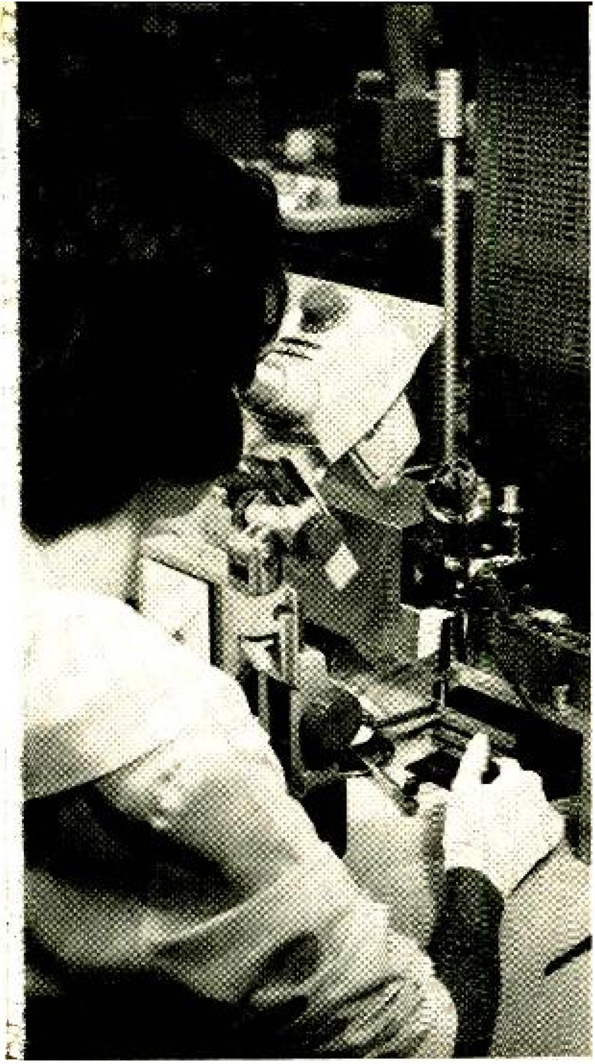


INTEGRATED

By DON LANCASTER

Testing integrated circuits is one of the costlier operations of the industry. Powerful semiautomatic optical instruments, such as the one shown at left, are used to inspect components a few thousandths of an inch thick. (Photo courtesy of Motorola)

THE MAGIC wand of microminiaturization has cast a spell on the electronics industry—a spell that will lead in the next few years to unheard-of new electronic devices and applications. Picture-on-the-wall TV, vehicular anticollision radars, home computer centers, portable electronic calculators smaller than a slide rule, precision controls for home appliances, person-to-person televiewers—these are but a few samples of the vast cornucopia of low-cost, high-reliability, and extremely small size electronic miracles that are to be ours in the very near future.

The components produced by this technology are called integrated circuits—or simply IC's. But just what *is* an integrated circuit? And why talk about IC's at all? Aren't they so expensive now that only the military can afford them, and so specialized that only computer specialists can use them? Not at all! Integrated circuits have become so cheap, reliable, and easy to use that most engineers consider it unwise to design new "ordinary" circuits with separate parts in applications where IC's can be used.

