

CHAPTER 1

MICROELECTRONICS

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each topic. These learning objectives serve as a preview of the information you are expected to learn in the topic. The comprehensive check questions are based on the objectives. By successfully completing the OCC-ECC, you indicate that you have met the objectives and have learned the information. The learning objectives are listed below.

Upon completion of this topic, you will be able to:

1. Outline the progress made in the history of microelectronics.
2. Describe the evolution of microelectronics from point-to-point wiring through high element density state-of-the-art microelectronics.
3. List the advantages and disadvantages of point-to-point wiring and high element density state-of-the-art microelectronics.
4. Identify printed circuit boards, diodes, transistors, and the various types of integrated circuits. Describe the fabrication techniques of these components.
5. Define the terminology used in microelectronic technology including the following terms used by the Naval Systems Commands:
 - a. microelectronics
 - b. microcircuit
 - c. microcircuit module
 - d. miniature electronics
 - e. system packaging
 - f. levels of packaging (0 to IV)
 - g. modular assemblies
 - h. cordwood modules
 - i. micromodules
6. Describe typical packaging levels presently used for microelectronic systems.
7. Describe typical interconnections used in microelectronic systems.
8. Describe environmental considerations for microelectronics.

INTRODUCTION

In *NEETS, Module 6, Introduction to Electronic Emission, Tubes, and Power Supplies*, you learned that Thomas Edison's discovery of thermionic emission opened the door to electronic technology. Progress was slow in the beginning, but each year brought new and more amazing discoveries. The development of vacuum tubes soon led to the simple radio. Then came more complex systems of communications. Modern systems now allow us to communicate with other parts of the world via satellite. Data is now collected from space by probes without the presence of man because of microelectronic technology.

Sophisticated control systems allow us to operate equipment by remote control in hazardous situations, such as the handling of radioactive materials. We can remotely pilot aircraft from takeoff to landing. We can make course corrections to spacecraft millions of miles from Earth. Space flight, computers, and even video games would not be possible except for the advances made in microelectronics.

The most significant step in modern electronics was the development of the transistor by Bell Laboratories in 1948. This development was to solid-state electronics what the Edison Effect was to the vacuum tube. The solid-state diode and the transistor opened the door to microelectronics.

MICROELECTRONICS is defined as that area of technology associated with and applied to the realization of electronic systems made of extremely small electronic parts or elements. As discussed in topic 2 of *NEETS, Module 7, Introduction to Solid-State Devices and Power Supplies*, the term microelectronics is normally associated with integrated circuits (IC). Microelectronics is often thought to include only integrated circuits. However, many other types of circuits also fall into the microelectronics category. These will be discussed in greater detail under solid-state devices later in this topic.

During World War II, the need to reduce the size, weight, and power of military electronic systems became important because of the increased use of these systems. As systems became more complex, their size, weight, and power requirements rapidly increased. The increases finally reached a point that was unacceptable, especially in aircraft and for infantry personnel who carried equipment in combat. These unacceptable factors were the driving force in the development of smaller, lighter, and more efficient electronic circuit components. Such requirements continue to be important factors in the development of new systems, both for military and commercial markets. Military electronic systems, for example, continue to become more highly developed as their capability, reliability, and maintainability is increased. Progress in the development of military systems and steady advances in technology point to an ever-increasing need for increased technical knowledge of microelectronics in your Navy job.

- Q1. What problems were evident about military electronic systems during World War II?*
- Q2. What discovery opened the door to solid-state electronics?*
- Q3. What is microelectronics?*

EVOLUTION OF MICROELECTRONICS

The earliest electronic circuits were fairly simple. They were composed of a few tubes, transformers, resistors, capacitors, and wiring. As more was learned by designers, they began to increase both the size and complexity of circuits. Component limitations were soon identified as this technology developed.

VACUUM-TUBE EQUIPMENT

Vacuum tubes were found to have several built-in problems. Although the tubes were lightweight, associated components and chassis were quite heavy. It was not uncommon for such chassis to weigh 40 to 50 pounds. In addition, the tubes generated a lot of heat, required a warm-up time from 1 to 2 minutes, and required hefty power supply voltages of 300 volts dc and more.

No two tubes of the same type were exactly alike in output characteristics. Therefore, designers were required to produce circuits that could work with any tube of a particular type. This meant that additional components were often required to tune the circuit to the output characteristics required for the tube used.

Figure 1-1 shows a typical vacuum-tube chassis. The actual size of the transformer is approximately $4 \times 4 \times 3$ inches. Capacitors are approximately 1×3 inches. The components in the figure are very large when compared to modern microelectronics.

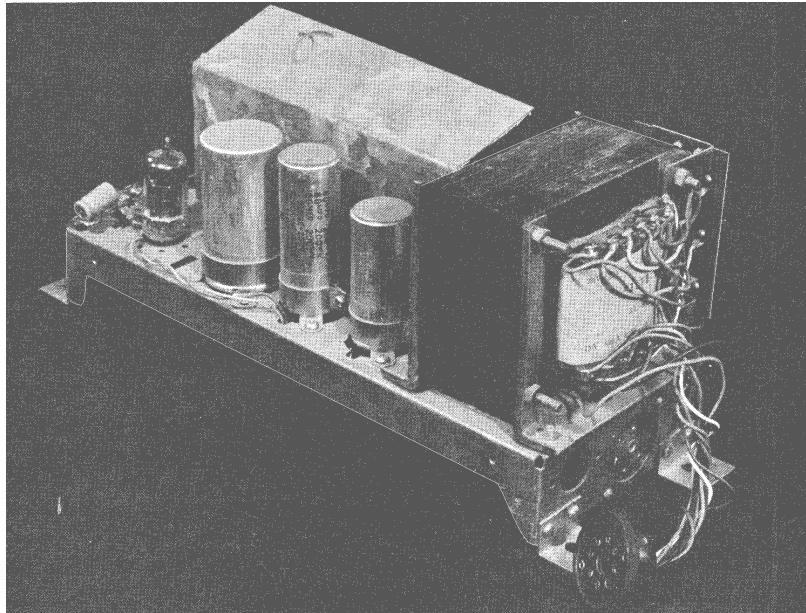


Figure 1-1.—Typical vacuum tube circuit.

A circuit could be designed either as a complete system or as a functional part of a larger system. In complex systems, such as radar, many separate circuits were needed to accomplish the desired tasks. Multiple-function tubes, such as dual diodes, dual triodes, tetrodes, and others helped considerably to reduce the size of circuits. However, weight, heat, and power consumption continued to be problems that plagued designers.

Another major problem with vacuum-tube circuits was the method of wiring components referred to as POINT-TO-POINT WIRING. Figure 1-2 is an excellent example of point-to-point wiring. Not only did this wiring look like a rat's nest, but it often caused unwanted interactions between components. For example, it was not at all unusual to have inductive or capacitive effects between wires. Also, point-to-point wiring posed a safety hazard when troubleshooting was performed on energized circuits because of exposed wiring and test points. Point-to-point wiring was usually repaired with general purpose test equipment and common hand tools.

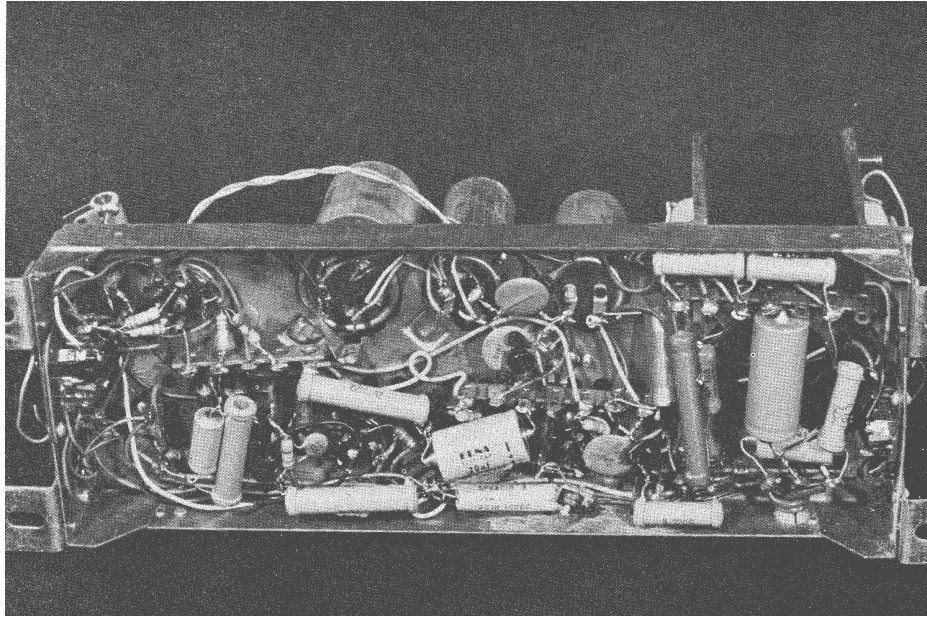


Figure 1-2.—Point-to-point wiring.

Vacuum-tube circuits proved to be reliable under many conditions. Still, the drawbacks of large size, heavy weight, and significant power consumption made them undesirable in most situations. For example, computer systems using tubes were extremely large and difficult to maintain. ENIAC, a completely electronic computer built in 1945, contained 18,000 tubes. It often required a full day just to locate and replace faulty tubes.

In some applications, we are still limited to vacuum tubes. Cathode-ray tubes used in radar, television, and oscilloscopes do not, as yet, have solid-state counterparts.

One concept that eased the technician's job was that of MODULAR PACKAGING. Instead of building a system on one large chassis, it was built of MODULES or blocks. Each module performed a necessary function of the system. Modules could easily be removed and replaced during troubleshooting and repair. For instance, a faulty power supply could be exchanged with a good one to keep the system operational. The faulty unit could then be repaired while out of the system. This is an example of how the module concept improved the efficiency of electronic systems. Even with these advantages, vacuum tube modules still had faults. Tubes and point-to-point wiring were still used and excessive size, weight, and power consumption remained as problems to be overcome.

Vacuum tubes were the basis for electronic technology for many years and some are still with us. Still, emphasis in vacuum-tube technology is rapidly becoming a thing of the past. The emphasis of technology is in the field of microelectronics.

- Q4. What discovery proved to be the foundation for the development of the vacuum tube?*
- Q5. Name the components which greatly increase the weight of vacuum-tube circuitry.*
- Q6. What are the disadvantages of point-to-point wiring?*
- Q7. What is a major advantage of modular construction?*
- Q8. When designing vacuum-tube circuits, what characteristics of tubes must be taken into consideration?*

SOLID-STATE DEVICES

Now would be a good time for you to review the first few pages of *NEETS, Module 7, Introduction to Solid-State Devices and Power Supplies*, as a refresher for solid-state devices.

The transition from vacuum tubes to solid-state devices took place rapidly. As new types of transistors and diodes were created, they were adapted to circuits. The reductions in size, weight, and power use were impressive. Circuits that earlier weighed as much as 50 pounds were reduced in weight to just a few ounces by replacing bulky components with the much lighter solid-state devices.

The earliest solid-state circuits still relied on point-to-point wiring which caused many of the disadvantages mentioned earlier. A metal chassis, similar to the type used with tubes, was required to provide physical support for the components. The solid-state chassis was still considerably smaller and lighter than the older, tube chassis. Still greater improvements in component mounting methods were yet to come.

One of the most significant developments in circuit packaging has been the PRINTED CIRCUIT BOARD (pcb), as shown in figure 1-3. The pcb is usually an epoxy board on which the circuit leads have been added by the PHOTOETCHING process. This process is similar to photography in that copper-clad boards are exposed to controlled light in the desired circuit pattern and then etched to remove the unwanted copper. This process leaves copper strips (LANDS) that are used to connect the components. In general, printed circuit boards eliminate both the heavy, metal chassis and the point-to-point wiring.

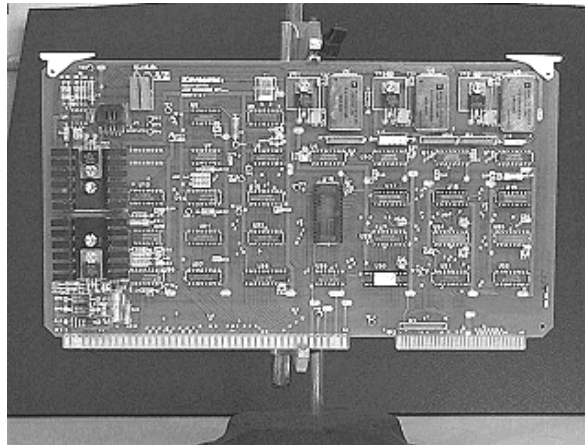


Figure 1-3.—Printed circuit board (pcb).

Although printed circuit boards represent a major improvement over tube technology, they are not without fault. For example, the number of components on each board is limited by the sizes and shapes of components. Also, while vacuum tubes are easily removed for testing or replacement, pcb components are soldered into place and are not as easily removed.

Normally, each pcb contains a single circuit or a subassembly of a system. All printed circuit boards within the system are routinely interconnected through CABLING HARNESES (groups of wiring or ribbons of wiring). You may be confronted with problems in faulty harness connections that affect system reliability. Such problems are often caused by wiring errors, because of the large numbers of wires in a harness, and by damage to those wires and connectors.

Another mounting form that has been used to increase the number of components in a given space is the CORDWOOD MODULE, shown in figure 1-4. You can see that the components are placed perpendicular to the end plates. The components are packed very closely together, appearing to be stacked like cordwood for a fireplace. The end plates are usually small printed circuit boards, but may be insulators and solid wire, as shown in the figure. Cordwood modules may or may not be ENCAPSULATED (totally imbedded in solid material) but in either case they are difficult to repair.

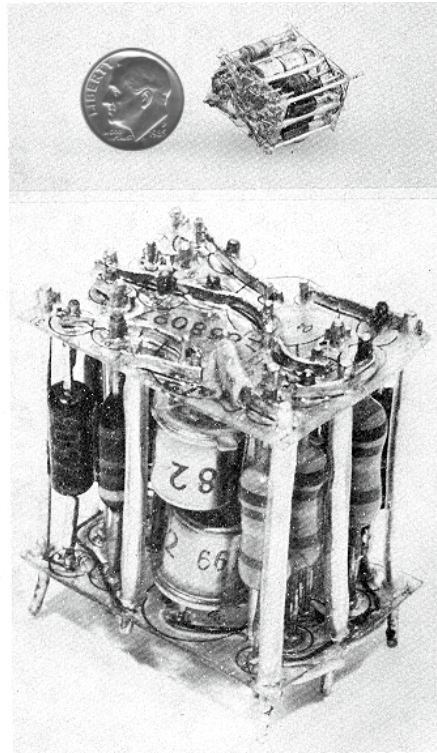


Figure 1-4.—Cordwood module.

Q9. List the major advantages of printed circuit boards.

Q10. What is the major disadvantage of printed circuit boards?

Q11. The ability to place more components in a given space is an advantage of the _____.

INTEGRATED CIRCUITS

Many advertisements for electronic equipment refer to integrated circuits or solid-state technology. You know the meaning of the term solid-state, but what is an INTEGRATED CIRCUIT? The accepted Navy definition for an integrated circuit is that it consists of elements inseparably associated and formed on or within a single SUBSTRATE (mounting surface). In other words, the circuit components and all interconnections are formed as a unit. You will be concerned with three types of integrated circuits: MONOLITHIC, FILM, and HYBRID.

MONOLITHIC INTEGRATED CIRCUITS are those that are formed completely within a semiconductor substrate. These integrated circuits are commonly referred to as SILICON CHIPS.

FILM INTEGRATED CIRCUITS are broken down into two categories, THIN FILM and THICK FILM. Film components are made of either conductive or nonconductive material that is deposited in desired patterns on a ceramic or glass substrate. Film can only be used as passive circuit components, such as resistors and capacitors. Transistors and/or diodes are added to the substrate to complete the circuit. Differences in thin and thick film will be discussed later in this topic.

HYBRID INTEGRATED CIRCUITS combine two or more integrated circuit types or combine one or more integrated circuit types and DISCRETE (separate) components. Figure 1-5 is an example of a hybrid integrated circuit consisting of silicon chips and film circuitry. The two small squares are chips and the irregularly shaped gray areas are film components.

