical capacitance of every McMOS device input is 5 pF. On complex functions, additional circuitry is added on-chip to maintain the same fan-in characteristics as for simpler units. All functions also have the same excellent immunity to external noise. Regardless of logic levels, noise voltages up to 30% of the power supply voltage will be rejected.

This designed-in standardization philosophy virtually eliminates part-by-part idiosyncrasies and frees the McMOS component user from the traditional ns, μA, specsmanship game.

In today's fast moving electronic environment, timing plays a major part in determining the success of a new product or a new technology. When a market is ready to accept a new technology as viable, the successful company will concentrate its resources and move with single-minded purpose toward establishing a comprehensive capability. For McMOS, Motorola feels the time is *now*.

**For a more detailed discussion of scheduled McMOS functions, send for the brochure "McMOS 72." While the discussion of these parts does not constitute a guarantee that all parts will be available exactly as planned, the calendar is on target to date and there is a high degree of confidence that future introductions will adhere closely to the schedule.*


A BIT BETTER
PROM

Programmable Read Only Memories are becoming increasingly important in digital system design. A new twist, an added test bit, gives the Motorola MCM5003/MCM5004 PROM a unique pre-use test capability.

By John Linford, Section Manager, Bipolar Memory Design

Until recently, Read Only Memories (ROMs) served as good topics for exposition in technical articles and papers, but generated a less than spectacular dollar volume in sales. This was due to the fact that the number of logic bits available on a semiconductor chip had been too low, at prices too high, to compete with existing magnetic techniques. As late as 1965, only 4 to 8 bits of information could be stored per semiconductor chip. But now ROMs are beginning to receive wider acceptance due to recent advances that have changed economic perspectives.

A major reason for increased usage of semiconductor ROMs stems from an increase in availability of more complex devices at lower prices. Advances in both MOS and bipolar technologies have provided complex structures with as many as 1024 bits per chip on an off-the-shelf basis, and up to 8192 bits per chip as the newest state-of-the-art capability. This availability at last gives the system designer the large, fast semiconductor ROMs needed for microprogramming.

Enter the PROM

With expanding ROM usage has come the need for greater versatility in programmability in less time. The field programmable read only memory has stepped in to fill that need. The ability to program a ROM at the customer's premise not only eliminates possible expensive mask changes, but has also done away with the usual four to eight weeks turn-around time required to obtain a new ROM program. Now, turn-around time for special application ROMs has been reduced, literally, to minutes. This provides increased flexibility in making product design changes and modifications.

Programmable ROMs also affect the spare parts stocking situation. Keeping on hand many different ROMs that might be needed in the development of a computer system could be a formidable problem. Using programmable ROMs eases the situation considerably. A single device type and a programmer are all that are needed for many different custom ROM applications.

True, field programming of a ROM wasn't meant to compete with vendor ROM production on large quantity runs. Some circuits such as code converters, character generators, look-up tables, keyboard encoders, and some microprograms are off-the-shelf items at relatively low cost. That should be looked into first. But for special custom program applications, versatility makes the PROM a valuable tool in system design.

Both bipolar and MOS technologies are used to manufacture PROMs. The bipolar approach used in the PROM discussed here provides both a high-speed access time of 75 ns, and a new concept in flexibility. This device, the MCM5003/MCM5004 512-bit PROM, adds a bit extra to conventional field programmable memory design.

How it Works

The Motorola MCM5003/MCM5004 (64 x 8 bit) programmable read only memory is a bipolar device with nichrome resistors as fusible links in a memory array. The nichrome resistor links are between the decoding word drivers and output buffers (see Figure 1). The PROM is manufactured with all fusible-link resistors intact,

BINARY WORD ADDRESS						PROGRAMMED BCD WORD OUTPUT							
A5	A4	A3	A2	A1	A0	B7	B6	B5	B4	B3	B2	B1	B0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	0	0	0	0	0	0	0	1
0	0	0	0	1	0	0	0	0	0	0	0	1	0
0	0	0	0	1	1	0	0	0	0	0	0	1	1
0	0	0	1	0	0	0	0	0	0	0	1	0	0
0	0	0	1	0	1	0	0	0	0	1	0	0	0
0	0	0	1	1	0	0	0	0	0	1	0	0	1
0	0	0	1	1	1	0	0	0	0	1	0	1	0
0	0	1	0	0	0	0	0	0	0	1	0	1	1
0	0	1	0	0	1	0	0	0	0	1	1	0	0

TABLE I. POSSIBLE PROM CODE CONVERSION PROGRAM
(binary address input for BCD output)

representing the logic 0 state for all cells. To obtain a logic 1 output for a particular cell, it is necessary to open its corresponding nichrome resistor element.

