

# 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 design 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 (0.0018 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 621° F [327 °C]), PTFE substrates were able to meet all the technical requirements of RF/wireless design. When commercial applications demanded high performance substrates, there were certain disadvantages with conventional PTFE substrates. Firstly, PTFE substrates were expensive; typically the price ranged from 8-10x the price of the epoxy glass laminates (popularly called FR-4). Secondly, due to the inert nature of PTFE, the processing of the PTFE substrates needed one extra step viz. pre-treating the hole wall by a plasma process or by a chemical process (such as a sodium naphthanate etch) to achieve excellent adhesion of the copper to the hole wall. Thirdly, conventional PTFE substrates were “soft”, meaning that they needed special care during the processing step. Finally, the CTE of conventional PTFE substrates were high (typically, 180-250 ppm/°C depending on the dielectric constant of the substrates).

To fill the requirements 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 (thermoset resins are resins which form an non-meltable mass after cross-linking) based system. Due to the chemical nature of most of the thermoset systems, they burn when exposed to a open flame. To make these resin systems viable for PCB use, flame retardant additives (a bromine or a chlorine based compound) has to be added. Hence, even though the electrical performance of the pure resin might be able 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 a high frequency use. For example, polybutadiene has a loss tangent of 0.0005 at 10 GHz, but the loss tangent ( $\tan \delta$ ) increases to 0.006 with the addition of a flame retardant additive and other fillers (a 12x increase). Furthermore, as some European countries (for e.g. the Scandinavian 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 adsorb processing chemicals during the processing creates the need to add an extra step of baking after the drilling step (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 are 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 a RF design, but it is a major disadvantage for the newer high-speed digital applications. Furthermore, 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.

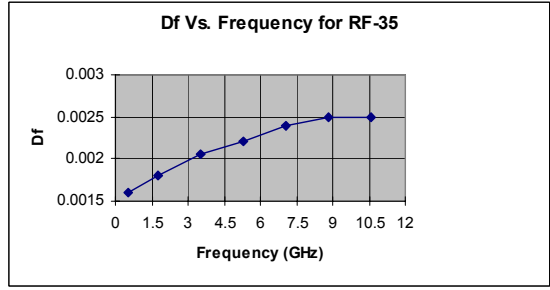
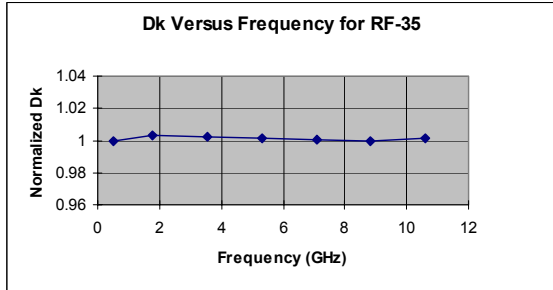
All these issues have brought the high performance; low cost high frequency substrates industry and its user back to the drawing board. Is a high performance low cost substrate a reality, or is it still a myth?

After exhaustive analysis, engineers at Taconic Advanced Dielectric Division 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-35.

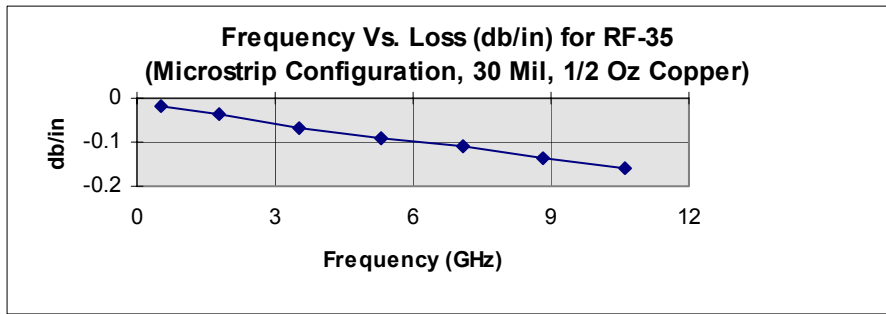
RF-35 is a ceramic filled, low-cost PTFE substrate. RF-35 not only satisfies the price requirement, but also exceeds every electrical and mechanical property that is sought in a PCB substrate for high frequency applications. The dielectric constant is 3.5, with a tight tolerance (+/-0.1), offered in thicknesses that are increments of 10 mil [0.25 mm]. (RF-35 is currently offered in 10, 20, 30, and 60 mil [0.25 mm, 0.5 mm, 0.76 mm & 1.52 mm]). With the introduction of **RF-35P** in January 2002 the same attributes are now available in increments of 2mil [0.05 mm]. RF-35P is available in laminate thicknesses of 2 mil, 4 mil, 6 mil & 8 mil [0.05 mm, 0.10 mm, 0.15 mm & 0.20 mm]. The thickness tolerance for RF-35 & RF-35P is per IPC-L-125, Class C (e.g., the tolerance for a 0.020” [0.5mm] substrate is +/-0.0015”).