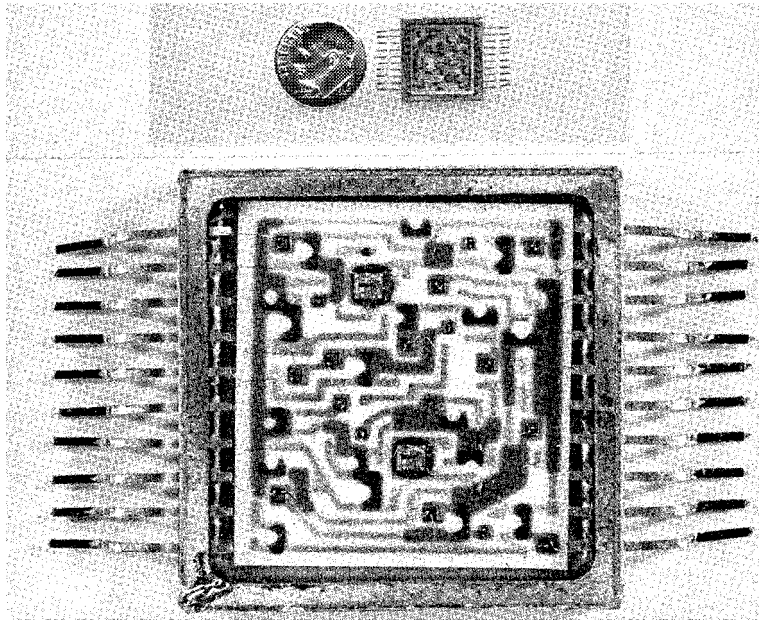


Figure 1-5.—Hybrid integrated circuit.

STATE-OF-THE-ART MICROELECTRONICS.

Microelectronic technology today includes thin film, thick film, hybrid, and integrated circuits and combinations of these. Such circuits are applied in DIGITAL, SWITCHING, and LINEAR (analog) circuits. Because of the current trend of producing a number of circuits on a single chip, you may look for further increases in the packaging density of electronic circuits. At the same time you may expect a reduction in the size, weight, and number of connections in individual systems. Improvements in reliability and system capability are also to be expected.

Thus, even as existing capabilities are being improved, new areas of microelectronic use are being explored. To predict where all this use of technology will lead is impossible. However, as the demand for increasingly effective electronic systems continues, improvements will continue to be made in state-of-the-art microelectronics to meet the demands.

LARGE-SCALE INTEGRATION (lsi) and VERY LARGE-SCALE INTEGRATION (vlsi) are the results of improvements in microelectronics production technology. Figure 1-6 is representative of lsi. As shown in the figure, the entire SUBSTRATE WAFER (slice of semiconductor or insulator material) is

used instead of one that has been separated into individual circuits. In lsi and vlsi, a variety of circuits can be implanted on a wafer resulting in further size and weight reduction. ICs in modern computers, such as home computers, may contain the entire memory and processing circuits on a single substrate.

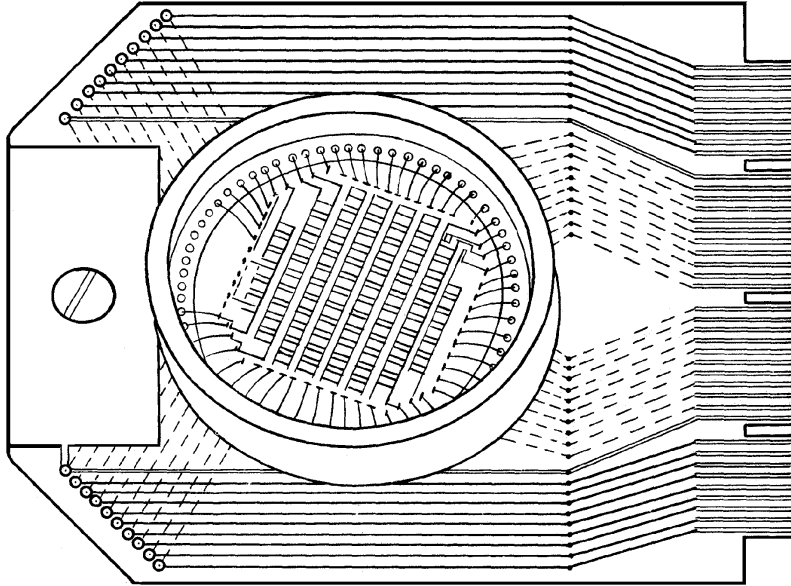


Figure 1-6.—Large-scale integration device (lsi).

Large-scale integration is generally applied to integrated circuits consisting of from 1,000 to 2,000 logic gates or from 1,000 to 64,000 bits of memory. A logic gate, as you should recall from *NEETS, Module 13, Introduction to Number Systems, Boolean Algebra, and Logic Circuits*, is an electronic switching network consisting of combinations of transistors, diodes, and resistors. Very large-scale integration is used in integrated circuits containing over 2,000 logic gates or greater than 64,000 bits of memory.

Q12. Define integrated circuit.

Q13. What are the three major types of integrated circuits?

Q14. How do monolithic ICs differ from film ICs?

Q15. What is a hybrid IC?

Q16. How many logic gates could be contained in lsi?

FABRICATION OF MICROELECTRONIC DEVICES

The purpose of this section is to give you a simplified overview of the manufacture of microelectronic devices. The process is far more complex than will be described here. Still, you will be able to see that microelectronics is not magic, but a highly developed technology.

Development of a microelectronic device begins with a demand from industry or as the result of research. A device that is needed by industry may be a simple diode network or a complex circuit consisting of thousands of components. No matter how complex the device, the basic steps of production are similar. Each type of device requires circuit design, component arrangement, preparation of a substrate, and the depositing of proper materials on the substrate.

The first consideration in the development of a new device is to determine what the device is to accomplish. Once this has been decided, engineers can design the device. During the design phase, the engineers will determine the numbers and types of components and the interconnections, needed to complete the planned circuit.

COMPONENT ARRANGEMENT

Planning the component arrangement for a microelectronic device is a very critical phase of production. Care must be taken to ensure the most efficient use of space available. With simple devices, this can be accomplished by hand. In other words, the engineers can prepare drawings of component placement. However, a computer is used to prepare the layout for complex devices. The computer is able to store the characteristics of thousands of components and can provide a printout of the most efficient component placement. Component placement is then transferred to extremely large drawings. During this step, care is taken to maintain the patterns as they will appear on the substrate. Figure 1-7 shows a fairly simple IC MASK PATTERN. If this pattern were being prepared for production, it would be drawn several hundred times the size shown and then photographed. The photo would then be reduced in size until it was the actual desired size. At that time, the pattern would be used to produce several hundred patterns that would be used on one substrate. Figure 1-8 illustrates how the patterns would be distributed to act as a WAFER MASK for manufacturing.

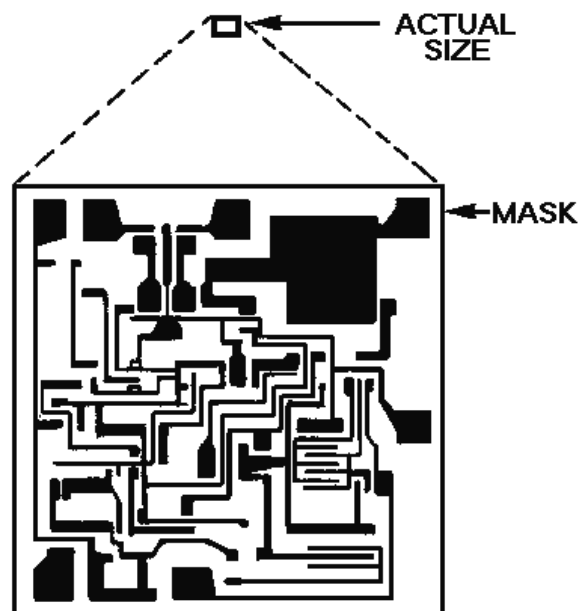


Figure 1-7.—IC mask pattern.

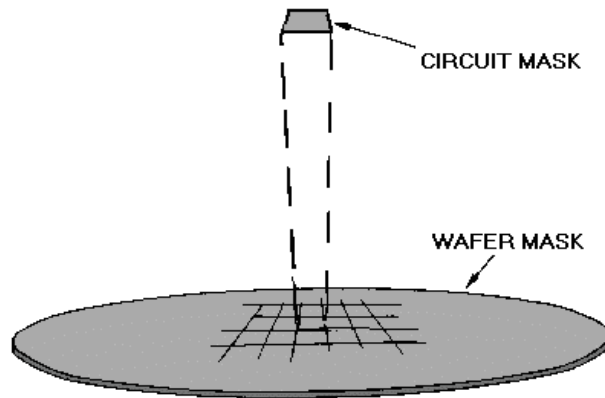


Figure 1-8.—Wafer mask distribution.

A wafer mask is a device used to deposit materials on a substrate. It allows material to be deposited in certain areas, but not in others. By changing the pattern of the mask, we can change the component arrangement of the circuit. Several different masks may be used to produce a simple microelectronic device. When used in proper sequence, conductor, semiconductor, or insulator materials may be applied to the substrate to form transistors, resistors, capacitors, and interconnecting leads.

SUBSTRATE PRODUCTION

As was mentioned earlier in this topic, microelectronic devices are produced on a substrate. This substrate will be of either insulator or semiconductor material, depending on the type of device. Film and hybrid ICs are normally constructed on a glass or ceramic substrate. Ceramic is usually the preferred material because of its durability.

Substrates used in monolithic ICs are of semiconductor material, usually silicon. In this type of IC, the substrate can be an active part of the IC. Glass or ceramic substrates are used only to provide support for the components.

Semiconductor substrates are produced by ARTIFICIALLY GROWING cylindrical CRYSTALS of pure silicon or germanium. Crystals are "grown" on a SEED CRYSTAL from molten material by slowly lifting and cooling the material repeatedly. This process takes place under rigidly controlled atmospheric and temperature conditions.

Figure 1-9 shows a typical CRYSTAL FURNACE. The seed crystal is lowered until it comes in contact with the molten material-silicon in this case. It is then rotated and raised very slowly. The seed crystal is at a lower temperature than the molten material. When the molten material is in contact with the seed, it solidifies around the seed as the seed is lifted. This process continues until the grown crystal is of the desired length. A typical crystal is about 2 inches in diameter and 10 to 12 inches long. Larger diameter crystals can be grown to meet the needs of the industry. The purity of the material is strictly controlled to maintain specific semiconductor properties. Depending on the need, n or p impurities are added to produce the desired characteristics. Several other methods of growing crystals exist, but the basic concept of crystal production is the same.

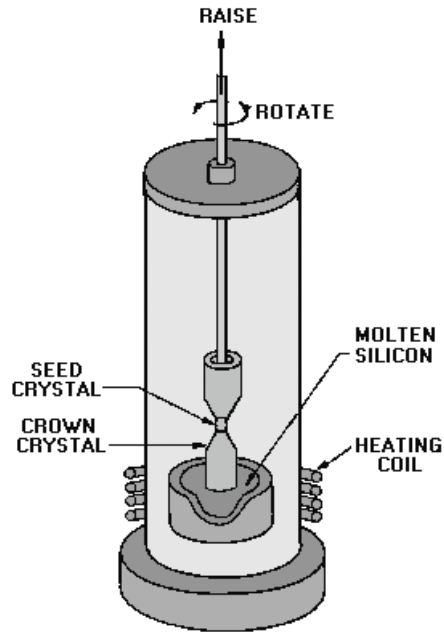


Figure 1-9.—Crystal furnace.

The cylinder of semiconductor material that is grown is sliced into thicknesses of .010 to .020 inch in the first step of preparation, as shown in figure 1-10. These wafers are ground and polished to remove any irregularities and to provide the smoothest surface possible. Although both sides are polished, only the side that will receive the components must have a perfect finish.

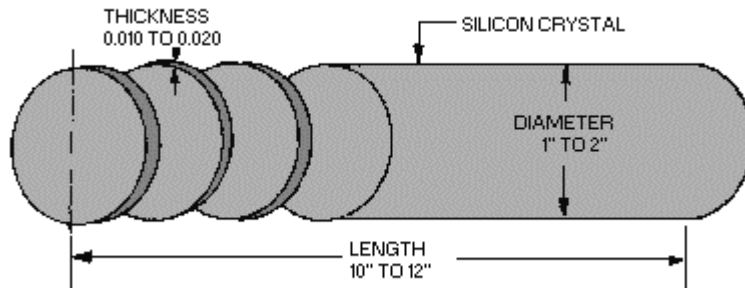


Figure 1-10.—Silicon crystal and wafers.

Q17. What are the basic steps in manufacturing an IC?

Q18. Computer-aided layout is used to prepare _____ devices.

Q19. What purpose do masks serve?

Q20. What type of substrates are used for film and hybrid ICs?

Q21. Describe the preparation of a silicon substrate.

FABRICATION OF IC DEVICES

Fabrication of monolithic ICs is the most complex aspect of microelectronic devices we will discuss. Therefore, in this introductory module, we will try to simplify this process as much as possible. Even though the discussion is very basic, the intent is still to increase your appreciation of the progress in microelectronics. You should, as a result of this discussion, come to realize that advances in manufacturing techniques are so rapid that staying abreast of them is extremely difficult.

Monolithic Fabrication.

Two types of monolithic fabrication will be discussed. These are the DIFFUSION METHOD and the EPITAXIAL METHOD.

DIFFUSION METHOD.—The DIFFUSION process begins with the highly polished silicon wafer being placed in an oven (figure 1-11). The oven contains a concentration impurity made up of impurity atoms which yield the desired electrical characteristics. The concentration of impurity atoms is diffused into the wafer and is controlled by controlling the temperature of the oven and the time that the silicon wafer is allowed to remain in the oven. This is called DOPING. When the wafer has been uniformly doped, the fabrication of semiconductor devices may begin. Several hundred circuits are produced simultaneously on the wafer.

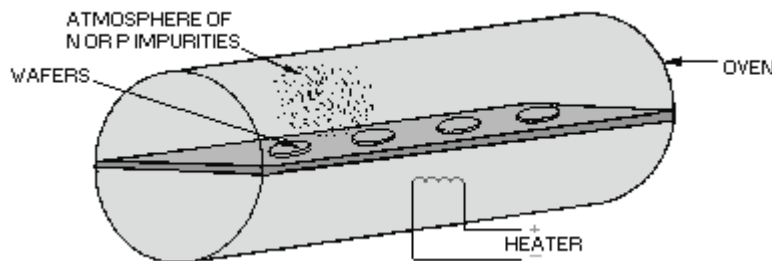


Figure 1-11.—Wafers in a diffusion oven.

The steps in the fabrication process described here, and illustrated in figure 1-12, would produce an npn, planar-diffused transistor. But, with slight variations, the technique may also be applied to the production of a complete circuit, including diodes, resistors, and capacitors. The steps are performed in the following order:

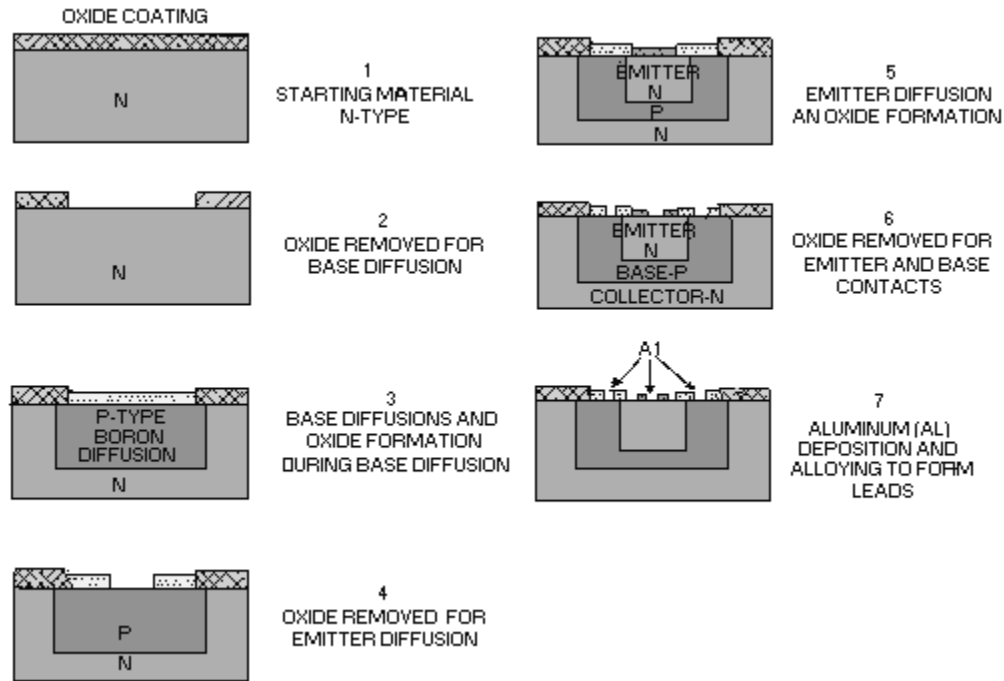


Figure 1-12.—Planar-diffused transistor.

1. An oxide coating is thermally grown over the n-type silicon starting material.
2. By means of the photolithographic process, a window is opened through the oxide layer. This is done through the use of masks, as discussed earlier.
3. The base of the transistor is formed by placing the wafer in a diffusion furnace containing a p-type impurity, such as boron. By controlling the temperature of the oven and the length of time that the wafer is in the oven, you can control the amount of boron diffused through the window (the boron will actually spread slightly beyond the window opening). A new oxide layer is then allowed to form over the area exposed by the window.
4. A new window, using a different mask much smaller than the first, is opened through the new oxide layer.
5. An n-type impurity, such as phosphorous, is diffused through the new window to form the emitter portion of the transistor. Again, the diffused material will spread slightly beyond the window opening. Still another oxide layer is then allowed to form over the window.
6. By means of precision-masking techniques, very small windows (about 0.005 inch in diameter) are opened in both the base and emitter regions of the transistor to provide access for electrical currents.
7. Aluminum is then deposited in these windows and alloyed to form the leads of the transistor or the IC.