The following functional description of the PROM refers to Figure 1. Six address lines (A0 through A5) are used to select 1 of 64 binary coded words. The memory array consists of 64 words by 9 bits. The customer normally uses only 8 bits of the 9 bits available in each word for in-system memory functions since many codes such as ASC II-8 and EBCDIC-8 require 8 bits per character. The 8-bit words appear on outputs B0 through B7.

The PROM has two chip enables (CE1 and CE2) which are ANDed together internally. Both chip enables must be high to enable the selection of 1 or 64 words (W0 through W63) in the memory array. The MCM5003 has open collector outputs while the MCM5004 has 2 kilohm pull-up resistors on the outputs.

A possible PROM program for code conversion, Binary to BCD, is shown in Table I. The binary word address selects the proper BCD word bits for output.

Memory Array and Programming

As seen in Figure 2, a typical memory array consists of nichrome resistors R0, 0 through R63, 7. (Circuitry in the shaded area of Figure 2 is a ninth bit that has been added for testing purposes, and will be discussed later.) Each nichrome resistor has a nominal value of 150 ohms. Vacuum deposition techniques are used to deposit these thin film nichrome resistors on a planar surface to ensure uniform thickness (see Figure 3).

The MCM5003/MCM5004 PROM provides additional programming circuitry to make certain that enough current gain is available to open, or blow, memory links (see Figure 4). To program a logic 1 into a memory location, at R0, 0 for example; the proper bit output line, B0 in this case, is connected to —6.0 volts. This causes the associated transistor in the program circuitry to turn on, allowing fuse current to flow through the nichrome resistor R0, 0. It takes 25 to 35 mA of current to open a nichrome link. During this programming time the sense amplifier circuitry is turned off. The circuit technique described above results in a high ratio of programming current to operating current in order to ensure that the nichrome resistor does not program during normal operation.

A Problem

One major problem faces the engineer when he receives an unprogrammed PROM. That is how can he test the device before he inserts his program? How can the new PROM be tested for

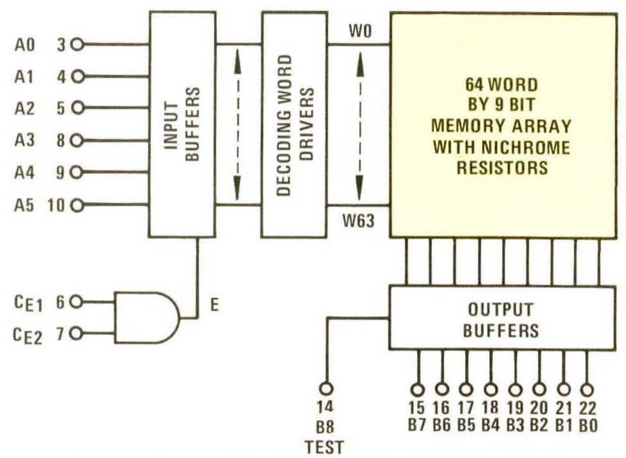


FIGURE 1 — BLOCK DIAGRAM OF THE MCM5003/MCM5004 512-Bit PROM. Before programming, all output bits are in the logic 0 state. This means that all of the nichrome resistors situated between the output buffers and decoding word drivers are unopened.

programmability? How can read-out time to an actual address be tested? It turns out, that for most available PROMs, this can't be done.

The problem can be seen more readily by returning to Figure 2. The decoder driver selects and drives a single word line. Current then flows through all of the transistors connected to that word line. For example, word line 0 turns on Q0, 0 through Q0, 7. That same current flows through all of the unopened nichrome resistor links on that word line, R0, 0 — R0, 7, and provides base drive for the sense amplifiers QB, 0 through QB, 7. Note that with all of the nichrome resistors present, the output bits B0 through B7 will always read low, or logic 0.