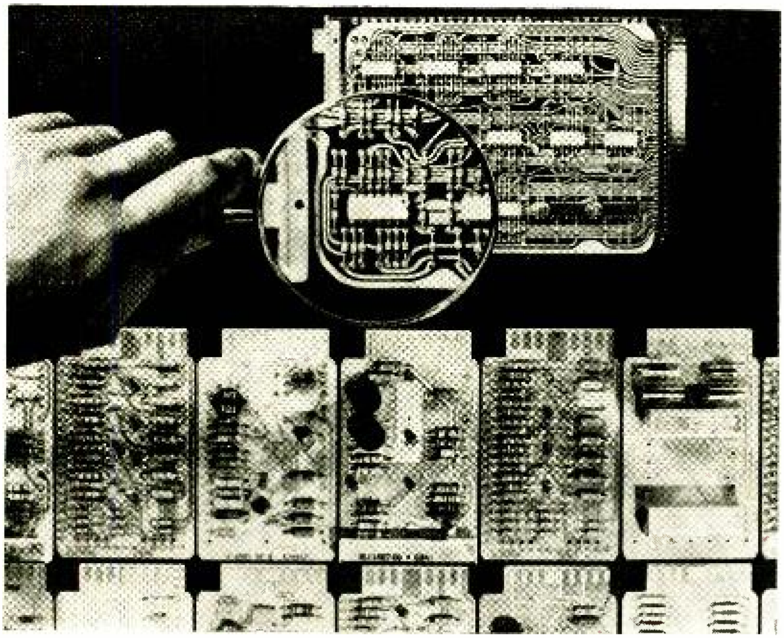
An Old Concept. Remember the 6SN7 radio tube? There must have been millions of them in use at one time or another. This tube is the octal-based dual triode that helped start the computer industry, served as a tone generator in electronic organs, and starred in the horizontal circuits of countless TV sets. The 6SN7's big advantage over its older counterparts was its two-for-the-price-of-one feature. Now two tubes occupied the space of one, and only one socket was needed. You saved two filament wires, four stripping operations, two solder joints, and lots of space. No longer did you talk of a single tube function, since *a system of devices and interconnections in a single compact package was now available.* And this is precisely what an integrated circuit is.

The 6SN7 was followed by the smaller 12AU7 and 12BH7, after which came the semiconductor devices with a new set of problems. The devices (transistors and diodes) got smaller and smaller while

CIRCUITS

THERE IS A BRIGHT FUTURE FOR A NEW TECHNOLOGY IN MOLECULAR ELECTRONICS THAT COULD MAKE POSSIBLE A NEW GENERATION OF PRODUCTS FOR INDUSTRY AND HOME

WHAT ARE THEY?



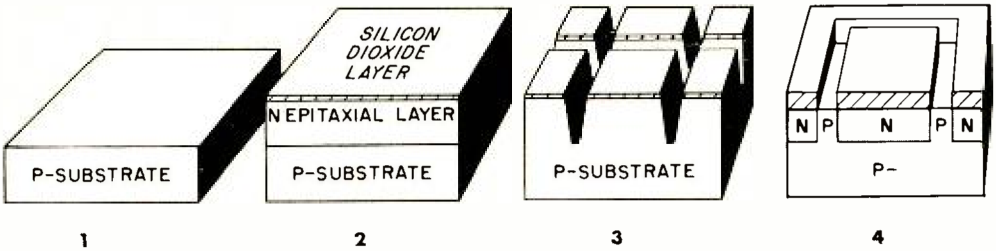
Monolithic integrated circuits, such as the one shown magnified above, are used in Sperry Rand's new UNIVAC 9000 series data processing systems. They perform the same functions as the large conventional printed circuit boards. One chip is the equivalent of 14 conventional printed circuit boards like the ones shown in the lower area of the photo.

external circuit wiring remained essentially as bulky as ever. However, since the transistor and diode generate little or no heat, the normal requirement for air ventilation was no longer critical. This being the case, the only remaining obstacles to miniaturization were the other circuit components.

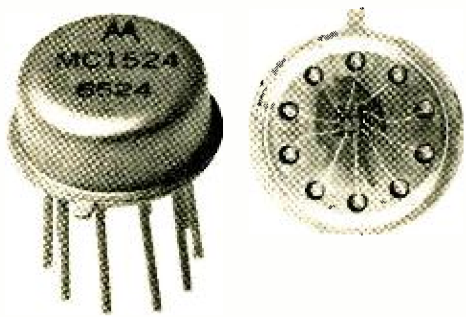
The next step in the stride toward miniaturization was the putting together of two transistors in a single six-legged can to form what seemed like a "2N-6SN7" unit. Not only did this procedure simplify the wiring and basing requirements, but it also brought along other definite advantages. Since the two transistors were made side by side on a single slab of silicon perhaps no bigger than 25 mils square, they maintained the same temperature—which provided perfect tracking in critical, wide-temperature-range circuits. Identical geometry made the pair perfectly balanced, and for the first time it was possible to get a truly complementary *pnp-npn* pair.

