CHAPTER 5.5

CONNECTORS

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INTRODUCTION

This chapter provides an overview of the structure and function of electronic connectors. Because of space limitations a limited number of topics will be discussed. References are given to provide additional detail for interested readers.

Defining a Connector

A connector can be defined in terms of its structure or its function. A functional definition describes what the connector is expected to do, such as carry a signal or distribute power, and the requirements it must meet, such as the number of mating cycles and electrical requirements. A structural definition describes the materials of manufacture and design of the connector. The discussion will begin with a functional definition.

A connector provides a *separable* connection between two functional units of an electronic system without *unacceptable* effects on signal integrity or power transmission.

A few comments on the highlighted elements in the definition are in order. The *separable* interface is the reason for using a connector. Separability may be required for manufacturing, maintenance/upgrading or portability/multifunction capability. The number of mating cycles a connector must support without degradation in performance depends on the reason for the separability requirement. A manufacturing application may require only a few matings while portability/multifunctional capability may require hundreds or thousands of mating cycles. Once in place, however, the connector must not introduce any *unacceptable* effects on the electrical/electronic function. The effects of connectors on signal degradation is becoming increasingly important as pulse rise times fall to a nanosecond and below.

To understand how these requirements are considered in connector design and selection, a short discussion of connector structure follows.

CONNECTOR STRUCTURE

A connector consists of four basic elements as outlined by Mroczkowski (Ref. 1).

1. The contact interface
2. The contact finish
3. The contact spring element
4. The connector housing

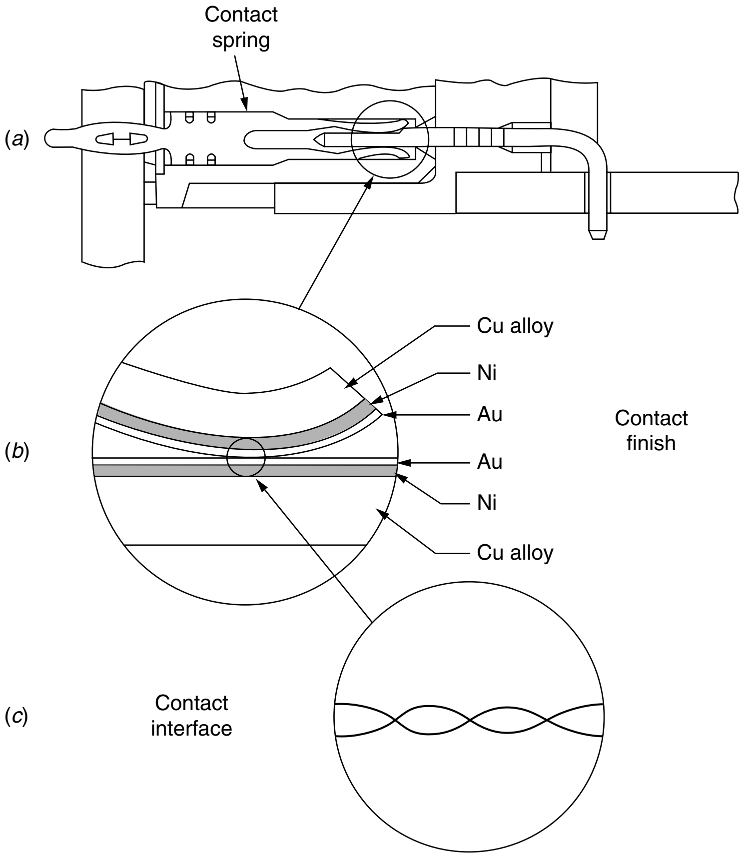

FIGURE 5.5.1 The structural components of a connector: (*a*) the contact spring and connector housing, (*b*) the contact finish, and (*c*) the contact interface.

A schematic illustration of these components is provided in Fig. 5.5.1. Each of these components will be briefly considered.