If an address circuit or part of the decoders were defective, the fault possibly would not be detected. For example, if portions of the decoder word lines were shorted to each other the output buffers could still all read logic 0's just as if the PROM were operating properly.

This means that a significant portion of the PROM cannot be tested until an actual pattern is inserted into the memory array. For a field programmable ROM, the customer then, not the manufacturer, finds these defects. This is a problem common to many PROMs, but is now solved in Motorola's 512 bit PROM.

The Solution: An Extra Bit

Motorola's solution to the testing problem in PROMs is to add a ninth bit, B8 to all 64 of the usual 8-bit words (see the shaded area of Figure 2). The ninth bit is used during manufacturing final test to determine if decoding logic is operating properly. Approximately 16 of the 64 word

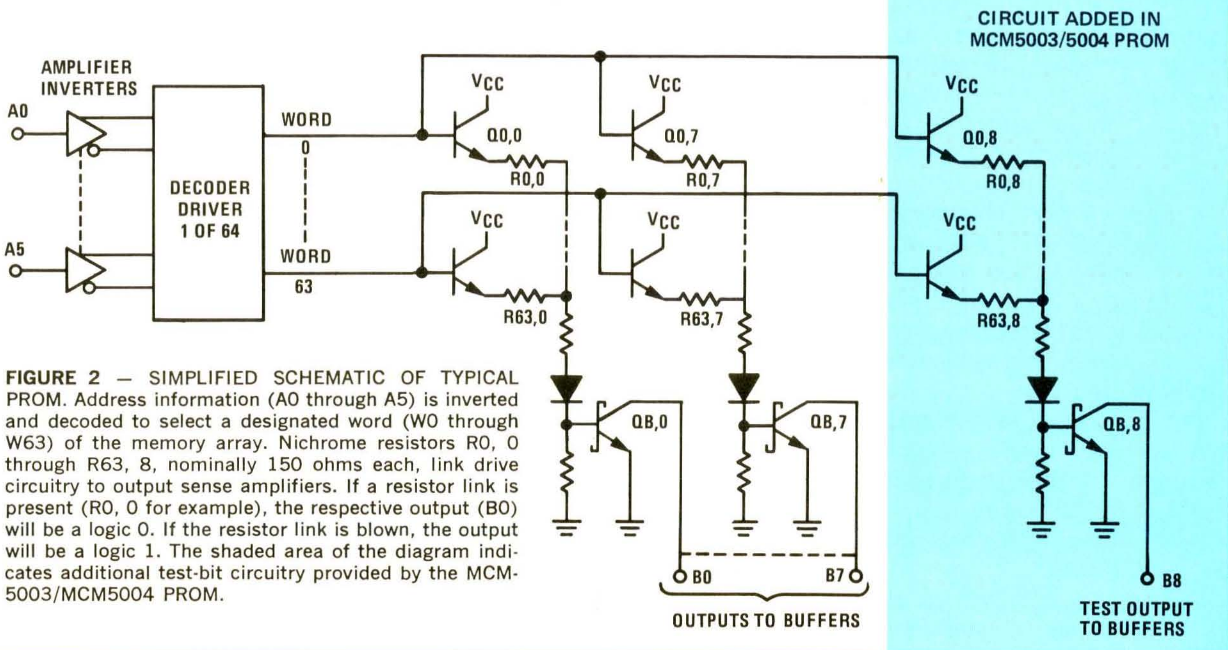


FIGURE 2 — SIMPLIFIED SCHEMATIC OF TYPICAL PROM. Address information (A0 through A5) is inverted and decoded to select a designated word (W0 through W63) of the memory array. Nichrome resistors R0, 0 through R63, 8, nominally 150 ohms each, link drive circuitry to output sense amplifiers. If a resistor link is present (R0, 0 for example), the respective output (B0) will be a logic 0. If the resistor link is blown, the output will be a logic 1. The shaded area of the diagram indicates additional test-bit circuitry provided by the MCM-5003/MCM5004 PROM.

