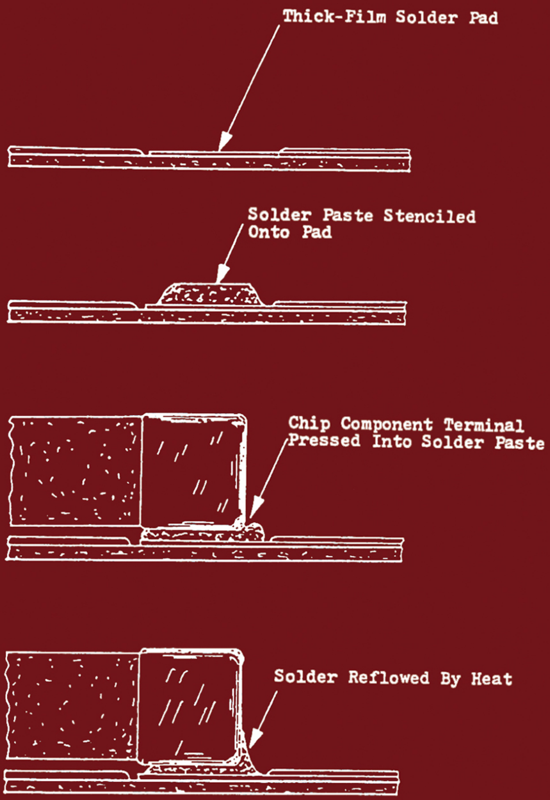
HYBRID ASSEMBLIES AND MULTICHIP MODULES



FRED W. KEAR

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To my granddaughters,
Lisa Marie Mendenhall,
Sara Lynn Mendenhall,
Lori Ann Mendenhall

Preface

Distinctions in electronic packaging technology sometimes become blurred when performance requirements dictate that the designer incorporate the best features of each technology into a single package in order to achieve the desired results. Printed circuit subassemblies, hybrid assemblies, ASICs, and multichip modules all blend their technologies in the packaging designer's list of resources so that the end product is sometimes difficult to classify. Hybrid circuits are essentially electronic subassemblies that function in the same role as a black box or an integrated circuit. Manufacturing technologies that were once used for hybrid circuits sometimes set them apart as ''thick-film circuits,'' but, as this book will show, this distinction is no longer valid. The term ''hybrid'' implies the union of two or more unlike features to produce a single functioning unit. Ideally, this union should combine the best features of its constituents. Hybrid circuits combine various substrates, conductors, active components, passive components, and encapsulating materials to meet their design objectives. The union of these materials and the design criteria that must be met in their use are the subject of this book. The intended audience includes electronics designers and manufacturers and manufacturing, packaging, and system design engineers.

Although the primary focus will be on electronic assemblies that use ceramic substrates, this book would hardly be useful without providing significant coverage of alternative materials and packaging methods such as are currently being used for multichip modules and other special electronic applications. There are obvious difficulties in attempting to describe a technology in such a rapid state of change, but, at the same time, there is a need to examine the current state of hybrid assembly technology.

It is important to understand the significant role that hybrid circuits play in electronics packaging. Why, with all the other options that are available to designers, would we elect to use a stand-alone subassembly with special design and manufacturing requirements? Does the function, cost, or convenience of these assemblies compel the designer to consider them as a valid means of achieving design objectives? The answer to these questions lies in a thorough understanding of how the assemblies are put together and what properties their materials possess.

Hybrid assemblies have been in widespread use in electronic products for many years. Their unique properties have made them mandatory for fulfilling specific applications involving thermal management restrictions and specific electrical performance. They have been widely used in automotive products, telecommunications, ordnance products, and in computer products. Many of these products have mandated the use of hybrid assemblies based on the properties of substrate materials. In the past, alumina has been the predominant material because of its electrical and thermal properties as well as its cost. Currently, alumina is being challenged both by the availability of new materials and by the stringent demands placed on the performance of these assemblies.

