ALTIIUM LIVE 2018: NAVIGATING THE COMPLEXITIES OF PCB MATERIAL SELECTION

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Insulectro, VP of Technology
San Diego
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Outline

1. PCB Material Overview
2. What is the Dielectric Constant of a material?
3. Copper foil for making circuits
4. PCB building blocks: Prepregs
5. Best signal performance
Who needs a PCB?
- Supports components and devices
  - Holds everything together!!!
- Electrically interconnects devices
- Transmission lines (data or RF)

MORE AND MORE its becoming electrically important!

Connecting point A and B are not enough, faster data requires better transmission lines for signals between components.
Two basic components for PCB’s

Conductors

Dielectrics
Why Glass Fabric?

- **In Fabrication**
  - Supports B-Stage (prepreg)
  - Controls spacing
  - Cost

- **In Use**
  - Strength
  - Cost
Subtractively Processed PCB Layer
PCB Materials: The Basics

• Start with rigid and thin core copper clad.
• Circuits are formed in the copper.
• The PrePreg is the “glue” to stack these layers (AKA: B-Stage).
• Copper foil or CAC is used on the outer most layers.
• Everything is aligned and then laminated with heat and pressure.
Some PCB Construction Terms

• **Foil Lam**
  - Copper foil bonded with prepreg to make the outermost circuit layers, usually where components are mounted.

• **Cap Lam**
  - Copper clad core is circuit image one side, then laminated to the outermost part of the PCB. The blank copper side will become the circuits and pads for components.

• **Alternative Oxide**
  - Bond treatment used on copper foil after imaging to increase resin adhesion.

• **Buried Via**
  - Copper plated via that links internal layers in the z-axis.

• **Blind Via**
  - Maybe surface or buried. Typically laser drilled, it is plated with one end open only.

• **Sub Lam (Subs)**
  - Multilayer components of a complex PCB built in stages with multiple lamination cycles.

• **Via in Pad**
  - Plated z-axis interconnect that is filled with additional copper or resin in a surface mount pad.

• **Hybrid Construction**
  - Use two or more types of resin systems in the same PCB.
Plating or metal paste makes the interconnects between layers.
Material Properties

- Glass Transition Temperature: $T_g$
- Decomposition Temperature: $T_d$
- CTE
- Dielectric Constant: $D_k$
- Dissipation Factor: $D_f$
Resin System Groups