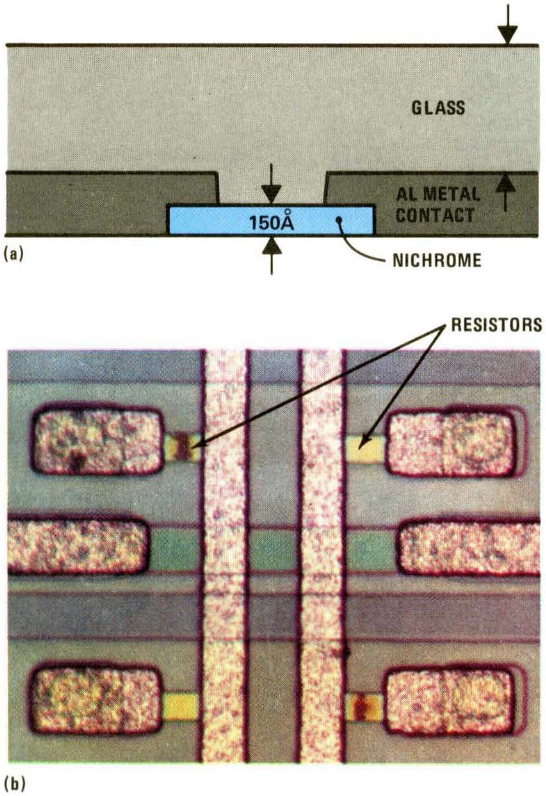


FIGURE 3 — NICHROME RESISTORS.
a) Profile of the nichrome-aluminum-glass layers.
b) Programmed resistors compared with unblown resistors.

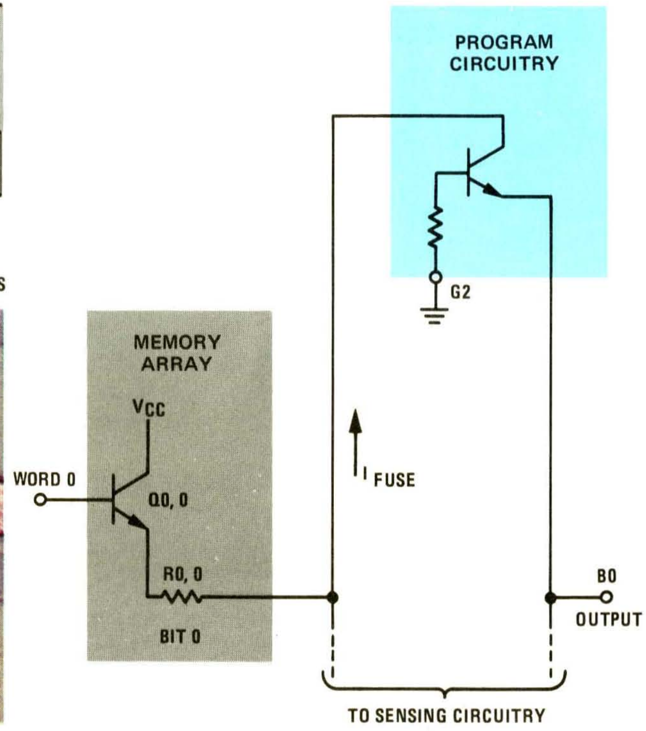


FIGURE 4 — PROGRAMMING ARRANGEMENT.
To program a logic 1 into Bit 0 of word 0, nichrome resistor link R0, 0 must be blown.

ninth bits are made with open links. The locations of these open links are chosen such that all of the amplifier inverters, and a portion of the decoders, can be tested during manufacturer wafer probe.

Then, 16 more of the ninth bits are opened by the manufacturer using a method similar to that which the customer would use. This in-house programming checks nichrome-resistor quality on the chip, while at the same time checking drive capability of the program circuitry and word drivers under actual operating conditions. Since all of the ninth bits are physically arranged on the chip to be in worst-case condition with regard to propagation delay, worst-case delay testing can also be done.