In addition to challenging traditional materials, modern applications are also challenging the packaging methods that have been used so successfully for many years. With the availability of flip-chip technology and tape automated bonding, designers are looking to new methods for placing discrete components onto the assemblies. At the same time, thin-film circuits often augment or replace thick-film circuits, drawing these assemblies into a configuration that sometimes defies identification as a traditional hybrid assembly. Thus the advent of the multichip module (MCM) in all its variations. Although MCMs have been discussed for some time, they are still seeking their identity as a generally used form of electronic packaging, and their manufacturing processes are still evolving. They are, however, sufficiently well established to warrant serious discussion in this book.

Equally important as the discussion of materials and of the design of hybrid assemblies are the processes used in their manufacture. It is obvious that, as materials change, manufacturing processes must also change. Changes in design also call for changes in manufacturing processes. As component densities increase and conductor sizes (and spacing) decrease, new methods must be found to provide reliable interconnections and meet all the other functional requirements of the design. Each of these circumstances, although simple in concept, can present serious challenges to the manufacturing process engineer. These issues are addressed in this text, where appropriate.

In our global economy, manufacturing companies must devote careful consideration to the competitive aspects of their products if they are to survive. Not only are the markets shifting from military products to commercial products, but the strong markets for personal computers and telecommunications products have also seen downturns and adjustments. What was once a wide-open market for good-quality electronic products has turned soft and has challenged manufacturers (and especially their product designers) to take a fresh look at cost reduction and product enhancement.

These enhancements are a primary concern of designers of hybrid assemblies and multichip modules. Faster data-processing speeds call for better dielectrics and reduced signal-propagation times. These concerns strongly affect the way that these products are designed. They also strongly affect manufacturing processes. Poor process control, poor material quality, and inadequate quality assurance practices can make a well-designed product unacceptable. Significantly faster computer chips, the accelerated demand for more sophisticated data-processing equipment in homes, offices, and industry, and expanding foreign markets leave us with many opportunities to demonstrate our ability to tackle these challenges and to produce subassemblies that will perform well under any circumstances. With the recognition that the principles of total quality management and statistical process control as well as other modern management techniques are in use in many facilities, these topics are brought into the discussion. These management tools have proven themselves to be helpful in increasing yields and reducing costs and are therefore of significant interest to hybrid assembly manufacturers.

The emergence of multichip modules represents a new era in packaging technology, and also represents, in essence, the state of the art in hybrid processing; thus a section is devoted exclusively to MCMs. So much new material is constantly being published regarding MCM design, packaging, and materials that it is impossible to provide a comprehensive up-to-date coverage of this subject, but the material in Chapter 13 presents a fairly complete picture of the technology as of this book's publication.

Fred W. Kear

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HYBRID ASSEMBLIES AND MULTICHIP MODULES

1

An Overview of Hybrid Assemblies

INTRODUCTION

Modern electronic assembly technology provides many options to the designer for achieving the objectives dictated by equipment performance criteria. Among the most demanding of these criteria are the restraints on packaging density, the ability to endure environmental fluctuations, and the reliability of the equipment. Hybrid assemblies offer features that assist the designer in meeting these requirements and others.

Hybrid assemblies are essentially electronic subassemblies that incorporate a specific function of the overall equipment design that can be fabricated as a separate module. If sufficient real estate exists on the printed circuit board or chassis, there may be some question as to the advisability of considering the use of hybrid assemblies in equipment design. However, even when space considerations are not binding, the designer should consider the following:

1. Hybrid assemblies are a convenient means for isolating specific electronic functions requiring unique testing, handling, or environmental protection.

2. Hybrid assemblies, like other electronic subassemblies, allow manufacturing planners an opportunity to buy the assembly labor and associated parts rather than load their own plant with these requirements.
3. Hybrid assemblies provide an opportunity to isolate maintenance problems to a specific section of the circuit that can be replaced more conveniently than an entire printed circuit assembly.
4. Hybrid assemblies are amenable to having printed resistors and other components trimmed by laser or abrasive cutting to extremely close tolerances.

