Advanced PCB Material Development for 5G and mm Wave Applications

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Trends for High Speed Applications

Internet environment will dramatically increase by 2022 (ie: number of devices and amount of traffic).

(Cisco Systems, Cisco Visual Networking Index (2018))
Trends for High Speed / High Frequency Applications

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Wave length[m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100MHz</td>
<td>1m</td>
</tr>
<tr>
<td>1GHz</td>
<td>10cm</td>
</tr>
<tr>
<td>10GHz</td>
<td>1cm</td>
</tr>
<tr>
<td>100GHz</td>
<td>1mm</td>
</tr>
</tbody>
</table>

- **TV broadcasting**
  - VHF: 50 - 230MHz
  - UHF: 470 - 890MHz

- **Electronic car keys**
  - 400 - 900 MHz

- **FM Radio**
  - 88 - 108 MHz

- **3.9G, 4G Mobile communication**
  - 800 MHz – 3.8 GHz

- **RFID**
  - 850–950 MHz

- **W-LAN**
  - 2.4 – 5.8 GHz

- **Networking systems**
  - 3 – 6 GHz

- **Router**
  - 5-12 GHz

- **Server**
  - 4-10 GHz

- **GPS**
  - (1.2 – 1.6 GHz)

- **Bluetooth**
  - 2.4 GHz

- **3.9G, 4G Mobile communication**
  - 800 MHz – 3.8 GHz

- **Optical system**
  - >10 GHz

- **5G Mobile communication**
  - 28 – 90 GHz

- **Car radar system**
  - 24 – 79 GHz

- **D-TV satellites**
  - 11 – 15 GHz

- **WiGig**
  - 60 GHz

- **Laptop**
  - 2-5 GHz

- **GPS**
  - (1.2–1.6 GHz)

- **Optical system**
  - >10 GHz

- **5G Mobile communication**
  - 28 – 90 GHz
Technology Trends for PCB

- **ICT Infrastructure**
  - High signal speed
  - High density
  - High layer count
  - Environmentally friendly

- **Wireless**
  - High Frequency
  - Stability under high temperature
  - Environmentally friendly
Technology Trends for PCB / FPC

- High Signal Speed
- High Frequency (5G)
- High density
- Thinner PCB
- Environmentally friendly

Flexible Printed Circuit

- High Frequency
- Low Dk/Df – stable with temperature & humidity.
- Environmentally friendly
Trends for High Speed Applications

High speed signal
- High Frequency

High density
- Low Transmission Loss
- Stability under high temperature

Environmental friendly
- High Insulation Reliability
- High Heat Resistance
- Dimensional Stability

Flexible Printed Circuit
- Halogen Free

ICT Infrastructure
- Thermo Stability for Dk/Df

Wireless
- Environmental friendly

Mobile
- 1. High Frequency
- 2. Low Transmission Loss

Thermal Stability for Dk/Df
- 3. High Heat Resistance
- 4. Dimensional Stability
- 5. High Insulation Reliability
- 6. Halogen Free
Requirements for Dk / Df of PCB / FPC Materials

Formula for transmission loss (by Edward A Wolff)

Transmission Loss ($\alpha_t$) = Conductor Loss ($\alpha_c$) + Dielectric Loss ($\alpha_d$)

$$\alpha_c = \sqrt{\varepsilon_r} \cdot R(f)$$

$$\alpha_d = 27.3 \cdot \sqrt{\varepsilon_r} \cdot \lambda_o \cdot \tan\delta$$

Where:
- $\varepsilon_r$: Dielectric constant
- $R(f)$: Surface resistance
- $\lambda_o$: Wavelength

Reduction of $\alpha_d$: Lower Dk / Df Dielectric materials
Reduction of $\alpha_c$: Lower profile or Profile-free conductor

Signal transmission loss is sum of Conductor and Dielectric loss. Dk and Df are both impacting on transmission loss.
High Speed Laminate Technical Trend

Next Generation High Speed Material

Future High Speed Material
Ultra low loss material for ICT equipment
✔ Lower transmission loss
✔ Suitable for higher layer count
✔ Good processability
✔ Lead free reflow applicable

To combine with these technologies, we can achieve the better transmission loss.
# High Speed Laminate Technical Trend

## Glass Cloth: Electrical Properties (Dk / Df)

<table>
<thead>
<tr>
<th></th>
<th>E-glass</th>
<th>Low Dk glass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2GHz</td>
<td>6.62</td>
<td>5.02</td>
</tr>
<tr>
<td>10GHz</td>
<td>6.43</td>
<td>4.70</td>
</tr>
<tr>
<td><strong>Df</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2GHz</td>
<td>0.0062</td>
<td>0.0038</td>
</tr>
<tr>
<td>10GHz</td>
<td>0.0127</td>
<td>0.0078</td>
</tr>
</tbody>
</table>

### Dk/Df comparison data of glass itself

- **E-glass**
- **Low Dk glass**

### The other properties (by glass suppliers)

<table>
<thead>
<tr>
<th></th>
<th>E-glass</th>
<th>Low Dk glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>2.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td>CTE</td>
<td>ppm/°C</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.8</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>GPa</td>
<td>77.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62.1</td>
</tr>
<tr>
<td>Volume resistivity</td>
<td>Ω·cm</td>
<td>1E+15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1E+15</td>
</tr>
<tr>
<td>Surface resistivity</td>
<td>Ω</td>
<td>1E+14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1E+14</td>
</tr>
</tbody>
</table>