RF-35 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-35, was measured at n = 1,2,3,... harmonic, and the frequency

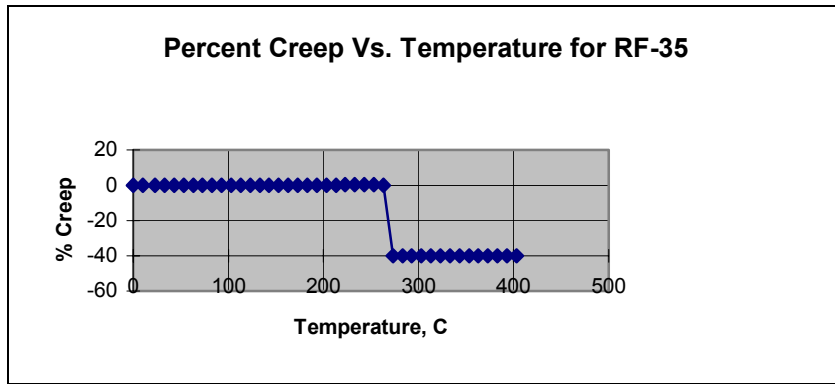
ranged from 500 MHz to 11.2 GHz. As the figure below indicates, there is virtually no variation in dielectric constant across the frequency spectrum, and the loss of RF-35 was 0.0018 at 1.9 GHz and 0.0025 at 10 GHz.



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



The water absorption is less than 0.02% when exposed to water for 24 hours at 23° C. RF-35 is available in ½ oz, 1 oz and 2 oz copper, and the peel strength (after the RF-35 substrate is exposed to a solder float @ 550°F [287 °C] 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. As a result of this work, the hardness of the substrate was increased to 34, as measured by the Rockwell hardness scale. Furthermore, RF-35 was engineered to have the best dimensional stability. RF-35 has a dimensional change of 40 PPM in the X-axis (fill direction) and a dimensional change of -100 ppm in the Y-axis (warp direction) after etching the copper. These numbers, which translate into excellent registration in the finished substrates, are the best that can be found in any PCB substrate. The CTE in the Z axis for RF-35 is 64 ppm/°C, which ensures excellent reliability of the plated through holes. To ensure the mechanical integrity of RF-35 and to dispel the myth that PTFE substrates exhibits creep, RF-35 was tested for creep by an independent lab, according to BSI-125. The results are given below:



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

What makes RF-35 so unique? What gives RF-35 **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 enables RF-35 to get the synergy effects of both, PTFE and the ceramic filler. Hence as explained above, RF-35 has the best dimensional stability, low CTE, an excellent mechanical integrity, a tight tolerance on DK and thickness, very high peel strength, and is the cheapest high performance laminate available in the marketplace today. Furthermore, due to the inherent nature of PTFE, RF-35 has a flammability of UL-94 V0.

Furthermore, a comparison of the processing steps for RF-35 and for a typical thermoset resin PCB material indicates that contrary to popular belief, processing RF-35 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-35 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 listed in the article, RF-35 offers all the electrical advantages of PTFE, all the mechanical advantages of the ceramic filler, negates all the disadvantages of PTFE substrates and disproves all the “myths” surrounding Teflon® substrates and processing Teflon® substrates.