A close look at the construction of ceramic hybrid assemblies gives a better appreciation for their versatility and usefulness. Electronic subassemblies are used in a variety of situations and follow many design criteria, depending on the constraints provided. It is not uncommon to see equipment designs that have backplanes (which usually serve a primary function as a means of interconnection) with a number of "daughter" printed circuit assemblies plugged into them. These printed circuit assemblies, in turn, may have one or more electronic subassemblies mounted on them. Sometimes these subassemblies are plugged into connectors on the printed circuit board and sometimes they are hard-wired into the printed circuit. Subassemblies are also sometimes connected to the printed circuit by a flexible cable or other means, such as individual jumper wires. When these subassemblies are on printed circuit substrates, they are almost always fabricated by the same assembly lines that produce the main printed circuit assembly. On the other hand, hybrid circuits can supply the same function as a printed circuit subassembly while offering the advantage of a prepackaged module with a custom design.

Hybrid assemblies offer further advantages in heat isolation and the use of specific components that would be difficult or impossible to incorporate into traditional printed circuit designs. The unique properties of ceramic materials, when incorporated with thin-film, and thick-film technology, offer the designer a special means for using electronic building blocks to meet manufacturing requirements.

Thick-film circuits are created by print-and-fire techniques. Thin-film circuits are usually created by sputtering or other metal deposition processes. Both of these processes, as well as a variety of other techniques, are used for manufacturing hybrid assemblies. The current technologies used for these assemblies involve not only a variety of techniques for producing the conductors and deposited discrete components, but also a variety of ways in which components may be mounted on and attached to the ceramic substrate. Historically, the transition from loaded components to surface-mount components was initiated by the hybrid integrated circuit business at a time when surface-mount components were not always available. Chip components and leadless chip carriers were a rarity at that time. To solve this problem, many manufacturers produced their own chip capacitors, formed lead components for surface mounting, and took other measures to adopt components for surface mounting. Now, after interest in surface mounting has had time to mature and the hybrid assembly industry has had time to develop its own component requirements, designers have a better component base and more options for hybrid assembly design than ever before. Most of these developments are in the areas of component design, attachment methods, and interconnect methods. Details on these subjects will be provided in the chapters that follow.

When the term *hybrid* is used, it implies the combining of two or more packaging methods into a single packaging scheme. For instance, the print-and-fire process allows certain components to be manufactured by deposition in conjunction with the creation of printed circuits that are screened onto the ceramic substrate. This is followed by screening of solder paste, placement of surface-mount components, and reflow soldering. Wire bonding, tape automated bonding, flip-clip technology, and other techniques enhance the options offered by the modern user of hybrid assemblies. The use of through-hole components, although not completely excluded from this technology, is diminishing rapidly. When a hybrid circuit assembly is complete, it is not unlike an integrated circuit (and, indeed, these are often called "integrated hybrid circuits"). From this perspective it is easier to differentiate between a hybrid circuit assembly and an ordinary printed circuit assembly.

MULTICHIP MODULES

When hybrid assembly requirements dictate that strict control be maintained over propagation delays and other signal transmission parameters, many designers seriously consider the use of multichip modules.

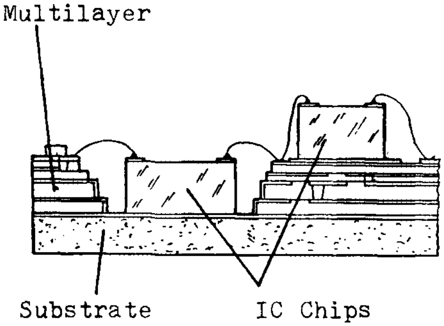

Figure 1.1a Basic multichip module section.

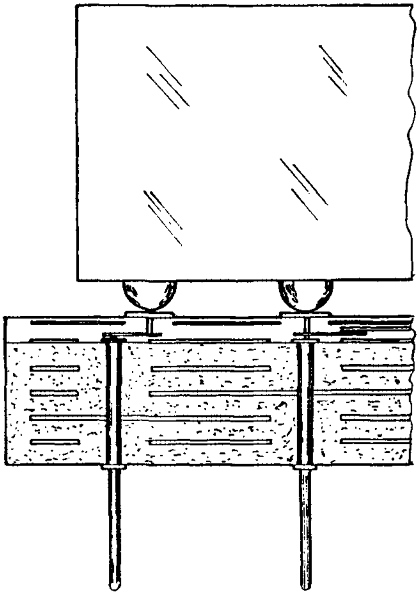

Figure 1.1b Multichip module with pinout and flip-chip bonding.

