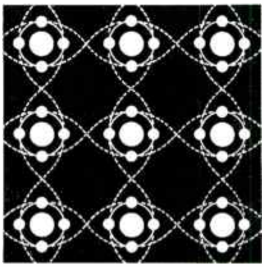
The Lenkurt

DECEMBER 1968

DEMODULATOR

solid state review



Today's profusion of novel electronic devices is but one result of the phenomenal growth in the solid-state art.

Every area of activity has its jargon and its catch-phrases. This is as true of industry as it is of politics or the arts. And, undoubtedly, the most widely heard phrase in electronics marketing today is "solid-state". The term spans the entire industry from consumer products to super-sophisticated communications systems – anything from a teen-ager's vestpocket radio to a phased-array radar acquisition system. The term is rapidly becoming a catch-all and losing its original meaning.

Originally, the term solid-state applied only to devices and circuits which were fabricated using principles of applied solid-state physics. New devices such as transistors and diodes were called solid-state to distinguish them from their gas-state or other non-solid-state predecessors.

Later, numbers of solid-state devices were incorporated into modules or subassemblies. These in turn were assembled into operating systems. The upshot of all this is the current practice of calling any apparatus that contains so much as a single transistor solid-state. We now have "solid-state" radios, TV receivers, electric shavers and even kitchen mixers. In fact, most people call a transistor radio simply a "transistor". Plainly then, with the help of advertising and marketing people, the term solid-state has taken on new applications and meanings.

Solid-State Physics

The term, solid-state, refers to the internal devices and circuits that make an apparatus function.

In general these devices belong to that unique electronic species known as semiconductors. As a rule, the materials found in electronics are either conductors or nonconductors. The latter are sometimes called insulators or dielectrics. All these terms are used to indicate a given material's ability to pass an electric current. In the case of conductors and insulators, the names are self-explanatory. But what about semiconductors?

Obviously, a material either passes electric current or it does not. It is difficult to imagine a material that only "half-passes" or *almost* conducts electricity. Nonetheless, this is the term we use to describe materials that, in their native state, will not allow current to pass. But when properly treated or "doped" with a foreign element they will carry current. Most often these elements are germanium or silicon doped with a small amount of arsenic, indium, or some other impurity.

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"Solid-state" is not the only term in electronics which is widely misunderstood or loosely used. There is also considerable confusion surrounding the following:

Microcomponents refers to an assembly of very small, interconnected discrete components – active or passive – which forms an electronic circuit. Interconnection of the various leads is by soldering or welding. Microcomponents use no substrates.

Microcircuits, on the other hand, satisfy the same criteria as do microcomponents but they do employ substrates.

Active substrates are usually a working part of the electronic circuit which they support physically. They possess ohmic and electrical values.

Passive substrates perform no electronic function but provide physical support and a thermal sink for their circuits.

An **integrated circuit** is an electrical network – active or passive – composed of two or more circuit elements inextricably bound on a single semiconductor substrate.

Transistance, a function of transistors, is an electrical property that causes applied voltages to create amplification or accomplish switching.

Any element's capacity to allow the free flow of electrons depends directly on the atomic structure of the element. Elements such as copper or gold have rather loosely bound atoms in which some electrons are free to move. Consequently they make good conductors. Other materials like lead and air possess very tight atomic structures with no free electrons.

An atom consists of a nucleus with a number of surrounding electrons in concentric rings. In this respect, atoms can be thought of as planetary systems with the sun as nucleus and the planets as the circling electrons. It is the number of these electrons – specifically in the outer ring – which determines a material's willingness to allow the flow of electricity (Fig. 1).

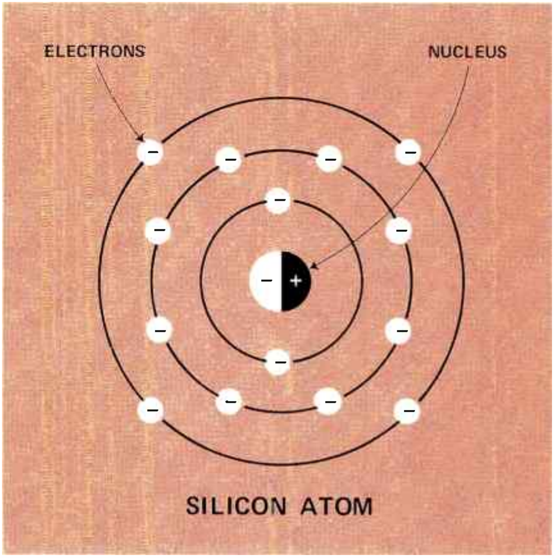
One of nature's phenomena is that eight electrons in the outer ring compose the firmest shell. These are the valence or free electrons. Elements or compounds possessing such strong atomic shells are not usually good conductors because they have no free electrons.