(Note that the pn junctions are covered throughout the fabrication process by an oxide layer that prevents contamination.)

EPITAXIAL METHOD.—The EPITAXIAL process involves depositing a very thin layer of silicon to form a uniformly doped crystalline region (epitaxial layer) on the substrate. Components are produced by diffusing appropriate materials into the epitaxial layer in the same way as the planar-diffusion method. When planar-diffusion and epitaxial techniques are combined, the component characteristics are improved because of the uniformity of doping in the epitaxial layer. A cross section of a typical planar-epitaxial transistor is shown in figure 1-13. Note that the component parts do not penetrate the substrate as they did in the planar-diffused transistor.

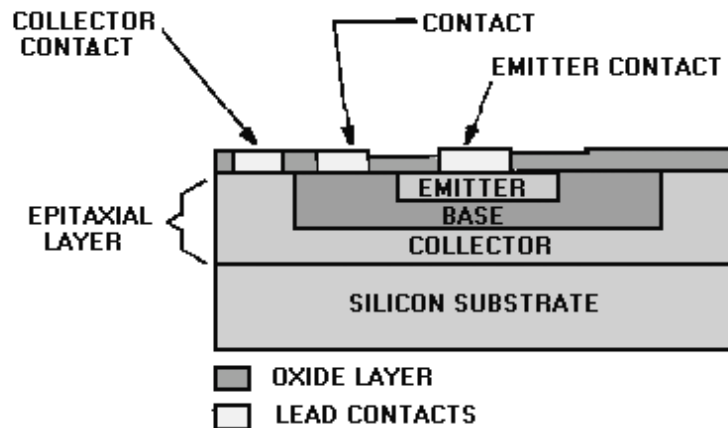


Figure 1-13.—Planar-epitaxial transistor.

ISOLATION.—Because of the closeness of components in ICs, ISOLATION from each other becomes a very important factor. Isolation is the prevention of unwanted interaction or leakage between components. This leakage could cause improper operation of a circuit.

Techniques are being developed to improve isolation. The most prominent is the use of silicon oxide, which is an excellent insulator. Some manufacturers are experimenting with single-crystal silicon grown on an insulating substrate. Other processes are also used which are far too complex to go into here. With progress in isolation techniques, the reliability and efficiency of ICs will increase rapidly.

Thin Film

Thin film is the term used to describe a technique for depositing passive circuit elements on an insulating substrate with coating to a thickness of 0.0001 centimeter. Many methods of thin-film deposition exist, but two of the most widely used are VACUUM EVAPORATION and CATHODE SPUTTERING.

VACUUM EVAPORATION.—Vacuum evaporation is a method used to deposit many types of materials in a highly evacuated chamber in which the material is heated by electricity, as shown in figure 1-14. The material is radiated in straight lines in all directions from the source and is shadowed by any objects in its path.

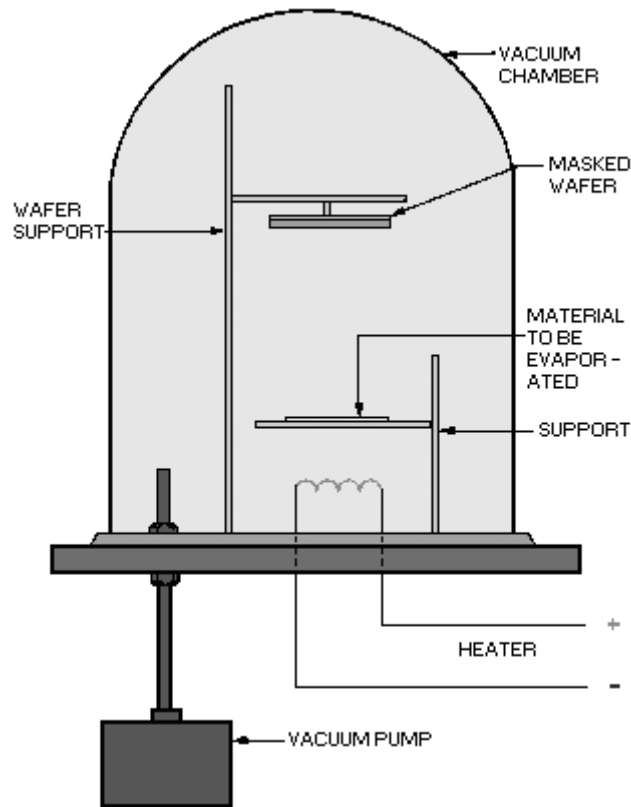


Figure 1-14.—Vacuum evaporation oven.

The wafers, with appropriate masks (figure 1-15), are placed above and at some distance from the material being evaporated. When the process is completed, the vacuum is released and the masks are removed from the wafers. This process leaves a thin, uniform film of the deposition material on all parts of the wafers exposed by the open portions of the mask. This process is also used to deposit interconnections (leads) between components of an IC.

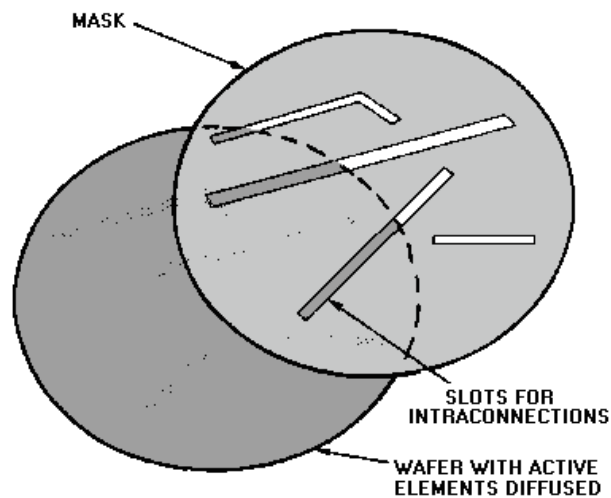


Figure 1-15.—Evaporation mask.

The vacuum evaporation technique is most suitable for deposition of highly reactive materials, such as aluminum, that are difficult to work with in air. The method is clean and allows a better contact between the layer of deposited material and the surface upon which it has been deposited. In addition, because evaporation beams travel in straight lines, very precise patterns may be produced.

CATHODE-SPUTTERING.—A typical cathode-sputtering system is illustrated in figure 1-16. This process is also performed in a vacuum. A potential of 2 to 5 kilovolts is applied between the anode and cathode (source material). This produces a GLOW DISCHARGE in the space between the electrodes. The rate at which atoms are SPUTTERED off the source material depends on the number of ions that strike it and the number of atoms ejected for each ion bombardment. The ejected atoms are deposited uniformly over all objects within the chamber. When the sputtering cycle is completed, the vacuum in the chamber is released and the wafers are removed. The masks are then removed from the wafers, leaving a deposit that forms the passive elements of the circuit, as shown in figure 1-17.

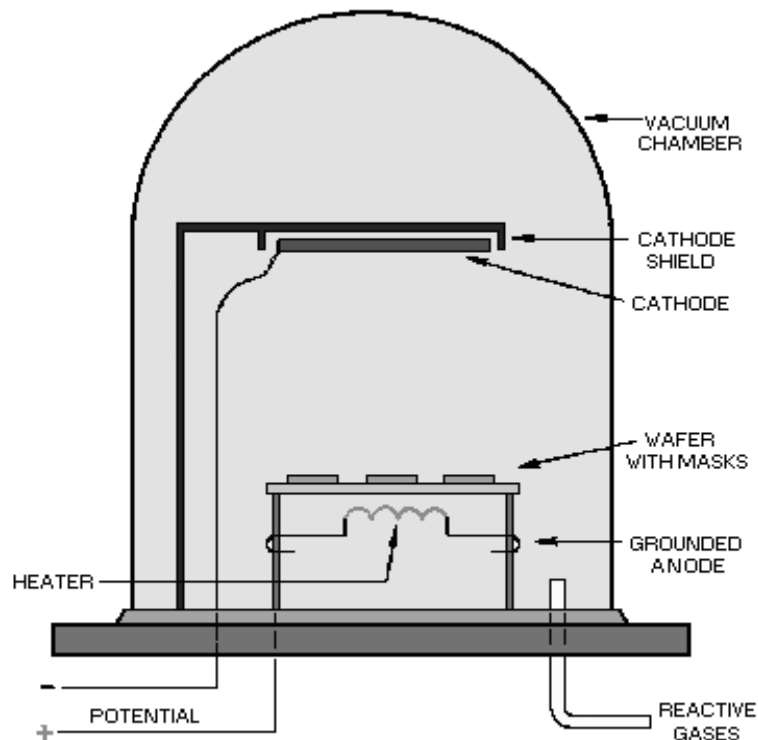


Figure 1-16.—Cathode-sputtering system.

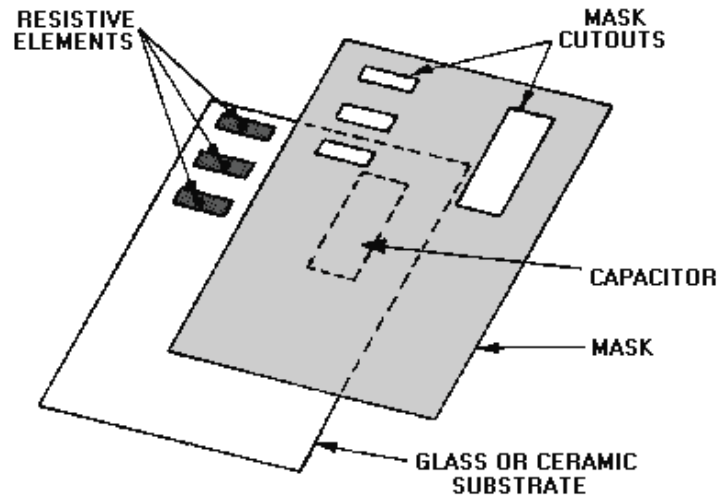


Figure 1-17.—Cathode-sputtering mask.

Finely polished glass, glazed ceramic, and oxidized silicon have been used as substrate materials for thin films. A number of materials, including nichrome, a compound of silicon oxide and chromium cermet, tantalum, and titanium, have been used for thin-film resistors. Nichrome is the most widely used.

The process for producing thin-film capacitors involves deposition of a bottom electrode, a dielectric, and finally a top electrode. The most commonly used dielectric materials are silicon monoxide and silicon dioxide.

Thick Film

Thick films are produced by screening patterns of conducting and insulating materials on ceramic substrates. A thick film is a film of material with a thickness that is at least 10 times greater than the mean free path of an electron in that material, or approximately 0.001 centimeter. The technique is used to produce only passive elements, such as resistors and capacitors.

PROCEDURES.—One procedure used in fabricating a thick film is to produce a series of stencils called **SCREENS**. The screens are placed on the substrate and appropriate conducting or insulating materials are wiped across the screen. Once the conducting or insulating material has been applied, the screens are removed and the formulations are fired at temperatures above 600 degrees Celsius. This process forms alloys that are permanently bonded to the insulating substrate. To a limited extent, the characteristics of the film can be controlled by the firing temperature and length of firing time.

RESISTORS.—Thick-film resistance values can be held to a tolerance of ± 10 percent. Closer tolerances are obtained by trimming each resistor after fabrication. Hundreds of different cermet formulations are used to produce a wide range of component parameters. For example, the material used for a 10-ohm-per-square resistor is quite different from that used for a 100-kilohm-per-square resistor.

CAPACITORS AND RESISTOR-CAPACITOR NETWORKS.—Capacitors are formed by a sequence of screenings and firings. Capacitors in this case consist of a bottom plate, intraconnections, a dielectric, and a top plate. For resistor-capacitor networks, the next step would be to deposit the resistor material through the screen. The final step is screening and firing of a glass enclosure to seal the unit.

Hybrid Microcircuit

A hybrid microcircuit is one that is fabricated by combining two or more circuit types, such as film and semiconductor circuits, or a combination of one or more circuit types and discrete elements. The primary advantage of hybrid microcircuits is design flexibility; that is, hybrid microcircuits can be designed to provide wide use in specialized applications, such as low-volume and high-frequency circuits.

Several elements and circuits are available for hybrid applications. These include discrete components that are electrically and mechanically compatible with ICs. Such components may be used to perform functions that are supplementary to those of ICs. They can be handled, tested, and assembled with essentially the same technology and tools. A hybrid IC showing an enlarged chip is shown in figure 1-18.

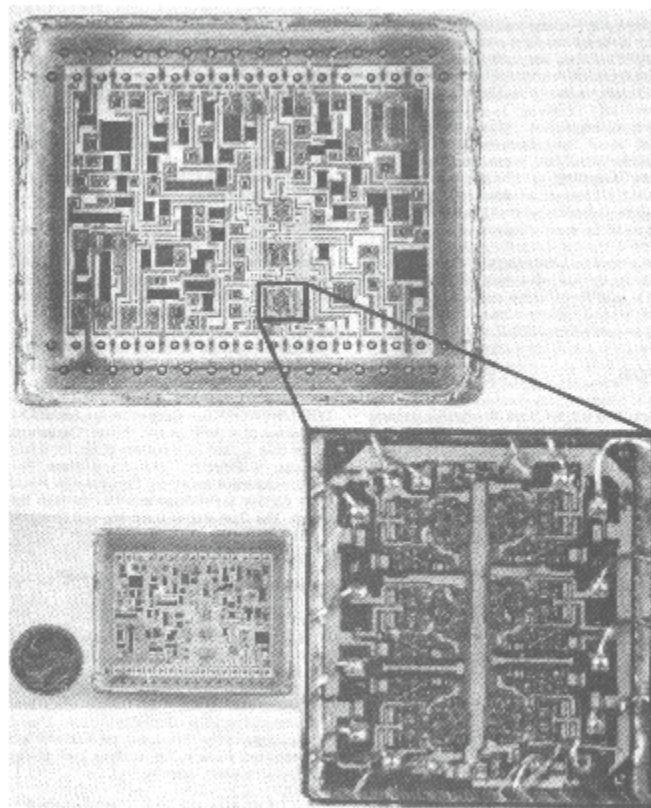


Figure 1-18.—Hybrid IC showing an enlarged chip.

Complete circuits are available in the form of UNCASSED CHIPS (UNENCAPSULATED IC DICE). These chips are usually identical to those sold as part of the manufacturer's regular production line. They must be properly packaged and connected by the user if a high-quality final assembly is to be obtained. The circuits are usually sealed in a package to protect them from mechanical and environmental stresses. One-mil (0.001-inch), gold-wire leads are connected to the appropriate pins which are brought out of the package to allow external connections.

Q22. Name the two types of monolithic IC construction discussed.

Q23. How do the two types of monolithic IC construction differ?

Q24. What is isolation?

Q25. What methods are used to deposit thin-film components on a substrate?

Q26. How are thick-film components produced?

Q27. What is a hybrid IC?

Q28. What is the primary advantage of hybrid circuits?

PACKAGING TECHNIQUES

Once the IC has been produced, it requires a housing that will protect it from damage. This damage could result from moisture, dirt, heat, radiation, or other sources. The housing protects the device and aids in its handling and connection into the system in which the IC is used. The three most common types of packages are the modified TRANSISTOR-OUTLINE (TO) PACKAGE, the FLAT PACK, and the DUAL INLINE PACKAGE (DIP).

Transistor-Outline Package

Transistor-Outline Package. The transistor-outline (TO) package was developed from early experience with transistors. It was a reliable package that only required increasing the number of leads to make it useful for ICs. Leads normally number between 2 and 12, with 10 being the most common for IC applications. Figure 1-19 is an exploded view of a TO-5 package. Once the IC has been attached to the header, bonding wires are used to attach the IC to the leads. The cover provides the necessary protection for the device. Figure 1-20 is an enlarged photo of an actual TO-5 with the cover removed. You can easily see that the handling of an IC without packaging would be difficult for a technician.

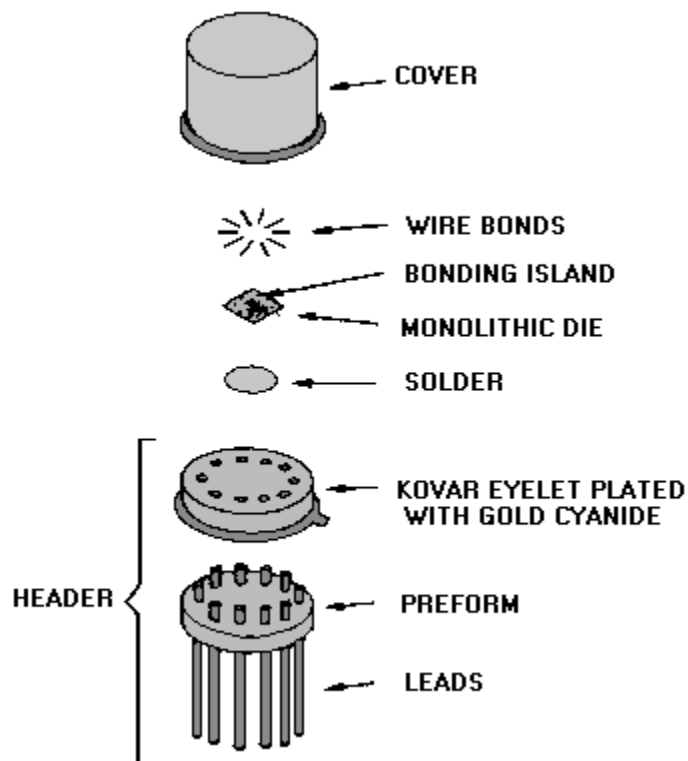


Figure 1-19.—Exploded TO-5.