These modules are, in essence, hybrid assemblies, but some of their construction detail is uniquely different from the typical hybrid assembly (Figures 1.1a and 1.1b). At the same time, a comparison of the basic features between conventional hybrid assemblies and multichip modules tends to cast them in the same packaging technology family.

The method of classifying multichip modules includes the following symbols:

MCM-L	Uses traditional printed circuit substrates
MCM-C	Uses ceramic substrates with thick-film circuits
MCM-D	Uses ceramic substrates with thin-film circuits

Multichip modules use soldering, wire bonding, tape automated bonding, flip-chip technology, and metallized epoxies for making their electrical interconnections. They also use a variety of substrate materials such as silicon, alumina, aluminum nitride, silicon carbide, beryllium oxide, copper-clad beryllium, and nickel-clad beryllium. Dielectric materials used for conductor isolation in multichip modules are typically polyamides, silicon dioxide (glass), or polymer material.

Specific data on multichip modules are included in the chapters that follow.

HYBRID ASSEMBLY CONSTRUCTION

Although a variety of substrates is available for use in hybrid circuit fabrication, the most common substrate material is alumina (Al_2O_3). The chapter on materials will deal extensively with this material as well as others that are commonly used for this purpose. Conductive inks are screened onto the surface of the substrate wafer and the ink is fired to produce a permanent conductor. Insulating material is then screened over this conductor pattern, and other conductor patterns are in turn screened over the insulation until sufficient layers are produced to complete the circuit as designed. Electrical access between the conductor layers is provided through openings in the insulation layers. These openings are called *vias*, in keeping with the terminology used with printed circuits for plated through holes that function primarily as electrical feedthroughs in that technology. The completed thick-film substrate is very much like a multilayer printed circuit in function if not appearance.

Although options for screened-in-place components are limited, screened resistors are certainly possible and widely used. In fact, because they are so easily fabricated, screened resistors are commonly preferred over chip resistors for this application. This is especially true if specific values (requiring trimming) are needed. Screened resistors lend themselves to laser trimming or abrasive trimming, making them attractive for circuit applications requiring precision values or a component matching.

Ceramic substrates also offer the advantage of having a thermal coefficient of expansion (TCE) that matches the TCE of the discrete components used in surface-mount applications. Given their physical size, it would not seem that TCE match would be important for most surface-mount components. However, in some applications, TCE mismatch can aggravate vulnerable features on components and conductors, causing them to fail, even with small package outlines.

It is difficult to modify the geometry of fired ceramic substrates, but before they are fired, the raw material can easily be formed into almost any desired shape. Fired ceramic sheets are normally used for thick-film circuitry. These sheets are scribed along the separation lines of individual circuit assemblies for separation at some convenient point in the processing. The size of the scribed master wafer is usually chosen to suit manufacturing process capability and may leave some waste ceramic material if the individual circuit geometry does not match perfectly with the wafer size.

The ability to form unfired ceramic provides an opportunity for the designer to use these materials in a variety of ways. Integrated circuits, for instance, use molded ceramics for their base and cap. In this case, ceramics offer the further advantage of being hermetically sealable with a glass bead. Many hybrid thick-film circuit manufacturers offer the option of hermetically sealed or protected assemblies. In many cases, these sealed assemblies are placed in cans or other packages to simplify manufacturing and improve the product.

INTERCONNECTION OPTIONS

Connector pins are normally soldered to conductor pads that have been screened and fired as part of the circuit pattern. These pins provide the connections between the hybrid circuit and the rest of the electronic equipment. If design constraints dictate, other connection schemes may be used successfully between the components and the outside equipment. Headers and rigidly mounted connector pins may be used if the ceramic has been properly molded before firing and precautions are taken to prevent unnecessary mechanical stress due to TCE mismatch and handling. Automotive components associated with electronic ignition and other functions use special interconnection methods to allow the use of rigid connectors to prevent failure in their extreme environments.