Because transistors were able to operate at extremely low power levels, and the power dissipated in load and bias resistors was negligible, substantially

Typically, the manufacturing sequence for a monolithic IC is as follows: (1) Processing starts with a chip of lapped and polished P-type silicon wafer (P-substrate) about 0.010 of an inch thick. (2) An N-type epitaxial layer is grown over the wafer; this is followed by a thin layer of silicon dioxide that is formed by heating in an oxidizing atmosphere. (3) Grooves are etched around the areas to be isolated using normal photo-engraving process. (4) A highly doped P-type impurity is diffused into the grooves down through the epitaxial layer to the substrate. This impurity is covered by a second layer of silicon dioxide formed by heating again. (5) A photo-resist pattern masks those areas that must be etched to form the transistor base area and resistor patterns. (6) A P-type impurity is diffused into the etched areas to (continued on next page)



smaller components could be used. Having gotten this far in the size reduction scheme, the next step could be easily anticipated: how to put resistors, capacitors, and inductors in the same can with the transistors. After all, since there are many identical circuits that are used over and over again with only slight changes, a few standard circuits would allow a wide variety of applications. Therefore, if the designer used lots of transistors and resistors, and built entire systems in small cans, he could eliminate countless interconnections.



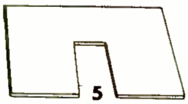
The standard package for most integrated circuits is the multi-lead TO-5 case. Shown above is a 10-lead version of the common transistor case. Wires 0.001" in diameter link each contact pad on the circuit with a pin on the base as shown at right.

Ways To Make IC's. The resistors were easy to put on a silicon slab. Nichrome or nickel can be evaporated in place through a mask to build up the approximate resistance and trimmed to an exact value by abrasion or electron beam cutting. Other possibilities include the use of resistive inks, which can be directly silk-screened or offset-printed into place. Or, as is more popular today, silicon substrate (semiconductor material) itself can be made into resistors. By controlling the doping level, it is possible to obtain a given resistivity from which a desired resistance value can be derived. A reverse bias technique is used to isolate the various resistors, which are made from *n*-type material.

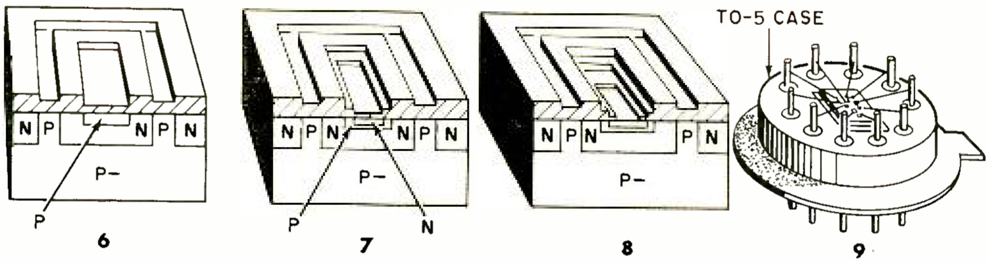
If all resistors are connected to a positive supply, the *pn* junctions formed will be reverse-biased, neatly isolating the resistors from the substrate and from each other, since the junctions cannot conduct current under reverse bias conditions. Newer techniques add a thin layer of glass between the substrate and the resistors to minimize the effects of nonlinear stray capacitance in high-frequency IC's.

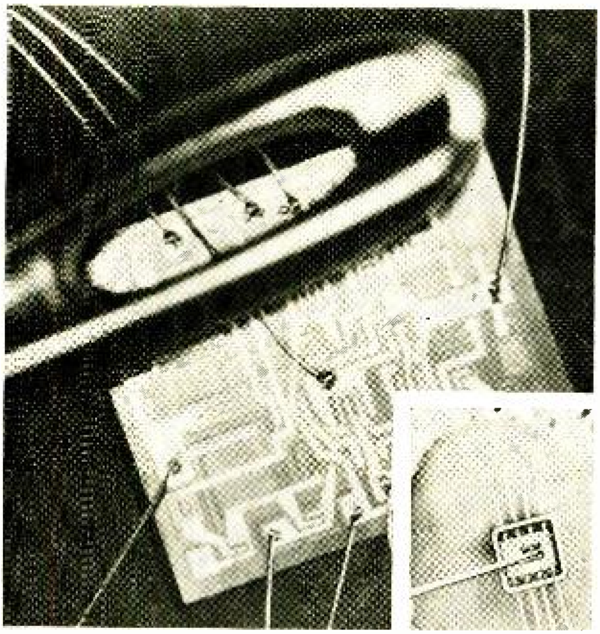
Newer transistors like the metal-oxide semiconductor (MOS) variety, and the insulated gate field-effect transistor (IGFET), can be made to exhibit the property of resistance or conductance, depending on the biasing employed. Furthermore, since these transistors do not require any special manufacturing process, they can be formed together with resistors, resulting in higher yields at lower costs.