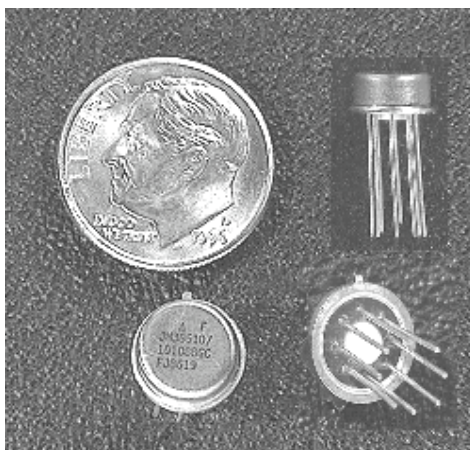


Figure 1-20.—TO-5 package.

The modified TO-5 package (figure 1-21) can be either plugged into [view (A)] or embedded in [view (B)] a board. The embedding method is preferred. Whether the package is plugged in or embedded, the interconnection area of the package leads must have sufficient clearance on both sides of the board. The plug-in method does not provide sufficient clearance between pads to route additional circuitry. When the packages are embedded, sufficient space exists between the pads [because of the increased diameter of the interconnection pattern, shown at the right in view (B)] for additional conductors.

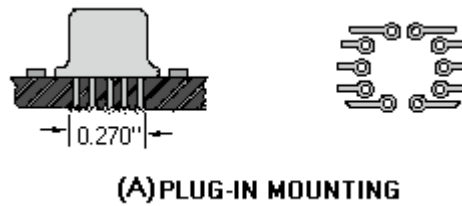


Figure 1-21A.—TO-5 mounting PLUG-IN MOUNTING

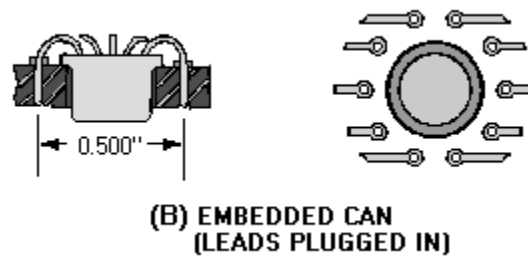


Figure 1-21B.—TO-5 mounting EMBEDDED CAN(LEADS PLUGGED IN)

Flat Pack

Many types of IC flat packs are being produced in various sizes and materials. These packages are available in square, rectangular, oval, and circular configurations with 10 to 60 external leads. They may be

made of metal, ceramic, epoxy, glass, or combinations of those materials. Only the ceramic flat pack will be discussed here. It is representative of all flat packs with respect to general package requirements (see figure 1-22).

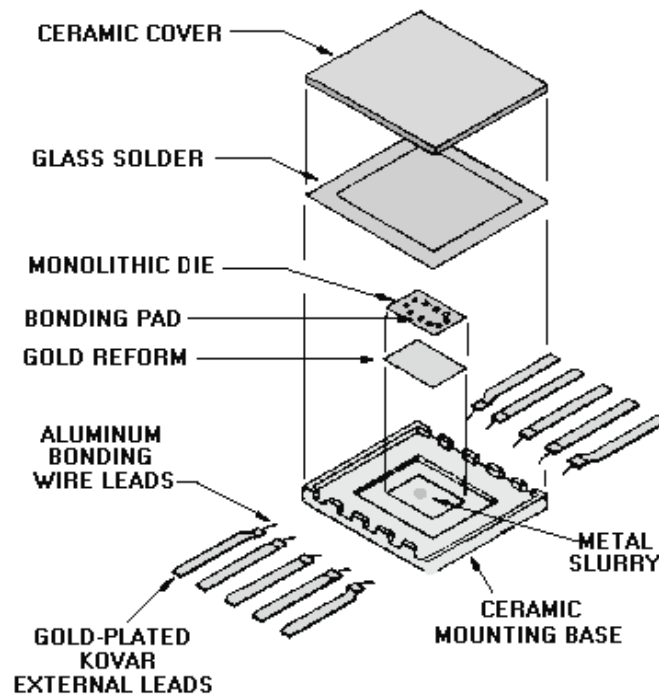


Figure 1-22.—Enlarged flat pack exploded view.

After the external leads are sealed to the mounting base, the rectangular area on the inside bottom of the base is treated with metal slurry to provide a surface suitable for bonding the monolithic die to the base. The lead and the metalized area in the bottom of the package are plated with gold. The die is then attached by gold-silicon bonding.

The die-bonding step is followed by bonding gold or aluminum wires between the bonding islands on the IC die and on the inner portions of the package leads. Next, a glass-soldered preformed frame is placed on top of the mounting base. One surface of the ceramic cover is coated with Pyrocera glass, and the cover is placed on top of the mounting base. The entire assembly is placed in an oven at 450 degrees Celsius. This causes the glass solder and Pyrocera to fuse and seal the cover to the mounting base. A ceramic flat pack is shown in figure 1-23. It has been opened so that you can see the chip and bonding wires.



Figure 1-23.—Typical flat pack.

Dual Inline Package

The dual inline package (DIP) was designed primarily to overcome the difficulties associated with handling and inserting packages into mounting boards. DIPs are easily inserted by hand or machine and require no spreaders, spacers, insulators, or lead-forming tools. Standard hand tools and soldering irons can be used to field-service the devices. Plastic DIPs are finding wide use in commercial applications, and a number of military systems are incorporating ceramic DIPs.

The progressive stages in the assembly of a ceramic DIP are illustrated in figure 1-24, views (A) through (E). The integrated-circuit die is sandwiched between the two ceramic elements, as shown in view (A). The element on the left of view (A) is the bottom half of the sandwich and will hold the integrated-circuit die. The ceramic section on the right is the top of the sandwich. The large well in view (B) protects the IC die from mechanical stress during sealing operations. Each of the ceramic elements is coated with glass which has a low melting temperature for subsequent joining and sealing. View (B) shows the Kovar lead frame stamped and bent into its final shape. The excess material is intended to preserve pin alignment. The holes at each end are for the keying jig used in the final sealing operation. The lower half of the ceramic package is inserted into the lead frame shown in view (C). The die is mounted in the well and leads are attached. The top ceramic elements are bonded to the bottom element shown in view (D) and the excess material is removed from the package. View (E) is the final product.

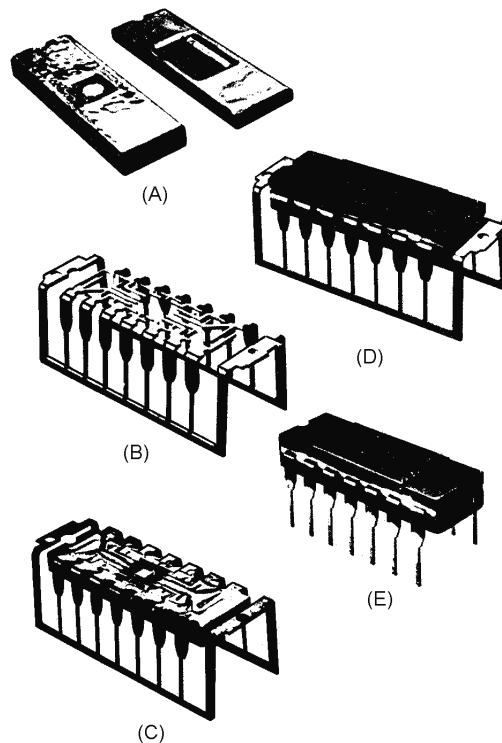


Figure 1-24.—DIP packaging steps.

Ceramic DIPs are processed individually while plastic DIPs are processed in quantities of two or more (in chain fashion). After processing, the packages are sawed apart. The plastic package also uses a Kovar lead frame, but the leads are not bent until the package is completed. Because molded plastic is

used to encapsulate the IC die, no void will exist between the cover and die, as is the case with ceramic packaging.

At present, ceramic DIPs are the most common of the two package types to be found in Navy microelectronic systems. Figure 1-25 shows a DIP which has been opened.

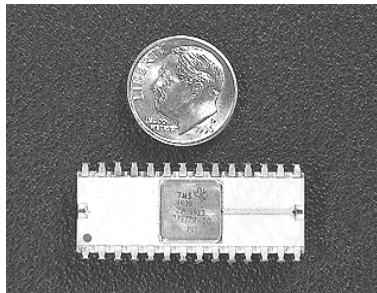


Figure 1-25.—Dual inline package (DIP).

RECENT DEVELOPMENTS IN PACKAGING

Considerable effort has been devoted to eliminating the fine wires used to connect ICs to Kovar leads. The omission of these wires reduces the cost of integrated circuits by eliminating the costs associated with the bonding process. Further, omission of the wires improves reliability by eliminating a common cause of circuit failure.

A promising packaging technique is the face-down (FLIP-CHIP) mounting method by which conductive patterns are evaporated inside the package before the die is attached. These patterns connect the external leads to bonding pads on the inside surface of the die. The pads are then bonded to appropriate pedestals on the package that correspond to those of the bonding pads on the die (figure 1-26).

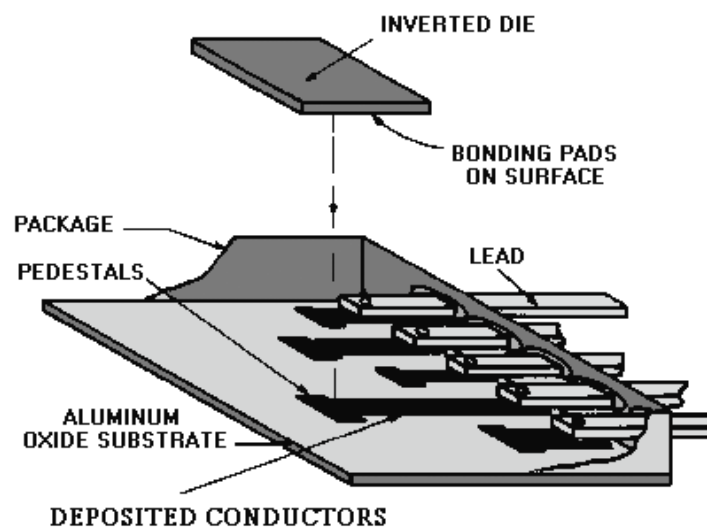


Figure 1-26.—Flip-chip package.

The BEAM-LEAD technique is a process developed to batch-fabricate (fabricate many at once) semiconductor circuit elements and integrated circuits with electrodes extended beyond the edges of the

wafer, as shown in figure 1-27. This type of structure imposes no electrical difficulty, and parasitic capacitance (under 0.05 picofarad per lead) is equivalent to that of a wire-bonded and brazed-chip assembly. In addition, the electrodes may be tapered to allow for lower inductance, impedance matching, and better heat conductance. The beam-lead technique is easily accomplished and does not have the disadvantages of chip brazing and wire bonding. The feasibility of this technique has been demonstrated in a variety of digital, linear, and thin-film circuits.

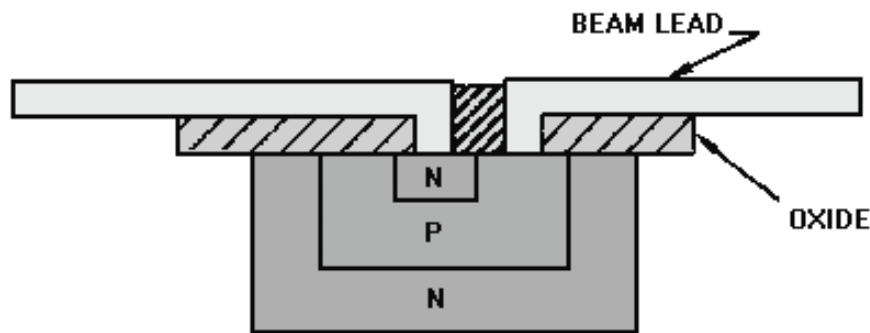


Figure 1-27.—Beam-lead technique.

Another advance in packaging is that of increasing the size of DIPs. General purpose DIPs have from 4 to 16 pins. Because of lsi and vlsi, manufacturers are producing DIPs with up to 64 pins. Although size is increased considerably, all the advantages of the DIP are retained. DIPs are normally designed to a particular specification set by the user.

Q29. What is the purpose of the IC package?

Q30. What are the three most common types of packages?

Q31. What two methods of manufacture are being used to eliminate bonding wires?

EQUIVALENT CIRCUITS

At the beginning of this topic, we discussed many applications of microelectronics. You should understand that these applications cover all areas of modern electronics technology. Microelectronic ICs are produced that can be used in many of these varying circuit applications to satisfy the needs of modern technology. This section will introduce you to some of these applications and will show you some EQUIVALENT CIRCUIT comparisons of discrete components and integrated circuits.

J-K FLIP-FLOP AND IC SIZES

Integrated circuits can be produced that combine all the elements of a complete electronic circuit. This can be done with either a single chip of silicon or a single chip of silicon in combination with film components. The importance of this new production method in the evolution of microelectronics can be demonstrated by comparing a conventional J-K flip-flop circuit incorporating solid-state discrete devices and the same type of circuit employing integrated circuitry. (A J-K flip-flop is a circuit used primarily in computers.)

You should recall from *NEETS, Module 13, Introduction to Number Systems, Boolean Algebra, and Logic Circuits*, that a basic flip-flop is a device having two stable states and two input terminals (or types of input signals), each of which corresponds to one of the two states. The flip-flop remains in one state until caused to change to the other state by application of an input voltage pulse.

A J-K flip-flop differs from the basic flip-flop because it has a third input terminal. A clock pulse, or trigger, is usually applied to this input to ensure proper timing in the circuit. An input signal must occur at the same time as the clock pulse to change the state of the flip-flop. The conventional J-K flip-flop circuit in figure 1-28 requires approximately 40 discrete components, 200 connections, and 300 processing operations. Each of these 300 operations (seals and connections) represents a possible source of failure. If all the elements of this circuit are integrated into one chip of silicon, the number of connections drops to approximately 14. This is because all circuit elements are intraconnected inside the package and the 300 processing operations are reduced to approximately 30. Figure 1-29 represents a size comparison of a discrete J-K circuit and an integrated circuit of the same type.

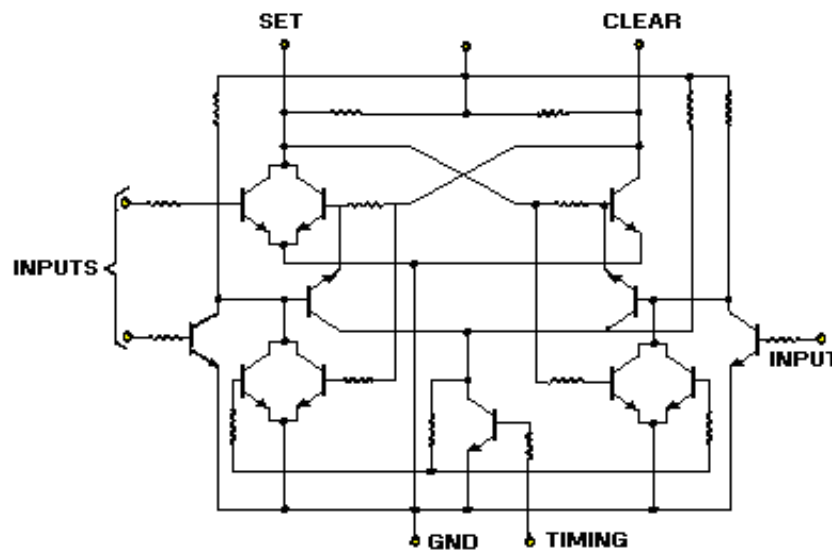


Figure 1-28.—Schematic diagram of a J-K flip-flop.