COMPONENTS

Although leaded components may be used on ceramic thick-film circuits, it is uncommon to see this done in current designs. Through-hole mounting of components for these assemblies is rare but not impossible. The mechanical characteristics of the ceramic material and the thick-film circuits tend to limit the size and geometry of components that may be used in these assemblies. Integrated circuits, transistors, diodes, and chip components are used extensively in hybrid circuit assemblies. On the other hand, it is rare to see transformers or electrolytic capacitors used. Obviously, the size, complexity, and heat radiation properties of components determine whether or not they may be used on thick-film circuits. At the same time, the highly reliable planarity of these substrates makes them good candidates for the use of chip components, especially with pick-and-place assembly equipment.

The two most common methods for mounting components onto hybrid substrates are hand placement and automated pick-and-place equipment. Automated assembly processes are, of course, ideal for this type of product. However, production quantities are often small enough to prohibit the tooling and setup charges associated with automated assembly (unless the complexity or density of the assembly prohibits hand assembly). Many job shops specializing in hybrid assembly prefer to use hand assembly for most of their operations simply because of the broad customer base and the large variety of assemblies that they manufacture. Captive assembly operations, on the other hand, usually prefer automated assembly since they are dealing with high volumes of a small variety of assemblies.

Wire bonding (welding of interconnecting wires between components and the print-and-fire circuits on the ceramic substrate) allows the use of components for hybrid circuits that might otherwise be precluded. Ceramic chips containing integrated circuits (as well as other components) may be bonded to the thick-film substrate followed by the welding of jumper wires between the chip terminations and various points on the thick-film circuit. These jumper wires are very small and very fragile and must be protected by encapsulation or other methods of covering so that they are not exposed to handling. When wire bonding is used for chip connection, it is almost always in conjunction with traditional solder-paste and reflow technology. The soldering is done first, then the adhesive bonding of the chip, and finally, the wire bonding. This is followed by encapsulation or other means of covering for the wire bonds. Another method for installing chips on thick-film substrates employs flip-chip technology. This process calls for solder bumps to be predeposited on the top surface of the ceramic chip so that the chip can be flipped over on the substrate and soldered in place by convention reflow methods.

PACKAGE CONSIDERATIONS

Thick-film hybrid assemblies are produced in a wide variety of package styles and geometric shapes. They are used in many applications, especially those involving harsh environments. The advantages offered by their ability to withstand these environments are somewhat offset by the difficulty they present to any machining or modification. Metallization of ceramics requires special processes not used in the manufacture of printed circuits (i.e., sputtering or print-and-fire versus photo imaging and electroplating). The consequent processing problems, although manageable, require special knowledge and experience. The substrate scribing, the print-and-fire operations, the solder-paste application, the component placement, the soldering, and the wire bonding all give hybrid circuit assembly manufacture a uniqueness that is appealing to many process engineers. As will be shown in later chapters, each of these processes has many ramifications that makes it interesting to engineers. At the same time, enough is known about these processes to make them amenable to automation and other modern technological advances.

In considering components for use in hybrid assemblies, the designer is naturally inclined to select only those that are specifically intended for use in surface-mount applications. However, these assemblies have been manufactured extensively using traditional leaded components intended for through-hole mounting applications. Since through-hole mounting is difficult on hybrid assemblies, it is necessary to form the leads specifically for surface mount. When this approach is used, the assembly operations tends to be less precise than for traditional surface-mounting techniques, and lends itself more readily to hand assembly.

Having the flexibility to use certain leaded components in these assemblies, both the designer and the manufacturing engineer should make sure that these components are properly mounted and protected from damage (Figure 1.2). Such damage may occur after mounting

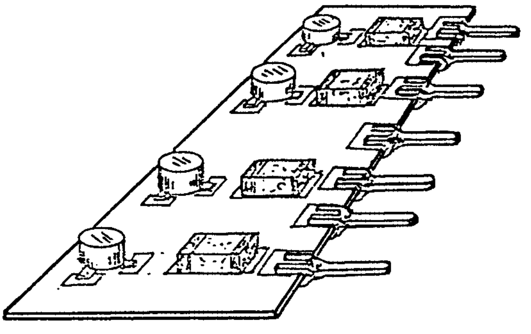

Figure 1.2 Hybrid assembly with chip components and three-lead components in place.

because of the vulnerability of the component. Vulnerability, of course, is determined by the fragility of the component and the way it is mounted on the substrate; more will be said about this in the chapter on component mounting. Conformal coating, adhesive bonding, and other measures will help to strengthen components and protect them from damage, however. During the manufacturing cycle, these protective measures will not always be in place. After soldering, hybrid assemblies need to be treated as if they were fragile.