Reference from data sheet of Glass Cloth Suppliers

By Cavity resonance method at Panasonic R&D
High Speed Laminate Technical Trend

Glass Cloth: Transmission Loss Property

- Line length: 1000mm
- Impedance: 50Ω
- Copper thickness: 35um
- Copper type: H-VLP
- Inner Cu treatment: no-surface treatment
- Core type: #1078 (RC64~67%) * 2ply
- PP type: #1078 * 2ply

Ex) M7 + H-VLP foil

Low Dk glass offer better electrical performance for high speed PCBs due to lower Dk/Df.
Copper Foil: Copper Foil Roughness

<table>
<thead>
<tr>
<th>Type</th>
<th>RTF</th>
<th>H-VLP</th>
<th>H-VLP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-section</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>Rz (um) (JIS B 0601-2001)</td>
<td>2.5</td>
<td>1.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Copper profile is one of the main contributors for transmission loss for high frequency signals.
**Copper Foil: Copper Foil Roughness / Skin Effect**

\[ d = \sqrt{\frac{2\rho}{\omega \mu}} \]

- **d**: Skin effect depth
- **\( \rho \)**: Electrical Resistivity
- **\( \omega \)**: Frequency
- **\( \mu \)**: Magnetic Transmission

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Skin effect depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 kHz</td>
<td>660 µm</td>
</tr>
<tr>
<td>100 kHz</td>
<td>210 µm</td>
</tr>
<tr>
<td>1 MHz</td>
<td>65 µm</td>
</tr>
<tr>
<td>10 MHz</td>
<td>21 µm</td>
</tr>
<tr>
<td>100 MHz</td>
<td>6.6 µm</td>
</tr>
<tr>
<td>1 GHz</td>
<td>2.1 µm</td>
</tr>
<tr>
<td>10 GHz</td>
<td>0.7 µm</td>
</tr>
</tbody>
</table>

@1MHz: Fig1:1MHz Density of current  
@100MHz: Fig2:100MHz Density of current  
@1GHz: Fig3:1GHz Density of current

Higher the frequency – more significant impact of skin effect to transmission loss.
Trends for High Speed Applications

Copper Foil: Transmission Loss vs Copper Foil Type

SI performance is influenced by both copper foil roughness and shape of nodule.

Ex) M7 + Low-Dk Glass

Matte side

- Line length: 1000mm
- Impedance: 50Ω
- Copper thickness: 18um
- Inner Cu treatment: no-surface treatment
- Core type: #1078(RC67%)*2ply
- PP type: #1078*2ply

SEM x10000

RTF Rz=2.5um

H-VLP2 Rz=1.8um

H-VLP Rz=1.3um
Copper Foil: Net Technology on Inner Layer Treatment

SI performance for new inner layer treatment is getting closer to no treatment.
**Trends for High Speed Applications**

**Next Generation Infrastructure Material**

<table>
<thead>
<tr>
<th>Resin</th>
<th>M7</th>
<th>Next Gen target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Cloth</td>
<td>Low-Dk</td>
<td>Ultra Low-Df</td>
</tr>
<tr>
<td>Copper Foil</td>
<td>H-VLP</td>
<td>Next Gen CF</td>
</tr>
<tr>
<td>Dk@12GHz</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Df@12GHz</td>
<td>0.002</td>
<td>0.0015</td>
</tr>
<tr>
<td>Resin Contents(%)</td>
<td></td>
<td>2116 55%</td>
</tr>
</tbody>
</table>

**PCB Design**

- Line length: 1000 mm
- Impedance: 50Ω(±2)
- Copper thickness: 18 um
- Inner Cu treatment: No-surface treatment
Trends for High Speed / High Frequency Applications

Mobile Materials – Trends

• Lower Dk / Lower Df
• Thinner material
• Low X/Y CTE
• Smooth Copper – good adhesion
### Trends for High Speed / High Frequency Applications

**FPC Materials for various applications**

<table>
<thead>
<tr>
<th></th>
<th>Mobile</th>
<th>Network</th>
<th>Automotive Medical Avionics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCCL (Polyimide)</strong></td>
<td>Main board, Module (Camera, RF)</td>
<td>Impedance Control</td>
<td>Gear BOX ECU</td>
</tr>
<tr>
<td>Thick PI</td>
<td></td>
<td></td>
<td>Antenna Medical</td>
</tr>
<tr>
<td>Thick Cu</td>
<td></td>
<td>Impedance Control</td>
<td>EV</td>
</tr>
<tr>
<td>Thin Cu</td>
<td></td>
<td>LCD module</td>
<td>Medical Equipment</td>
</tr>
<tr>
<td><strong>FCCL (LCP)</strong></td>
<td></td>
<td>High speed cable, Optical transceiver</td>
<td>mm Wave Radar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5G Antenna</td>
<td></td>
</tr>
<tr>
<td><strong>FRCC</strong></td>
<td>Camera Module</td>
<td></td>
<td>Medical Equipment</td>
</tr>
</tbody>
</table>
Trends for High Speed / High Frequency Applications

FPC Materials – Next Generation Requirements

- Lower loss dielectric material
- Smooth Copper foil – good adhesion
- Improved flexibility
- Low moisture absorption
- Substrate-Like
Conclusion:

- Lower Dk / Df
- Smooth Copper
  - Raw Foil
  - Innerlayer Adhesion Promoters
- Dimensional Stability
- Low CTE
- High Tg
- Thermal Performance / Stability
- Moisture Absorption