High Performance, Economical Substrates: Myth or Reality?

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Introduction

In the past decade, the wireless industry has undergone a metamorphosis. This industry has turned from a predominantly military driven market to a cost conscious, consumer driven commercial market. At the same time, the wireless applications are moving up in the frequency spectrum. A typical example would be the PCS system. The PCS systems are currently designed for 1.9 GHz spectrum, but the newer designs for wireless communications are moving up to 5.8 GHz.

As the commercial applications move up in the frequency spectrum, there is a renewed interest in high performance, high frequency low cost substrates. In the various military applications, PTFE substrates were always the materials of choice. With a very low loss tangent (0.0032 at 10 GHz), excellent resistance to processing chemicals, negligible water absorption and a high temperature resistance (PTFE, popularly known as Teflon®, has a melting point of 621F [327C]), PTFE substrates were able to meet all of the technical requirements of RF/wireless design.

When commercial applications demanded high performance substrates, there were certain disadvantages with conventional PTFE substrates. First, PTFE substrates were expensive; typically the price of PTFE substrates is roughly 10x the price of the epoxy glass laminates (popularly called FR-4). Second, due to the inert nature of PTFE, the processing of the PTFE substrates entailed one extra step: pre-treating the hole wall by a plasma process or by a chemical process (such as a sodium napthanate etch) to achieve excellent adhesion of the copper to the hole wall. Third, conventional PTFE substrates were “soft”, meaning that they needed special care during the processing step. Finally, the CTE of conventional PTFE substrates was high (typically, 180-250 ppm/C depending on the dielectric constant of the substrates).

To fill the requirement in the commercial arena, several proprietary and generic products were attempted. These products did offer some advantages over the conventional FR-4 substrates, but all of these products were “me too” products, and did not match or exceed the superior electrical performance of PTFE nor did they offer the cost advantages of FR-4.

Why do these products not meet the requirements? Most of these replacement products are thermoset resin based systems (thermoset resins are resins which form a non-meltable mass after cross-linking). Due to the chemical nature of most of the thermoset systems, they burn when exposed to an open flame. To make these resin systems viable for PCB use, flame retardant additives (a bromine or a chlorine based compound) have to be added. Hence, even though the electrical performance of the pure resin might fill the need at a high frequency, the addition of a flame retardant to render the resin useable for a PCB renders the PCB unusable for high frequency use. For example, polybutadiene has a loss tangent of 0.0005 at 10 GHz, but the loss tangent (tan) increases to 0.006 with the addition of a flame retardant additive and other filler (a 12x increase).

Furthermore, as European countries become extremely sensitive to the effect of their products/process on the environment, the thermoset resin based systems, which are processed in an organic solvent medium, might not be an environmentally friendly alternative. Most of the thermoset-based systems have an unsaturated, exposed carbon atom, hence leading to high moisture absorption and to a greater tendency to absorb processing chemicals during the processing stage. This leads to two unwanted developments:

1. The tendency to absorb processing chemicals during processing creates the need to add an extra step of baking after drilling (hence the advantage over PTFE substrates of eliminating the process of hole treatment is lost) to eliminate the blistering during the solder reflow process.
2. A high absorption leads to a shift in dielectric constant (hence a shift in resonant frequency), a higher loss tangent, and a phase shift with frequency. This is an important factor in applications where the PCB is exposed to high humidity, such as an antenna in a base station application.

From an economic standpoint, these products are cheaper than conventional PTFE substrates, but they are definitely much more expensive than FR-4. Furthermore, a typical thermoset resin has a very low viscosity past its melt temperature. Hence when the laminates are manufactured under high temperature and pressure, the resin tends to flow. This phenomenon tends to give a “pillow effect”, which is a greater variation of dielectric constant and thickness within a sheet than most RF designs can handle. For example, a greater variation of thickness within a sheet can adversely affect the linearity of power amplifiers, and a loose tolerance on dielectric constant will make it very difficult to maintain a tight tolerance on the impedance of a trace width in a microstrip configuration.

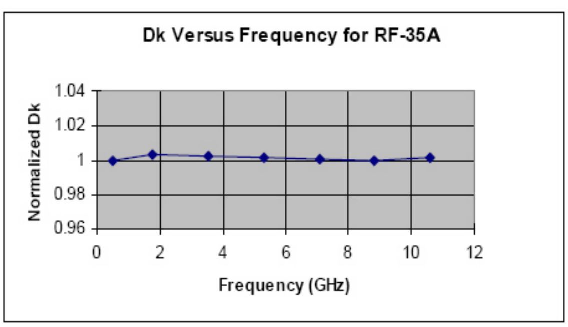
In addition, due to the chemical nature of some thermoset resin systems, the dendrite structure of the copper is not able to bond with the thermoset resin. The addition of additives and fillers exacerbates this disadvantage. Due to this characteristic, the peel strength of some of the latest high performance thermoset products is extremely low, making it very difficult (hence increasing the processing cost) to work with, and extremely expensive when rework is warranted. Furthermore, due to the low peel strength, some of the newer products are not offered in ½ oz copper (18 µm thickness) making it impossible or very difficult to do fine lines and fine features. This feature is not much of a disadvantage for an RF design, but it is a major disadvantage for the newer high-speed digital applications. Since the processing of these products is different than traditional FR-4 substrates, a premium is charged for processing these substrates, therefore the cost advantage of processing the "high performance FR-4 like" products is lost.