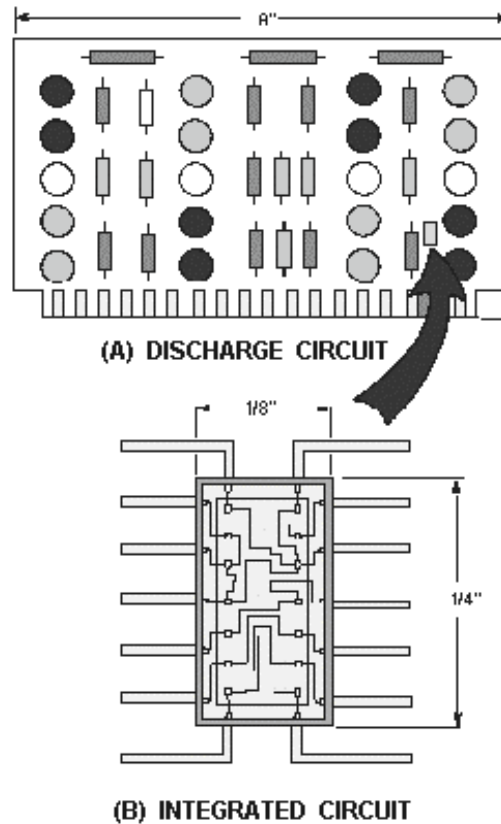


Figure 1-29.—J-K flip-flop discrete component and an IC.

IC PACKAGE LEAD IDENTIFICATION (NUMBERING)

When you look at an IC package you should notice that the IC could be connected incorrectly into a circuit. Such improper replacement of a component would likely result in damage to the equipment. For this reason, each IC has a **REFERENCE MARK** to align the component for placement. The dual inline package (both plastic and ceramic) and the flat pack have a notch, dot, or impression on the package. When the package is viewed from the top, pin 1 will be the first pin in the *counterclockwise* direction next to the reference mark. Pin 1 may also be marked directly by a hole or notch or by a tab on it (in this case pin 1 is the counting reference). When the package is viewed from the top, all other pins are numbered consecutively in a *counterclockwise* direction from pin 1, as shown in figure 1-30, views (A) and (B).

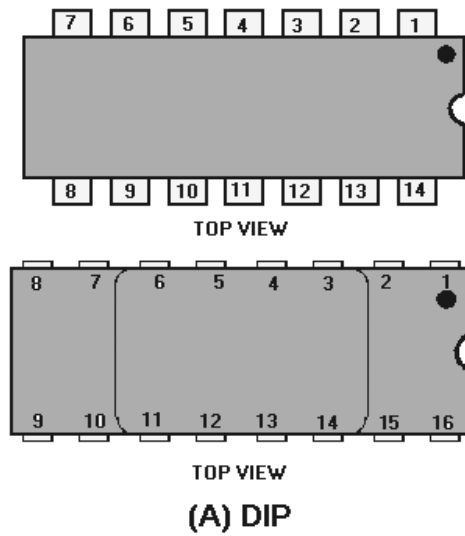


Figure 1-30A.—DIP and flat-pack lead numbering, DIP

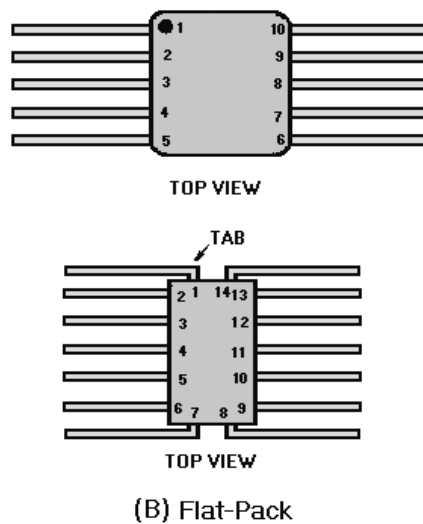


Figure 1-30B.—DIP and flat-pack lead numbering, Flat-Pack

The TO-5 can has a tab for the reference mark. When numbering the leads, you must view the TO-5 can from the *bottom*. Pin 1 will be the first pin in a *clockwise* direction from the tab. All other pins will be numbered consecutively in a clockwise direction from pin 1, as shown in figure 1-31.

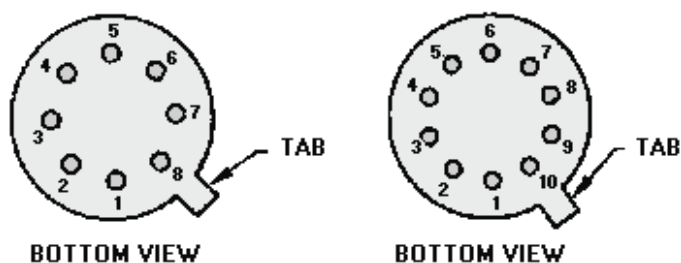


Figure 1-31.—Lead numbering for a TO-5.

IC IDENTIFICATION

As mentioned earlier, integrated circuits are designed and manufactured for hundreds of different uses. Logic circuits, clock circuits, amplifiers, television games, transmitters, receivers, and musical instruments are just a few of these applications.

In schematic drawings, ICs are usually represented by one of the schematic symbols shown in figure 1-32. The IC is identified *according to its use* by the numbers printed on or near the symbol. That series of numbers and letters is also stamped on the case of the device and can be used along with the data sheet, as shown in the data sheet in figure 1-33, by circuit designers and maintenance personnel. This data sheet is provided by the manufacturer. It provides a schematic diagram and describes the type of device, its electrical characteristics, and typical applications. The data sheet may also show the pin configurations with all pins labeled. If the pin configurations are not shown, there may be a schematic diagram showing pin functions. Some data sheets give both pin configurations and schematic diagrams, as shown in figure 1-34. This figure illustrates a manufacturer's data sheet with all of the pin functions shown.

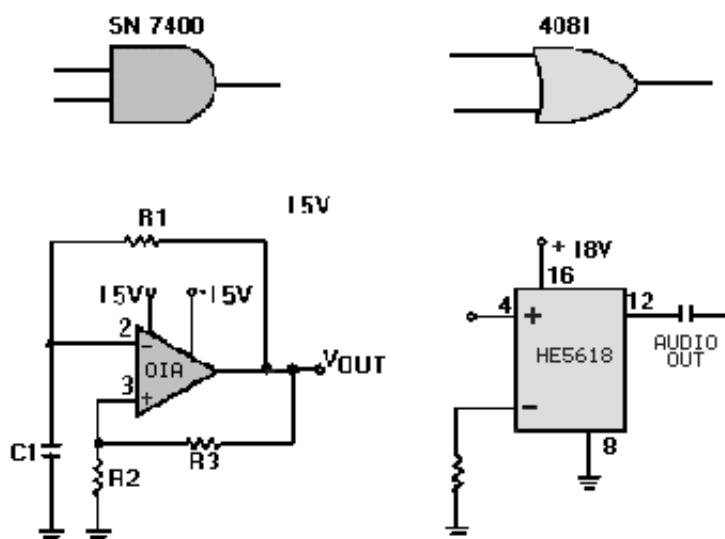


Figure 1-32.—Some schematic symbols for ICs.

LH101 LH201 OPERATIONAL AMPLIFIER

FOR AMPLIFIERS, VOLTAGE COMPARATORS, LOW DRIFT SAMPLE-AND-HOLD

Features

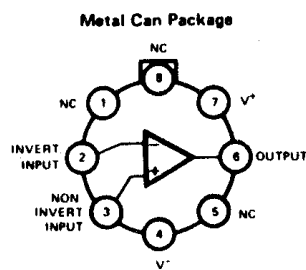
- Low Offsets and Temperature Drift
- Internal 30 pF Capacitor for Frequency Compensation
- Operation from ± 5 to ± 20 Volt Power Supplies
- Low Current Drain, 1.8 mA at ± 20 Volts Typical
- Continuous Short-Circuit Protection

- No Latch Up When Common Mode Range Is Exceeded
- Same Pin Configuration as 709 Amplifier

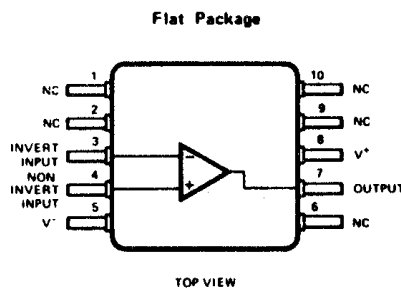
Description

The LH101/LH201 is stable for all feedback configurations, even with capacitive loads, with no external compensation capacitors. Low power dissipation permits high voltage operation across the full temperature range.

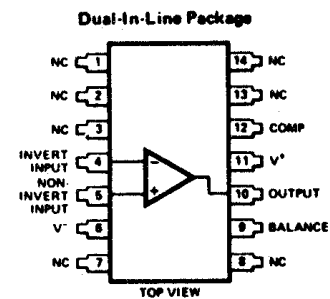
PIN CONFIGURATIONS



ORDER NUMBERS: LH101H OR LH201H
SEE PACKAGE 1

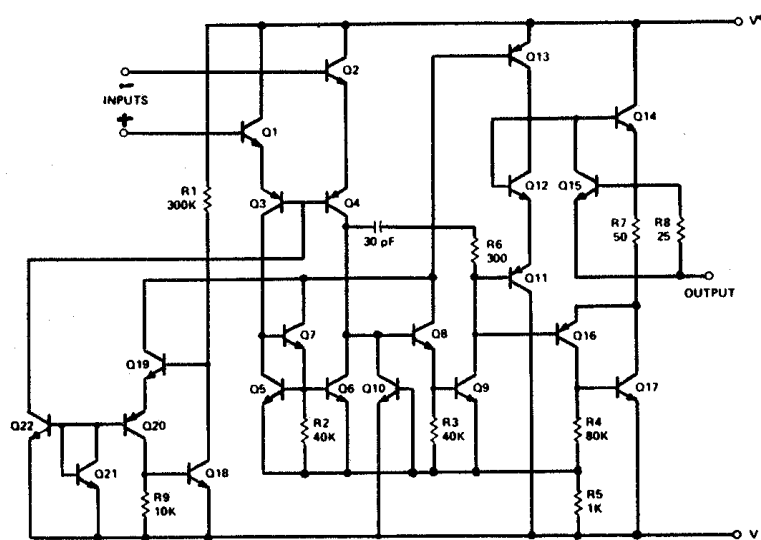


ORDER NUMBERS: LH101F OR LH201F
SEE PACKAGE 4



ORDER NUMBERS: LH101D OR LH201D
SEE PACKAGE 11

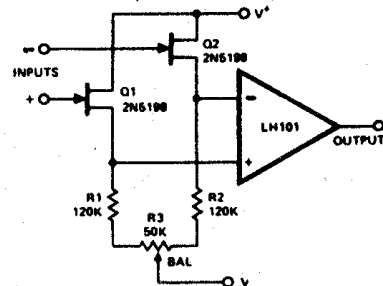
SCHEMATIC DIAGRAM



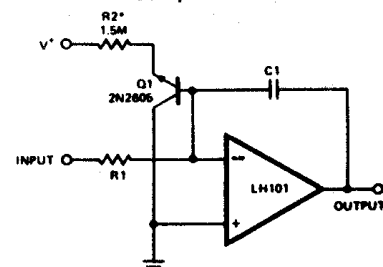
* NC - NOT CONNECTED INTERNALLY

TYPICAL APPLICATIONS

FET Operational Amplifier



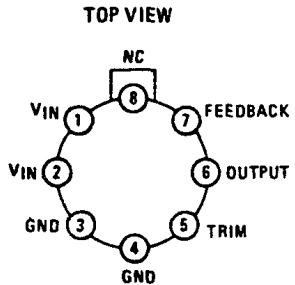
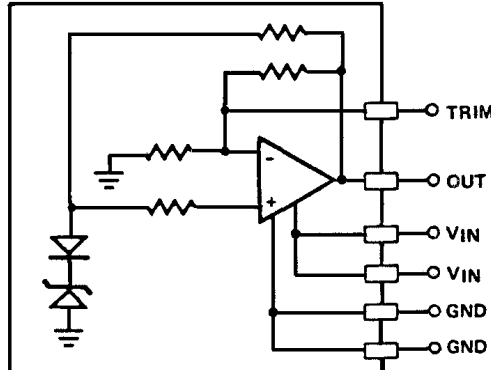
Integrator with Bias Current Compensation



*SELECT FOR ZERO INTEGRATOR DRIFT.

Courtesy of Siliconix Incorporated

Figure 1-33.—Manufacturer's Data Sheet.

FEATURES	DESCRIPTION
<ul style="list-style-type: none"> ● MONOLITHIC CONSTRUCTION ● INITIAL ACCURACY $+10V \pm 0.010V$ ● OUTPUT VOLTAGE ERROR, TOTAL $\pm 1/4$ LSB ● LOW NOISE $20\mu V_{p-p}$ ● WIDE INPUT RANGE 12V TO 30V ● LOW POWER DISSIPATION 30mW ● OUTPUT SHORT CIRCUIT PROTECTION ● ADJUSTABLE OUTPUT 	<p>HA-1608 is a monolithic +10V adjustable voltage reference featuring accuracy and temperature stability specifications detailed exclusively for 8 bit data conversion systems. A stable +10V output is provided by a reference zener and buffer amplifier coupled with laser trimmed feedback and zener bias resistors. Long term stability is ensured through integration of all reference components into a monolithic design. Flexibility of HA-1608 is provided through an external trim control which allows the user to adjust the output voltage for binary or BCD applications without affecting overall performance.</p> <p>These devices provide a total output voltage error of $\pm 1/4$ LSB for 8 bit D/A or A/D converters. Low standby power (0.3mW) makes HA-1608 a natural selection for portable battery operated equipment, comparator references, and reference stacking circuits. These devices can also be used on -10V references.</p>
APPLICATIONS	
<ul style="list-style-type: none"> ● AN ECONOMICAL EXTERNAL REFERENCE FOR: HI-5608; DAC 08; AD1408; AD559 ● VOLTAGE REGULATOR REFERENCE ● PORTABLE BATTERY OPERATED EQUIPMENT ● NEGATIVE 10V REFERENCE 	<p>HA-1608 is packaged in 8 pin metal cans (TO-99) and 8 pin DIPs. The pinout is arranged for convenient replacement of other less accurate regulators in applications demanding minimal change with temperature and time. HA-1608-2 is specified for -55°C to +125°C operation while the HA-1608-5 operates from 0°C to +75°C.</p>
PINOUT	FUNCTIONAL SCHEMATIC
<p style="text-align: center;">Section 11 for Packaging</p> <p style="text-align: center;">TOP VIEW</p>  <p>✱ NC - NOT CONNECTED INTERNALLY</p>	

Courtesy of Harris Semiconductors

Figure 1-34.—Manufacturer's Data Sheet.

Q32. On DIP and flat-pack ICs viewed from the top, pin 1 is located on which side of the reference mark?

Q33. DIP and flat-pack pins are numbered consecutively in what direction?

Q34. DIP and flat-pack pins are numbered consecutively in what direction?

Q35. Viewed from the bottom, TO-5 pins are counted in what direction?

Q36. The numbers and letters on ICs and schematics serve what purpose?

MICROELECTRONIC SYSTEM DESIGN CONCEPTS

You should understand the terminology used in microelectronics to become an effective and knowledgeable technician. You should be familiar with packaging concepts from a maintenance standpoint and be able to recognize the different types of assemblies. You should also know the electrical and environmental factors that can affect microelectronic circuits. In the next section of this topic we will define and discuss each of these areas.

TERMINOLOGY

As in any special electronics field, microelectronics terms and definitions are used to clarify communications. This is done so that everyone involved in microelectronics work has the same knowledge of the field. You can imagine how much trouble you would have remembering 10 or more different names and definitions for a resistor. If standardization didn't exist for the new terminology, you would have far more trouble understanding microelectronics. To standardize terminology in microelectronics, the Navy has adopted several definitions with which you should become familiar. These definitions will be presented in this section.

Microelectronics

Microelectronics is that area of electronics technology associated with electronics systems built from extremely small electronic parts or elements. Most of today's computers, weapons systems, navigation systems, communications systems, and radar systems make extensive use of microelectronics technology.

Microcircuit

A microcircuit is not what the old-time technician would recognize as an electronic circuit. The old-timer would no longer see the familiar discrete parts (individual resistors, capacitors, inductors, transistors, and so forth). Microelectronic circuits, as discussed earlier, are complete circuits mounted on a substrate (integrated circuit). The process of fabricating microelectronic circuits is essentially one of building discrete component characteristics either into or onto a single substrate. This is far different from soldering resistors, capacitors, transistors, inductors, and other discrete components into place with wires and lugs. The component characteristics built into microcircuits are referred to as ELEMENTS rather than discrete components. Microcircuits have a high number of these elements per substrate compared to a circuit with discrete components of the same relative size. As a matter of fact, microelectronic circuits often contain thousands of times the number of discrete components. The term HIGH EQUIVALENT CIRCUIT DENSITY is a description of this element-to-discrete part relationship. For example, suppose you have a circuit with 1,000 discrete components mounted on a chassis which is $8 \times 10 \times 2$ inches. The equivalent circuit in microelectronics might be built into or onto a single substrate which is only $3/8 \times 1 \times 1/4$ inch. The 1,000 elements of the microcircuit would be very close to each other (high density) by

comparison to the distance between discrete components mounted on the large chassis. The elements within the substrate are interconnected on the single substrate itself to perform an electronic function. A microcircuit does not have any discrete components mounted on it as do printed circuit boards, circuit card assemblies, and modules composed exclusively of discrete component parts.

