High-Frequency PCB Manufacturing

New Materials Combined with Advanced Technology

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High-frequency electronic devices are currently evolving at a dizzying pace, and particularly in the field of wireless communication. Therefore, in the development of new products, emphasis is placed on the usage of materials suitable for work at high frequencies, above 1 GHz.

When selecting materials intended for the manufacture of PCB's adapted for work at high frequencies, several characteristics are of high importance:

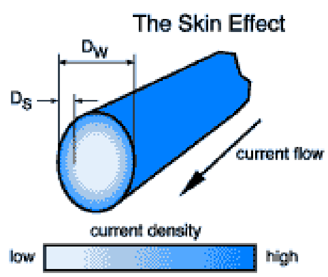
- ✓ D_k Dielectric Constant – the dielectric constant (coefficient) or relative permittivity of resin. This parameter must be low and stable in a wide range of high frequencies. High D_k values may decelerate the signal transmission speed.
- ✓ D_f Dissipation Factor – the parameter responsible for signal quality. The D_f must be low. The lower this value, the more stable the signal will be and the losses reduced.
- ✓ Moisture absorption – another parameter that is very important when selecting the materials for high-frequency works. This item of data is important since the D_k of water is $D_{k;water}$ = 80.4, a very high value, to such an extent that the absorption of a very small amount of moisture will cause a significant increase in the overall D_k of the material.
- ✓ CTE (Coefficient Thermal Expansion) - the thermal dimensional expansion material of the dielectric material. This parameter must be close to the CTE of the conductive material, in cases of PCB's it will be copper. Work at high frequencies causes increased heating of the PCB, and therefore, if a significant discrepancy exists in the CTE of the dielectric material and the copper, structural delamination may occur during the activation of heating/cooling cycles.
- ✓ Additional important characteristics:
  - Thermal resistance.
  - Chemical resistance.
  - Bonding (adhesion) strength between copper and the dielectric material.

Traditionally, high-frequency PCB's are designed or manufactured using Polyfluortetraethylene (PTFE)-based materials, which is better known by its trade name Teflon®. In fact, presently there is a very wide variety of materials based on glass epoxy resin that can be suitable for the manufacture of PCB's for diverse fields of high-frequency works.

One of the most common methods for improving the performance of non-Teflon®-based materials (and actually in Teflon® as well) at high frequencies is the selection of a suitable type of copper, that is the roughness profile (R-profile).

When working at high frequencies, one of the most influential and important phenomena indicating the quality of signal transmission is a phenomena called Skin Effect. As the frequency increases, the electromagnetic field generated by electron conduction in the conductive metal, influences the electric current flow through the conductor and "pushes" it close to the external skin.

The Skin Effect phenomena intensifies the impedance and causes increased conduction losses and decelerated signal transmission. As the frequency increases, the Skin Depth decreases (the skin's thickness).



Frequency	Skin Depth (Copper)
50 Hz	9.3 mm
10 MHz	21 micron
100 MHz	6.6 micron
500 MHz	2.95 micron
1 GHz	2.1 micron
5 GHz	0.93 micron
10 GHz	0.66 micron
30 GHz	0.38 micron
50 GHz	0.30 micron
80 GHz	0.23 micron

Figure 1: "Skin Effect" and typical values

In order to diminish the Skin Effect in CCL (Copper Clad Laminate) manufacturing intended for use with high frequencies, Low-Profile Copper should be used on the bonding side – the side adjacent to the dielectric resin.

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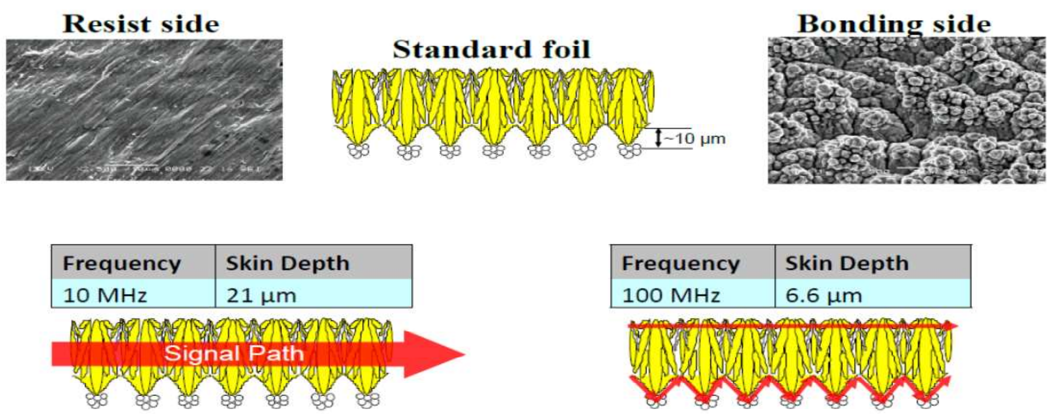


Figure 2: Copper roughness and "Skin Effect"

The three main copper types used in CCL manufacturing are: Standard, Low-Profile and Very Low-Profile.

