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Advances in High-Frequency PCB Materials

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Advances in High-Frequency PCB Materials

Traditionally, RF/microwave printed circuit board applications were developed based on the needs that came out of the military market. Applications like radar and guidance systems were operating at frequencies where traditional printed circuit board (PCB) materials like epoxy/woven glass did not have the properties — mainly tight dielectric constant control and low dielectric loss — that allowed them to be used at frequencies in the +1GHz range. Instead of PCBs, designers had to use waveguide structures as the first RF/microwave circuits; however, this meant bulky and heavy solutions.

Along came the first resin system that, when combined with woven glass, gave designers the opportunity to develop approaches with conventional PCB fabrication techniques. This first resin was PTFE that began being used in the 1950s, and combined with glass, dielectric circuits with low dielectric constants began to emerge in the military market. Variations of these early materials were then introduced, mainly trying to address the needs of RF/microwave designers, like higher dielectric constants to enable the reduction in size of the circuits. Two further developments came about that significantly changed the use of PCB materials in the military market in the 1990s. The first one was the development of temperature-stable PTFE/ceramic composites. Designers now had the option to work on multilayer PCB (MLB) approaches as a means to increase functionality in a fixed area. The second was the introduction of a new type of resin system. Unlike PTFE, this resin was a thermoset resin. Materials using this resin were rigid in nature and were the precursors of a series of materials to be introduced in the mid 1990s that revolutionized the total RF/microwave market.

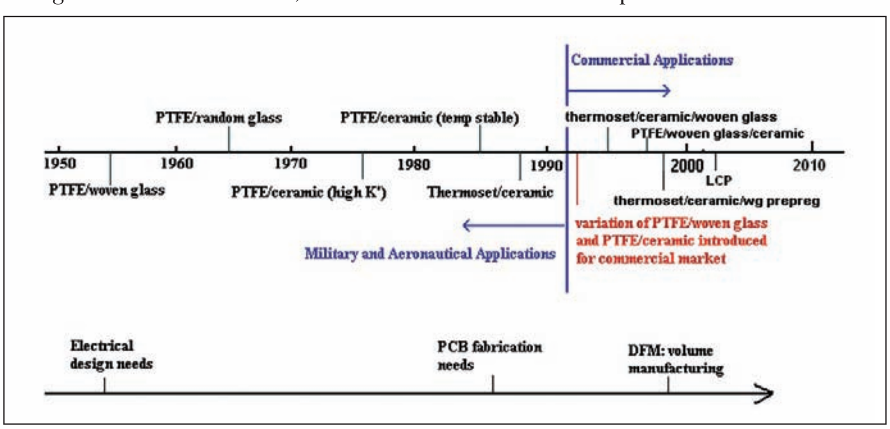

Figure 1. Evolution of PCB materials for high-frequency applications.

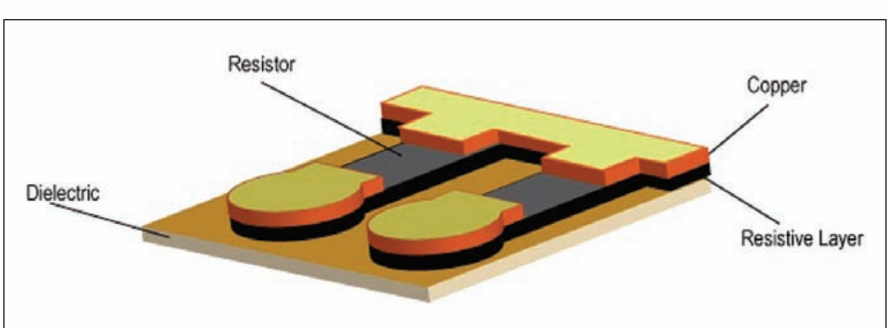

Figure 2. Example of a planar resistor using resistive copper foil.

