Techniques and Technologies for High Frequency Interconnections

There are many choices for engineers when it comes to making interconnections. Those choices are guided by the particular combination of performance, cost and reliability needed for the individual application. This report takes a look at current and developing technology for the many types of interconnections that might be needed in a high frequency/high speed system.

Die-to-Package Connections

The "old standard" of connecting a semiconductor die to its package is wire bonding. While still extensively used, it is gradually falling out of favor, being replaced by methods that allow higher density and a greater degree of process automation.

The largely manual wire bonding process is often replaced with flip-chip mounting of the die to either the package lead frame or to a direct-mounting substrate. The term "flip-chip" comes from the fact that the connection points are on the top metal of the die, so the chip must be "flipped" or placed "face down" to make the connection.

Among the alternatives is Chip On Board (COB) packaging. With COB, the die is mounted directly on a circuit substrate without its own package. A common application is in multi-chip modules (MCM), which integrate the bare die by mounting it directly onto the substrate that interconnects all the die that make up the MCM functional block.

Another popular option is Low Temperature Co-fired Ceramic (LTCC) packaging, where a die is also mounted directly to a substrate. LTCC can provide a combination of package and substrate, accommodating a significant range of lumped components, distributed elements and active devices.

A key point for all die-level interconnection is integration into multi-function modules. Often, performance requirements dictate that various portions of the "IC" subsystem make use of different semiconductor processes—CMOS for low power and high density digital, bipolar for low noise and higher currents, GaAs for efficient high frequency power and integrated passives, etc. With MCM or LTCC technology, a single module can be fabricated that can be dealt with as a single "device" by the designer of its final application.

Package-to-Board Connections

It is still common for lead frame and SMD packages to be soldered directly to a printed circuit board, ceramic substrate, flexible circuit, or other supporting and interconnecting substrate. For high-density circuits, solder bump technology such as the ball-grid array (BGA) has become widely used for applications that include RF, microwave and high-speed digital. Considerable development time and effort has been made to characterize this type of interconnection's "RF" properties.

As with MCMs and LTCC, flip-chip, wire bond, and other direct mounting methods can be used with typical PCB construction. Compression mounting with elastomeric connectors and adhesives have also been explored and are now used in many applications. Although it is common for an LCD display to be mounted this way, these techniques have seen limited use for high frequency circuits, due to inconsistent resistance and inductance properties.

An interesting area of research involves optical interfaces from a chip to external circuitry. The optical driver circuitry can be integrated onto the die, maintaining the small geometries needed for high frequency/high speed performance. With an optical interface, there is no metallic connection with its associated physical size and resulting effect on circuit behavior.

As devices get smaller and functions are packed more densely, thermal considerations have become important, even for "low power" devices. As any power amplifier designer knows, semiconductor reliability is related to junction temperature, but even a tiny junction must be able to dissipate the heat generated by the current flow in it and its surrounding circuitry.

Board-to-Board Interconnection

This area of interconnection technology may be the most active in recent times. Growth of computing technology has placed significant demands on its designers and their suppliers. Rapidly-increasing bus speeds have made the old-style header pins obsolete, since they are not impedance matched, or even well-characterized.

Many different configurations of impedance-matched pin or blade type connectors for board-to-board connection are being promoted by manufacturers. Most of these

are designed for 100 ohms impedance to match the classic "twisted-pair" wiring familiar to the digital industry. Variations include the number of circuits, spacing of conductors (pitch), space between boards if stacked, or type of cable to be used between connectors.

Some board-to-board connectors include traditional circular coaxial connectors, to be used where the improved high frequency performance of coaxial cable is required. These integrated coaxial connectors are also widely used in backplane assemblies, such as VXI-bus.

Cable assemblies using a variety of ribbon, twisted-pair and coaxial cables and associated connectors are commonly used when the boards are not adjacently located. The flat cables between the mother board, power supply and data storage devices in a personal computer are a well-known example.

As previously noted with component-to-board mounting, elastomeric compression connections are becoming increasingly common. The larger size of boards (vs. components) allows greater connection force, which may permit reliable high frequency signal integrity, at least in some moderate-speed or non-critical applications.

Clearly, the type of signal dictates the connector and cable type. A single RF interconnection may use miniature coaxial cable and MCX or MMCX push-on connectors, while a high-speed data bus may need an impedance-controlled connector and a high-performance multi-layer flat cable with controlled impedance and shielded conductors.

Box-to-Box Interconnections

For larger systems, such as a wireless base station or an automatic test system, several modules or instruments must be interconnected. The typical method for routing RF/microwave signals is with coaxial cable and appropriate connectors. This type of installation represents a large segment of the RF/microwave marketplace, as there are many applications to be served.

The choice of cable and connector depends on the signal and circuit characteristics—bandwidth, impedance, insertion loss, return loss and reliability. Also important is whether the interconnection will be removed or reconfigured for upgrades, maintenance and repair.

Because this particular group of applications is familiar to nearly all readers, and is well-served by connector and cable vendors, it is not necessary to provide a detailed analysis in this report.

Connections to External Devices

The electronic package of a communications, computing, power delivery or measuring system is usually connected to outside devices—antennas, transducers, sensors, network interfaces, switching systems, etc.

Environmental considerations are a significant part of the designer's job for systems that are installed outdoors, in industrial plants, or other locations where heat, moisture, abrasion or vibration may present problems. These connectors and cables must have the appropriate properties—usually with regulatory approvals—for their intended environment.

These performance requirements add cost and complexity, which can vary considerably from simple abrasion resistance to full plenum-rated non-flammable materials. The type of cable also affects the range of choices—RF, audio/video/baseband, microwave, optical or wired digital communications.

Special Applications

A few sub-groups of the above categories are worthy of note, since they are a signficant part of the industry. These "special applications" have a unique set of interconnection requirements:

Test systems—Whether in the laboratory or for production, test systems require higher accuracy (loss, return loss, phase stability) than typical interconnections. They also must be calibrated, since they are an extension of the measuring instruments. And this performance must be maintained under the mechanical conditions of repeated connector mating/unmating and cable flexure.

Military applications—Military systems require rugged/reliable products, with actual performance depending on the particular use. When used for weaponry or operational vehicles, aircraft or watercraft, reliability must be uncompromised. And when used in systems that will undergo service, upgrades or replacement, that reliability must be maintained for numerous mating/unmating cycles.

Commercial high-rel (aeronautical, vehicular)—These applications have requirements similar to military systems, but may have different cost expectations.

Space systems—In space, high reliability is also the top factor, compounded by a vacuum environment that has large thermal changes over both long and short term, as well as high levels of radiation.

Precision applications—Fundamental research relies on the maximum attainable precision in every part of the system. Sensors, power sources and other components of research equipment must be connected using cables and connectors that do not degrade that accuracy.

High power—The requirements for handling high power depend on the application's frequency, power, acceptable insertion loss and return loss, as well as environmental considerations. A short connection from a 13.56 RF power supply to a heating chamber must work in an industrial environment. A long run of coaxial cable or waveguide for a television transmitter requires that the cable and connectors tolerate an outdoor environment while maintaining low loss and low VSWR—in addition to high reliability, since repairs are costly and difficult on large cable/connector/antenna systems high on a tower.

Summary

The range of interconnections needed for high frequency electronic equipment is impressively wide. Power levels range from microwatts to megawatts, while frequencies cover DC to lightwave. Electrical, mechanical and environmental requirements are widely varied, to suit applications from the simplest to the most complex. It's no wonder cables and connectors are such a big part of this industry!