Hybrid assemblies may be mounted in larger electronic assemblies in various ways. One of the more common methods is mounting these assemblies through their interconnecting leads. This method works well when the assembly is small and lightweight. Many hybrid assemblies have a single set of in-line leads that provide a convenient means of mounting (Figure 1.3). This method usually leaves the hybrid assembly perpendicular to its mounting surface (which is usually a printed circuit board; Figure 1.4). Sometimes hybrid assemblies have connector pins in line on two or more edges. When this happens, the leads may be bent at a right angle to the plane of the ceramic substrate for insertion into the printed circuit board. If this is the case, the pins should be bent to the correct shape before they are attached to the ceramic. Assemblies mounted and held in place by their leads usually rely on convection for heat transfer from their components.

Since ceramic material may be molded into a variety of shapes before it is fired, mounting features may be included in its basic

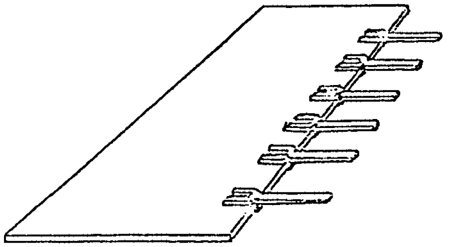

Figure 1.3 Hybrid assembly using single in-line (SIP) connector pattern along one edge.

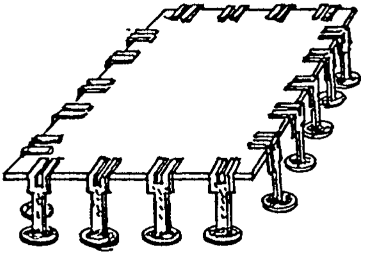

Figure 1.4 Hybrid assembly using connectors along all four edges (quad package).

design. This capability makes ceramic substrates interesting materials for automotive and military applications. In the unfired state, these materials may have mounting holes and cavities made in them, and at the same time, have other geometric features defined. Then, after firing, these features become rigid and firm. If the material is properly fired, the mechanical features of the finished substrate should be completely adequate.

The manufacturing processes used for thick-film circuits (e.g., firing, solder-paste application, and pick-and-place for components) limit the geometric designs that can be used for the ceramic substrate and final package configuration. Most of these processes require a flat assembly surface with no raised edges. This does not mean that the final package is strictly limited to a flat plane, but that the thick-film circuit must be applied to such a plane before the package is assembled.

In cases in which the total hybrid assembly must be hermetically sealed, the properties of ceramic make it ideal for achieving this requirement. However, the package must be designed so that its sections are bonded in a manner that facilitates the assembly of components on a flat plane before the hermetic sealing takes place. The use of tape automated bonding and wire bonding can help to facilitate this requirement.

The nature of hybrid ceramic assemblies allows them to be used in a variety of interesting package configurations employing materials that enhance their usefulness (Figure 1.5). Ceramic substrates work well with plastic or metal covers, provided they are not rigidly bonded to these materials. Hybrid assemblies also accept a variety of coating or encapsulating materials, which allows them to be used in exposed environments without expensive mounting provisions.

