Advanced Material Selection
IPC Designers Council

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Laminate Material Components
Resin, Glass, Copper

- Resin
- Glass
- Copper

Prepreg or B-Stage

B-Stage + Foil = Laminate
Glass Fabric - Yarn
Glass Yarn

Critical Differences

- Composition effects
- Electrical properties
- Mechanical properties
- PCB process-ability
- Cost – 1 to 10x
- Availability may be limited

Finished glass yarn bobbins
Glass Yarn Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>E-Glass</th>
<th>D-Glass</th>
<th>L-Glass</th>
<th>NE-Glass</th>
<th>T-Glass</th>
<th>S-Glass</th>
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<tr>
<td>SiO₂</td>
<td>Dk, Df</td>
<td>Drillability</td>
<td>52-56%</td>
<td>72-76%</td>
<td>52-56%</td>
<td>52-56%</td>
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<td>Al₂O₃</td>
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<td>Dk</td>
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</table>

- Composition determines the effects of glass on the composite
- Low glass CTE values increase the gap between other components of the composite
Glass Composition Decision Tree

- E-glass or LDk glass
  - Low Dk glass
    - Lower Dk & Df
    - Increases glass cost ~5-6x
    - Increases lead time
  - E-glass (Standard)
    - Standard Dk & Df
    - Low cost
    - Readily available
Glass Fabric – Weaving
Fabric Weaving Process

- Warping
- Slashing
- Weaving
- Finishing
Glass Fabric Types

- Spread (MS) weaves reduce the Fiber Weave Effect (FWE)
- Spread or expanded must be in both directions
Two Main Fiber Weave Effects

1. Effects due to location of trace with respect to fiber weave bundles

2. Effects due to periodic loading of trace by fiber weave bundles – resonance
Ultra Thin Glass

**1037**
- Warp & Fill Count: 70 x 73 (ends/in)
- Thickness: 0.0011” / 0.030 mm

**1078**
- Warp & Fill Count: 54 x 54 (ends/in)
- Thickness: 0.0017” / 0.040 mm

The above data are examples of actual measured values and not standard values.
Open vs Spread Weave

**1080**

- **Warp & Fill Count**: 60 x 47 (ends/in)
- **Thickness**: 0.0021” / 0.064 mm

**1086**

- **Warp & Fill Count**: 60 x 60 (ends/in)
- **Thickness**: 0.0022” / 0.050 mm

Photos courtesy of Isola R & D Laboratories
Glass Weave Decision Tree

- **Mechanically Spread Weave**
  - Reduces FWE (Fiber Weave Effect)
  - Increases glass cost ~1.2-1.4x
  - Improves dimensional stability
  - Improves thickness control

- **Open Weave**
  - Low cost
  - Notable FWE (Fiber Weave Effect)
  - Readily available
  - Through glass resin flow
Glass Fabric - Style
# Glass Styles

<table>
<thead>
<tr>
<th>Glass Style</th>
<th>Weave</th>
<th>Warp Count</th>
<th>Fill Count</th>
<th>Warp Yarn</th>
<th>Fill Yarn</th>
<th>Fabric Thickness inches</th>
<th>Fabric Thickness mm</th>
<th>Fabric Nominal Weight OSY</th>
<th>Fabric Nominal Weight g/m²</th>
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**Fiberglass Yarn Nomenclature**

1st Letter: E = E-glass (electrical grade)
2nd Letter: C = Continuous Filaments
3rd Letter: Filament Diameter C, D, E, DE, G
1st number: Yardage in one pound
2nd number: Number of strands in a yarn/strands plied or twisted

- **Square Weave**
- **E-glass and Low Dk glass nominal weights are not equal**
Glass Style Decision Tree

Square or Unbalanced

- Square Weave
  - Reduces FWE (Fiber Weave Effect)
  - Increases glass cost slightly
  - Improves dimensional stability

- Unbalanced Weave
  - Low cost
  - Notable FWE (Fiber Weave Effect)
  - Variation in x-y periodicity
## Guide to Selecting Glass

<table>
<thead>
<tr>
<th>Glass Styles</th>
<th>Square</th>
<th>Expanded</th>
<th>Spread</th>
<th>MS Spread</th>
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<td>Yes</td>
<td>Yes</td>
<td>Yes/No</td>
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</tbody>
</table>

- **Square weave** – same yarn count in warp and fill
- **Expanded or Spread weave** – Glass is expanded in only one direction warp or fill
- **MS Spread ( Mechanically spread )** - Glass spread in both directions
Resin
**Base Resin Components**

- Difunctional & Tetrafunctional Polymers, Oligomers
- Dicy, Phenolic, Novel curing
- Blends
  - Polyphenylene oxide PPO/Epoxy
  - Bismaleimide Triazine (BT)/Epoxy
  - Cyanate Ester/Epoxy
  - Polyphenylene ether PPE/Epoxy
- Polyimide, Hydrocarbon, Teflon, Acrylic, Melamine,
- Liquid Crystal Polymers
- *Proprietary Thermoset Polymers and Polymer blends*

“I have discovered something novel that will change the way we make laminates!”