Semiconductor elements such as silicon and germanium have four valence electrons in their atoms. When two of these atoms combine, a shell of eight electrons forms a perfect covalent bond. In such materials, resistance is very high – almost to the point of insulation.

There are ways to reduce this resistance and make the materials act as conductors. One way is using heat to cause excitation among the electrons sufficient to break the covalent bonds and allow electron movement. The other is to dope the material with an impurity and cause the atoms to rearrange themselves.

It works like this. Silicon and germanium are crystals. Their crystalline structure results from the formation of perfect shells composed of eight electrons. This happens when any two silicon atoms – each containing four electrons – join together forming covalent bonds. The result is a very stable atomic structure, whose resistance is high.

Figure 1. Atoms have a maximum of two electrons in the first ring, or energy level, eight in the second, eighteen in the third and a definite number in each succeeding ring. Usually, the rings nearest the nucleus will possess the maximum number of electrons before more appear in succeeding rings. When the number of electrons in the outer ring is less than the maximum, they are called "free" or valence electrons.



Now, if a foreign substance whose atoms have an odd number of valence electrons – say 5 – is added to the silicon, four of them will pair with the four host electrons. The fifth, or odd electron will remain free to move about in the compound and carry electric current. See Figure 2.

In cases like this where the added impurity or donor provides the free electron, an N type, negatively charged, semiconductor is created. If, on the other hand, the crystal is doped with an impurity whose atoms contain only three electrons, a "hole" is created by the absence of a fourth impure electron to pair with the fourth silicon electron. This hole is contributed by the host or acceptor atom and may therefore be remembered as creating a P-type semiconductor whose charge is positive. In both cases, electron/hole activity provides the means for conduction. A working circuit can be made by joining an N type and P type together. This is called a junction, hence the terms junction diode and junction transistor.

Junctions

A diode is the result of joining two pieces of semiconductor material of opposite polarities. They consist of either PN or NP junctions. Add another element to the diode and it is a transistor – PNP or NPN. In either case, the PN or NP junctions function as emitter, collector or base in the transistor. Methods of construction and intended uses vary widely, but in any case, transistors consist of those three elements. In an NPN transistor, the N-type carriers are called the majority carriers, and the P-type, minority. Just the opposite is true in PNP devices.

In most cases, the names of various transistors are a result of the construction method used in their fabrication and the resulting shape. Some of the types are: grown-junction, alloyed junction, drift-type transistors, microalloy diffused-base transistors (MADT), mesa and planar transistors. Each of these performs differently from the others and consequently, application differs with each.

Mesa, and more recently, planar transistors are representative of the current level of sophistication in the solid-state art. They are characterized by higher voltage and current capacities and, in the case of planar types, higher operating frequencies. However, the current trend is away from mesa types.

New solid-state devices seem to be appearing almost daily. Some of the more noteworthy and better-known are grouped below in two broad categories — transistors and diodes.

Transistors

There are many different Field Effect Transistors (FET's) currently available — among them, JFET's (J for Junction), IGFET's (IG for Insulated Gate), and MOSFET's (MOS for Metal Oxide Semiconductor). FET's differ from regular junction transistors in their polarity and construction. Junction transistors are bipolar whereas FET's are unipolar. This means that they use only the majority carriers — holes and electrons — as a means of conduction. Junction transistors use both majority and minority carriers simultaneously.

In a JFET the interface between input and output (channel and gate) is a junction. The interface in an IGFET is insulated by a dielectric, and in a MOSFET the insulating material is an oxide.

They are all extremely fast digital-type transistors. Applications are anywhere that switching or any on-off function is required.