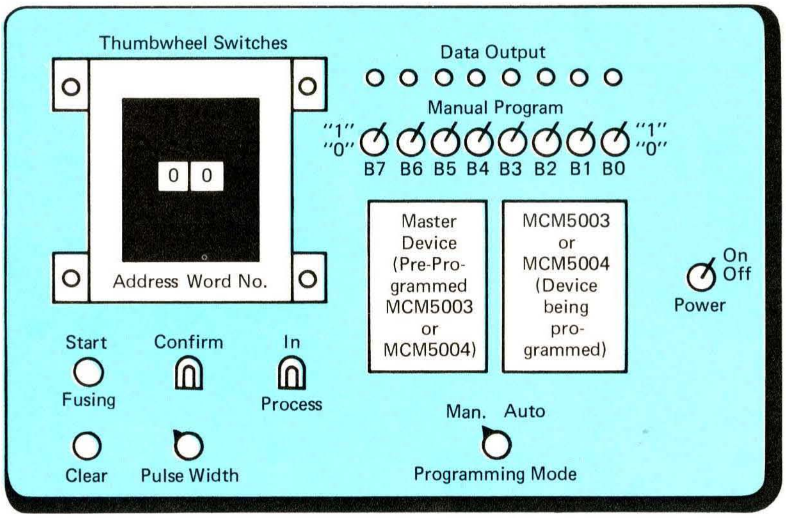
At this point, there are 32 of the ninth bit locations left unopened on the tested chip. The customer can now perform his own in-house testing prior to actual programming. These remaining 32 extra ninth bits allow him to test his programming circuitry both for logic capability and for power levels necessary to fuse the nichrome links.

Along with field programmable test bits, the logic levels of the MCM5003/MCM5004 PROM are compatible with all MDTL and MTTL families. This ease of interface offers wide applications possibilities.

The Next Step

A 1024-bit PROM currently being developed at Motorola also has additional bits on the chip to facilitate both manufacturer and customer pre-program testing. Its memory array is expanded from a typical 32 x 32 bit array to a 33 x 33 matrix.

When looking over the field of available PROMs, the designer should take a long look at the extra bit capability that provides for pre-program testing. It's the MCM5003/MCM5004 that provides a bit more testing versatility.



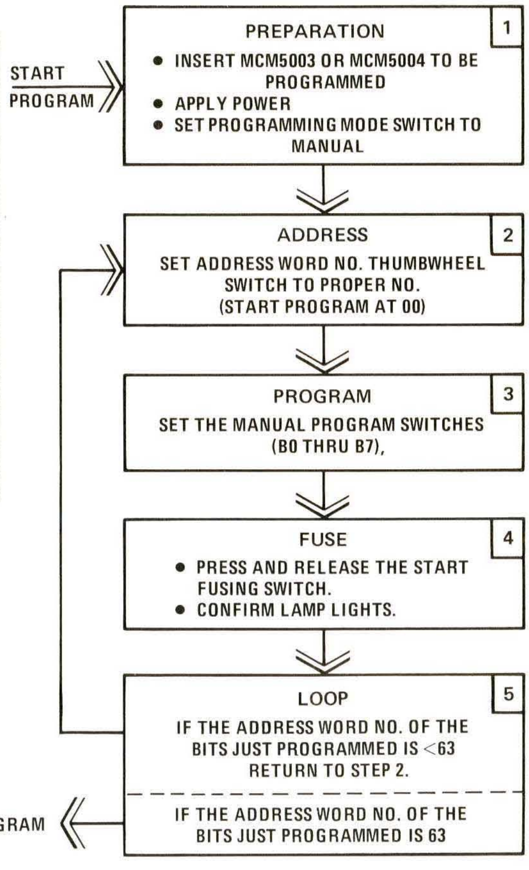


FIGURE 5 — PROGRAMMING THE MCM5003/MCM5004 PROM. A fusible link PROM, unlike some complicated and costly PROMs now on the market, is quickly and easily programmed. The programmer shown has a total of 13 integrated circuits.

An unprogrammed PROM is placed in the programming socket, and Address Word No. 00 is dialed into the programmer using the set of thumbwheel switches. This addresses the first word location inside the PROM. Then, the word bits to be entered into this first word location are set on the Manual Program switches B0 through B7. The Start Fusing switch is pressed to initiate programming; and, once the word has been entered, the Confirm lamp lights. The thumbwheel switch is set to 01 for the next word, and the same programming sequence is repeated until all 64 words have been programmed. Once programmed, the PROM provides non-destructible, read-only memory at fast semiconductor speeds.

If more than one PROM is to be programmed with the same pattern, additional devices can be programmed automatically. The already programmed device is moved over to the Master Device socket, and the Programming Mode switch is set to AUTO. The same sequence as above is followed, except that the most time consuming step of setting the MANUAL PROGRAM switches (step 3) is performed automatically by internal electronic switching. As many PROMs as are needed can be quickly programmed to the memory pattern initially stored in the Master Device.