**Next generation of non-PTFE laminate is expected to have**

\[ D_k < 3.0 \]
\[ D_f < 0.001 \]
Fillers - ‘Components’ which influence the electrical properties and thermal performance

- Various types of Silica
- Aluminum Silicate
- Talc (usage in laminate is patented)
- Rubber
- Glass microspheres
- Boron Nitride – Thermal management
- Size and shape effect
Flame retardants

- Brominated – TBBPA
  - Tetrabromobisphenol-A
- Halogen Free
  - Phosphorus based
  - Aluminum hydroxide
  - Magnesium hydroxide
  - Nitrogen based
- Solid vs reacted
Mixing & Blending Technology

Components
- Resin
- Solvent
- Catalyst
- Hardener
- Fillers
- Flame Retardants

- Woven filters – remove contaminants in liquid components
- Magnetic Filters – remove ferrous contaminates
- High Shear Milling/Mixing – ensures homogenous mixing of all components and sizes fillers
- Viscosity measurement and feedback

Filtration

High Shear Milling/Mixer
Viscosity Regulator
To the Treater
Comparing Resin Systems

Attenuation (dB/in) vs Frequency (GHz)

dB/in. Loss vs Freq for 8" Trace

-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
0 2 4 6 8 10 12 14 16
Frequency - GHz

Loss - dB/in.

- Ultra Low Loss
- Very Low Loss
- Very Low Loss
- Very Low Loss
- Low Loss
- Mid Loss
- Mid Loss

Standard Loss

Ultra Low Loss
Very Low Loss
Low Loss
Mid Loss

Courtesy of Speeding Edge
Approximately 400 material offerings available today

Tier 1
Standard Hi Tg FR4 Df > 0.02

Tier 2
Mid Loss Df 0.01 ~0.02

Tier 3
Low Loss Df 0.005~0.01

Tier 4
Df 0.0032~0.005

Tier 5
Df < 0.0032

Ultra Low Loss materials are becoming the main focus for future HSD designs.

Current Halogen Free Ceiling

Ultra Low Loss Materials
Very Low Loss Materials
Low Loss Materials
Standard Materials
Resin Decision Tree

Dielectric Properties

- **Dk > 4.0**: E-Glass with standard loss resin, $D_f \approx 0.25$
- **Dk 3.5-4.0**: E-Glass with mid/low loss resin, $D_f \approx 0.007$
- **Dk 3.0-3.5**: LDK Glass with ultra/very low loss resin, $D_f \approx 0.002$
- **Dk < 3.0**: Teflon E Glass & LDK Glass, $D_f < 0.002$

Where Dk is lower, Df tends to be slightly lower.
Glass Impregnation
Treating Technology

- Filtration
- Magnetic bars
- Tension controls
- Pre-dip
- Optimized primary dip
- Reversing metering rolls
- Automated inspection
Finished B-Stage

B-stage material to be used as prepreg

B-stage material to be used to make laminate
Copper
Copper Foil Plating

- ED Copper Grain Structure determines:
  - Surface roughness or profile
  - Physical properties of the copper
  - Almost No Profile (ANP) – <2 µm
  - Minimum thickness with carrier - 2,3, 5 µm

Warning:
- Copper is sold to the laminator by weight Oz. not by thickness.
- Copper thickness is specified in mils for PCB’s
- PCB processing reduces copper thickness
- Oz. ≠ Mils
Copper Foil Treatment

Foil Treatment Baths

- Barrier layer treatment
  - Transition layer
  - Treatment/coating maybe specific to a resin system

Matte/Prepreg Side

Reverse Treated Copper

Drum/Laminate Side

- Secondary plating – Nodulation
  - Reduction of conductor losses
  - Minimization of conductor path

Table:

<table>
<thead>
<tr>
<th></th>
<th>Crater/Matte</th>
<th>Crater/Drum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crater/Chrome</td>
<td>Crater/Crater</td>
<td>Crater/Crater</td>
</tr>
</tbody>
</table>

- Chromate
- Zinc
- Copper Nodules
- Nickel/Zinc
- Chromate
- Silane
Smoother copper results in reduced conductor losses

Courtesy Mitsui Copper Foil
## Skin Effect

**Table: Skin Depth (Copper)**

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

**Graph: Skin Depth vs. Frequency**
- Skin depth decreases as frequency increases.
- Conductor losses decrease as foil roughness decreases.
Copper Foil Decision Tree

Copper Foil Surface

RTF/HTE
- 5-6 um
- Standard Availability
- Low Cost

VLP
- 2-3 um
- Standard Availability
- Increased Cu Cost ~1.5x

NP/ANP
- <2 um
- Increased lead time
- Increased Cu cost ~5-10x
- Best for conductor loss

Reduces conductor loss component
Inner Layer Bonding Treatment (during PCB processing)

Cleaned copper surface

Matte/Prepreg Side

Bonding treatment

Warning:
Not all surface treatments are equal and result in significant variation from fab shop to fab shop
Lamination
Lamination

Lay up - Copper foil applied to b-stage

Laminate Kit

Build up – Kits built into a book

Master sheet lamination
Finished Products

Prepreg

Copper Clad Laminate
PCB Material Performance Needs

- PCB process ease and compatibility
- Thermal performance during PCB fabrication and assembly
  - Sequential lamination
  - Assembly cycles
  - Rework and localized performance
- Design appropriate dielectric properties
- Long term reliability
- Low cost to performance ratio
Selecting the Right Material

- Laminate material selection cannot be condensed into a single page chart (Data sheet) for easy selection. More information is needed.