Contact Interface(s)

There are two contact interfaces of interest. The separable, or mating, interface has already been mentioned as the major reason for using a connector. In addition to the separable interface, it is also necessary to attach the connector to the subsystems that are to be connected. Such connections are generally "permanent," such as solder joints or crimped connections. A wide variety of separable and permanent connection designs are used in connectors as will be discussed in the section on connector applications.

At this point it is sufficient to say that contact interfaces, whether separable or permanent, are established by generating metallic interfaces between the two halves of the connector or between the connector and the subunit to which it is connected. Williamson (Ref. 2) provides an informative discussion of the fundamental structure of contact interfaces. Design considerations for establishing contact interfaces are discussed in Whitley and Mroczkowski (Ref. 3).

TABLE 5.5.1 Selected Contact Finish Properties

	Hardness (Knoop@25g)	Durability	Coefficient of friction
Gold (soft)	90	Fair	0.4/0.7
(hard)	130/200	Good	0.3/0.5
Palladium	200/300	Very good*	0.3/0.5
Palladium (80)-Nickel (20)	300/450	Very good*	0.2/0.5
Tin	9/20	Poor	0.5/1.0
Silver	80/120	Fair	0.5/0.8
Nickel	300/500	Very good	0.3/0.6

*with gold flash.

Contact Finish

The contact finish consists of a metallic coating intended to provide mating surfaces that optimize the ability to establish and maintain a metallic contact interface. Optimization of the mating surfaces can be simply described as meeting the need to avoid the formation of, or facilitate displacement of, surface films at the mating interface. The dominant contact finishes are noble metals and tin. Noble metal finishes include gold, palladium, and alloys of these two metals. Noble metal finishes "optimize" performance by being corrosion resistant which minimizes film formation. Tin, on the other hand, has a surface oxide that is readily disrupted on mating of the connector. Tin finishes are, however, subject to reoxidation during use, a failure mechanism called *fretting corrosion* (Bock and Whitley, Ref. 4). For additional discussion of contact finishes, see Antler (Refs. 5, 6, 7) and Mroczkowski (Ref. 8).

A brief descriptive compilation of contact finish characteristics of importance for connectors is provided in Table 5.5.1. The values realized depend strongly on the processing of the finish and the state of lubrication of the surface in the case of durability and coefficient of friction. Selection of the appropriate finish for a given application depends on mechanical, electrical, and environmental requirements.

Mechanical requirements include the following.

Mating durability. The number of mating cycles the connector can support without degradation of the finish. Mating durability depends on the hardness of finish system, the contact normal force and the contact geometry.

Connector mating force. The force required to mate the connector depends on the contact normal force, the coefficient of friction of the finish system, the contact geometry, and the number of positions in the connector.

The dominant electrical requirement is a low and stable value of connector resistance. From a contact finish viewpoint the contact resistance is dependent on the film formation and displacement characteristics of the finish. It is in the respect that noble and non-noble finishes display significant differences a previously mentioned.

The environmental characteristics of the operating environment, in particular the temperature, humidity, and corrosive species, determine the type and structure of films, which will form on contact interfaces. Films on noble metal finishes generally result from corrosion of exposed copper. Tin shows good environmental stability in most environments because of the self-limiting oxide film. The degradation of tin is primarily related to small motions, called *fretting* of the contact interface leading to a fretting corrosion (Bock and Whitley, Ref. 4). Such motions can arise from mechanical disturbances or differential thermal expansion mismatch stresses.

Noble metal finishes are generally considered as more forgiving and versatile in connector applications. Evaluation of the sensitivity of an application to fretting susceptibility is the major consideration limiting the use of tin finishes.