If you would like complete schematics and more detailed programming information, write for Motorola Application Note AN-550, Programming the MCM5003/MCM5004 Programmable Read Only Memory.

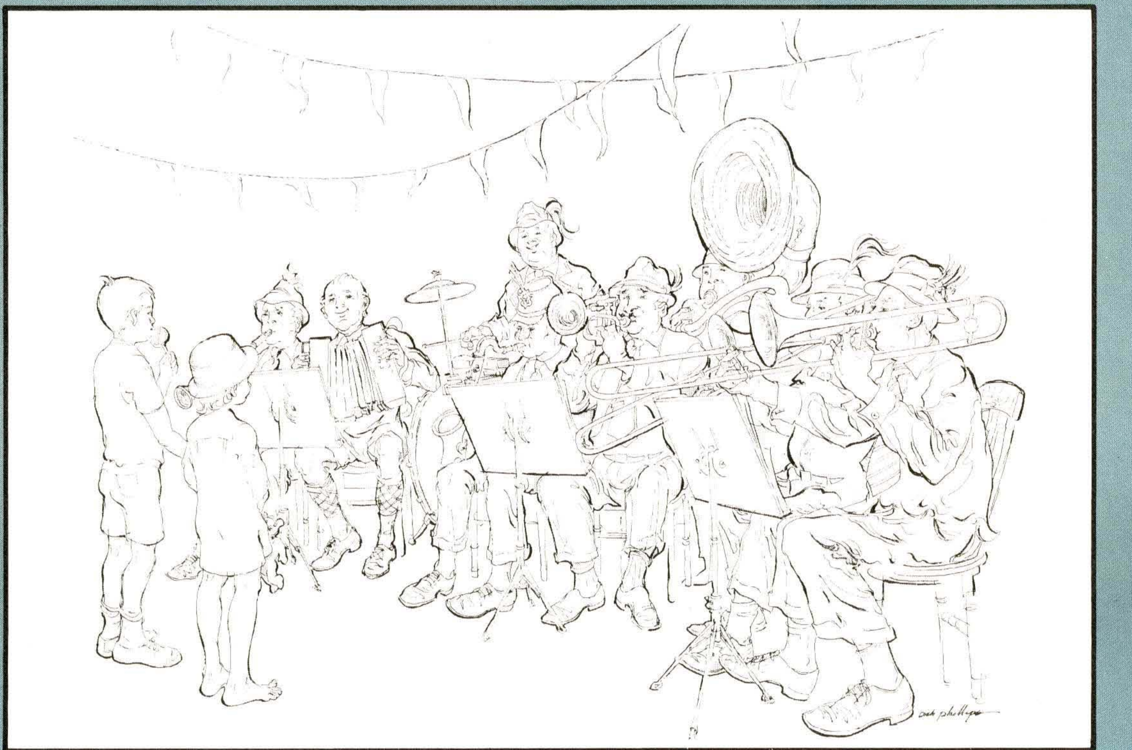
ARTISTLAND

"YOUNG PORCUPINE" 9" × 10" PEN AND INK
BY KENNETH MENHORN

Phoenix, Arizona is artistland.

The almost perpetual sunshine, the irresistible lure of easily accessible playgrounds, the most spectacular examples of nature's creations, the abundance of raw materials and stimulants all combine to arouse the urge toward creative expression. And, in Phoenix, expression takes many forms. On canvas and on film, with wood and in stone, with a hundred different methods and techniques Arizonans, both professional and amateur, apply their individual skills.

Shown on these pages are the works of some Motorola artists. For a few of these, art is a business. For most, it's a way of forgetting business – a recreation that's founded and fostered by the boundless perspective of the Arizona Territory.

