Technology Demands Drive Development of Passive Components

Semiconductor devices may be the glamorous stars of electronic technology, but they won't work without passive components! Fundamental building blocks like resistors, capacitors and inductors are essential. At high frequencies, passive structures using transmission line techniques are equally important. Specialized components like crystals, magnetic materials and surge protection devices are sometimes considered passive components, since they require no power. They are worthy of news coverage, but this report will emphasize the "classic" passive devices.

New Requirements for Passives

As electronic technology advances, performance demands for all devices change, passive components included. Although they are among the oldest and most fundamental electronic devices, their performance must be optimized for specific applications, such as high speed, high frequency, high power, low noise, and so on. Some of the recent demands on passives include the following:

Lead-free construction—The European mandate to make electronics lead-free (Directive 2002/9/EC—RoHS), requires more than simply replacing lead/tin solder with another formulation. All other practical solders have higher melting points, requiring components to withstand those higher temperatures and tolerate the longer time required for the terminals and substrate metal to heat up to the solder's melting point. Many components have simply required testing to assure their performance, but some have needed re-formulation of materials to provide reliable operation.

Miniaturization—We all know that products are getting smaller, with more features being stuffed inside. Of course, smaller passive components are required to meet this need. Design techniques that reduce the number of components have been developed, and some of the passives are being integrated into semiconductor die and packaging, as noted below.

Size is not the only reason for miniaturization. Smaller components have lower parasitic inductance and capacitance, which is required for higher frequency operation. Also, on-chip passives fabricated using IC processes do not always deliver sufficient performance. To get the high performance of optimized discrete components, passives must be scaled in size to fit the application.

Package and assembly effects—At higher frequencies, all interconnections should be considered as passive devices. Recently, much work has been undertaken to properly characterize the effects of packaging. This concept is being extended to the layout surrounding the components on a p.c. board or other substrate.

Multi-chip modules (MCMs), low temperature co-fired ceramic technology (LTCC), layered board techniques and passives-in-package (PiP) have changed the assembly methods of high frequency circuits. Some of these methods require low-height components, others need improved temperature performance or tolerance to mechanical stresses. Component manufacturers have responded with new efforts to provide the necessary form factors and performance capabilities.

Improved characterization—Engineers' reliance on circuit and system simulation has increased dramatically in recent years. Time-to-market and cost pressures require those engineers to work more efficiently, while market growth has thinned out the pool of available engineering talent. Fortunately, the availability of inexpensive computing power has been combined with innovative software development to make powerful simulation tools readily available.

To keep up with simulation, there is a demand for improved characterization and modeling of passive components. Operation at higher frequencies requires a combination of measurement-based and electromagnetic analysis-based component models to accurately predict the performance of the complete circuit.

Next, we'll point out the key issues with several specific types of passive components.

Resistors

Often considered a "generic" electronic component, resistors are more complex devices than many engineers appreciate. Because of their common usage, resistors are expected to be cheap. Much of the recent work in resistor technology has been focused on manufacturability, to reduce cost while implenting the performance enhancements required for new high-speed/high-frequenccy applications.

Attention to high frequency peformance in resistors usually means low inductance and low parasitic capacitance. Meeting these objectives is relatively easy in tiny surface-mount, small-signal devices, but are a significant challenge for resistors that must handle power. The large physical size necessary to withstand significant current and dissipate heat increases inductance and capacitance over smaller low-power devices.

Two approaches are used to deal with the additional parasitic reactances of power devices—keeping the size as small as possible using materials with high thermal performance, and accurately modeling the component so compensation for its effects can be designed into other portions of the circuit. Thermal performance improvements might go as far as using a diamond substrate, but there are less expensive materials that offer significant improvement over traditional ceramics.