Microcircuit Module

Microcircuits may be used in combination with discrete components. An assembly of microcircuits or a combination of microcircuits and discrete conventional electronic components that performs one or more distinct functions is a microcircuit module. The module is constructed as an independently packaged, replaceable unit. Examples of microcircuit modules are printed circuit boards and circuit card assemblies. Figure 1-35 is a photograph of a typical microcircuit module.

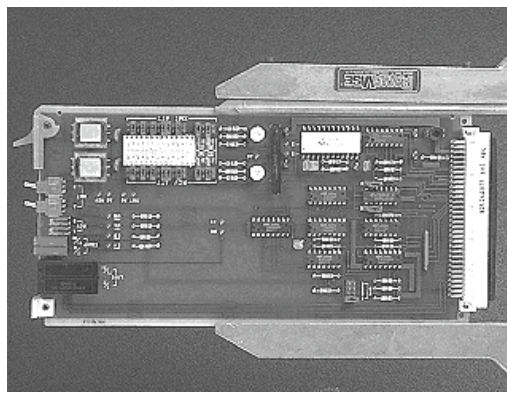


Figure 1-35.—Microcircuit module.

Miniature Electronics

Miniature electronics includes miniature electronic components and packages. Some examples are printed circuit boards, printed wiring boards, circuit card assemblies, and modules composed *exclusively* of discrete electronic parts and components (excluding microelectronic packages) mounted on boards, assemblies, or modules. MOTHER BOARDS, large printed circuit boards with plug-in modules, are considered miniature electronics. Cordwood modules also fall into this category. Miniature motors, synchros, switches, relays, timers, and so forth, are also classified as miniature electronics.

Recall that microelectronic components contain integrated circuits. Miniature electronics contain discrete elements or parts. You will notice that printed circuit boards and circuit card assemblies are mentioned in more than one definition. To identify the class (microminiature or miniature) of the unit, you must first determine the types of components used.

Q37. Standardized terms improve what action between individuals?

Q38. Microcircuit refers to any component containing what types of elements?

Q39. Components made up exclusively of discrete elements are classified as what type of electronics?

SYSTEM PACKAGING

When a new electronics system is developed, several areas of planning require special attention. An area of great concern is that of ensuring that the system performs properly. The designer must take into

account all environmental and electrical factors that may affect the system. This includes temperature, humidity, vibration, and electrical interference. The design factor that has the greatest impact on you, as the technician, is the MAINTAINABILITY of the system. The designer must take into account how well you will be able to locate problems, identify the faulty components, and make the necessary repairs. If a system cannot be maintained easily, then it is not an efficient system. PACKAGING, the method of enclosing and mounting components, is of primary importance in system maintainability.

Levels of Packaging

For the benefit of the technician, system packaging is usually broken down to five levels (0 to IV). These levels are shown in figure 1-36.

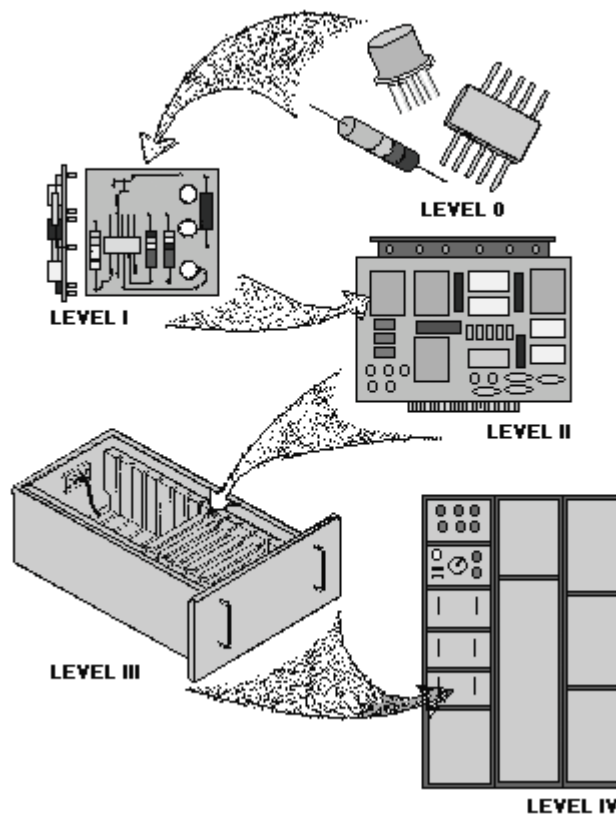


Figure 1-36.—Packaging levels.

LEVEL 0.—Level 0 packaging identifies nonrepairable parts, such as integrated circuits, transistors, resistors, and so forth. This is the lowest level at which you can perform maintenance. You are limited to simply replacing the faulty element or part. Depending on the type of part, repair might be as simple as plugging in a new relay. If the faulty part is an IC, special training and equipment will be required to accomplish the repair. This will be discussed in topic 2.

LEVEL I.—This level is normally associated with small modules or submodules that are attached to circuit cards or mother boards. The analog-to-digital (A/D) converter module is a device that converts a signal that is a function of a continuous variable (like a sine wave) into a representative number sequence in digital form. The A/D converter in figure 1-37 is a typical Level I component. At this level of

maintenance you can replace the faulty module with a good one. The faulty module can then be repaired at a later time or discarded. This concept significantly reduces the time equipment is inoperable.

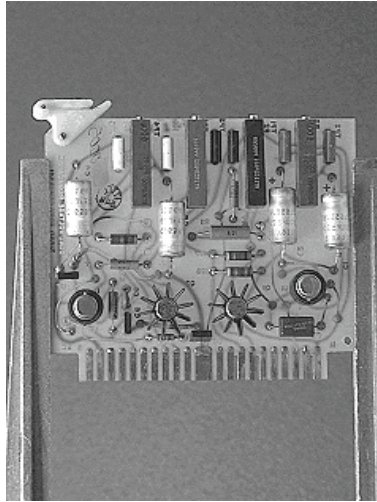


Figure 1-37.—Printed circuit board (pcb).

LEVEL II.—Level II packaging is composed of large printed circuit boards and/or cards (mother boards). Typical units of this level are shown in figures 1-37 and 1-38. In figure 1-38 the card measures 15×5.25 inches. The large dual in-line packages (DIPs) are 2.25 inches x 0.75 inch. Other DIPs on the pcb are much smaller. Interconnections are shown between DIPs. You should also be able to locate a few discrete components. Repair consists of removing the faulty DIP or discrete component from the pcb and replacing it with a new part. Then the pcb is placed back into service. The removed part may be a level 0 or I part and would be handled as described in those sections. In some cases, the entire pcb should be replaced.

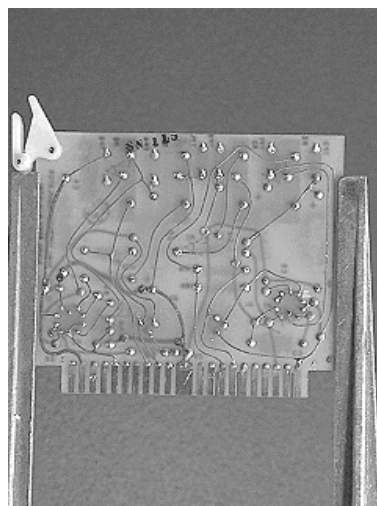


Figure 1-38.—Printed circuit board (pcb).

LEVEL III.—Drawers or pull-out chassis are level III units, as shown in figure 1-36. These are designed for accessibility and ease of maintenance. Normally, circuit cards associated with a particular subsystem will be grouped together in a drawer. This not only makes for an orderly arrangement of subsystems but also eliminates many long wiring harnesses. Defective cards are removed from such drawers and defective components are repaired as described in level II.

LEVEL IV.—Level IV is the highest level of packaging. It includes the cabinets, racks, and wiring harnesses necessary to interconnect all of the other levels. Other pieces of equipment of the same system classified as level IV, such as radar antennas, are broken down into levels 0 to III in the same manner.

During component troubleshooting procedures, you progress from level IV to III to II and on to level 0 where you identify the faulty component. As you become more familiar with a system, you should be able to go right to the drawer or module causing the problem.

Q40. Resistors, capacitors, transistors, and the like, are what level of packaging?

Q41. Modules or submodules attached to a mother board are what packaging level?

Q42. What is the packaging level of a pcb?

INTERCONNECTIONS IN PRINTED CIRCUIT BOARDS

As electronic systems become more complex, interconnections between components also becomes more complex. As more components are added to a given space, the requirements for interconnections become extremely complicated. The selection of conductor materials, insulator materials, and component physical size can greatly affect the performance of the circuit. Poor choices of these materials can contribute to poor signals, circuit noise, and unwanted electrical interaction between components. The three most common methods of interconnection are the conventional pcb, the multilayer pcb, and the modular assembly. Each of these will be discussed in the following sections.

Conventional Printed Circuit Board

Printed circuit boards were discussed earlier in topic 1. You should recall that a conventional pcb consists of glass-epoxy insulating base on which the interconnecting pattern has been etched. The board may be single- or double-sided, depending on the number of components mounted on it. Figures 1-37 and 1-38 are examples of conventional printed circuit boards.

Multilayer Printed Circuit Board.

The multilayer printed circuit board is emerging as the solution is interconnection problems associated with high-density packaging. Multilayer boards are used to:

- reduce weight
- conserve space in interconnecting circuit modules
- eliminate costly and complicated wiring harnesses
- provide shielding for a large number of conductors
- provide uniformity in conductor impedance for high-speed switching systems

- allow greater wiring density on boards

Figure 1-39 illustrates how individual boards are mated to form the multilayer unit. Although all multilayer boards are similarly constructed, various methods can be used to interconnect the circuitry from layer to layer. Three proven processes are the clearance-hole, plated-through hole, and layer build-up methods.

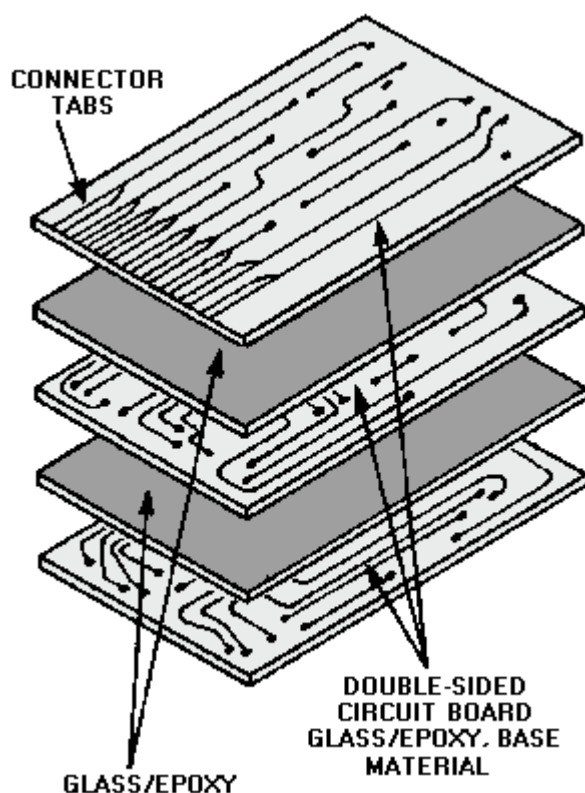


Figure 1-39.—Multilayer pcb.

CLEARANCE-HOLE METHOD.—In the CLEARANCE-HOLE method, a hole is drilled in the copper island (terminating end) of the appropriate conductor on the top layer. This provides access to a conductor on the second layer as shown by hole A in figure 1-40. The clearance hole is filled with solder to complete the connection. Usually, the hole is drilled through the entire assembly at the connection site. This small hole is necessary for the SOLDER-FLOW PROCESS used with this interconnection method.

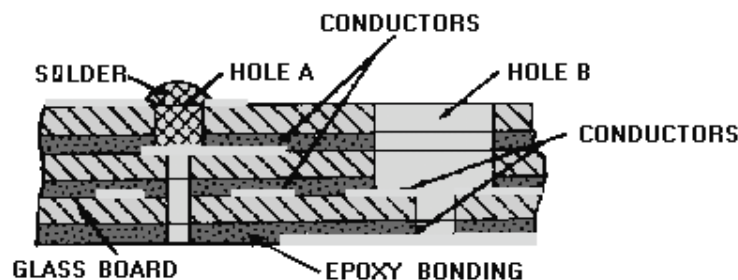


Figure 1-40.—Clearance-hole interconnection.

Conductors located several layers below the top are connected by using a STEPPED-DOWN HOLE PROCESS. Before assembly of a three-level board, a clearance hole is drilled down to the first layer to be interconnected. The first layer to be interconnected is predrilled with a hole smaller than those drilled in layers 1 and 2; succeeding layers to be connected have progressively smaller clearance holes. After assembly, the exposed portion of the conductors are interconnected by filling the stepped-down holes with solder, as shown by hole B in figure 1-40. The larger the number of interconnections required at one point, the larger must be the diameter of the clearance holes on the top layer. Large clearance holes on the top layer allow less space for components and reduce packaging density.

PLATED-THROUGH-HOLE METHOD.—The PLATED-THROUGH-HOLE method of interconnecting conductors is illustrated in figure 1-41. The first step is to temporarily assemble all the layers into their final form. Holes corresponding to required connections are drilled through the entire assembly and then the unit is disassembled. The internal walls of those holes to be interconnected are plated with metal which is 0.001 inch thick. This, in effect, connects the conductor on the board surface through the hole itself. This process is identical to that used for standard printed circuit boards. The boards are then reassembled and permanently bonded together with heat and pressure. All the holes are plated through with metal.

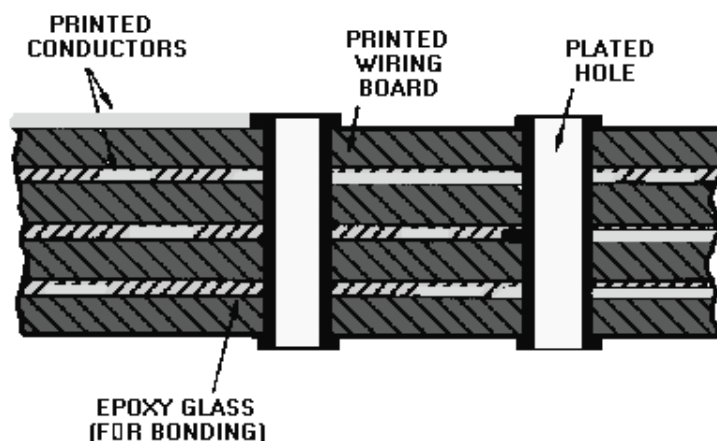


Figure 1-41.—Plated through-hole interconnection.

LAYER BUILD-UP METHOD.—With the LAYER BUILD-UP method, conductors and insulation layers are alternately deposited on a backing material, as shown in figure 1-42. This method produces copper interconnections between layers and minimizes the thermal expansion effects of dissimilar materials. However, reworking the internal connections in built-up layers is usually difficult, if not impossible.

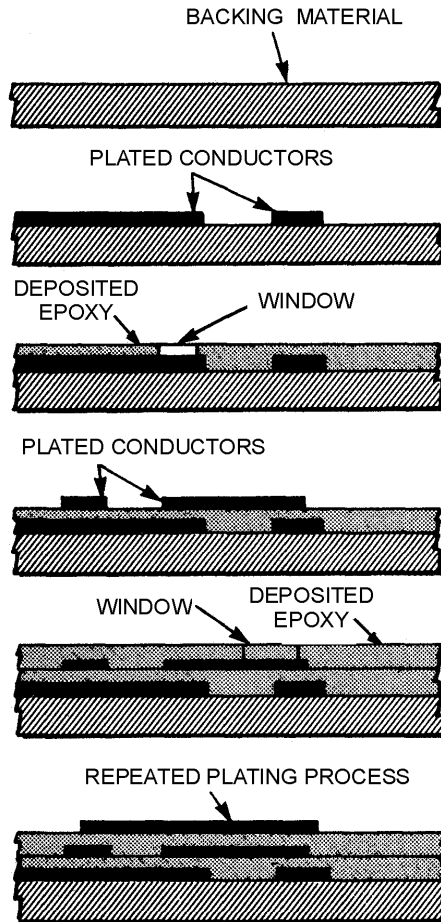


Figure 1-42.—Layer build-up technique.

Advantages and Disadvantages of Printed Circuit Boards

Some of the advantages and disadvantages of printed circuit boards were discussed earlier in this topic. They are strong, lightweight, and eliminate point-to-point wiring. Multilayer printed circuit boards allow more components per card. Entire circuits or even subsystems may be placed on the same card. However, these cards do have some drawbacks. For example, all components are wired into place, repair of cards requires special training and/or special equipment, and some cards cannot be economically repaired because of their complexity (these are referred to as THROWAWAYS).

MODULAR ASSEMBLIES

The MODULAR-ASSEMBLY (nonrepairable item) approach was devised to achieve ultra-high density packaging. The evolution of this concept, from discrete components to microelectronics, has progressed through various stages. These stages began with cordwood assemblies and functional blocks and led to complete subsystems in a single package. Examples of these configurations are shown in figure 1-43, view (A), view (B), and view (C).