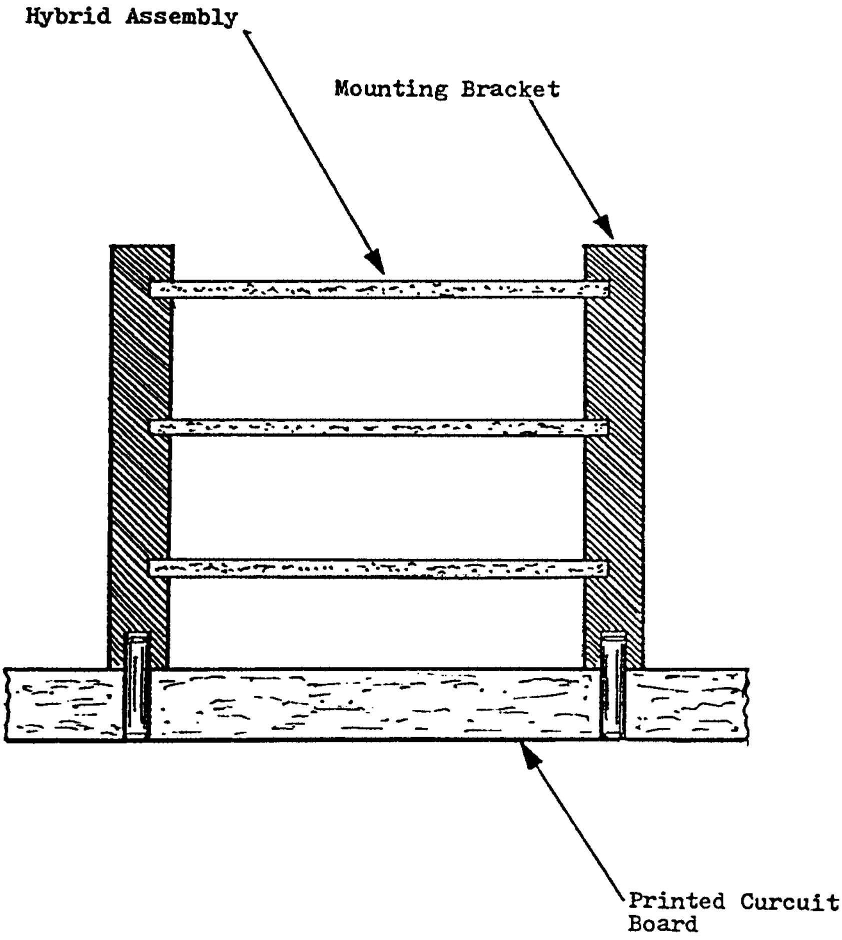

Figure 1.5 Hybrid assembly mounting using parallel grooved mounting brackets.

CIRCUIT DENSITIES

While the additive processes used for hybrid assembly manufacture (under normal conditions) do not allow the user to demand extremely small conductors and narrow spaces, they do satisfy most design requirements. (Thin-film techniques, although an additive process, provide extended circuit density capability for use in hybrid assemblies. Thin-film processes are not discussed in detail in this book because of the scope of the technology involved.) Thick-film circuits are not ordinarily considered to be candidates for fine pitch circuit applications. Although formal restrictions and circuit pitch are usually handled as a function of design criteria, it may be convenient to remember that conductor width and spacing dimensions below .020 inch may be difficult to produce with thick-film processes. Screening and firing of conductors and thick-film resistors is much less expensive when these dimensional restrictions are followed. Obviously, it is best to allow as much relief as possible when selecting hybrid circuits for electronic assemblies. This is especially important with regard to the circuit densities that are required for these assemblies. It is convenient to think of hybrid circuits in the same terms as for printed circuits, but the two interconnection methods do not use the same process technologies or the same design restrictions. This topic is explored in greater detail in Chapter 3.

Although most of the conductors on typical ceramic substrates are relatively short, these assemblies are sometimes used in applications requiring close control of circuit impedance. Distributed circuit constants such as resistance, inductance, and capacitance are not as easy to control for circuits that are screened and fired as they are for etched circuits. These constants depend primarily on the geometry of the total circuit, including conductor geometry, and to some extent, on the conductor composition. Even with the process refinements that are available with modern technology, it is not always possible to maintain close impedance control for thick-film circuits.

Circuit geometries are likewise restricted somewhat by the way in which they must be applied. Normal thick-film screening implies that the properties of the ink and the screen construction impose limits on the radii of circuit junctions and on the control of circuit dimensions.