For improved performance, it is preferable to use Low-Profile Copper with teeth size (roughness) that is less than 5 microns.

Nevertheless, when using this type of copper foil combined with Teflon® material, which is known to have a low bonding strength, it should be taken into account that the possibility of the occurrence of delamination between copper and Teflon® in the diverse manufacturing processes, as well as thermal shocks, is very high. It is precisely at this point that thermoset materials (for instance, glass epoxy), possessing a high bonding strength to copper, have an advantage over Teflon®.

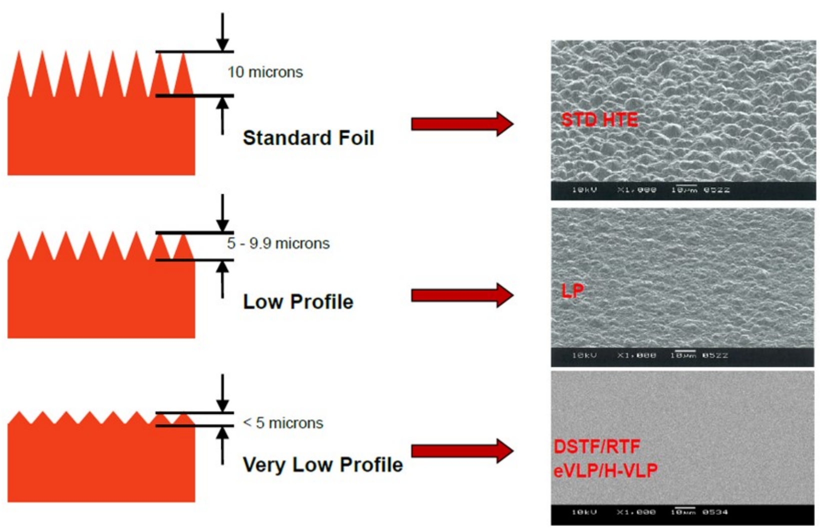
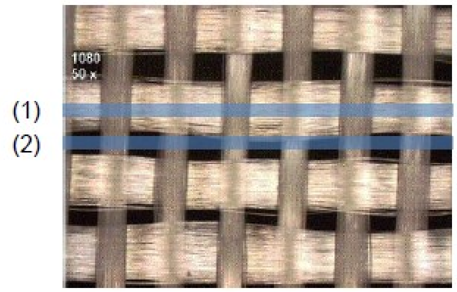


Figure 1: Copper roughness

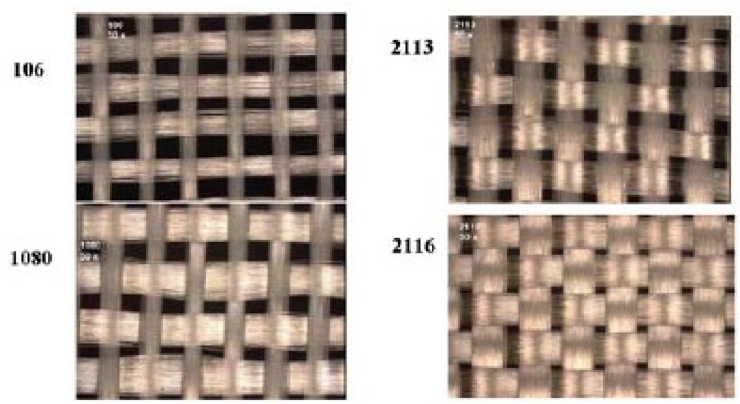
In addition to the copper type, that is the roughness characteristic, there exists yet another parameter which also contributes to the stability of signal transmission in a PCB. The dielectric base of CCL exhibits a non-homogenous and anisotropic structure in terms of D_k values.

In general, the D_k values for resin and for glass fibers are not identical: D_k resin < D_k glass fibers.



A conductor that will traverse over a bundle of fibers (1) and a conductor that will traverse over an area saturated with resin (2) will exhibit a different D_k.

The solution proposed for this phenomena is the use of a more homogenous glass fabric, for instance 2116 or 3113 instead of 1080 or 106, or the use of spread glass fibers which allow the manufacture of a more homogenous dielectric material.



