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Board-Level Packaging Moves To Higher Frequencies

Designers Should Be Exploiting The Natural Phenomenon That Comes With High-Frequency Applications.

Four design questions always seem to surface in any discussion of board-level packaging involving RF or higher frequencies, particularly for wireless applications. The first question is whether wireless printed-circuit-board (PCB) designs can use plain vanilla FR4 materials (FR4 is the most popular laminate type for printed circuits) and fabrication technology with high-frequency applications. Another question is at what frequency these issues "kick in." Also, what special construction needs have been identified to support these issues? And what special materials should be used? Everyone understands that the purpose of a PCB is to connect components with wires or traces. With high-frequency boards that are increasingly used for the fast-growing wireless telecommunications market, the wireless activity happens on the board platform.

Two closely-spaced adjacent traces might be designed to produce electromagnetic (EM) fields to function as a coupler, or a series of cascading patches might be a bandpass filter. Design engineers should be exploiting, not defeating the natural phenomenon that comes with high-frequency applications. One way to think of this is that wave size matters. At 100 MHz (the clock rate on a fairly low-performance Pentium chip), the wavelength is several meters long and even the harmonics that are used to generate the rapid rise times are still at a low frequency. As a result, the full sinusoidal wave is usually larger than the PCB that is carrying the wave. At 1 GHz, the wave is only 10 in. (25.4 cm) long and the normal effects of wave reflection can occur, causing the spurious performance "hiccups" that high-frequency designs are famous for.

Looking For New Things

At these frequencies and above, new things become important. For example, the neat 90-deg. turns that digital designers use to save routing space are destructive to high-frequency performance; they cause voltage-standing-wave-ratio (VSWR) problems. One version is a reflection that cancels the incoming signal because it is 180-deg. out of phase. Instead, the use of mitered or radiused corners is the norm. The length of traces relative to each other becomes important as designers try to match phases on the board. Etch precision becomes critical and in-trace pinholes are not allowed. Even the cross-sectional geometry of the trace becomes important as "skin effects" become dominant with rising frequency. Precision is important in these frequency domains. While the world of traditional electronics on FR4 packaging is moving to smaller, lighter, and lower power, the microwave world is still pushing for tighter tolerances. Since the three key variables to a particular transmission line are trace width, dielectric constant tolerance, and dielectric thickness spacing, the precision of these is paramount. It is not uncommon to have very "generous" trace widths of 20 mils, but with 60.0006 tolerance overall, measured at the flair. (In most FR4 shops, the inspection equipment cannot discern flair-to-crown differences.)

The particular frequency that these special issues "kick in" is important. Until recently, conventional wisdom held that FR4 is good up to 800 MHz and that it is too lossy at higher frequencies. While that may be true, the postponement of moving up to exotic laminate materials is very possible by specifying tighter tolerance or "tunable" components. This sometimes results in a kind of purchasing myopia as PCB prices are contained but component costs skyrocket as designers try to avoid the transition to full microwave packaging.

For example, some users routinely use FR4 way up into the 1.2-GHz band by specifying and controlling the glass and epoxy resin mix of the laminate construction-to the extent that a controlled dielectric constant (Dk) results. This approach takes a pronounced engineering investment to "discover" what to specify and control in FR4 and a strong purchasing diligence to ensure that suppliers do not vary glass weave, diameter, type, and placement from run to run.

Most circuit materials are made from epoxy resin and woven fiberglass. The glass features a Dk of four and the epoxy plastic (adhesive) has a value in the range of six. Therefore, epoxy-glass materials are typically somewhere between four and five due to the relative loading of these two materials. Since Teflon has a Dk of 2.1, the glass loading of a Teflon material tends to drive up the Dk-values such as 2.45 are common.

However, the real key to exotic materials used in circuits lies in the higher precision of the dielectric constant (see table). In FR4 laminate materials, it is not uncommon for Dk values to be 4.5 60.5. In Teflon materials, the Dk value might be 2.45 60.04-an order of magnitude of tighter control. Hybrid circuits have been made for years on very hard materials such as ceramic. These materials have dielectric constants in the 10 range. Some of the materials are filled Teflon composites that have been engineered to achieve CTE and Dk.