By the mid 1990s, much of the focus in this market was to find reduced-cost solutions. Tighter DoD budgets meant doing more with less, and the RF/microwave market began to be dominated by the wireless telecom market. This new market began to dictate the types of PCB materials that were being developed. In the past five years, we have begun to see a resurgence in high-frequency product development aimed at the very important defense market (see Figure 1). Advances in areas of weight, passives, and MLB techniques will be covered.

Buried Passives

An area where there has been increased interest is the use of buried passive components in multilayer constructions; to be more specific, buried planar resistors in high-frequency materials. Resistive layer copper foils have been available for over two decades, but their use has been hindered by the fact that resistor tolerances can typically exceed 20% unless a secondary trimming process is incorporated. Significant improvements to the "as etched" tolerance have been achieved by making slight modifications in the manufacturing process of the resistive layer that goes on the copper base and the dielectric construction.

A thin resistive layer is applied to an electrodeposited copper foil. The range of values of resistors that can be achieved in high-frequency materials ranges from 25 to 50 Ohms/square and for some particular construction/dielectric combinations, as high as 100 Ohms/square. A double etch process is required to achieve the desired resistor; the first etching process eliminates the copper on all surfaces where exposed dielectric is needed, while the second etching process is needed to expose the resistive layer at the desired length to create the needed resistor value. Figure 2 gives an example of a resistor using this technology.

In the past, final desired etching tolerances required the need of a trimming process after the secondary etching step to achieve resistor tolerance values within ±10%. Today, for some dielectric and resistive copper foil types, this tolerance can be achieved without the need of the trimming process. Figure 3 provides measured data comparing the old (red) and new (blue) process on a PTFE/woven glass/ceramic filled 0.005" thick dielectric.

These improvements allow designers to now have the ability to work with thin, temperature-stable dielectrics, achieved through the use of selected filler/resin combinations and tight dimensional tolerances (due to woven glass structures for reinforcement) in combination with resistive copper foils to achieve high-level passive integration within an MLB structure.

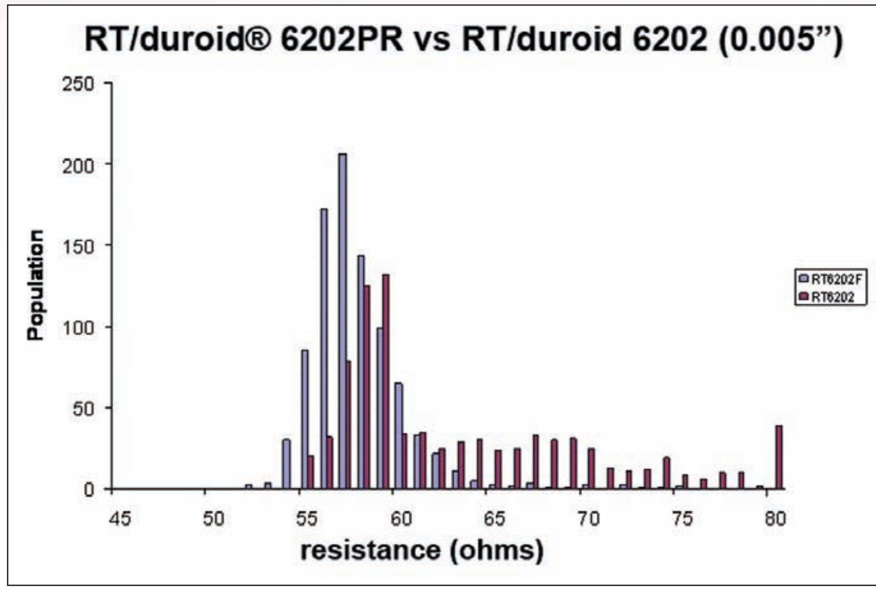

Figure 3. Improvements in resistor value achieved after the double etch process.