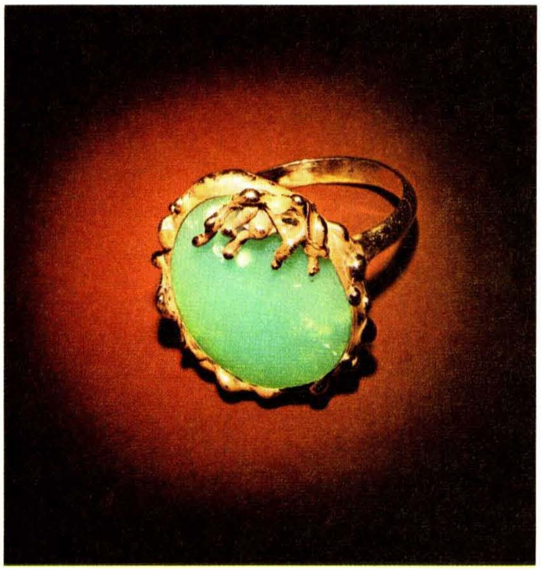


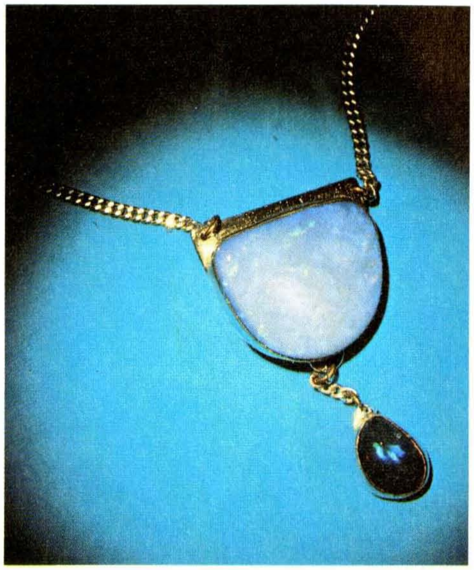
"HARRY'S GERMAN BAND" 15" × 20" PEN AND INK WITH WASH BY RICHARD PHILLIPS

JEWELRY BY JACK SADDLER

GREEN RING—CAST BY THE "LOST WAX" PROCESS IN 14 KARAT GOLD. SEMI-PRECIOUS STONE IS CHRYSOPRASE

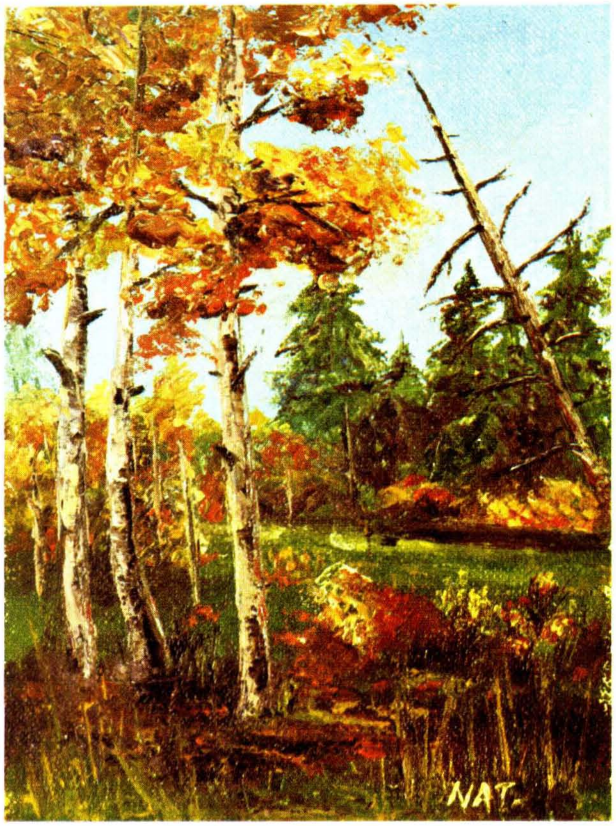
PENDANT—CREATED IN STERLING SILVER. THE OPAL STONES ARE CEMENTED ONTO BLACK JADE TO INTENSIFY THEIR BRILLIANCE