TABLE 5.5.2 Selected Properties of Commonly Used Contact Spring Materials

	Young's modulus, (E) (10^6 kg/mm^2)	Electrical conductivity (% IACS)	0.2 percent Offset yield strength (10^3 kg/mm^2)	Stress relaxation
Brass (C26000)	11.2	28	40/60	Poor
Phosphor bronze (C51000)	11.2	20	50/70	Good
Beryllium-copper (C17200)	13.3	20/26	55/95	Excellent

Contact Spring System

The contact spring system has two functions, mechanical and electrical. There are two different mechanical considerations, those for the separable interface and those for the permanent connection. In most separable connections the contact spring system consists of a spring member and a supporting surface. As indicated in Fig. 5.5.1 the deflection of the receptacle contact spring as it mates to the post provides the contact normal force, which establishes and maintains the integrity of the separable contact interface. The contact normal force is a major design consideration for connectors as discussed and Whitley and Mroczkowski (Ref. 3). Establishing a mechanical permanent connection, as opposed to a metallurgical connection such as a soldered or welded joint, involves controlled deformation and force considerations as discussed in Ref. 1. A balance of strength, for spring forces, and ductility, for manufacturing and formation of permanent connections, is required from a contact spring material. Most connector contact springs are copper alloys because such alloys have a good combination of strength, ductility, and electrical conductivity.

For a discussion of contact spring material selection issues see Bersett (Ref. 9), Spielgelberg (Ref. 10) and Lowenthal et al. (Ref. 11). Table 5.5.2 provides a limited selection of materials characteristics of importance for three of the more commonly used contact spring materials. A range of yield strength data is shown since different temper alloys may be used. From a user viewpoint, selection of an appropriate spring material for a given application depends primarily on the application temperature and the stress relaxation characteristics of the spring material. Stress relaxation resistance is important because it results in a reduction in the contact normal force as a function of time and temperature.

Electrically, the contact spring sections provide the conducting path between the permanent connection to the subsystems and the separable interface. The conductivity and geometry of the contact spring elements determine the resistance introduced by the connector. Figure 5.5.2 illustrates the sources of resistance in a connector. Three different resistances are indicated, the connection resistances of the permanent connections, R_{conn}, the bulk resistances of the receptacle spring and the post, R_b, and the resistance of the separable interface, R_c. In a typical connector the permanent connection resistances will be of the order of tens or hundreds of microohms, the bulk resistances of the order of a few to a few tens of milliohms, and the separable interface resistance of the order of milliohms. The resistivity of the contact spring material is a factor in all these resistances and is, therefore, a material selection parameter. As indicated in Table 5.5.2 however, the resistivity of the copper alloys used in connectors varies over a limited range. For power applications the bulk resistance becomes increasingly important and low resistivity alloys may be required.

Although the bulk resistance dominates the overall connector resistance, it is the contact and permanent connection resistances that are variable and can degrade during the application lifetime of a connector. An understanding of connector degradation mechanisms and how they can be controlled is a major element of connector design and selection. For an overview of connector design/degradation issues see Mroczkowski (Ref. 12).

Connector Housing

The connector housing also performs electrical and mechanical functions. There are two levels of electrical function, one at low frequencies and another for high frequencies. For low frequencies, the primary electrical function is insulation. The dielectric material of the housing insulates and isolates the individual contacts electrically, to allow

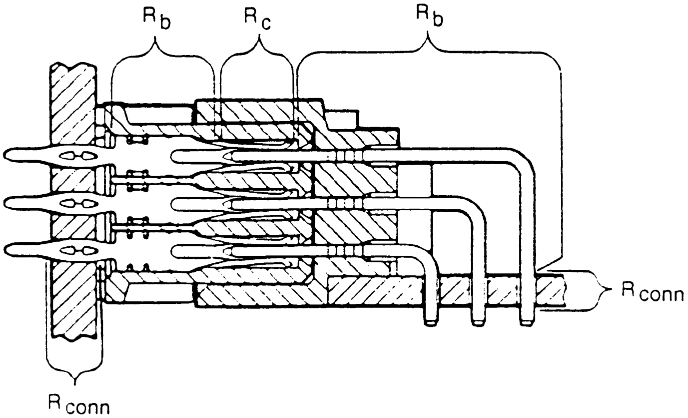

FIGURE 5.5.2 The contribution of various connector components to connector resistance: the connector resistance, R_{conn}; the bulk resistance of the contact spring, R_b; and the interface (contact) resistance R_c.

multiposition connectors. For high-frequency connectors in addition to insulation, the dielectric properties and geometry of the housing significantly impact on the characteristics of the connector as a transmission line. With the increasing processing speed capability of microelectronics, connector transmission line parameters such as characteristic impedance, propagation delay, and cross talk become major system design considerations. For additional discussion of these issues, see Southard (Ref. 13) and Aujia and Lord (Ref. 14).