Diodes

Limited Space-charge Accumulation (LSA), Impact Avalanche Transist

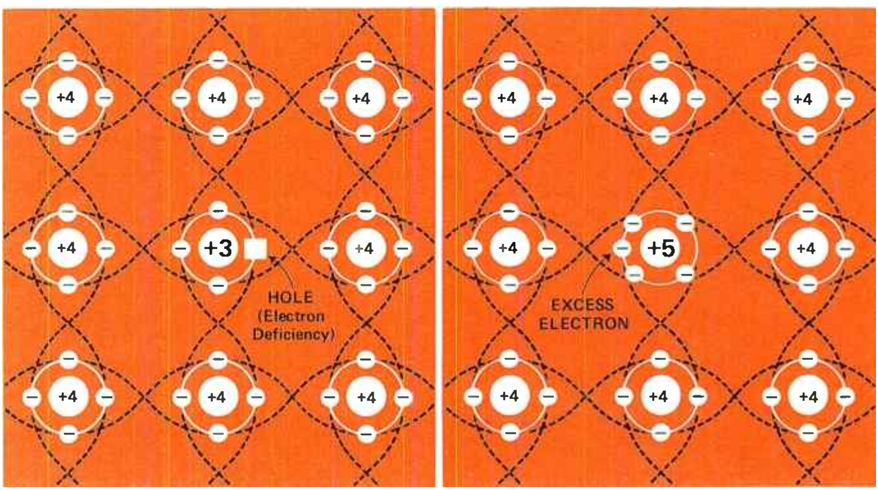


Figure 2. Depending upon the atomic structure of the impurity used, proper doping of semiconductor materials will create either "holes" or free electrons to act as conductors.

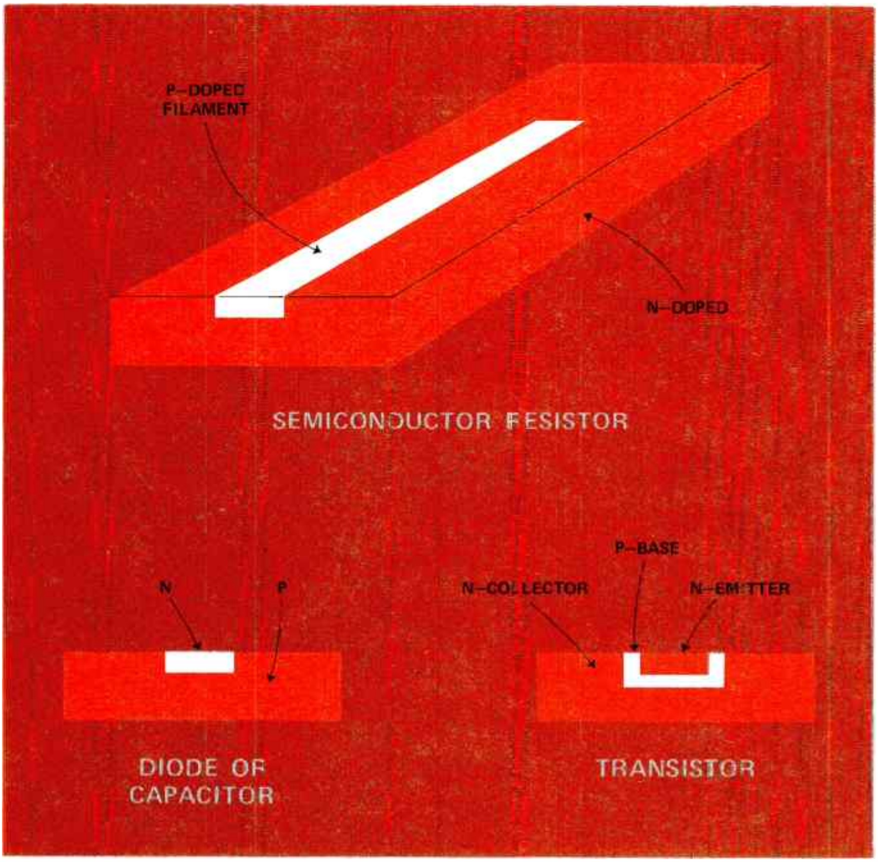


Figure 3. Semiconductor microelectronic devices

Time (IMPATT) and other avalanche-type diodes are semiconductor devices intended primarily for use as amplifiers and oscillators for microwave radio. This is also true of Gunn and other gallium-arsenide devices.

Schottky barrier diodes are metal semiconductor junctions having the property to allow current of only one polarity to pass. They are used in microwave mixers and frequency multipliers. Recently, Schottky devices have been improved by the addition of a silicon "collar" around the junction which enables the device to operate very near its theoretical efficiency limits. The diode itself is characterized by a molybdenum-gold Schottky contact.