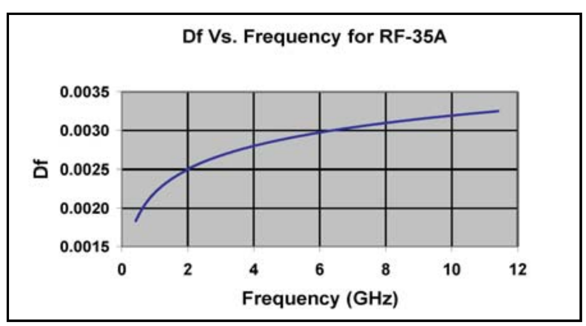
All these issues have brought the high performance, low cost, high frequency substrates industry and its user back to the drawing board. Is a high performance, low cost substrate a reality, or is it still a myth?

After exhaustive analysis, engineers at Taconic came to the conclusion that PTFE based products are still the substrates that give the best electrical and mechanical properties. Building on all the advantages of PTFE and by incorporating several proprietary technologies, Taconic came up with a true low cost RF/microwave substrate; RF-35A.

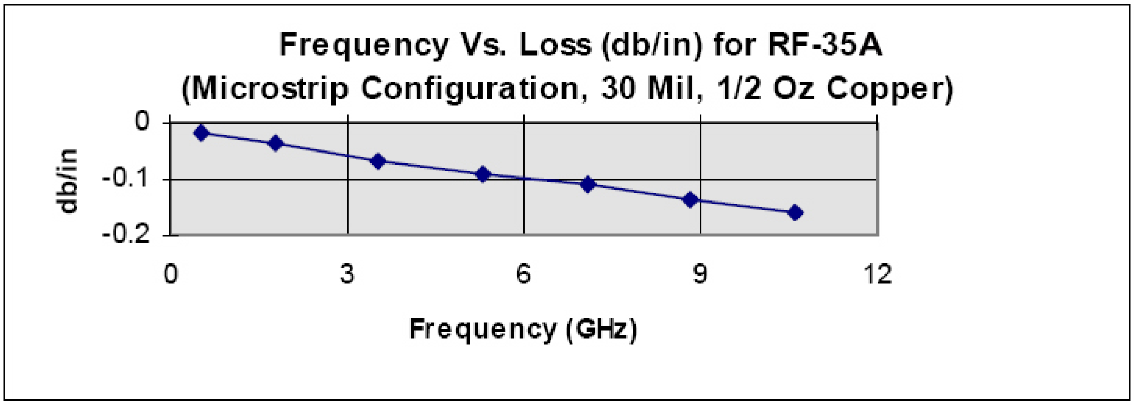
RF-35A is a ceramic filled, low-cost PTFE substrate. RF-35A not only satisfies the price requirement, but also exceeds every electrical and mechanical property that is sought in a PCB substrate for high frequency applications. The dielectric constant is 3.5 with a tight tolerance (+/- 0.05), offered in thicknesses in increments of 10 mil [0.25 mm]. RF-35A is currently offered in 10, 20, 30 and 60 mil [0.25, 0.5, 0.76, and 1.52 mm]. With the introduction of RF-35P, the same attributes are also available in increments of 2 mil [0.05 mm]. RF-35P is available in laminate thicknesses of 2, 4, 6, and 8 mil [0.05, 0.10, 0.15, and 0.20 mm]. The thickness tolerance for RF-35A and RF-35P is per IPC-4103, Class C (e.g., the tolerance for a 0.020" [0.5 mm] substrate is +/- 0.0015").

RF-35A demonstrates exceptional thickness and dielectric constant variation within a sheet. The standard deviation of dielectric constant within a sheet is 0.01, and the standard deviation of the thickness within a sheet is 0.00023". The loss tangent of RF-35A was measured at n = 1,2,3… harmonic, and the frequency ranged from 500 MHz to 11.2 GHz. As the figure below indicates, there is virtually no variation in dielectric constant across the frequency spectrum, and the loss of RF-35A was 0.0025 at 1.9 GHz and 0.0032 at 10 GHz.