Mechanically the connector housing latches and supports the contact springs within the housing and locates them mechanically. Control of mechanical location is critical to both mating characteristics of the connector separable interface and to proper permanent connections to the subunits to which the connector is attached.

Most connector housings are made from thermoplastic resins for cost and performance reasons. The electrical and, in most cases, mechanical properties of engineering thermoplastics are generally satisfactory for typical connector applications. Selection of a housing material is typically dependent on a particular manufacturing or application related requirement, such as molding of a long high pin count connector, high-temperature applications (greater than 100°C) or surface mount soldering requirements. For additional discussion on housing functions and material selection criteria see Walezak et al. (Ref. 15).

Table 5.5.3 contains a selection of housing material characteristics of importance in connector housings. The values shown are nominal values indicative of the resin families. For details the manufactures literature should be consulted because a wide variation in properties can be realized within a resin family depending on reinforcement and other additives. In most cases it is the stability of these characteristics through processing and in application that dictates the appropriate housing material for a connector. Surface mounting requirements are arguably the most demanding on connector housings.

One other housing function merits mention. The connector housing provides an environmental shield for the contacts and contact interfaces to decrease corrosion susceptibility in severe operating environments. This function is, of course, dependent on the housing design and independent of the housing material.

CONNECTOR DESIGN

As has been implied, the performance and reliability of electronic connectors depends on the design and material of manufacture of these connector components. Important design parameters for separable interfaces include selection of the contact finish, establishment of an appropriate contact normal force, and attention to

TABLE 5.5.3 Selected Properties of Commonly Used Polymers

	Flexural modulus (10^6 kg/mm^2)	Heat deflection temperature @264 psi(°F)	UL temperature Index (°C)	Dielectric strength (V/M)
Polyamide	0.7	666	130	17.4
Polybutylene Terephthalate	0.8	400	130/140	24.4
Polyethylene Terephthalate	1.0	435	150	26.0
Polycyclohexane Terephthalate	0.9	480	130	25.4
Polyphenylene Sulfide	1.2	500	200/230	18.0
Liquid crystal Polymers	1.5	650	220/240	38.0

the mating interface geometry all of which interact to determine mating mechanics, durability, and susceptibility to degradation of the separable interface. For a permanent interface minimizing the contact resistance and maximizing resistance stability, by control of the permanent connection process, are the dominant parameters of design. Housing performance characteristics of importance include the stability of the housing through the required assembly process, particularly surface mount, and its temperature and environmental stability relative to the application operating environment.

With this overview of connector structure as a context, attention now turns to connector applications and the functional requirements a connector is expected to meet.

CONNECTOR FUNCTION

As stated earlier, functionally, a connector is intended to provide a separable interface between two elements or subsystems of an electronic system without an unacceptable effect on the integrity of the signal, or power, being transmitted.

The requirement on separability is usually defined in terms of the number of mating cycles a connector must provide without an impact on performance, a number that will vary with the application.

For the purposes of this discussion, unacceptable refers to limits on the resistance that the connector introduces into the circuit or system. Both the magnitude of the resistance and the allowed change in resistance depend on the application. For signal applications the most important requirement is often resistance stability. However, the magnitude of the resistance is also important and may be dominant in power distribution applications.

A brief review of classes of connector applications is in order at this point. In this discussion, connector types are considered in terms of the structure of the connector and the medium to which the permanent connection is made. Connector applications are discussed in terms of the system architecture, a "levels of interconnection" approach, and the connector function, signal, or power applications.