IC's, A Logical Extension

Transistors, commonplace today, provided the foundation for all subsequent developments in component technology. Viewed from the vantage point of today's accumulated knowledge, they are basically simple devices. But without them, none of the devices discussed here would have been possible, nor, for that matter, would there be integrated circuits.

Now it seems a logical step to go from discrete semiconductor components to silicon-based integrated circuits containing these same components on a single chip.

Once it was established that an operational device could be fabricated from semiconductor material, it was only natural that some interest should be directed toward the idea that an entire circuit might be made the same way using the same materials.

Integrated circuit fabrication employs principles and techniques very similar to those used in the manufacture of discrete semiconductor devices. IC's are made from carefully grown and doped silicon. Within a single chip many individual components – transistors, diodes, and even resistors and diode-type capacitors – can be etched, diffused or otherwise fabricated. (For a detailed account of IC fabrication, see the December, 1967 *Lenkurt Demodulator*).

Recent developments in IC technology center around smaller, stabler and faster digital circuits and expanded applications for linear (analog) IC's. Linear circuits are now finding use in virtually every area of communications as well as in most solid-state consumer products.

Digital circuits find most of their application in data processing hardware where they are used as logic gates, memory cores and other functions peculiar to computer operations. They are also widely used in digital communications systems.

Linear circuits, on the other hand, have a much wider scope. They are used in every area of communications, telemetering, control and home entertainment systems. Linear IC's perform as amplifiers, oscillators and in scores of other more complex functions.

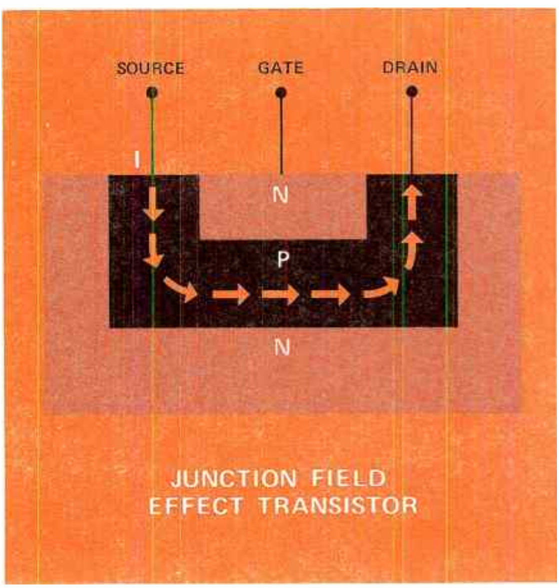


Figure 4. Current (I) flowing in the channel is controlled by varying the voltage across the gate. The applied voltage creates a field in the channel which has a "pinching" effect on the current. Thus, channel current can range from almost zero to full conduction. Since they are voltage controlled, unipolar FET's more closely resemble vacuum tubes than do their more common cousins which are bipolar and current controlled.

