Low Loss/ High Speed PCB Materials

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All PCB materials exhibit both conduction and dielectric loss.

- The conduction losses are primarily resistive \((i^2r)\) losses in the conduction layers and leakage of charge through the dielectric.

- The dielectric losses result from the varying field produced from the alternating electric field causing movement of the material’s molecular structure generating heat.
Conduction Losses

The copper conductor contributes with resistive losses and the following, which are explored further in the following slides:

- Skin Effect.
- Impedance changes due to non-homogeneous substrate structure.
Skin Effect

Induced magnetic fields in a conductor affect the distribution of current forcing it to flow nearer and nearer the surface as frequency increases. This effectively reduces the current carrying cross section and hence increases the effective resistance.

\[ \delta = \sqrt{\frac{2}{\omega \mu \sigma}} \]

- \(\delta\) = skin depth (m)
- \(\mu\) = permeability (4\(\pi\) * 10\(^{-7}\) H/m)
- \(\pi\) = \(\pi\)
- \(\rho\) = resistivity (\(\Omega\) * m)
- \(\omega\) = radian frequency = 2\(\pi\) * \(f\) (Hz)
- \(\sigma\) = conductivity (mho/m)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Skin Depth (Copper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Hz</td>
<td>9.3 mm</td>
</tr>
<tr>
<td>10 MHz</td>
<td>21 (\mu)m</td>
</tr>
<tr>
<td>100 MHz</td>
<td>6.6 (\mu)m</td>
</tr>
<tr>
<td>1 GHz</td>
<td>2.1 (\mu)m</td>
</tr>
<tr>
<td>10 GHz</td>
<td>0.66 (\mu)m</td>
</tr>
</tbody>
</table>
Copper Surface Profile

**Resist side**

**Standard foil**

**Bonding side**

<table>
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<tr>
<th>Frequency</th>
<th>Skin Depth</th>
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<tr>
<td>10 MHz</td>
<td>21 µm</td>
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The current is able to tunnel below the surface profile and through the bulk of the conductor.

The current is forced to follow every peak and trough of the surface profile, increasing path length and resistance.
Copper Profile Specifications

- **Standard Foil**: 10 microns
- **Low Profile**: 5 - 9.9 microns
- **Very Low Profile**: < 5 microns

Types:
- **STD HTE**
- **LP**
- **DSTF/RTF**
- **eVLP/H-VLP**
What Copper should be specified?

- **STD HTE** - At high frequencies, middle and high profile copper foil may present problems concerning their matte side (such as signal attenuation and signal delay owing to increased propagation distance.

- **DSTF, RTF & VLP** - Will provide improved quality on high frequency transmission lines. Will also provide smaller deviations on characteristic impedance due to improved etching capabilities.

- **e-VLP & H-VLP** - Since these foils are usually smooth on the resist side and have lower roughness than the DSTF and RTF foils, they will provide additional signal improvement. This is especially true at the higher frequencies because the signal is now travelling closer to the surface of the foil.
“By simply changing the style of glass used in the laminate, the problems of varying impedance and velocity have been substantially reduced.”
Glass Fabric Development

Isola Glass Fabrics Product Line is being re-engineered in terms of:

- 50+ year old constructions are converted to products having a more even distribution of filaments and equivalent weight, while enhancing Signal Integrity performance –
- Spread Fabrics Family, 1067, 1086, and others

Conventional fabric  ➔  Spread fabric
## Glass Fabric Development

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>Standard</th>
<th>Square Weave</th>
<th>Spread Fibres **</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Style</td>
<td>106</td>
<td>1067</td>
<td>1067 Spread **</td>
</tr>
<tr>
<td>Weight (grams/sq.m)</td>
<td>24</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Thread count</td>
<td>22.0 x 22.0</td>
<td>27.6 x 27.6</td>
<td>27.6 x 27.6</td>
</tr>
<tr>
<td>Yarn (warp/weft)</td>
<td>EC5 5.5/EC5 5.5</td>
<td>EC5 5.5/EC5 5.5</td>
<td>EC5 5.5/EC5 5.5</td>
</tr>
<tr>
<td>Glass thickness (mm)</td>
<td>0.033</td>
<td>0.035</td>
<td>0.035</td>
</tr>
<tr>
<td>Pressed thickness* (mm)</td>
<td>0.050 - 0.060</td>
<td>0.054 - 0.064</td>
<td>0.054 - 0.064</td>
</tr>
</tbody>
</table>

* Approximate thickness yield range dependant on design, resin content and resin type.