CONNECTOR STRUCTURE/TYPE

With respect to connector structure or type, categorization in terms of the circuit elements being connected is useful. There are three such categories:

1. Board to board
2. Wire to board
3. Wire to wire

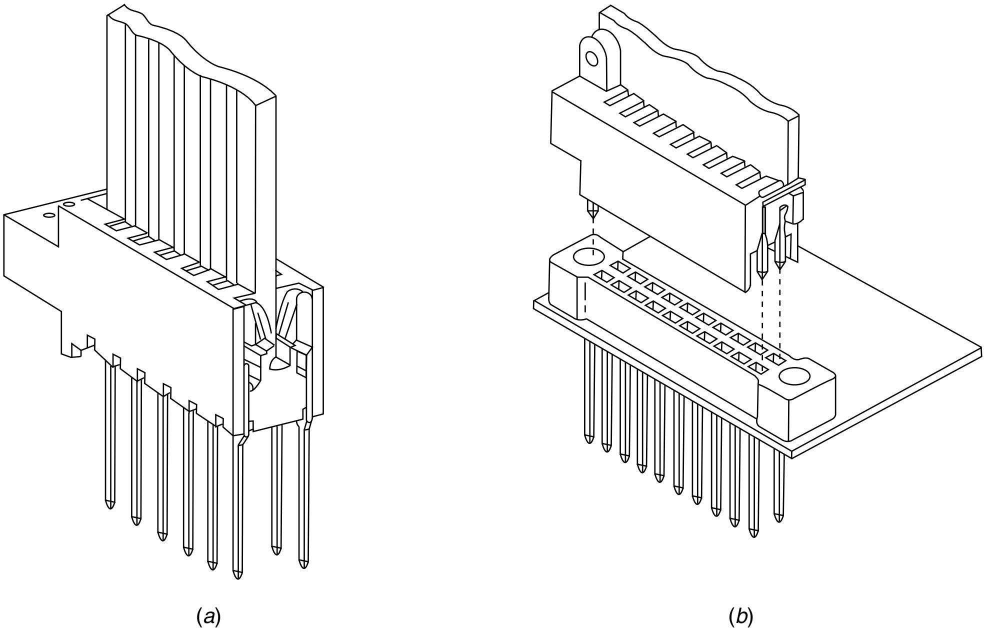

FIGURE 5.5.3 Printed circuit board connectors: (*a*) card edge (one piece) and (*b*) two piece.

It should be mentioned that the term *wire* also includes cables. In addition to the discussion of connector type, this section also includes a discussion of the classes of permanent connections, both mechanical and metallurgical.

Board-to-Board Connectors

It is in board-to-board connectors that the impact of the tremendous advances in speed of microprocessor chip technology are most apparent. These connectors are closest to the chip and, therefore, face the greatest requirements on maintaining the speed capability of the chip. In many cases board-to-board connectors must be considered as transmission lines with the accompanying requirements on controlled impedance, cross talk and shielding (EMI/RFI). Transmission line requirements have led to the development of connectors with intrinsic ground planes to provide improved high-speed performance with minimal effects on density. For a discussion of such connectors, see Sucheski and Glover (Ref. 16) and Aujla and Lord (Ref. 14). In addition to the transmission line requirements the increased functionality of microprocessor technology has led to a need for high input/output (I/O) connectors. Board-to-board connectors in pin counts in excess of 1000 are available.

There are two basic types of board-to-board connectors, one piece, or card edge, which mate to pads on the board, and two piece, which have an independent separable interface. Examples of each are shown in Fig 5.5.3.

Two-piece connectors are available in higher pin counts and densities because of greater multirow capability (up to eight rows), improved tolerance control, and the possibility of integral ground planes. In addition, they can be placed anywhere on the board. Centerline spacings in two-piece connectors include 0.100 and 0.050 in. and 1 mm with smaller spacings coming online.