The ability to provide devices in various form factors certainly applies to resistors, and not just for typical circuit implementations. RF/microwave resistive products—attenuators and terminations—require a wide range of physical sizes and dimensions. These devices are often packaged to match standard cable and connector sizes. When packaged as multi-resistor assemblies that resemble individual resistors, the physical structures may vary widely to meet requirements for ground connection, input/output isolation, parasitic capacitance and inductance, as well as conforming to standard package outlines to allow automated assembly.

Capacitors

In addition to reducing the physical dimensions, capacitors have had much recent development work in the area of dielectrics—ceramics, glass, porcelain, plastics, and even silicon IC-type construction. Each type of material has been developed to meet market demands for a particular performance and/or cost objective. Sometimes the "market" can be a single large customer, since some capacitor manufacturers have developed the capability to provide a range of performance options in their otherwise standard product lines.

Market demands include improved reliability, low effective series resistance (ESR) and high self-resonant frequency (SRF). Reliability specifications require more testing of the products, including the expected accelerated life tests at elevated temperatures, with vibration and with electrical stresses.

Low ESR means low losses and high Q, resulting in better performance for filters and matching networks. Low SRF will minimize unwanted responses in those filters and matching networks, and is highly desirable in coupling and decoupling (bypassing) applications. As expected, tradeoffs are required, especially at the smallest and largest sizes of devices.

Capacitor performance is one of most-often discussed topics among designers of high power equipment. High power applications require materials and testing to handle high voltages, high DC current, high RF current, high temperatures and thermal cycling. In addition, the range of applications includes all frequencies from DC to millimeter waves.

Inductors

With inductors, the "magic specification" is Q. Small size and high inductance values are the most difficult areas where achieving acceptable Q is most difficult. Also, small sizes place limits on wire size and, therefore, current-handling capability. Surface-mount inductors use a wide range of construction techniques to get the best Q while meeting other mechanical, electrical and cost requirements. Low-loss materials, air spaces, low-capacitance terminations and gold or silver (solid or plated) wire are among the techniques being used.

Perhaps the greatest effort has been made to develop better integrated inductors. On-chip inductors provide the ultimate convenience with automated fabrication, no additional components to place and short-distance interconnections. Unfortunately, silicon, GaAs and other common IC processes do have the best dielectric properties, or allow the best mechanical structures for high Q. These shortfalls can be partially overcome with air bridge techniques and, more recently, with MEMS (micro electromechanical systems) technology. Mostly, engineers have compensated for low inductor Q by improving performance elsewhere in the circuit, knowing that a better inductor would be a far better solution.

Couplers and Filters

Covering the transmission line family of passive assemblies could fill a book, so we'll simply note some of the most active application areas. Like the rest of high frequency electronics, there is a divergence in emphasis—small size and low cost vs. highest performance.

In the low cost area, wireless devices have created a demand for front-end duplexers and filters that isolate the receiver from the transmitter output, allowing them to share the same antenna. Surface acoustic wave (SAW) technology and film bulk acoustic resonator (FBAR) technology are used for these applications, using piezoelectric properties to provide the necessary filtering and isolation.

At higher power and higher performance, wireless base stations use coaxial ceramic resonator duplexers to separate the receive and transmit circuitry. In base stations, power control and linearization techniques require directional couplers to sample input or output signals and inject correction signals. Consistent performance at reasonable cost is the key specification.

Power amplifier combiners are a challenging market for transmission line components. Wireless base stations, broadcast transmitters, military communications and countermeasures, and satellite systems are key markets for combiners. Each has a unique set of requirements regarding electrical, mechanical and environmental performance. Traditional air dielectric devices in machined packages remain viable solutions, along with ceramic dielectric stripline coupler technologies.

High performance testing is another major market for passive couplers, both in laboratory instruments and production test systems. Flat frequency response over wide bandwidths, repeatable performance over time and temperature, good directivity and low insertion loss are the primary requirements.

Summary

Passive components continue to be essential elements in high frequency design, with the same evolving cost and performance demands as all other devices.

From March 2005 *High Frequency Electronics*