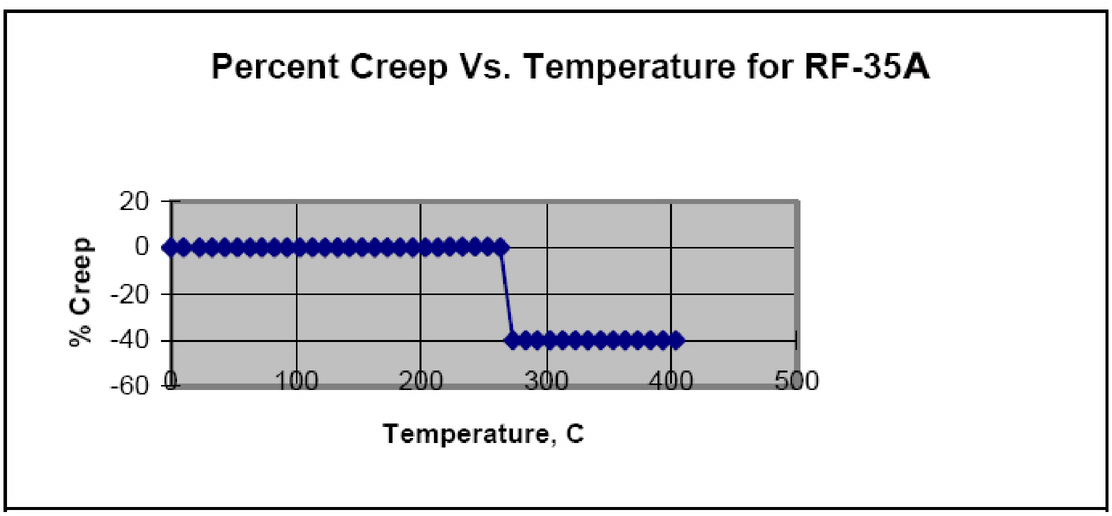


The total loss in db/in versus frequency is also plotted:



The water absorption is less than 0.04% when exposed to water for 24 hours at 23C. RF-35A is available in ½ oz, 1 oz and 2 oz copper, and the peel strength (after the RF-35A substrate is exposed to a solder float @ 550F [287C] for 10 seconds) is greater than 8 pounds/inch [1.4 N/mm] for ½ oz copper. To address the issue of the rigidity of the PCB substrate, a proprietary technology was used to utilize the structural integrity of the woven glass reinforcement. Furthermore, RF-35A has a dimensional change of 130 ppm in the X-axis (fill direction) and a dimensional change of 640 ppm in the Y-axis (warp direction) after etching the copper.

The CTE in the Z axis for RF-35A is 43 ppm/C, which ensures excellent reliability of the plated through holes. To ensure the mechanical integrity of RF-35A and to dispel the myth that PTFE substrates exhibit creep, RF-35A was tested for creep by an independent lab, according to BSI-125. The results are given below:



As the graph indicates, RF-35A does not exhibit any creep/negligible creep when exposed to a load of 4200 psi, up to a temperature of 550F [287C]. This result indicates that RF-35A should not exhibit any creep in a normal PCB application.

What makes RF-35A so unique? What gives RF-35A ALL the electrical and mechanical properties that RF designers look for? The answer lies in the unique, proprietary process that Taconic has developed. By modifying the surface chemistry of the ceramic filler, Taconic has been able to get a true interpenetrating polymer network of the ceramic filler and PTFE. This network ensures that the ceramic particles are encapsulated with PTFE, which enable RF-35A to get the synergy effects of both PTFE and the ceramic filler. Hence, as explained above, RF-35A has exceptional dimensional stability, low CTE, and excellent mechanical integrity, a tight tolerance on DK and thickness, very high peel strength, and is the most economical high-performance laminate available in the marketplace today. Furthermore, due to the inherent nature of PTFE, RF-35A has a flammability of UL-94 V0 and is WEEE and RoHS compliant.

Additionally, a comparison of the processing steps for RF-35A and for a typical thermoset resin PCB material indicates that contrary to popular belief, processing RF-35A does not entail a complex process compared to processing a thermoset resin based PCB.

PROCESS	PROCESS SIGNIFICANCE	RF-35	THERMOSETS
Hole Quality	-PTH Reliability	Good	Good
Tool Life	-Process Cost	Good	Poor
Burring	-Added Process	Good	Poor
Hole Treatment	-Added Process	Fair	Good
PTH	-PTH Quality	Good	Good
Image, Etch	-Trace/Line Definition	Good	Good
Copper Plating	-PTH Reliability	Good	Good
Strip, Etch	-Trace/Line Definition	Good	Good
Solder Coating	-Ease of soldering	Good	Good
Depanelizing	-Finished edge quality	Good	Good
Routing Tool and Wear	-Tool expense and replacement	Fair	Fair
Routing Feed Rate	-Routing cost	Fair	Fair
Fixturing	-Fixturing time and cost	Fair	Good
Pick and Place	-Ease and part location	Fair	Good
Reflow Soldering	-Warping and part integrity	Fair	Fair
Mounting	-Conformance to housing or pallet	Good	Fair

Conclusions

RF-35A does offer the combination of the best performance and best price for a high frequency application, indicating that a high-performance, low cost substrate is indeed a reality. As discussed in the article, RF-35A offers all of the electrical advantages of PTFE, all of the mechanical advantages of the ceramic filler, negates all of the disadvantages of PTFE substrates and disproves all of the “myths” surrounding PTFE substrates and processing PTFE substrates.

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