<table>
<thead>
<tr>
<th>Epoxy</th>
<th>Polyimide</th>
<th>PPO/PPE Blends</th>
<th>PTFE Systems</th>
</tr>
</thead>
</table>
| • FR-4 (most common)  
• High adhesion  
• Economical  
• Good mechanicals  
• Higher loss at higher frequencies  
  • Some blends are higher performing.  
• Filled and unfilled resin systems  
• IPC-4101  
  • 20/21/22/23/24/26/27/97/98/99/101/126 | • One of the highest in thermal performance  
• High cost  
• Low neat resin CTE  
• Long history in aerospace.  
• A little better than FR-4 for signal performance.  
• Hygroscopic  
• IPC-4101  
  • /40/41/43/44 | • Lower loss than FR-4 epoxies.  
• Higher cost  
• With low Dk glass, can approach PTFE performance  
• Most out perform epoxy thermally  
• Lower adhesion than epoxy  
• IPC-4101  
  • /25/90/91/96/102/103  
• IPC-4103  
  • /17 | • Can be very low loss and low Dk  
• Very high cost  
• Needs reinforcement  
• Low moisture absorbing  
• Usually high temp and/or high pressure lamination. |
<table>
<thead>
<tr>
<th>Product</th>
<th>Tg by TMA</th>
<th>Td</th>
<th>Dk</th>
<th>DF</th>
<th>VLP Foil</th>
<th>PIM Sensitive applications</th>
<th>IPC Slash Sheets, Comments and Recommended Bit Rate/Frequency range</th>
<th>Number of lamination cycles</th>
<th>Compatible with for Hybrid Builds</th>
</tr>
</thead>
<tbody>
<tr>
<td>185HR</td>
<td>180</td>
<td>340</td>
<td>4.01</td>
<td>0.02</td>
<td>N/A</td>
<td>N</td>
<td>IPC-4101 /98 /99 /101 /126 Low cost Lead free solder compatible FR4 PCB 2 to 3 GHz max</td>
<td>3 to 4</td>
<td>370HR, 408HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
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<tr>
<td>370HR</td>
<td>180</td>
<td>340</td>
<td>4.04</td>
<td>0.021</td>
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<td>N</td>
<td>IPC-4101 /101 /98 /99 /126 Legacy high rel and lead free compatible FR4 PCB 2 to 3 GHz max</td>
<td>8 to 4</td>
<td>185HR, 408HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
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<tr>
<td>FR408HR</td>
<td>190</td>
<td>360</td>
<td>3.08</td>
<td>0.0092</td>
<td>Available</td>
<td>N</td>
<td>IPC-4101 /98 /99 /101 /126 Multifunctional low loss resin up to 12 GHz</td>
<td>8 to 4</td>
<td>185HR, 370HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
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<tr>
<td>I-Speed®</td>
<td>180</td>
<td>360</td>
<td>3.64</td>
<td>0.006</td>
<td>Standard</td>
<td>N</td>
<td>IPC-4101 /98 /99 /101 /126 Best Spenformance at this cost. Up to 20 GHz</td>
<td>3 to 4</td>
<td>185HR, 370HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
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<tr>
<td>I-Tera® MT40</td>
<td>200</td>
<td>360</td>
<td>3.45</td>
<td>0.0031</td>
<td>Available</td>
<td>N</td>
<td>IPC-4103 /17 Very good signal and thermal performance. Up to 60 GHz</td>
<td>10</td>
<td>185HR, 370HR, 408HR, I-Speed, Tachyon 100G, Astra MT77</td>
</tr>
<tr>
<td>I-Tera® MT40 (RF/MW)</td>
<td>200</td>
<td>360</td>
<td>3.38 /3.38 /3.60 /3.75</td>
<td>0.0028 /0.0035</td>
<td>Available</td>
<td>Yes, with VLP-2 foil</td>
<td>IPC-4103 /17 Same as I-Tera MT40, but Dk tuned for RF applications</td>
<td>10</td>
<td>185HR, 370HR, 408HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
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<tr>
<td>TerraGreen®</td>
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<td>390</td>
<td>3.44</td>
<td>0.0039</td>
<td>Available</td>
<td>N</td>
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</tr>
<tr>
<td>TerraGreen® (RF/MW)</td>
<td>200</td>
<td>390</td>
<td>3.45</td>
<td>0.0032</td>
<td>Available</td>
<td>Yes, with VLP-2 foil</td>
<td>IPC-4103 /17 Halogen Free for RF Up to 77 GHz</td>
<td>6</td>
<td>185HR, 370HR, 408HR, I-Speed, I-Tera MT40, Tachyon 100G, Astra MT77</td>
</tr>
<tr>
<td>IS300MD</td>
<td>190</td>
<td>390</td>
<td>3.06</td>
<td>0.0033</td>
<td>Available</td>
<td>N</td>
<td>IPC-4103 /17 Low loss halogen free for thin build-up mobile devices. Up to 60 GHz</td>
<td>6</td>
<td>TerraGreen</td>
</tr>
<tr>
<td>IS880</td>
<td>200</td>
<td>360</td>
<td>2.80 -3.45</td>
<td>0.0025 /0.0035</td>
<td>Available</td>
<td>N</td>
<td>IPC-4103 /17 Low cost PTFE alternative for double sided RF applications. Up to 77 GHz</td>
<td>N/A</td>
<td>N/A double sided only</td>
</tr>
<tr>
<td>IS880 AG</td>
<td>200</td>
<td>360</td>
<td>3.08 /3.38 /3.45 /3.45 /3.45 /3.45 /3.45 /3.45</td>
<td>0.0029/0.0029</td>
<td>Standard</td>
<td>Yes</td>
<td>IPC-4105 /17 Low cost double sided material for PIM sensitive RF applications. Up to 77 GHz</td>
<td>N/A</td>
<td>N/A double sided only</td>
</tr>
<tr>
<td>Tachyon® 100G</td>
<td>200</td>
<td>360</td>
<td>3.02</td>
<td>0.0021</td>
<td>Standard</td>
<td>N</td>
<td>IPC-4103 /17 Ultra low loss and low Dk for HSD applications. Up to 100 GHz</td>
<td>10</td>
<td>185HR, 370HR, 408HR, I-Speed, I-Tera MT40, Astra MT77</td>
</tr>
<tr>
<td>Astra® MT77</td>
<td>200</td>
<td>360</td>
<td>3</td>
<td>0.0017</td>
<td>Standard</td>
<td>Yes</td>
<td>IPC-4103 /17 Ultra Low loss and Low Dk alternative for RF multilayer applications. Up to 100 GHz</td>
<td>10</td>
<td>185HR, 370HR, 408HR, I-Speed, I-Tera MT40, Tachyon 100G</td>
</tr>
</tbody>
</table>

* Frequency range and number of lamination cycles are general guidelines and are influenced by the actual design. *(7-30-2018)*
UL flame ratings group materials into categories based on their flammability. UL 94 covers two types of testing: vertical burn and horizontal burn. In addition to V-0, V1 and V2 there is VTM (very thin materials) and 5V, 5V-A and B.
PCB Flame retardants

• It’s important for a PCB to resist burning.
  • Almost all designs have circuits that carry enough current to start combustion under the right conditions.