But the forming of capacitors was a much more difficult task, and IC induc-



grow a new oxide coating. (7) The transistor emitter patterns are etched on the oxide and an N-type impurity is diffused to produce an N-region in the P-material under the etched windows. (8) Successively, every element of the circuit including transistor collectors, diodes, and resistors, is connected by holes etched in the oxide. (9) Contact points are established at every circuit element. The contacts are later brought out to terminals on a case by extremely fine wires. The TO-5 case typifies one of the various forms of packaging in common use. Other types include flat packages of varying dimensions and pin numbers.





Magnified view through eye of needle emphasizes minuteness of tiny welded connections that attach spider-web thin aluminum wire to elements of microelectronic circuit. (Photo courtesy Cutler-Hammer)

tors were essentially impossible to make. Capacitors had to be built up by metallization of silicon or glass, in repeated layers. But even then they were somewhat leaky, and large values of capacitances required large areas of the integrated substrate. As for inductors, it simply wasn't possible to achieve large "L" values or high Q's.

So the circuit designers backed away a bit and decided instead to redesign their circuits to fit the IC's. This meant the elimination of all inductance, and as much capacitance as possible, from the circuit. For r.f. applications, where tuning or filtering is a must, separate LC units were placed in separate miniature cans and used like r.f. transformers. Wherever possible, all circuits are d.c.-coupled to eliminate practically all capacitors. And although this requires the use of more transistors, there is no extra cost. Adding more transistors in an integrated circuit requires only the making of a few more holes in the series of masks used during manufacture. It costs just as much to make one transistor as it does to make a dozen. And a dozen often occupy less space than the single capacitor they replace in a d.c. circuit. The use of numerous transistors is usually less expensive, anyway, since the capacitor manufacturing steps are eliminated.

This is why integrated circuit schematics always seem so complicated. Extra transistors are used to eliminate any component that would be expensive or hard to include in a tiny space.

Common Types of IC's. Every manufacturer has his own way of putting the many tiny components or circuit functions and interconnections into a single IC. However, since production techniques change so fast, it really isn't important for the IC user to know just what manufacturing steps are in use. But there are several basic IC types that

Similar in appearance to a packaged electronic circuit, this Burroughs' IC package features rugged dependability, making its use in electronic equipment subject to shock and vibration most desirable.

are likely to be around for a while. You should learn to recognize these types. Here are some of them:

Monolithic IC's have all their individual components etched out on a solid silicon chip. Their construction is very rugged, and the manufacturing cost relatively low.

Hybrid IC's consist of a number of interconnected monolithic IC's, discrete transistors, capacitors, and possibly power resistors. The hybrids lend themselves to high power outputs and custom-designed circuitry where the interconnections can be altered to suit a particular requirement. They are usually low-frequency devices and generally quite expensive.

Thin-Film IC's employ an IC technique through which layers consisting of a few atoms of a semiconductor material are evaporated onto a ceramic substrate (the newest designs use sapphire) through a series of masks. This technique permits exceptionally high frequency response and extremely small size. Some low-priced models operate with power in the nanowatt range.

Thick-Film IC's employ an old and cheap method similar to the printed circuit couplates. Resistors are silk-screened or offset printed in place; capacitors are made by overlapping layers of ceramic and metallic material. Ordinary transistors without cases are cemented or ultrasonically welded in place. This type of IC is recognized by its postage-stamp size and shape, and its external protective epoxy dip.

What's Available Now? Today there are thousands of different IC's available.