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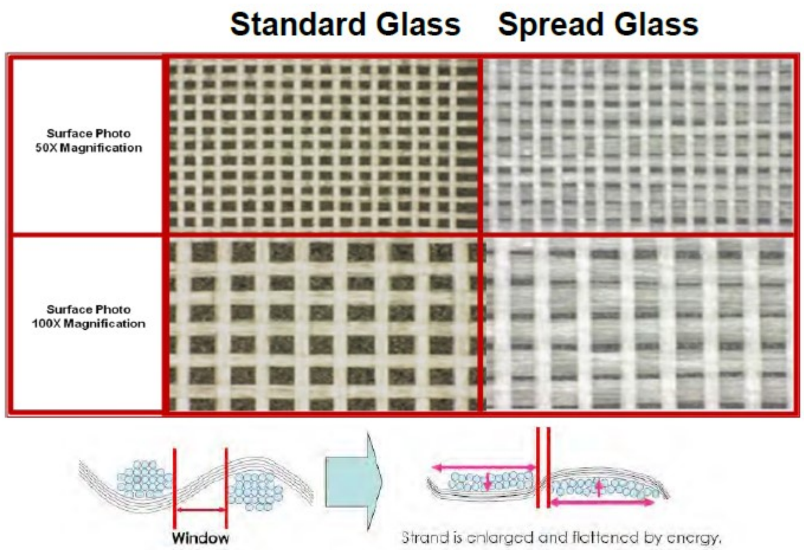

Figure 4: Different glass fibers types

Naturally, Teflon® resin takes an important place in a very wide variety of raw materials utilized in the manufacture of PCB's.

Currently, different companies that manufacture Teflon®-based CCL's, possess a variety of solutions for improving the electronic performance of materials, for example: improving the dimensional stability by using glass fiber fabrics or other hardening agents, usage of ceramic fillers for controlling the D_k or D_f values.

Another advantage of using Teflon® is the fact that it has very low moisture absorption and high durability in aggressive work environments.

On the other hand, Teflon® also has significant disadvantages in the manufacturing processes of PCB's: high cost, low bonding strength to copper, substantial difficulties in preparing the surface for copper plating in holes and/or for lamination with other materials. In most cases, the use of Teflon®-based CCL's requires the PCB manufacturer to use expensive, complex and aggressive multi-processes, which naturally raise the cost of the final product and also influence the yield of the manufacture of Teflon®-based PCB´s.

In work frequencies above 10 GHz, Teflon®-based raw materials have very few competitors, nonetheless, in a frequency range of 1 – 5 GHz, there exists a wide variety of alternative materials based on glass epoxy, PPO (Polyphenylene Oxide) or PPE (Polyphenylene Ether) as well as various polymer mixtures.

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Currently there are many companies on the market that manufacture CCL's intended for high frequency ranges. For Teflon®-based laminates, there are several leading companies:

- ✓ Rogers with the following series of materials - RO3000, RT/Duroid, AD and CuClad Series, as well as several other types.
- ✓ AGC (Taconic) with the following series of materials - RF ,TLC ,TLY and others.
- ✓ Ventec with the following series of materials – Tex-Speed 30.0 (a relatively new material on the market).

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Following are some technical data for PTFE (Teflon®) materials:

Rogers

Property	RO3203	RT/duroid 5880	RT/duroid 6002	AD250C	CuClad250
Dk	3.02	2.20	2.94	2.5	2.5
Df	0.0016	0.0004	0.0012	0.0013	0.0017
CTE (ppm/ºC) **X/Y** **Z**	 13 58	 31/48 237	 16/16 24	 47/29 196	 18/16 177
Water Absorption (%)	<0.1	0.02	0.02	0.04	0.03
Td (ºC)	500	500	500	500	N/A

AGC

Property	RF30A	TLC32	TLE95	TLY5A	TLY5Z
Dk	2.97	3.2	2.95	2.17	2.20
Df	0.002	0.003	0.0026	0.0009	0.0015
CTE (ppm/ºC) **X/Y** **Z**	 8/11 60	 9/12 70	 9/12 70	 26/12 217	 30/40 130
Water Absorption (%)	N/A	N/A	0.02	0.02	0.03

Ventec

Property	Tec-Speed 30.0 (VT-6702)	Tec-Speed 30.0 (VT-3703)
Dk	2.94	3.0
Df	0.0011	0.0019
CTE (ppm/ºC) **X/Y** **Z**	 N/A 24	 16/17 25
Water Absorption (%)	0.02	0.04
Td (ºC)	520	520

For laminates based on non-Teflon® materials, there are also several companies on the market, when the leading ones being Isola and Ventec:

- ✓ Isola with the following series of materials - I-Tera MT40, Astra MT77, Tachyon 100G.
- ✓ Ventec with the following series of materials - Tec-Speed.