** Courtesy of Isola Fabrics
Dielectrics are materials which are poor conductors of electric current. They are insulators because they have few free electrons available to carry current.

However, when subjected to an electric field polarisation occurs whereby positive and negative charges are displaced relative to the electric field. This polarisation reduces the electric field in the dielectric thus causing part of the applied field to be lost.
The amount of polarisation that can occur in a dielectric material depends on the symmetry of the molecular structure and can be quantified by the “Dipole Moment”.

Within most molecular structures, although the overall charge is zero, the positive and negative charges do not overlap completely thus giving rise to a permanent Dipole Moment.

A good example of how this works is exhibited by water molecules in a microwave oven. As the field oscillates the molecules continuously rotate releasing kinetic energy as they collide with neighbouring molecules. The microwave frequency is 2.45GHz as this frequency allows the optimal time needed for the molecules to rotate exactly 180°.

The time delay is crucial to the process and explains why the dielectric loss reduces at higher frequencies for some advanced dielectrics where there isn’t enough time for the molecules to polarise before the charge reverses.
Loss Factor

The effect of the dipole moment in a dielectric is quantified as “loss tangent” and describes the dielectric’s inherent dissipation of an applied electric field. The loss tangent derives from the tangent of the phase angle between the resistive and reactive components of a system of complex permittivity. The property is dimensionless and is often referred to by the following synonyms;

• Loss Factor
• Dissipation Factor
• Dielectric Loss
• Loss angle
• Tan δ
The “Eye”

One Bit Length

Signal with Noise

The “Eye”

Good Sampling Period

Noise Margin

Noise

Jitter
Simulated Eye Diagrams by Loss

At Source

Zero Dielectric Loss

Loss = 0.004

Loss = 0.008

Loss = 0.012

Standard FR4, Loss = 0.020

Simulated Eye Diagrams @ 5 Gbps -1 M -50 Ohms impedance
5 Mil Track width PRBS 35 PS Rise time
## Indicative Loss Factor Values

<table>
<thead>
<tr>
<th>Material</th>
<th>Loss factor (1GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>~ 0</td>
</tr>
<tr>
<td>Alumina</td>
<td>0.0002</td>
</tr>
<tr>
<td>Water</td>
<td>0.06</td>
</tr>
<tr>
<td>E-glass</td>
<td>0.0012</td>
</tr>
<tr>
<td>NE-glass</td>
<td>0.0006</td>
</tr>
<tr>
<td>Standard FR4</td>
<td>0.015</td>
</tr>
<tr>
<td>Phenolic cured FR4</td>
<td>0.020</td>
</tr>
<tr>
<td>Ceramic filled low loss substrate</td>
<td>0.003</td>
</tr>
<tr>
<td>PTFE based PCB substrate</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>New Generation PCB substrate</strong></td>
<td><strong>0.003</strong></td>
</tr>
</tbody>
</table>

PTFE materials and more recently highly ceramic filled materials have been the standard choice for designers of high speed circuits.

With the market growth and technological demands for multilayer circuits, new unfilled, non PTFE substrates have been developed enabling greater complexity, improved processability and offering a lower cost alternative to traditional solutions.
Loss Tangent vs. Frequency

IS680-338 IPC Df

Loss Tangent

Frequency in GHz

2.46  4.93  7.40  9.86  12.32  14.75  17.19

Df
dB Loss vs. Frequency

Complex scattering parameter S21 = forward transmission gain for a 2 port network
Improving Thermal Performance – T260 / Td / IST

Improving Electrical Performance – Lower Dk/Df – Higher Speed

Product positioning - perceptual map

Lead Free Assembly Compatible

DE156 155 Tg Halogen Free

370HR 180 Tg Phenolic-Filled

IS410 180° Tg Phenolic

G200/ GI 180 BT Epoxy

FR406 High Tg 170° Epoxy

FR408 180Tg Low Dk & Df

P95 260 Tg Polyimide HB

P96 260 Tg Polyimide V0/V1

IS620i Tg 225 Low Loss Df < 0.0070 @10 GHz

GETEK 180Tg Mid Dk & Df

More reliable

T260 – 10 min.
Td – 300°C**

T288 – 60 Min.
Td – 400°C**

T260 – 60 Min.
Td – 350°C**

1 GHz

Improving Electrical Performance – Lower Dk/Df – Higher Speed

20 GHz

Speed is a function of design such as line length etc.

** Laminate Data - IST performance is a function of Hole diameter, board thickness, plating parameters and laminate attributes.
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