Lightweight PCB Materials

New materials have been designed that are enabling new technologies to move forward. Airborne radar antennas are becoming more complex and a greater part of the military's arsenal of tools to monitor the world's hot spots. To better serve the designers' needs, lightweight/low-dielectric-constant PCB dielectrics are needed. Foam PCB materials have been introduced before with limited success. Their main drawback was the lack of true circuit board processability; in particular, plated through-holes. A unique approach was taken to develop a dielectric that gave RF/microwave antenna designers an option for low-dielectric-constant, low-loss, lightweight applications. In this case, lightweight hollow glass spheres have been incorporated into a PTFE matrix to give a substrate that has a dielectric constant of 1.96 and light weight of 1.37 g/cm^3 (40% lower than conventional PTFE/woven glass materials). Figure 4 shows a cross-section of a multilayer construction with the substrate where the hollow glass spheres can be seen.

Most of the low-dielectric-constant, low-loss substrate materials available today have the disadvantage of having high-temperature coefficient of dielectric constant (TCDk) and high coefficient of thermal expansion (CTE) in the Z-axis. When operating in a thermal cycling environment, as are many airborne applications, designers are challenged with compensating for changes in electrical and mechanical performance of the circuit. The combination of PTFE and glass spheres allows this material to have a TCDk of 22 ppm/°C (vs. -125 ppm/°C for comparable PTFE sub-

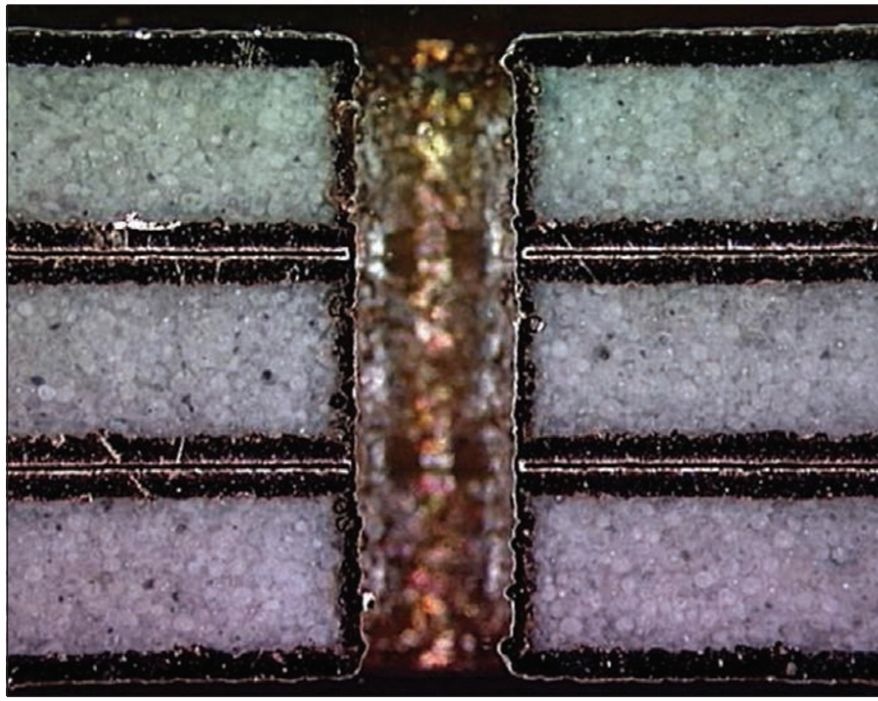

Figure 4. Cross-section of MLB low-dielectric-constant lightweight circuit.