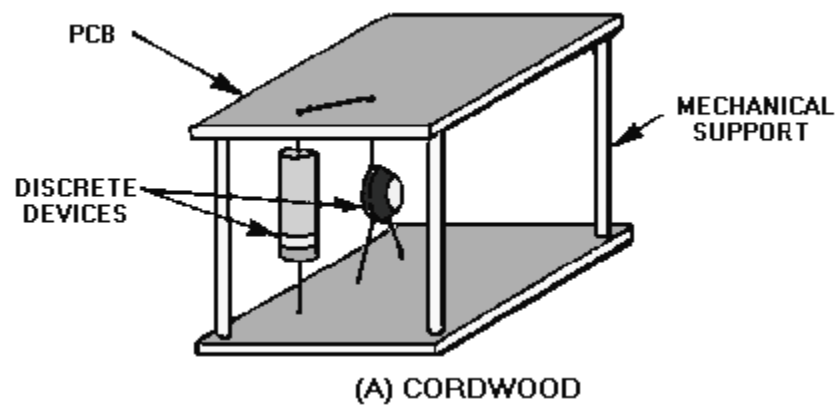


Figure 1-43A.—Evolution of modular assemblies. CORDWOOD.

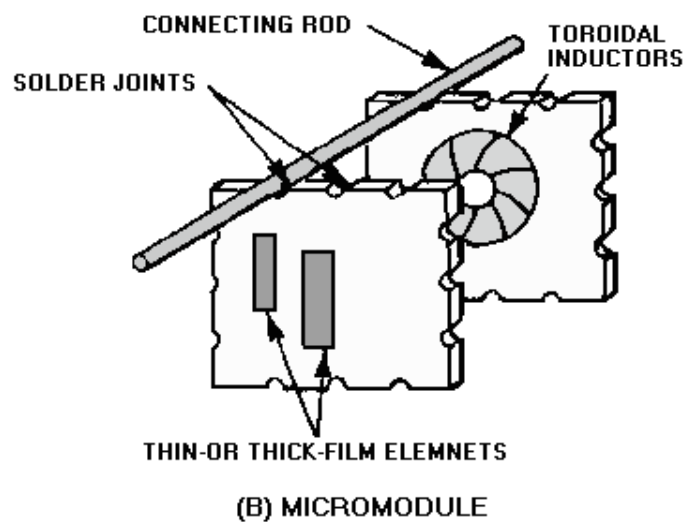
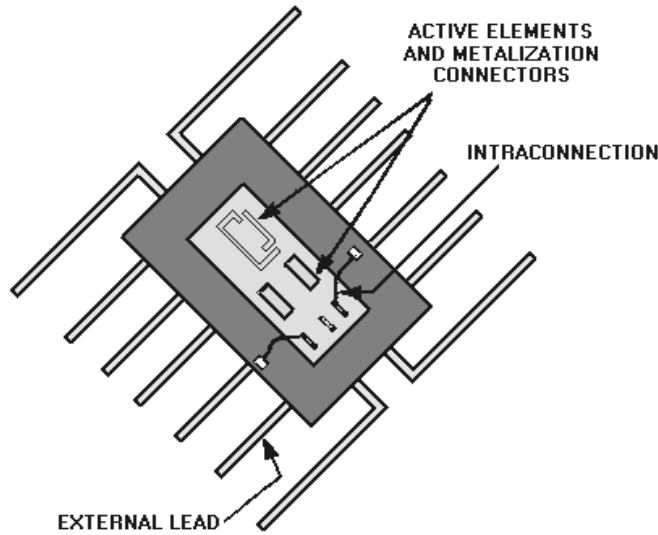


Figure 1-43B.—Evolution of modular assemblies. MICROMODULE.



(C) INTEGRATED CIRCUIT

Figure 1-43C.—Evolution of modular assemblies. INTEGRATED-CIRCUIT.

Cordwood Modules.

The cordwood assembly, shown in view (A) of figure 1-43, was designed and fabricated in various forms and sizes, depending on user requirements. This design was used to reduce the physical size and increase the component density and complexity of circuits through the use of discrete devices. However, the use of the technique was somewhat limited by the size of available discrete components used.

Micromodules

The next generation assembly was the micromodule. Designers tried to achieve maximum density in this design by using discrete components, thick- and thin-film technologies, and the insulator substrate principle. The method used in this construction technique allowed for the efficient use of space and also provided the mechanical strength necessary to withstand shock and vibration.

Semiconductor technology was then improved further with the introduction of the integrated circuit. The flat-pack IC form, shown in view (C), emphasizes the density and complexity that exists with this technique. This technology provides the means of reducing the size of circuits. It also allows the reduction of the size of systems through the advent of the lsi circuits that are now available and vlsi circuits that are being developed by various IC manufacturers.

Continuation of this trend toward microminiaturization will result in system forms that will require maintenance personnel to be specially trained in maintenance techniques to perform testing, fault isolation, and repair of systems containing complex miniature and microminiature circuits.

Q43. What are the three most common methods of interconnections?

Q44. Name the three methods of interconnecting components in multilayer printed circuit boards.

Q45. What is one of the major disadvantages of multilayer printed circuit boards?

Q46. What was the earliest form of micromodule?

ENVIRONMENTAL CONSIDERATIONS

The environmental requirements of each system design are defined in the PROCUREMENT SPECIFICATION. Typical environmental requirements for an IC, for example, are shown in table 1-1. After these system requirements have been established, components, applications, and packaging forms are considered. This then leads to the most effective system form.

Table 1-1.—Environmental Requirements

Temperature Operating Nonoperating	–28° C to +65° C –62° C to +75° C (MIL-E-16400E)
Humidity	95 percent plus condensation (MIL-E-16400E)
Shock	250 to 600 g (MIL-S-901C)
Vibration	5 to 15 Hz, 0.060 DA 16 to 25 Hz, 0.040 DA 26 to 33 Hz, 0.020 DA Resonance test in three mutual perpendicular planes. (MIL-STD-167)
RF Interference	30 Hz to 40 GHz

In the example in table 1-1, the environmental requirements are set forth as MILITARY STANDARDS for performance. The actual standard for a particular factor is in parentheses. To meet each of these standards, the equipment or component must perform adequately within the test guidelines. For example, to pass the shock test, the component must withstand a shock of 250 to 600 G_s (force of gravity). During vibration testing, the component must withstand vibrations of 5 to 15 cycles per second for 0.06 day, or about 1 1/2 hours; 16 to 25 cycles for 1 hour; and 26 to 33 cycles for 1/2 hour. Rf interference between 30 hertz and 40 gigahertz must not affect the performance of the component. Temperature and humidity factors are self-explanatory.

When selecting the most useful packaging technique, the system designer must consider not only the environmental and electrical performance requirements of the system, but the maintainability aspects as well. The system design will, therefore, reflect performance requirements of maintenance and repair personnel.

ELECTRICAL CONSIDERATIONS

The electrical characteristics of a component can sometimes be adversely affected when it is placed in a given system. This effect can show up as signal distortion, an improper timing sequence, a frequency shift, or numerous other types of unwanted interactions. Techniques designed to minimize the effects of system packaging on component performance are incorporated into system design by planners. These techniques should not be altered during your maintenance. Several of the techniques used by planners are discussed in the following sections.

Ground Planes and Shielding.

At packaging levels I and II, COPPER PLANES with voids, where feed-through is required, can be placed anywhere within the multilayer board. These planes tend to minimize interference between circuits and from external sources.

At other system levels, CROSS TALK (one signal interfering with another), rf generation within the system, and external interference are suppressed through the use of various techniques. These techniques

are shown in figure 1-44. As shown in the figure, rf shielding is used on the mating surfaces of the package, cabling is shielded, and heat sinks are provided.

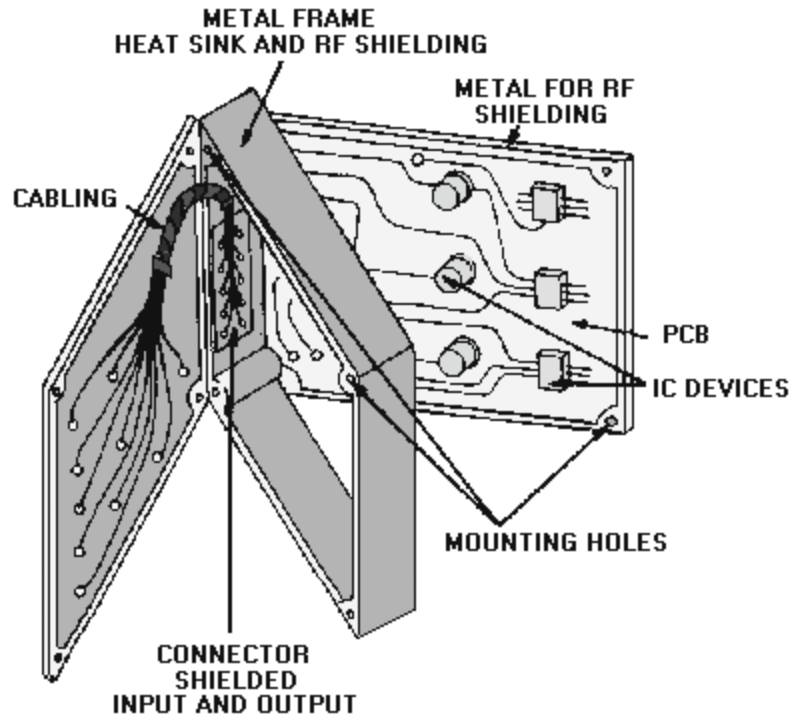


Figure 1-44.—Ground planes and shielding.

Interconnection and Intraconnections

To meet the high-frequency characteristics and propagation timing required by present and future systems, the device package must not have excessive distributed capacitance and/or inductance. This type of packaging is accomplished in the design of systems using ICs and other microelectronic devices by using shorter leads internal to the package and by careful spacing of complex circuits on printed circuit boards. To take advantage of the inherent speed of the integrated circuit, you must keep the signal propagation time between circuits to a minimum. The signal is delayed approximately 1 nanosecond per foot, so reducing the distance between circuits as much as possible is necessary. This requires the use of structures, such as high-density digital systems with an emphasis on large-scale integration, for systems in the future. Also, maintenance personnel should be especially concerned with the spacing of circuits, lead dress, and surface cleanliness. These factors affect the performance of high-speed digital and analog circuits.

Q47. In what publication are environmental requirements for equipment defined?

Q48. In what publication would you find guidelines for performance of military electronic parts?

Q49. Who is responsible for meeting environmental and electrical requirements of a system?

Q50. What methods are used to prevent unwanted component interaction?

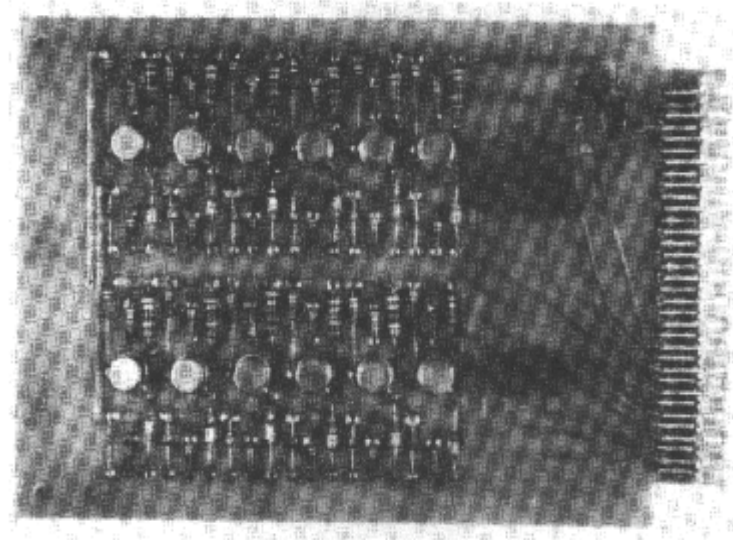
SUMMARY

This topic has presented information on the development and manufacture of microelectronic devices. The information that follows summarizes the important points of this topic.

VACUUM-TUBE CIRCUITS in most modern military equipment are unacceptable because of size, weight, and power use.

Discovery of the transistor in 1948 marked the beginning of **MICROELECTRONICS**.

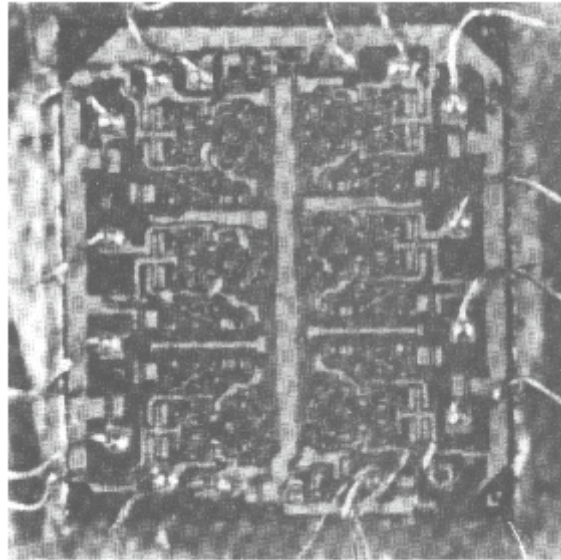
The **PRINTED CIRCUIT BOARD (pcb)** reduces weight and eliminates point-to-point wiring.



The **INTEGRATED CIRCUITS (IC)** consist of elements inseparably associated and formed on or within a single **SUBSTRATE**.

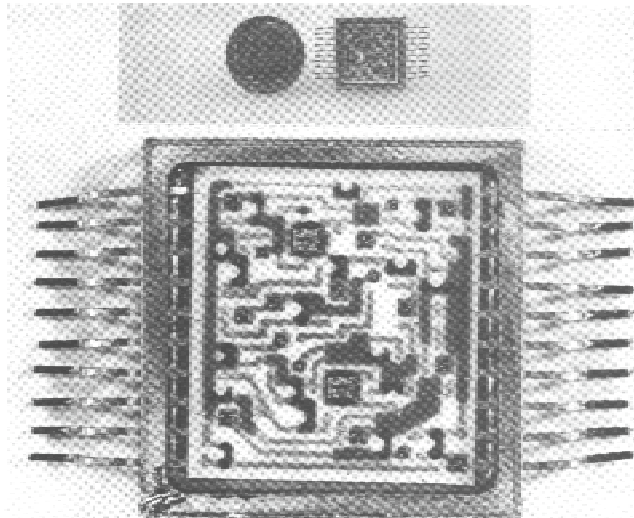
ICs are classified as three types: **MONOLITHIC**, **FILM**, and **HYBRID**.

The **MONOLITHIC IC**, called a chip or die, contains both active and passive elements.



FILM COMPONENTS are passive elements, either resistors or capacitors.

HYBRID ICs are combinations of monolithic and film or of film and discrete components, or any combination thereof. They allow flexibility in circuits.

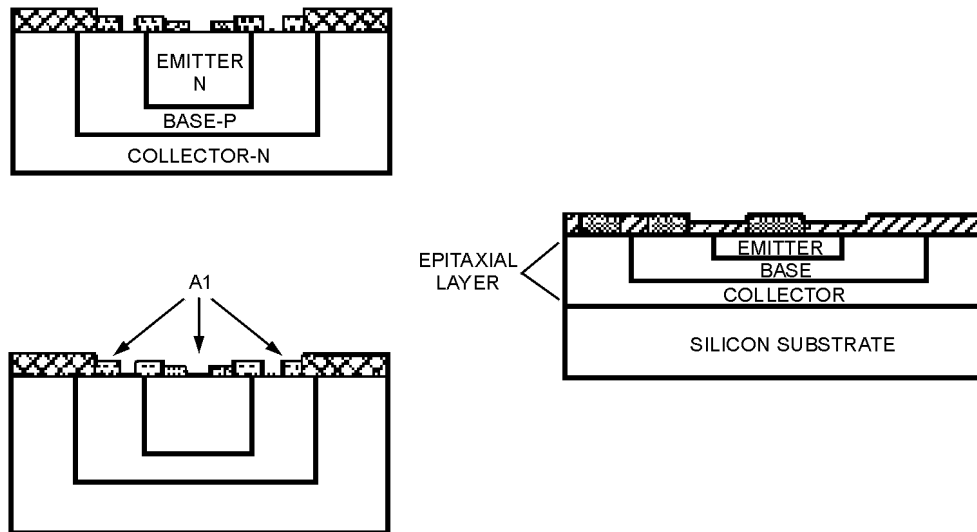


Rapid development has resulted in increased reliability and availability, reduced cost, and higher element density.

LARGE-SCALE (lsi) and **VERY LARGE-SCALE INTEGRATION (vlsi)** allow thousands of elements in a single chip.

MONOLITHIC ICs are produced by the diffusion or epitaxial methods.

DIFFUSED elements penetrate the substrate, **EPITAXIAL** do not.