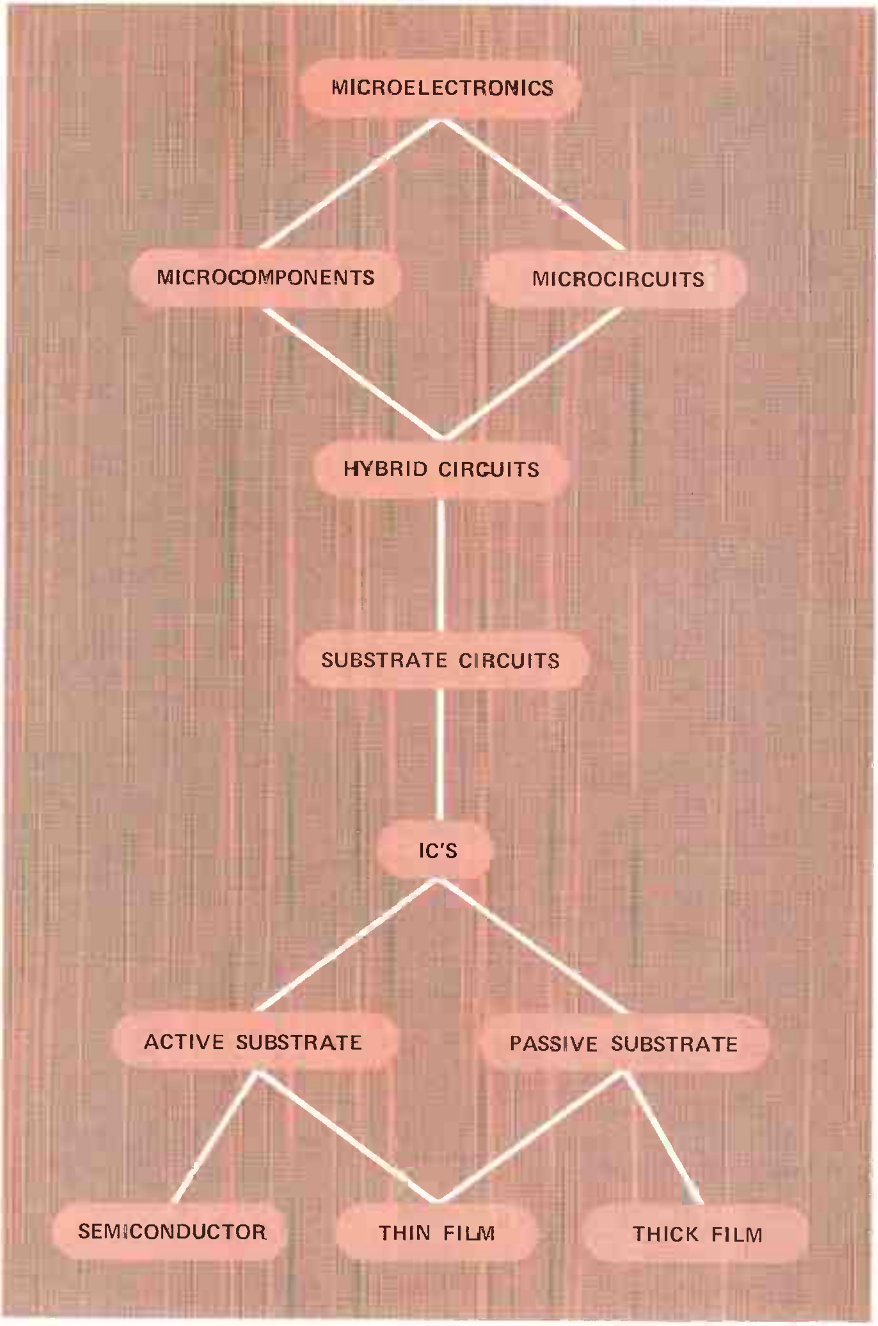


Figure 5. All of the various technologies under the broad umbrella of microelectronics depend on solid-state physics.

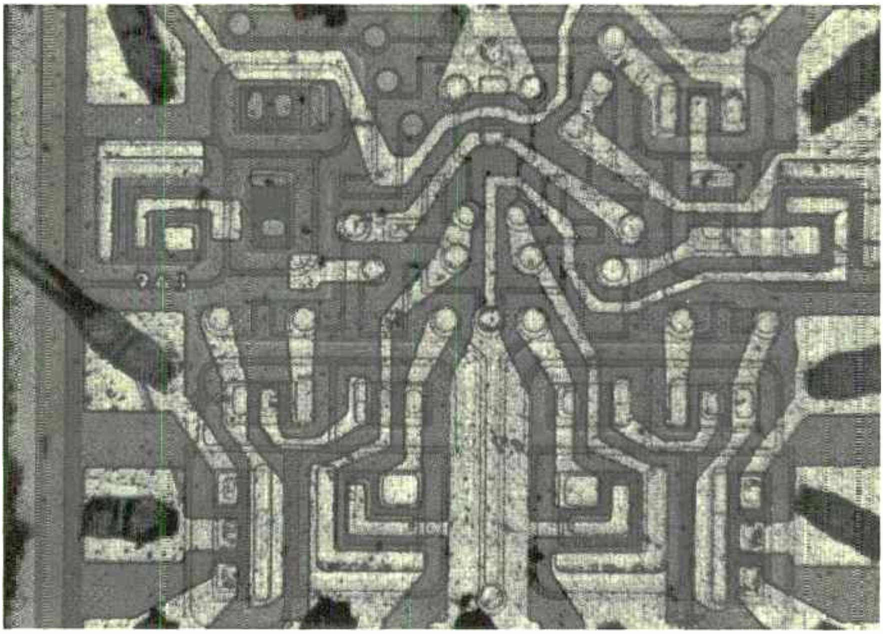


Figure 6. Called a Triple–3 Input Gate, this integrated logic circuit contains three triple input NAND gates. It is used in the Lenkurt 91A PCM Carrier System.