Wire-to-Board Connectors

In some cases wire-to-board, or cable-to-board, connectors also face high speed requirements, which impacts on both the connector and the cable design. However, many wire-to-board connectors are used in applications where speed is not as important. The I/O densities also tend to be lower, but connectors with over 100 positions are not uncommon. There are a wide variety of connector styles and configurations in wire-to-board connectors. Connectors using 25-square technology, square posts 0.025 in. on a side, are one of the dominant wire-to-board technologies with connector systems using 1 mm and 15-square (0.015 in on a side) posts coming on line. Pin and socket connectors are also common.

Wire-to-Wire Connectors

Wire-to-wire connectors are generally located at a distance from the chip and may not face high-speed requirements, with the exception of coax connectors where controlled impedance and cross talk remain important parameters. Many wire-to-wire connectors are used external to the enclosure or equipment so ruggedness, grounding, and shielding become important design considerations. Wire-to-wire connectors are often variations on wire-to-board design, differing only in the media to which the permanent connections are made, to a wire or cable instead of a board.

Types of Permanent Connections

Because these connector types are discussed in terms of their permanent connections to the circuit elements or subsystems being interconnected, a brief discussion of permanent connection types is in order. There are two basic types of permanent connections: mechanical and metallurgical.

Mechanical Permanent Connections. The dominant mechanical permanent connection technologies include:

- Crimped connections
- Insulation displacement connections (IDC)
- Press-in or compliant connections
- Wrapped connections

Crimped and ID connections are wire/cable connections. Press-in connections are made to plated through holes in printed wiring boards. Wrapped connections are made to square posts. A brief description of the mechanisms of contact generation and maintenance for each of these technologies is in order. Illustrations of each permanent connection technology are provided in Fig. 5.5.4.

Crimped connections. The permanent interface in crimped connections is established when the striped wire and crimp barrel are deformed in a controlled fashion by the crimp tooling. The deformation process displaces surface films and creates the contact interface. Residual stresses in the wire and wire barrel provide a restraining force that maintains the permanent connection interface integrity.

Insulation displacement connections. Insulation displacement connections are made by insertion of a wire into a properly designed IDC terminal. The wire insulation is displaced and the conductors deformed in a controlled fashion during the insertion process, which disrupts surface films and generates the contact interface. Elastic restoring forces resulting from the deflection of the terminal contact beams maintain the interface integrity. A wide variety of IDC terminal designs are used depending on the application requirements.

Press-in connections. Press-in connections are made by insertion of pins with controlled geometry compliant sections into a plated through hole (PTH) in a printed wiring boards. The contact interface is generated as the pin is inserted into the PTH, disrupting surface films and creating elastic restoring forces in the compliant section of the pin. The pin restoring force maintains the interface integrity. A wide variety of IDC terminal designs are available.

Wrapped connections. Wrapped connections are made to square posts with controlled radii on the post corners. The contact interface is generated by wrapping a stripped wire section around the post several times under controlled tension. The contact interface is generated as the post corners penetrate the wire. Residual tensile forces in the wire after wrapping maintain the interface integrity.