• Flame retardants
  • Halogen: Bromine is the most common.
  • Non-Halogen:
    • Phosphorus compounds
    • Some metal hydroxides (aluminum, magnesium)

• Polyimide
  • Because of it’s high decomposition temperature, most pure polyimides (no flame retardants, epoxy) have an HB rating.
PCB Material Overview

2. What is the Dielectric Constant of a material?

3. PCB building blocks: Prepregs

4. Copper foil for making circuits

5. Best signal performance
Permittivity, also known as Dielectric Constant

“a quantity measuring the ability of a substance to store electrical energy in an electric field.”

Microstrip

Stripline
Dk and PCB (composite) Materials

**Material Ratings:**
- Data Sheet Values
- Different Test Methods
- Field Orientation
- Stripline X-Band,
- Bereskin Stripline,
- Split post dielectric resonator

**Material Make-up:**
- Fabric Type
- Fabric Weave
- Glass to resin ratio
- Micro Dk Effects

**Impact on the Design:**
- Impedance
- Calculators
- Speed/Frequency
- PCB shop realities

*PCB materials are composites and have a combination of properties*
“Why does the same material have different Dk?”

- Glass to resin Ratio.
- Copper roughness (not really changing the Dk, but changes capacitance).
- Micro Dk effects along the transmission line.

*Spread glass prepregs and laminates have a more uniform composition and therefore Dk*
### Some Examples, Dk and Df Charts (@ 10GHz)

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>% Resin</th>
<th>Thickness (inch)</th>
<th>Dk</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x 1067</td>
<td>65.0</td>
<td>0.0020</td>
<td>3.74</td>
<td>0.0280</td>
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<tr>
<td>1x 3313</td>
<td>51.0</td>
<td>0.0035</td>
<td>4.03</td>
<td>0.0230</td>
</tr>
<tr>
<td>1x 1080</td>
<td>58.0</td>
<td>0.0025</td>
<td>3.88</td>
<td>0.0260</td>
</tr>
<tr>
<td>2x 1080</td>
<td>58.0</td>
<td>0.0050</td>
<td>3.88</td>
<td>0.0260</td>
</tr>
<tr>
<td>1x 7628</td>
<td>44.0</td>
<td>0.0075</td>
<td>4.19</td>
<td>0.021</td>
</tr>
</tbody>
</table>

### Glass Style % Resin Thickness (inch) Dk Df

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>% Resin</th>
<th>Thickness (inch)</th>
<th>Dk</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x 1067</td>
<td>72.0</td>
<td>0.0025</td>
<td>3.45</td>
<td>0.0058</td>
</tr>
<tr>
<td>1x 3313</td>
<td>52.0</td>
<td>0.0035</td>
<td>3.89</td>
<td>0.0060</td>
</tr>
<tr>
<td>1x 1080</td>
<td>66.0</td>
<td>0.0030</td>
<td>3.57</td>
<td>0.0059</td>
</tr>
<tr>
<td>2x 1080</td>
<td>66.0</td>
<td>0.0060</td>
<td>3.57</td>
<td>0.0059</td>
</tr>
<tr>
<td>3x 7628</td>
<td>42.5</td>
<td>0.0210</td>
<td>4.14</td>
<td>0.0061</td>
</tr>
</tbody>
</table>

### Glass Style % Resin Thickness (inch) Dk Df

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>% Resin</th>
<th>Thickness (inch)</th>
<th>Dk</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x 1067</td>
<td>70.0</td>
<td>0.0020</td>
<td>3.05</td>
<td>0.0017</td>
</tr>
<tr>
<td>1x 3313</td>
<td>59.5</td>
<td>0.0040</td>
<td>3.24</td>
<td>0.0022</td>
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<tr>
<td>1x 1078</td>
<td>67.5</td>
<td>0.0030</td>
<td>3.09</td>
<td>0.0018</td>
</tr>
<tr>
<td>2x 1078</td>
<td>67.5</td>
<td>0.0030</td>
<td>3.09</td>
<td>0.0018</td>
</tr>
<tr>
<td>4x 2116</td>
<td>59.0</td>
<td>0.0200</td>
<td>3.25</td>
<td>0.022</td>
</tr>
</tbody>
</table>

#### FR-4

#### Mid Dk/Df

#### Low Dk/Df
1. PCB Material Overview
2. What is the Dielectric Constant of a material?
3. PCB building blocks: Prepregs
4. Copper foil for making circuits
5. Best signal performance
Fiberglass Standard Weave

106
- About 2.0 mils
- Great for fill of heavy coppers.
- Least dimensionally stable.