"THE HUNTING LODGE"
14" × 16" PEN AND COLORED INKS BY SHERMAN ROGERS

"HIGH COUNTRY"
5" × 7" OIL PAINTING
BY NATALIE CECIL



"ARIZONA WILDLIFE" LIFE SIZE SCULPTURES
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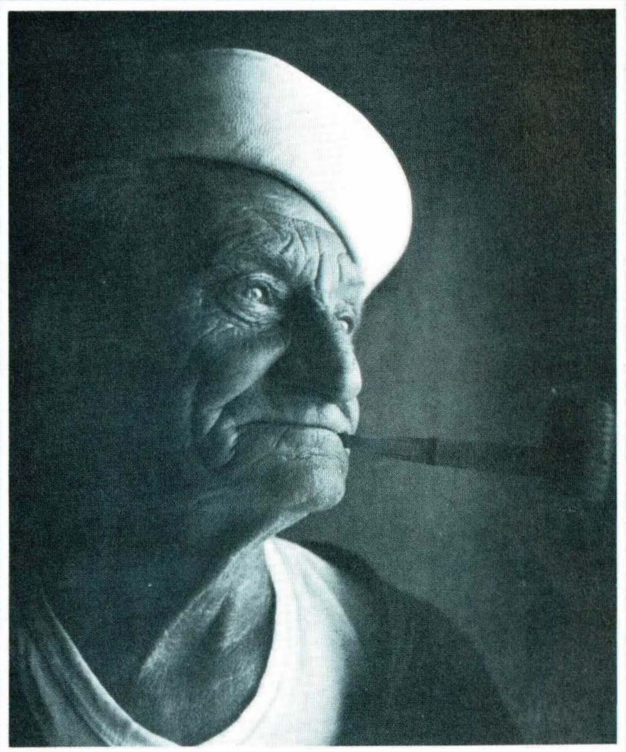
"SPOTTED CORN KACHINA DOLL" 10" × 20" WATER-COLOR BY JOSEPH M. LEONARD

"MUSHROOMS"
9" × 12" LINO-CUT
BY JOHN T. FITZGERALD

"LOSERS" 15" × 20" WASH AND LITHO-PENCIL
BY WILLIAM PREISS



"OLD SALT"
11" × 14" COLOR PHOTOGRAPH
BY EDWIN RITTERSHAUS

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The LOGICal Trend

It isn't really a trend anymore. The die has been cast and the decisions made. The mainframe computers now on the drawing boards for the next major introductions will have a balanced system with more "memory," *and with high-speed operational sections using emitter-coupled logic*. That's because T^2L logic, even Schottky T^2L, has run up against an inherent barrier that just plain can't reach the speed that the new machines require. Computer technology itself has resolved the controversy of high-speed saturated logic vs. current-mode logic in favor of ECL*. The only real remaining question is . . . *whose?*

In addition to the MECL I, II, and III product lines, there are two new ECL families vying for recognition today. These are the MECL 10,000 Series and the 9500 family. MECL 10,000, with a propagation delay of 2 ns, is ideal for the high-speed functions of new computers. And, its power dissipation of 25 mW/gate gives it a very favorable speed/power product.

The 9500 series specs are similar though it's slower and uses more power. But the main difference is that it has built-in output pull-down resistors where MECL 10,000 does not. That means that MECL 10,000 can be efficiently transmission-line matched where 9500 can't — and, from a lot of industry reports, that limitation all but knocks 9500 out of the running for mainframe computer designs (and from a lot of other designs, too, where its terminated outputs have severely curtailed flexibility). In fact, recent introduction of a limited number of parts for a new 95100 series modifies the 9500 line towards a MECL 10,000 orientation.

I don't want to get involved in a specsmanship game here. The specs are published and available to all for a detailed study. But I would like to make a few points that I think are of overriding importance.

One — MECL 10,000 has the largest repertoire of functions of any lines, and new, industry-researched functions are coming at a steady and rapid pace.

Two — Some major large-computer houses have already publicly committed to MECL 10,000 and *Motorola production is geared to handle volume requirements.*

Three — MECL 10,000 is compatible with ultra-high-speed MECL III (1 ns) providing the most powerful combination of speed and functional capabilities available for computer architectural concepts.

Four — A number of major semiconductor firms have recognized the merits of MECL 10,000 and we think it will become one of the most widely sourced logic lines available.

We're making available across-the-board application support to help you most effectively utilize the broad selection of MECL 10,000 functions.

Take advantage of it! We can tell you more about MECL than anyone in the industry. After all — **we invented it.**

Douglas Powell
Marketing Manager, Computers

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*Please don't misunderstand. TTL isn't dead! Lots of present computers will be retro-fitted with Schottky TTL for a "quick fix" toward higher speed. And they'll do a job. But they aren't designed to be competitive with the coming high-speed machines.

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