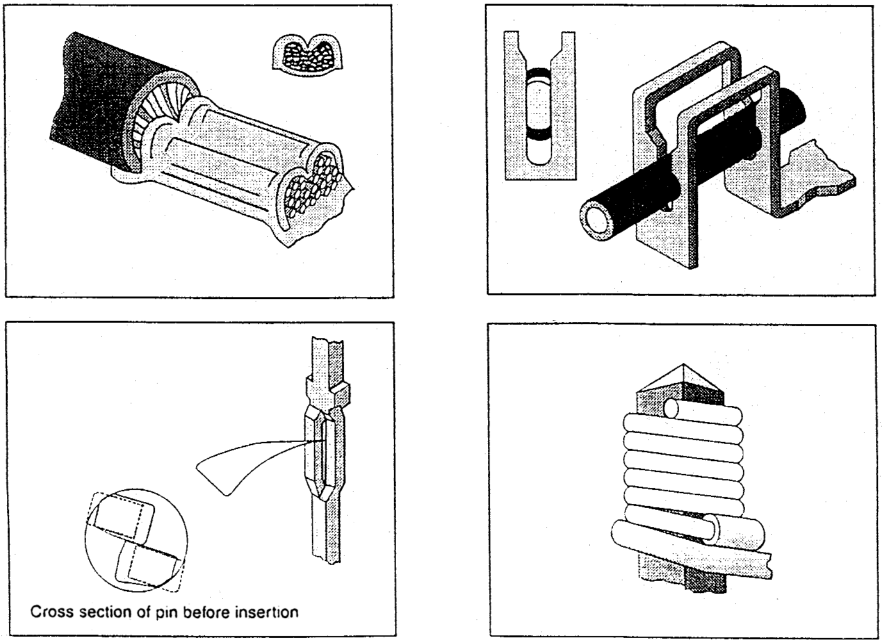

FIGURE 5.5.4 Permanent connection technologies.

For additional discussion of these technologies, see Ref. 1.

Metallurgical Permanent Connections. Metallurgical permanent connections include soldered and welded connections. Soldered connections are generally to printed wiring boards and welded connections to wire and cable. There are two basic soldering technologies used today, through hole technology (THT) and surface mount technology (SMT). In most cases, THT consists of leads inserted into plated through holes and wave soldered. SMT connections are made to pads on the printed wiring board surface. SMT processing generally involves secondary source of solder applied to the leads or the board and a solder reflow process. Several different reflow processes are used, but the technology appears to be trending toward conduction reflow in inert gas with an infrared assist. For a discussion of soldering technologies, see Manko (Ref. 17).

From this structural discussion of connectors, attention now turns to a more application related categorization.

APPLICATION FACTORS

As mentioned previously, connector applications will be considered from two viewpoints, where the connector is used (levels of interconnection), and how the connector is used (signal/power).

Levels of Interconnection

The level of interconnection is defined by the points in the system that are being connected, not the connector type, as discussed by Granitz (Ref. 18). In brief, the six levels of packaging, and an associated connection or connector type, are:

1. Chip pad to package leads, e.g., wire bonds
2. Component to circuit board, e.g., DIP socket

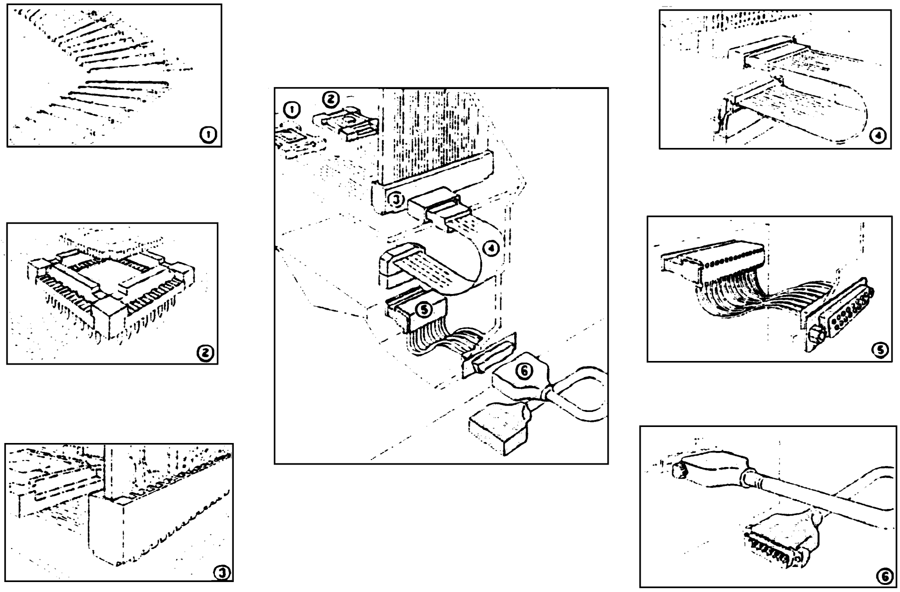

FIGURE 5.5.5 Levels of packaging in a typical electronic system.