EM effects start to show up in board-level packaging at 800 MHz, assuming a normal power level with traditional signal-to-noise ratios (SNRs). Beyond that and depending on the design, a designer should consider high-frequency materials as part of the design solution set.

Nickel Instead Of Gold

The use of nickel is another critical area in board performance. A lot of money has been spent on thick gold because a nickel undercoat barrier layer was thought to be too lossy and, as a result, should be avoided completely in microwave designs. However, designers indicate that while this may be generally true, the degrading effect of nickel is lost in the background noise of performance until approximately 5 GHz. At this point, it becomes barely noticeable.

Serious problems can arise when combining RF design with standard high-volume assembly technology. For example, the use of soldermask for area coverage of surface traces, which only exposes pads that will have solder paste on them at some point, is a workhorse standard approach of the assembly business using surface-mount "pick and place" technology in solder paste. On an RF design, the broad use of soldermask has a degrading impact on microstrip transmission lines since the soldermask has very uncertain dielectric constant attributes and thickness. One answer is to specify and use solder dams that minimize the use of the mask, while providing the assembly function of "damming" the trace so that the solder does not wick down the trace during reflow. These dams only need a 20-mil footprint to do their job and the microstrip function is practically untouched by their presence in this size configuration.

The most popular volume construction today in use is copper-backed co-planar waveguide (CBCPW), which is a microstrip design with extensive use of ground area on the top or component side of the circuits and lots of mode-suppression holes to provide massively-redundant RF ground. This approach provides robust-shielded areas for filters and other microwave-etched functions while still supporting low-cost surface-mount technology (SMT) and low board-fabrication cost.

For amplifiers, the implications for constructions in RF packaging include transistor-based power supplies that are on the board, requiring heat dissipation and usually involving the use of a carrier plate for thermal transfer. Other solutions involve localized heat sinks that are backside mounted, sometimes requiring machined cavities to "seat" the localized area conductors for maximum efficiency. One recent trend is to integrate more functions. Functions previously supplied as a component are now supplied as an etched area on the board, and will someday move to full multilayer constructions with buried planar resistors, side-launch constructions, enhanced shielding, and the use of multilayers to avoid connectors in order to achieve superior price and performance.

Sometimes the end use of the unit drives construction design. An example is residential restrictions on parabolic dishes that may be overcome by phased-array receive-only cellular, or satellite flat-panel antennas that are mounted on the side of a house. On cars, vehicle designers don't want the antennas to be visible, leading to the development of conformal designs (so-called "smart skins") and antennas embedded in license plates.

Obviously, materials are an important factor. The good news in the material segment of the market is that the major high-performance laminate suppliers are showing new products that solve many of the inherent difficulties, such as coefficient of thermal expansion (CTE), dimensional stability, and cost, with traditional materials that have long served the RF and microwave markets.

The need for multilayer high-frequency materials and high-reliability plated-through-hole (pth) applications has created a market for a series of highly-engineered polytetraflouroethelyne (PTFE)-based, but heavily-filled laminates that solve z-axis pth CTE mismatches. The price of these laminates has dropped significantly-from $100 to $30 per square foot.

Even newer laminate products have tackled the cost agenda (partly a result of new suppliers entering the high-performance laminate segment) and several good candidates are emerging in the $10 to $12 per square foot range.

The next step is a complex area. The best approach for making a success of any high-frequency board-level packaging includes these three points:

- Form supply alliances for high-frequency commercial success, particularly if the strategy includes getting to market on time and a successful initial robust design. In today's time-critical markets, there isn't time to "walk in" an RF design. The trick is to get it right the first time.

- Be certain that the supplier base can accommodate high volumes when the time comes. This is an explosive market and it is important to select capacity that matches the expectations for a successful product launch.

- When confronted with the choice, the "exploit" rather than the "defeat" approach is the better engineering solution for RF/microwave designs. The most successful approach is one that uses EM field effects to an advantage, along with a better understanding of RF/microwave board-level packaging.