- Cost-to-performance evaluations must be done by the system design team to ensure selection of the lowest cost material that is good enough.

- Collaboration between laminate material suppliers, key PCB fabricators and the OEM designer is important to achieve peak price/performance results.
Laminate Material Processing

- **Cost Considerations**
  - Lamination cycle
    - 60-90 minute cure
  - Temperature
  - Drill tool cost
  - Hit count
  - Special BU and/or Entry
  - Desmear processing
    - Plasma
    - Chemical
  - Baking requirements
    - When and how long?
  - Special processing
Laminate Thermal Performance

- **Fabrication processing**
  - Multiple lamination ~ 8-10 cycles
  - Lead Free HASL
  - Multiple baking steps

- **Assembly processing**
  - Multiple reflow cycles
  - Rework processing
  - Minimal moisture uptake
  - HDI Compatible – Stacked micro vias on blind
Laminate Material Capability

- There is no one single Test Vehicle to learn everything, but we can learn a lot from them

- MRT6 Industry TV
  - Thermal performance
  - CAF performance
  - Electrical performance
  - IST performance
  - Cycling performance

- Others – not public

TV created by members of HDPUG
**Laminate Electrical Properties**

**Basic Categories**

- **Dielectric Constant Dk**
  - **Standard** Dk $\geq 4.0$
  - **Mid** Dk: 3.5 – 4.0
  - **Low** Dk: 3.0 – 3.5
  - **Ultra Low**: $\leq 3.0$

- **Dissipation Factor Df**
  - **Ultra Low Loss** Df $\leq 0.0032$
  - **Very Low Loss** Df: 0.032 – 0.005
  - **Low Loss** Df: 0.005 – 0.007
  - **Mid Loss** Df: 0.010 – 0.02
  - **Standard** Df $\geq 0.020$

- **Conductor losses of copper foil**
  - RTF
  - VLP
  - NP/ANP

- Ultra Low Loss materials are becoming the main focus for future HSD designs

- Current Halogen Free Ceiling

- Approximately 400 material offerings available today

Ultra Low Loss Materials

Very Low Loss Materials

Low Loss Materials

Standard Materials
Laminate properties are tested across a range of resin contents, frequencies, constructions, using appropriate ‘laminate / dielectric’ test methods.

Laminate $D_k$ and $D_f$ values at 1 MHz and 1 GHz alone do not provide sufficient data for designers for High-speed Digital applications.

Laminate data sheets provide ‘single points’ of information for $D_k$ and $D_f$ based on a single resin content (usually ~40-60% RC range).
## Typical Laminate Construction Data

### Core Data

<table>
<thead>
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<th>Core Constructions</th>
<th>Resin Content (%)</th>
<th>Thickness (inch)</th>
<th>Thickness (mm)</th>
<th>Dielectric Constant(DK)</th>
<th>Dissipation Factor(DF)</th>
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<td></td>
<td></td>
<td>100 MHz</td>
<td>500 MHz</td>
<td>1.0 GHz</td>
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<tr>
<td>1x1067 MS</td>
<td>70.0</td>
<td>0.0020</td>
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### Tachyon-100G DK/DF Constructions

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<th>Resin Content (%)</th>
<th>Thickness (inch)</th>
<th>Thickness (mm)</th>
<th>5.0 GHz</th>
<th>10.0 GHz</th>
<th>15.0 GHz</th>
<th>20.0 GHz</th>
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<td>70.0</td>
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<tr>
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<td>0.0635</td>
<td>2.96</td>
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</tr>
</tbody>
</table>
Typical Industry SI Test Vehicles
Comparing Resin Systems

Attenuation (dB/in) vs Frequency (GHz)

dB/in. Loss vs Freq for 8” Trace

Courtesy of Speeding Edge
Selection Summary

- Select a material with proven SI & thermal performance on an industry accepted or internal TV
- Collect the laminate Dk/Df data for the construction set and properties that fit your design criteria
- Consider glass type and how it influences your design
- Consider copper type and how it influences your design
- Evaluate hybrid construction opportunities
- Compare major processing steps for hidden cost
- Evaluate cost to performance of material options
Laminate Cost

Cost Ratio

- Standard
- Mid Loss
- Low Loss
- Very Low Loss
- Ultra Low Loss
Thank You!