(*Continued on page* 106)

LOW-COST INTEGRATED AMPLIFIERS FOR THE EXPERIMENTER

CIRCUIT	TYPE	NUMBER	MANUFACTURER	PRICE (Approx.)
OPERATIONAL AMPLIFIER	Linear	uA702	Fairchild Semiconductor	$14.40
R.F. OR I.F. AMPLIFIER	Linear	uA703	313 Fairchild Drive	4.50
COMPARATOR	Linear	uA710	Mountain View, Calif.	7.50
BUFFER	Digital	uL900		1.63
DUAL TWO-INPUT GATE	Digital	uL914		1.63
COUNTING FLIP-FLOP	Digital	uL923		3.95
LATCHING FLIP-FLOP	Digital	MC352	Motorola Semiconductor	4.55
DUAL TWO-INPUT GATE	Digital	MC359	Box 955	3.70
DUAL-COUNTING FLIP-FLOP	Digital	MC790	Phoenix, Ariz.	5.30
OPERATIONAL AMPLIFIER	Linear	MC1430		18.00
1-WATT AUDIO AMPLIFIER	Linear	MC1519		70.00
D.C. AMPLIFIER	Linear	CA3000	RCA Electronic Components	6.80
VIDEO AMPLIFIER	Linear	CA3001	Harrison, N. J.	6.40
I.F. AMPLIFIER	Linear	CA3002		4.40
R.F. AMPLIFIER	Linear	CA3004		4.40
AUDIO DRIVER	Linear	CA3007		6.80
OPERATIONAL AMPLIFIER	Linear	CA3010		12.00
COMPLETE FM I.F. STRIP	Linear	CA3013		2.65
HEARING-AID AMPLIFIER	Linear	SN1220	Texas Instruments Box 5012 Dallas, Texas	16.20
HIGH-GAIN AUDIO AMPLIFIER	Linear	WC183	Westinghouse Electronics	10.00
R.F. AMPLIFIER	Linear	WC1146	Box 7737 Elkridge, Md.	10.00

INTEGRATED CIRCUITS

(*Continued from page* 56)

Some are experimenter units that are priced at less than a dollar each when purchased in large quantities. Others are of the expensive variety, limited to a few critical applications.

The table on page 56 lists some of the lower-priced integrated circuits that can be purchased from distributors as off-the shelf items; data sheets are available from the manufacturers represented. Digital IC's are of the flip-flop switching variety used in computer or counting circuits, while linear IC's are used as r.f. and a.f. amplifiers.

None of the IC's listed is as expensive as the corresponding parts would be if purchased separately, not counting the extra assembly time and reduced reliability that discrete parts provide. Furthermore, with discrete parts it is impossible to obtain the temperature tracking inherent in integrated circuits.

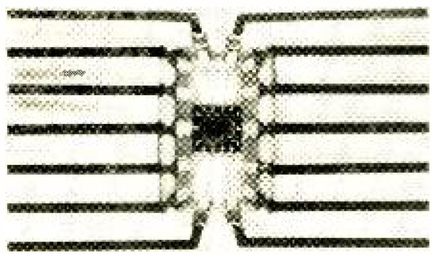
In The Cards For Tomorrow. The trend is plain to see—more, smaller, and better integrated circuits at lower costs. The experts call for a 10:1 price cut in IC's in the next fifteen years. So the time to obtain a working familiarity with these circuits is—now!

Even more exciting is today's development of IC's using some astounding new electronic techniques that will become important factors in the manufacture of tomorrow's distributor components. The MOS-type transistors have essentially infinite input impedance and zero switching time, but are built with half the steps necessary for a conventional transistor and in a tiny fraction of its size.

The *Gunn* effect and the *Read* effect are new techniques through which the avalanching semiconductors directly generate substantial microwave power. Microwave IC's are already in the works, as are switching mode amplifiers—produced through the use of a "why didn't they think of it before?" technique by which a 40-watt amplifier is put in a TO5 case with no heat sink required, and no heat problems either.

There is also a totally molecular approach by which entire functional blocks are built up on a molecular scale. Then there's a resonant gate transistor—a spanking-new device with a built-in tuning fork that gives you high-Q, stable resonant circuits—from audio to microwave—in extremely cramped quarters. And the list goes on.

Today's laboratories are turning out tomorrow's IC's. Will you be ready for them when they arrive? —30—



Ceramic flat pack is used when maximum miniaturization is required. It occupies less than half the space of a TO-5 transistor package. This configuration sometimes replaces as many as 50 components.