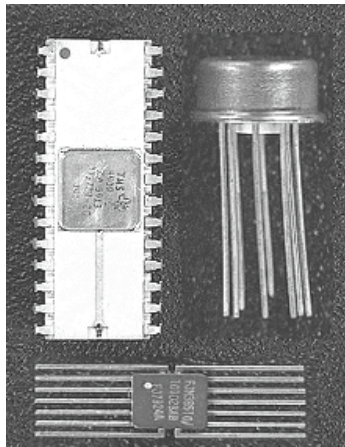


ISOLATION is a production method to prevent unwanted interaction between elements within a chip.

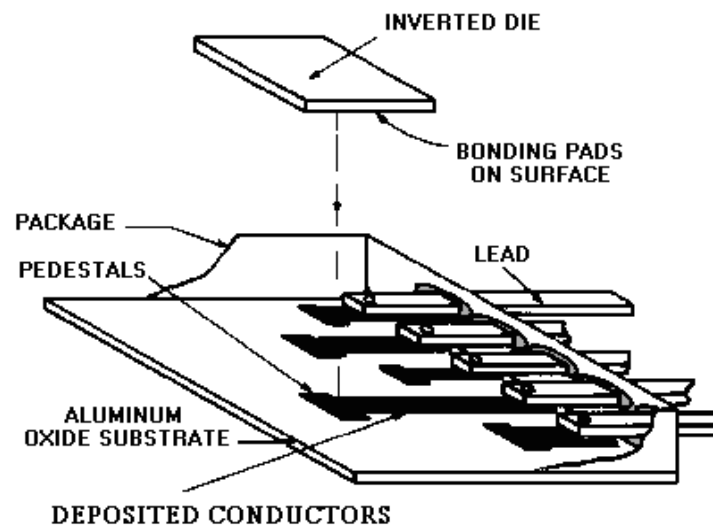
THIN-FILM ELEMENTS are produced through **EVAPORATION** or **CATHODE SPUTTERING** techniques.

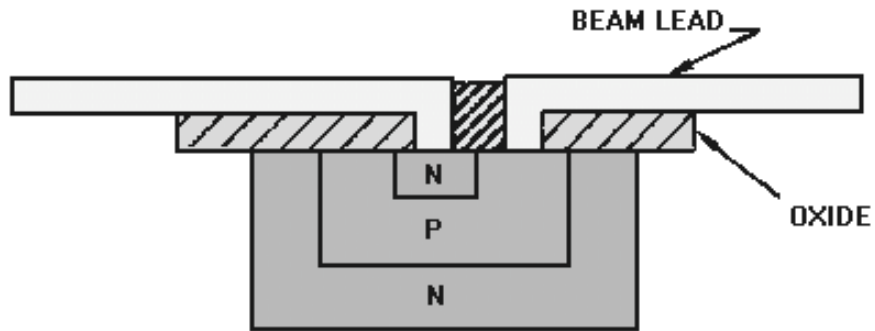
THICK-FILM ELEMENTS are screened onto the substrate.

The most common types of packages for **ICs** are **TO**, **FLAT PACK**, and **DUAL INLINE**.



FLIP CHIPS and **BEAM-LEAD CHIPS** are techniques being developed to eliminate bonding wires and to improve packaging.

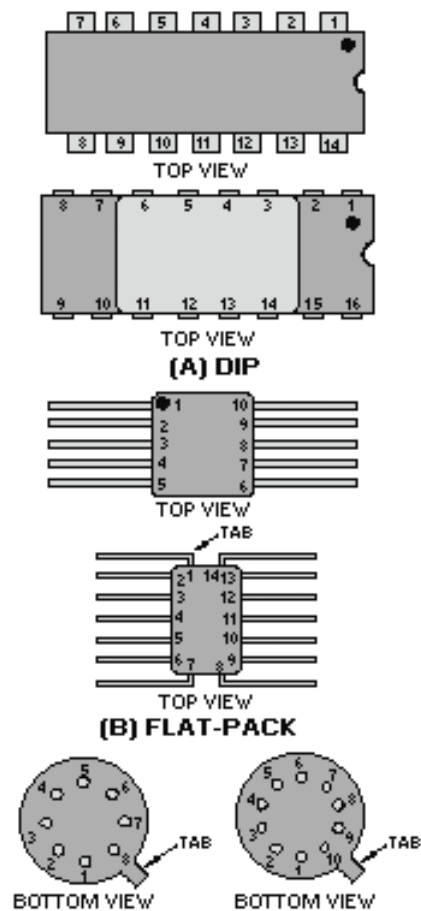




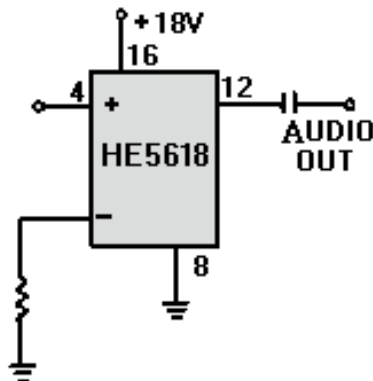
Large **DIPs** are being used to package lsi and vlsi. They can be produced with up to 64 pins and are designed to fulfill a specific need.

Viewed from the tops, **DIPS** and **FLAT-PACK LEADS** are numbered counterclockwise from the reference mark.

Viewed from the bottom, **TO-5 LEADS** are numbered clockwise from the tab.



Numbers and letters on schematics and **ICs** identify the **TYPE OF IC**.

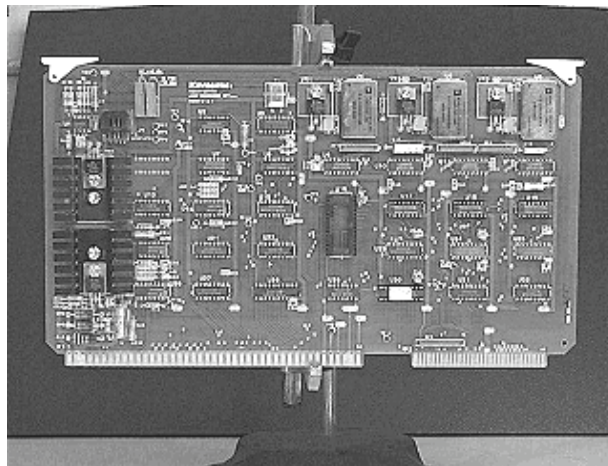


Knowledge of **TERMINOLOGY** used in microelectronics and of packaging concepts will aid you in becoming an effective technician.

STANDARD TERMINOLOGY has been adopted by the Navy to ease communication.

MICROELECTRONICS is that area of technology associated with electronic systems designed with extremely small parts or elements.

A **MICROCIRCUIT** is a small circuit which is considered as a single part composed of elements on or within a single substrate.



A **MICROCIRCUIT MODULE** is an assembly of microcircuits or a combination of microcircuits and discrete components packaged as a replaceable unit.

MINIATURE ELECTRONICS are card assemblies and modules composed exclusively of discrete electronic components.

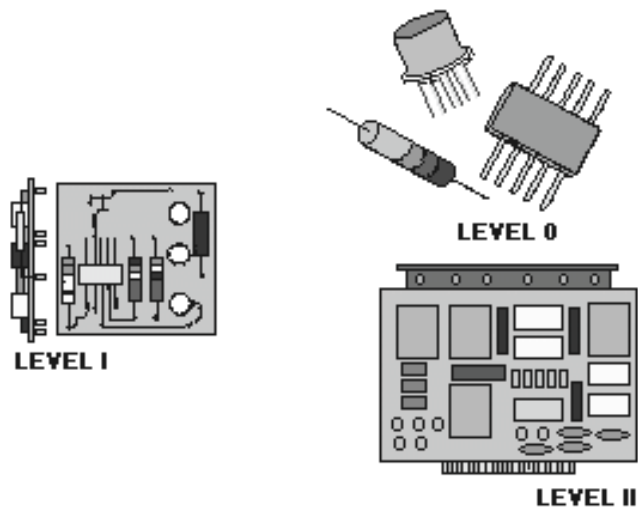
SYSTEM PACKAGING refers to the design of a system, taking into account environmental and electronic characteristics, access, and maintainability.

PACKAGING LEVELS 0 to IV are used to identify assemblies within a system. Packaging levels are as follows:

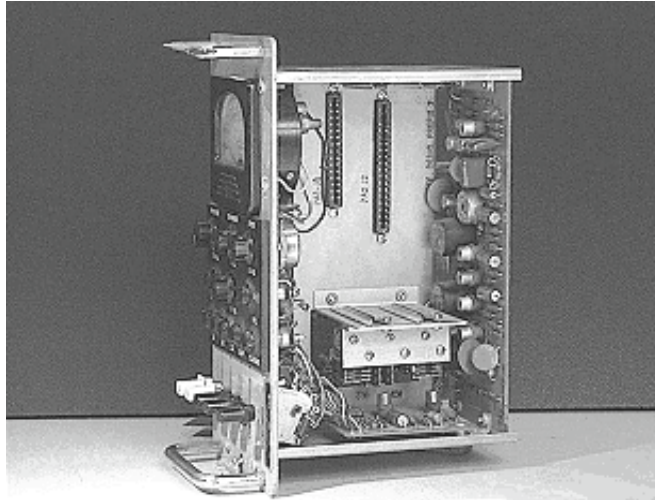
LEVEL 0-Nonrepairable parts (resistors, diodes, and so forth.)

LEVEL I -Submodules attached to circuit cards.

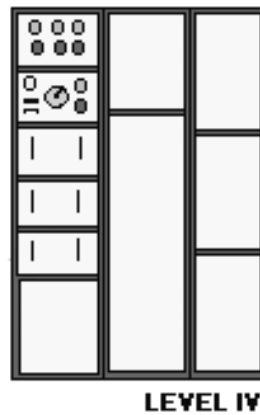
LEVEL II -Circuit cards and **MOTHER BOARDS**.



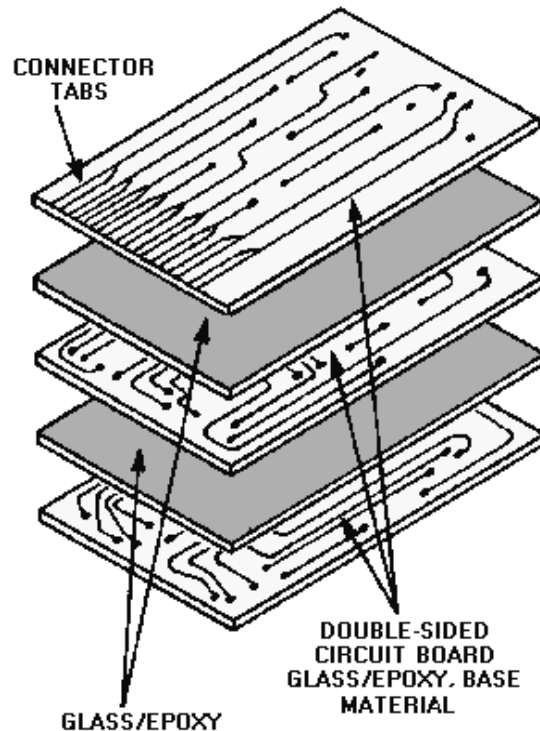
LEVEL III - Drawers.



LEVEL IV - Cabinets.



The most common **METHODS OF INTERCONNECTION** are the conventional pcb, the multilayer pcb, and modular assemblies.

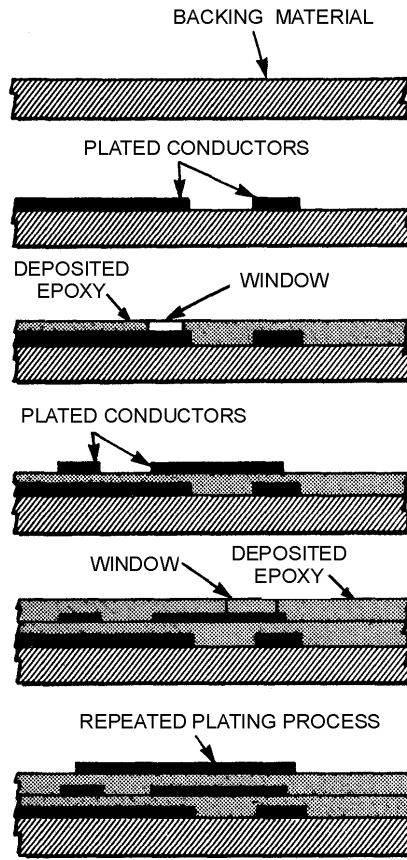


Three methods of interconnecting circuitry in multilayer printed circuit boards are the **CLEARANCE-HOLE**, the **PLATED-THROUGH-HOLE**, and **LAYER BUILD-UP**.

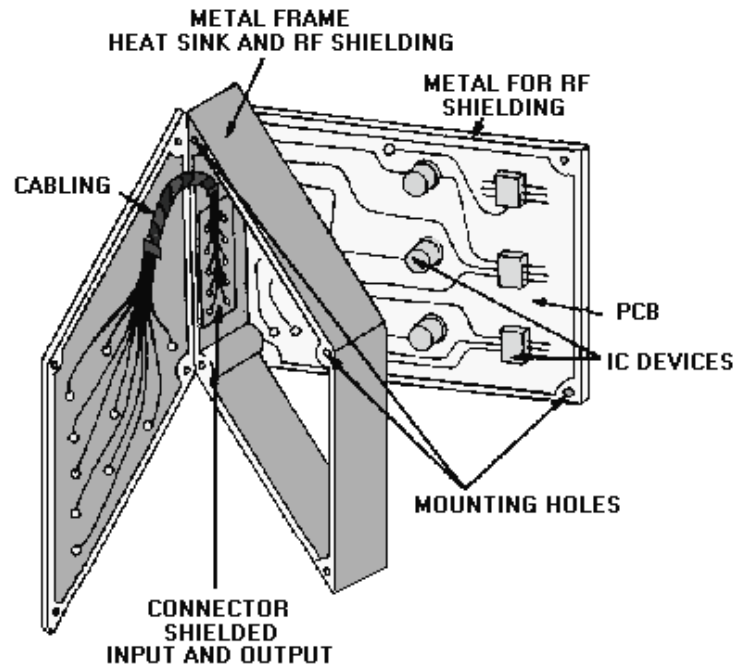
MODULAR ASSEMBLIES were devised to achieve high circuit density.

Modular assemblies have progressed from **CORDWOOD MODULES** through **MICROMODULES**. Micromodules consist of film components and discrete components to integrated and hybrid circuitry.

ENVIRONMENTAL FACTORS to be considered are temperature, humidity, shock, vibration, and rf interference.



ELECTRICAL FACTORS are overcome by using shielding and ground planes and by careful placement of components.



ANSWERS TO QUESTIONS Q1. THROUGH Q50.

- A1. Size, weight, and power consumption.
- A2. The transistor and solid-state diode.
- A3. Technology of electronic systems made of extremely small electronic parts or elements.
- A4. The Edison Effect.
- A5. Transformers, capacitors, and resistors.
- A6. "Rat's nest" appearance and unwanted interaction, such as capacitive and inductive effects.
- A7. Rapid repair of systems and improved efficiency.
- A8. Differences in performance of tubes of the same type.
- A9. Eliminate heavy chassis and point-to-point wiring.
- A10. Components soldered in place.
- A11. Cordwood module.
- A12. Elements inseparably associated and formed in or on a single substrate.
- A13. Monolithic, film, and hybrid.
- A14. Monolithic ICs contain active and passive elements. Film ICs contain only passive elements.

- A15. Combination of monolithic ICs and film components.*
- A16. 1,000 to 2,000.*
- A17. Circuit design, component placement, suitable substrate, and depositing proper materials on substrate.*
- A18. Complex.*
- A19. Control patterns of materials on substrates.*
- A20. Glass or ceramic.*
- A21. Crystal is sliced into wafers. Then ground and polished to remove any surface defect.*
- A22. Diffusion; epitaxial growth.*
- A23. Diffusion penetrates substrate; epitaxial does not.*
- A24. Electrical separation of elements.*
- A25. Evaporation and cathode sputtering.*
- A26. Screening.*
- A27. Combination of monolithic and film elements.*
- A28. Circuit flexibility.*
- A29. Protect the IC from damage; make handling easier.*
- A30. TO, flat pack, DIP.*
- A31. Flip-chip, beam lead.*
- A32. Left.*
- A33. Counterclockwise.*
- A34. Reference mark.*
- A35. Clockwise.*
- A36. Identify the type of IC.*
- A37. Communication.*
- A38. Integrated circuits.*
- A39. Miniature.*
- A40. Level 0.*
- A41. Level I.*
- A42. Level II.*

- A43. Conventional printed circuit boards, multilayer printed circuit boards and modular assemblies.*
- A44. Clearance hole, plated-through hole, and layer build-up.*
- A45. Difficulty of repair of internal connections.*
- A46. Cordwood modules.*
- A47. Procurement specifications.*
- A48. Military Standards.*
- A49. Equipment designers (planners).*
- A50. Ground planes, shielding, component placement.*