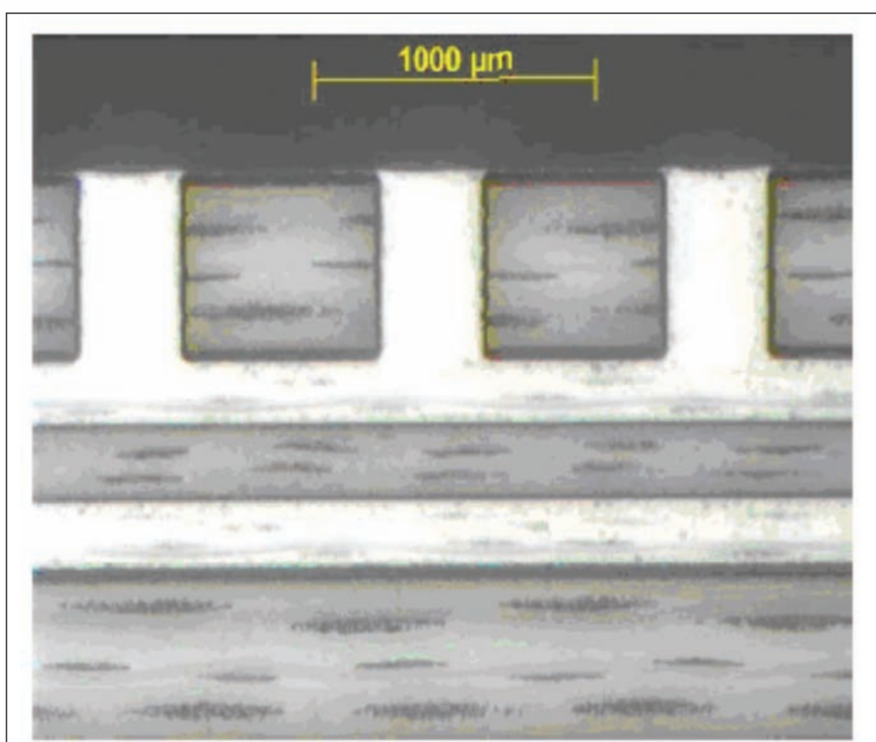

Figure 5. RF thermoset MLB with filled vias using new higher-flow prepregs.

strates), and a CTE-Z axis of 46 ppm/°C (vs. 200 for comparable PTFE substrates). By selecting this material, the designer's job is simplified, and changes in electrical and mechanical performance are reduced.

Improved MLB Manufacturing

Military RF/microwave designs have traditionally not been considered complex, high-layer count constructions, mainly because the material choices limited the designer's ability to achieve a high level of complexity. In particular, the selection of bonding film usually required high lamination temperatures, and the thermoplastic nature of the film made sequential lamination more complex (a secondary lamination step could re-melt a previously bonded layer). In the early 2000s, adoption of high-frequency thermoset materials (hydrocarbon resin/ceramic/woven glass) began to take place in the defense market, and available bond films (prepregs) that followed traditional epoxy/woven glass (FR-4) processing techniques made designing and building true RF MLBs less complex.

Thermoset RF materials have posed an advantage over PTFE because of their processing similarity to FR-4 and inherent lower processing costs, but limitations in design existed due to the low flow nature of the matched prepregs; in particular, fill of blind vias. Increased flow, high-frequency prepregs are now available. Besides having ideal RF performance, these prepregs can now be used to fill blind vias, as shown in Figure 5. RF engineers now have the flexibility to design complex MLBs with low-cost practices commonly found in the FR-4 industry.

A limitation to selecting these low-loss multilayer thermoset laminates had been that the selection of dielectric constants had been restricted to values ranging from 3 to 4. Today, that is no longer the case. We have now seen new thermoset laminates/prepregs introduced that have a dielectric constant of 6.15, and have matching higher-flow RF prepregs, expanding the material choices available for RF MLB designs. This new family of products has also given designers a second option where previously, LTCC would have been the only approach.

Conclusion

The world of high-frequency PCB materials is going through many changes, and the material choices available to designers continue to expand. Design centers are interfacing more openly with substrate suppliers in order to develop products that continue to enable further advances in technology. Successful designs require close interaction among the designer, the PCB facility, and the laminate supplier working together to continue to push the envelope of what can be achieved. This has been the trademark of the military RF/microwave market. The materials presented have unique properties and can be optimized in various ways depending on the application. When selecting a PCB material, one is also selecting a PCB material supplier. Choosing a material supplier that stands behind the products they sell and is willing to work with the customer base to further develop the next generation of materials in a timely fashion is as important as the material itself.

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