Following are some technical data for non-PTFE (Teflon®) materials:

Isola

Property	I-Tera MT40	Astra MT77	Tachyon 100G
Tg ⁰C (DSC)	200	200	200
Td ⁰C	360	360	360
Dk	3.45	3.0	3.04
Df	0.0031	0.0017	0.0021
CTE X/Y ppm/⁰C	12/13	12/13	15/15
CTE Z (50-260⁰C) %	2.8	2.9	2.5
Water Absorption (%)	0.01	0.1	0.1

Ventec

Property	Tec-Speed 20 (VT870)	Tec-Speed 7.0 (VT463-H)	Tec-Speed 5.0 (VT464-G)
Tg ⁰C (DMA)	280	220	175
Td ⁰C	402	430	400
Dk	3.3	3.7	3.81
Df	0.0025	0.0018	0.0031
CTE Z (50-250⁰C) ppm/⁰C	35	45	35
Peel Strength lib/in	6.0	4.5	5.0
Water Absorption (%)	N/A	0.1	0.08

In addition to rigid materials, special flexible materials are used for the manufacture of flexible/rigid PCB´s intended for high-frequency use. In fact, in the field of flexible materials for high frequencies, currently, the selection of materials is quite modest compared with rigid materials. Today, only two companies supply flexible materials designed for high-frequency use – DuPont with the Pyralux TK material and Thinflex with the Thinflex LK material.

The Pyralux TK material is an Adhesive material which utilizes Teflon®-based adhesive for bonding the flexible base, polyamide (Kapton®) and copper. As a result of using a Teflon®-based adhesive, this flexible material is characterized by advantages and disadvantages that are similar to Teflon®-based rigid materials.

The Thinflex LK material is an Adhesiveless material made from a polyamide base layer and a copper foil on both sides. The manufacturing processes of PCB's with a Thinflex

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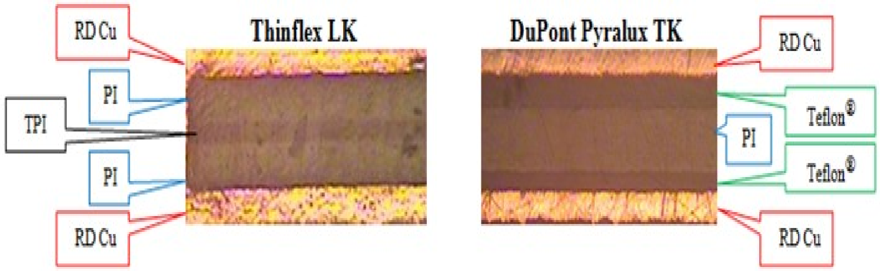
LK layer are identical to the manufacturing processes that make use of standard flexible materials.



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Following are several technical data that characterize Pyralux TK and Thinflex LK:

Property	Pyralux TK	Thinflex LK
Dk (10 GHz)	2.5	2.8
Df	0.002	0.005
Peel Strength (kgf/cm**)**	>0.7	>0.6
CTE (ppm/ºC**)**	27	28
Peel Strength (lib/in)	6.0	4.5
Water Absorption (%)	0.6	1.0

In summary,
The most suitable materials for conventional and standard manufacturing processes are glass epoxy-based thermoset materials and non-Teflon®-based materials which are adapted for use in the field of high-frequency works. Unlike Teflon®-based materials, thermoset materials can be used for manufacturing a wide variety of rigid, flex-rigid and HDI (High Density Interconnects) PCB's. it is impossible to ignore the fact that the most efficient materials for high-frequency performance, which are suitable for a very wide range of frequencies, are Teflon®-based materials, yet, these materials pose numerous difficulties in the manufacture of PCB's, the cost of this type of product is very high and its manufacturing time is significantly longer compared with the other materials.

The Eltek Company manufactures a wide variety of rigid, flex-rigid and hybrid PCB's intended for the high-frequency field using many materials produced by Rogers, AGC, Isola Ventec and other Companies, and all our manufacturing processes are adapted to contend with every challenge.

Sources:

1. What is High Frequency (HF) PCB, RayMing Technology.
2. PCB Material Selection for High-Speed Digital Designs, Isola.
3. Understanding Glass Fabric, Isola.

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