Since they manufacture both digital and conventional telecommunications systems, Lenkurt is of course deeply involved with solid-state development. Both digital and linear IC's are more and more widely used in Lenkurt systems. These systems are characterized by higher reliability, lower operating costs and longer life.

Current Trends

One recent development in the fabrication of IC's is growing square silicon wafers rather than round ones. The result is more usable chips per wafer since the loss incurred through wasted area has been eliminated.

Currently, the growing debate in semiconductor technology involves packaging and interconnection techniques. Proponents of flip-chips and beam lead devices are vying for acceptance by the industry at large.

Primarily, beam leads are favored for their superior uniformity, flexibility of application and overall reliability. Considerations such as thermal dissipation and power handling capabilities seem about equal. Flip-chips, on the other hand, allow for greater packaging density.

There also is an intriguing economic aspect of the boom in semi-conductor technology which is just emerging. As applications for IC's become standardized, more and more semiconductor manufacturers are providing more and more input to the finished product. They are developing their own packaging techniques and subassemblies, and in some cases they even supply whole integrated systems.

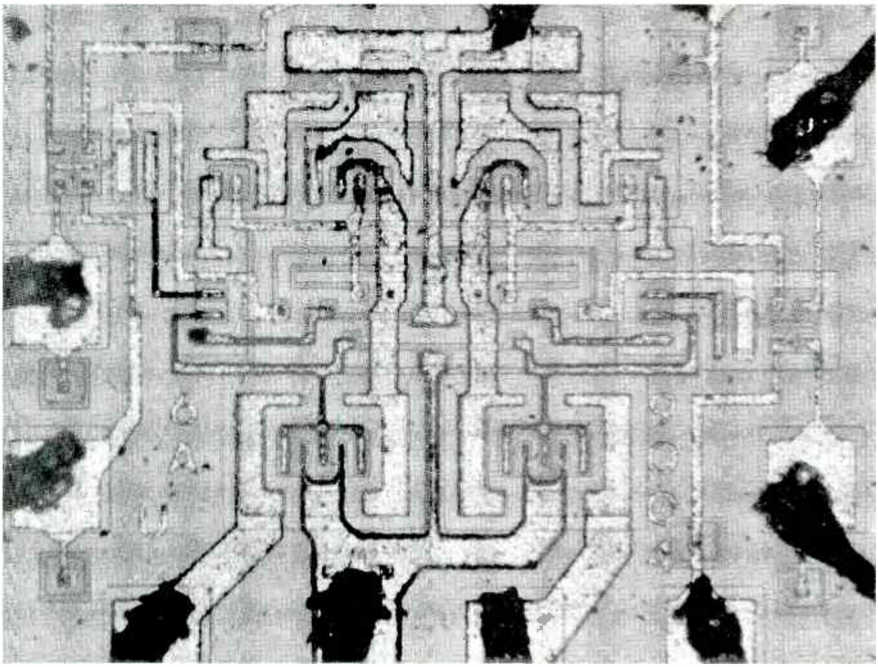
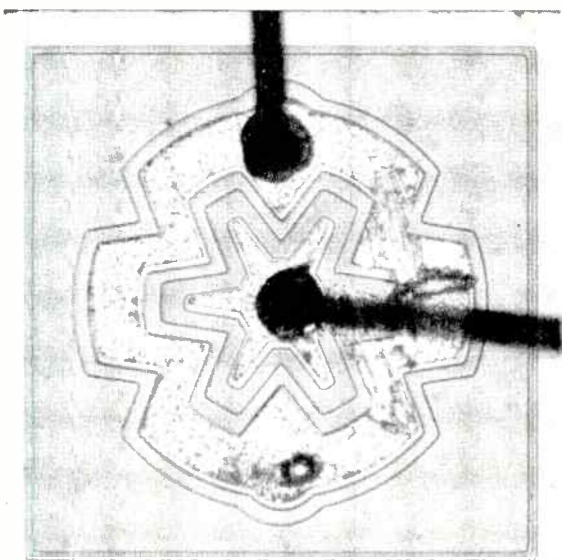


Figure 7. Also used in the 91A, this digital IC has two 4-input NAND gates.