3. Circuit board to circuit board, e.g., card edge connector
4. Subassembly to subassembly, e.g., ribbon cable assembly
5. Subassembly to input/output, e.g., D subcable assembly
6. System to system, e.g., coax cable assembly

A schematic illustration of these levels of packaging is provided in Fig. 5.5.5.

Level-1 connections are intended to be permanent connections and will not be discussed. Level-2 connections, generally accomplished through sockets, share many of the design features and requirements of connectors, but generally are subjected to only a few mating cycles. The separability requirement that has been used as a defining characteristic of a connector becomes important at levels 3 and above.

These levels of interconnection differ primarily in the application environment, but also in the durability requirements on the connector. Levels 3 through 5, being inside the enclosure, are expected to be benign with respect to corrosion and mechanical disturbances, but possibly more demanding with respect to temperature than level 6. In general, the number of mating cycles the connector must support increases, and the level of training of the user decreases, from level 3 to level 6. These differences impact on the ruggedness and "user friendliness" required of the connector. Electrically, performance requirements, particularly in terms of signal speed, are more stringent the closer the connection is to the chip level. Cables and cable connectors, however, may face more demanding electrical requirements even at higher levels of interconnection. It should also be noted that many connector types see usage in more than one level of interconnection.

Signal Connectors

Signal connectors are those that carry relatively small currents, milliamps to a few amperes. The functional requirements the connector must meet, however, depend primarily on the frequencies of signals that the connector must conduct. Signal connectors to be used at high frequencies, hundreds of megahertz or rise times less than 1 ns, conditions, which are increasingly common, must be considered as transmission lines. For such connector systems, characteristic impedance, propagation delay, and cross talk become critical performance parameters. For connectors, control of characteristic impedance is of particular interest. Controlled impedance requires constancy of materials and geometries, both of which are difficult to realize in connectors. Impedance control in connectors can be addressed, however, by signal/ground ratios in open pin field connectors or by added ground planes to the connector. Both approaches are used with intrinsic ground planes receiving increased attention. For cables and printed wiring boards, characteristic impedance control is more readily attained, but propagation delay and cross talk become more important because of the longer length of the associated transmission lines. Electromagnetic compatibility (EMC) also becomes important for high-speed connectors. EMC includes consideration of the impact of both external and internal electromagnetic radiation on system performance. Shielding and grounding considerations take on increased importance. For additional discussion of these issues, see Southard; Aujla & Lord; Sucheski & Glover; and Katyl & Simed (Refs. 13, 14, 16, and 19).

Power Contacts/Connectors

Contacts and connectors for power applications face different requirements. For power contacts/connectors two effects become important. The first is the loss of voltage arising from the resistance the connector introduces in the system. Systems have a millivolt drop budget to ensure that sufficient driving voltage is available to the chips. Excessive losses in the connector, whether bulk or interface related, can disrupt system performance. Second, the Joule, or I^2R, heating, which accompanies high current flow becomes a factor in system operating temperature. Increasing system temperature generally results in degraded performance or system life. Reduction and control of connector resistance addresses both these issues. From a bulk resistance perspective, selection of high conductivity spring materials is imperative. From a control perspective, ensuring the stability of connector interface resistance takes on new significance. For additional discussion of power contact/connector considerations see Corman and Mroczkowski (Ref. 20).

There are two approaches to power distribution, discrete power contacts and the use of multiple signal contacts in parallel. Discrete power contacts are generally large, to reduce bulk resistance and allow for higher normal forces to ensure interface stability. The size becomes a limiting factor and leads to the parallel signal contact approach. With the development of high pin count connectors allocation of some of the pins to current distribution becomes a viable option. Parallel signal contact consideration include:

- Ensuring an equal distribution of current through the contacts
- Accounting for thermal interactions between the contacts
- Appropriate derating of the contact current capacity for multiple contact applications

For additional discussion of parallel contact application considerations, see Ref. 2.

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