1080
- About 2.5 mils
- Good for fill.

2113
- 3.0 to 3.5 mils
- Some fill properties
- Good stability

7628
- 7.0 to 8.0 mils
- Good for building thickness.
- Best for dimensional stability.
Fiberglass Spread Weave

- **1067**
  - About 2.0 mils
  - Great for thickness control
  - Good for laser drilling
  - Low signal skew
  - Not good for filling

- **1086**
  - About 2.0 mils
  - Great for thickness control
  - Good for laser drilling
  - Low signal skew
  - Not good for filling

- **3313**
  - About 3.0 Mils
  - Great for thickness control
  - Also low skew
  - Great for thickness control

- **1652**
  - 3.0 to 4.0 mils
  - Also low skew
  - Great for thickness control
  - Great for thickness control

- **1067**
  - About 3.0 Mils
  - Great for thickness control
  - Also low skew
  - Great for thickness control

- **1086**
  - 3.0 to 4.0 mils
  - Also low skew
  - Great for thickness control

- **3313**
  - 5.0 to 6.0 mils
  - Also low skew
  - Great for thickness control

- **1652**
  - 5.0 to 6.0 mils
  - Also low skew
  - Great for thickness control
Spread Glass for Differential Pairs

- Reduces micro Dk effects
- Reduces signal skew
- Much better for cost and fabrication than rotating board on panel.

Differential Stripline

1080 vs 1086 with surface resin removed
1. PCB Material Overview

2. What is the Dielectric Constant of a material?

3. PCB building blocks: Prepregs

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5. Best signal performance
Copper Foil for PCB

Shiny Side

- Stain Proof Layer
- Anti Tarnish Layer
- Drum Foil
- Dendrite Plating
- Barrier Layer
- Stain Proof Layer
Copper Foil Acronyms

- ED – Standard Shiny Copper
- HP – High Performance Foil with extra tooth for high peels*
- HTE– High Tensile of Elongation, Standard Shiny Copper
- DSTF ® – Drum Side Treated Foil*
- RTF – Reverse Treated Foil
- VLP – Very Low Profile
- e-VLP – Extra(?) Very Low Profile*
- H-VLP – H (Hyper) Very Low Profile*
- VLP-2 – Isola’s designation for very low profile copper

* Not IPC Designations
Profile Thickness Ranges

- Std – Rz~≈10 microns
- RTF – Rz~≈7 microns
- VLP – Rz~≈5 microns
- EVLP (HVLP) – Rz~≈3 microns
  - VLP-2 (2 micron)
  - VLP-1 (1 micron)
Copper Foils
SEMs @ 5000X

- ED or Shiny Foil
- Reverse Treat Foil (RTF)
- Rolled & Annealed Foil
Processes that treat copper in PCB Fab

• Copper clean/prep for Photoresist Adhesion
  • Acid Clean
  • Microetch
  • Hand pumice
  • Mechanical scrub (machine)

• Bond Treatment
  • Hand pumice
  • Mechanical scrub
  • Microetch
  • **Alternative Oxide – Most common**
  • Brown Oxide (reduced) – Old process
What is Alternative Oxide?

• A bond treatment was developed that contains both an “inter-granular’ etch, and organic complexing agent that reacts with copper to form a brown surface coat.

• It is an alternative to Black/Brown oxide as a bond treatment for copper foil in printed circuit boards.

• It can produce high peels, does not suffer from “pink ring” and is easy to conveyorize. It has become the most popular bond treatment method.

• The main adhesion mechanism is from roughening of the copper surface. It does this by etching the grain boundaries faster than the surface.

• Excessive roughness will increase signal loss.

• Grain boundaries can cause foil cracks in flex if they are too deep.
Effect of Copper Bond Treatment

Heavy Alt. Oxide

Lighter Alt. Oxide

Sometimes less is more
PCB Material Overview

What is the Dielectric Constant of a material?

PCB building blocks: Prepregs

Copper foil for making circuits

Bring it together for best signal performance
Work with the Fabricator

• What does my design need?
  • Signal performance, HSD or RF?
  • Thermal? Mechanical?
  • Density?
  • Flex?

• Material Selection
  • Dk, Df, Cost, Availability, Hybrid, etc.
  • Spread Glass Options
  • What kind of copper foil? RTF, HVLP, etc.

• PCB Fab
  • Bond Treatment
  • Impedance control
  • Surface finish
  • Soldermask
More PCB Technology:

- Embedded components
- Resin coated copper
- Embedded coax
- Molded Circuits
- Paste interconnects
Special thanks to:

Altium

DuPont Electronic Materials

Isola Laminate Systems

Judy and Megan, thanks for your help!