Figure 8. Using star geometry, semiconductor manufacturers are able to increase the peripheral length of the transistor. This enables it to handle greater power and current loads and still maintain low input and output capacitance.



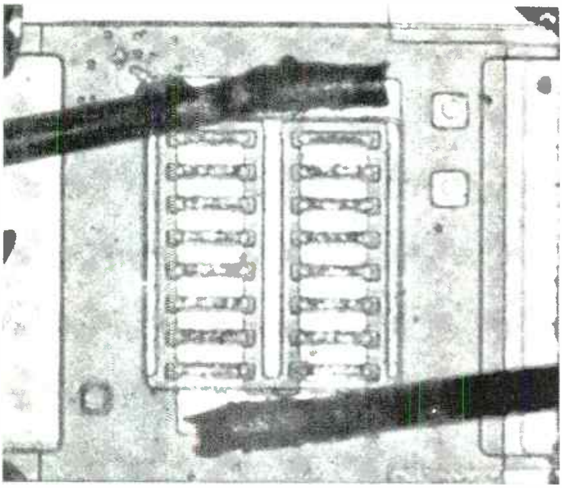


Figure 9. Characteristic of the present state of the art, multiple emitter type transistors are used at Lenkurt in wideband amplifier circuits.

Generally, electronics may be divided into three broad areas – design, component fabrication, and system assembly. Heretofore, design and system assembly were the function of the equipment manufacturer. The semiconductor vendor fabricated only the components to the specifications set by the manufacturer. This is changing. Makers of semiconductor components and circuits are penetrating deeper and deeper into the areas traditionally allotted to equipment manufacturers.

Is it possible that present manufacturers eventually will become only clearing houses or wholesalers for entire electronic systems manufactured totally by the erstwhile makers of semiconductors?

This prospect is not so farfetched as it seems at first blush. It has already begun to happen in the computer hardware manufacturing industry. Stripped of their packages and peripheral devices, there can be little operational difference between two computers whose internal circuitry is manufactured by the same company.

Linear IC's are finding ever wider application in the communications industry. If designers and manufacturers of communications systems become as dependent upon vendors of linear IC's as computer manufacturers are upon digital IC suppliers, they will find themselves in the same position.

The fast-closing developmental gap between digital and linear IC's makes this possibility somewhat less clear in the communications sector of the electronics industry. But communications manufacturers are going to have to choose between buying more "ready-made" components, or, as some have in the past, making their own.

Beyond such business considerations, it is unwise – if not impossible – to attempt any meaningful predictions as to the future of solid-state technology. Conceivably, any of the circuits or components mentioned in these pages may be obsolete before the ink is dry.

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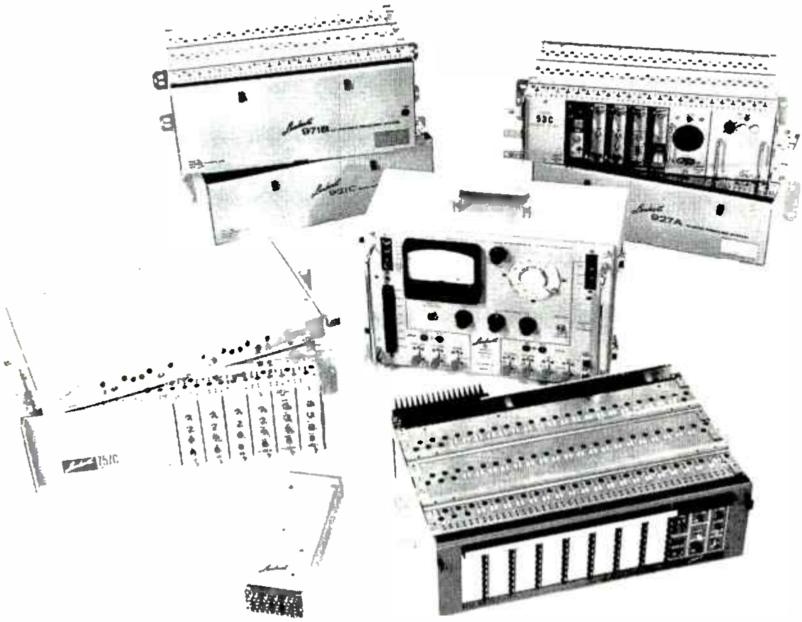

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