Advanced Material Selection

IPC Designers Council

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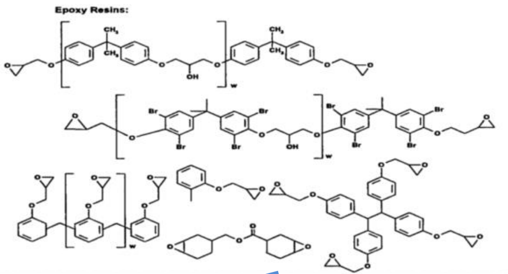
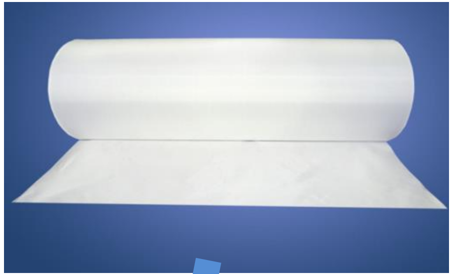
Laminate Material Components

Resin, Glass, Copper

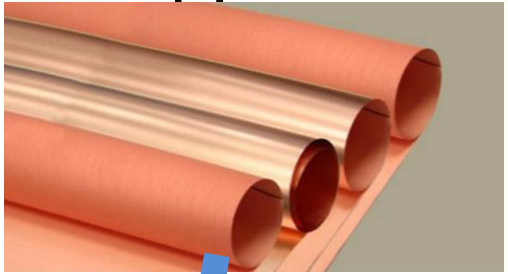
Resin

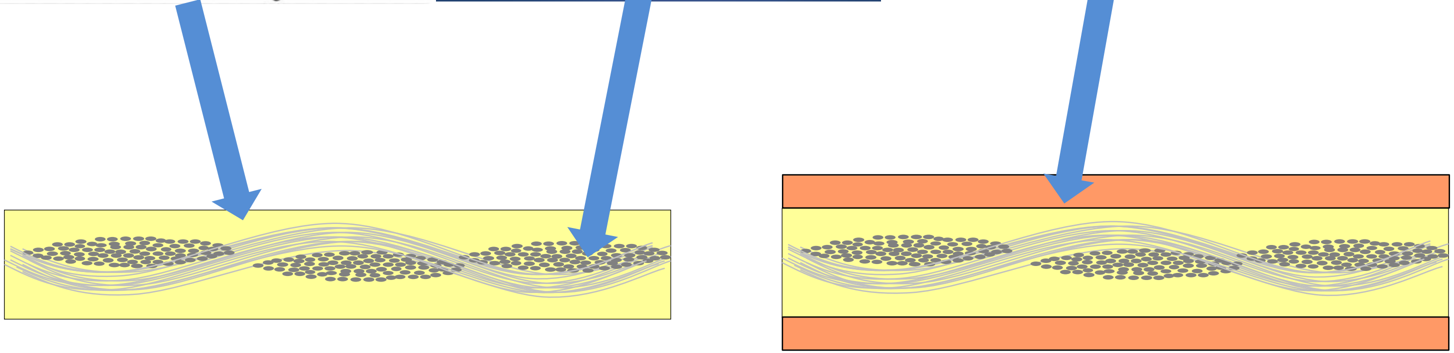


Glass



Copper



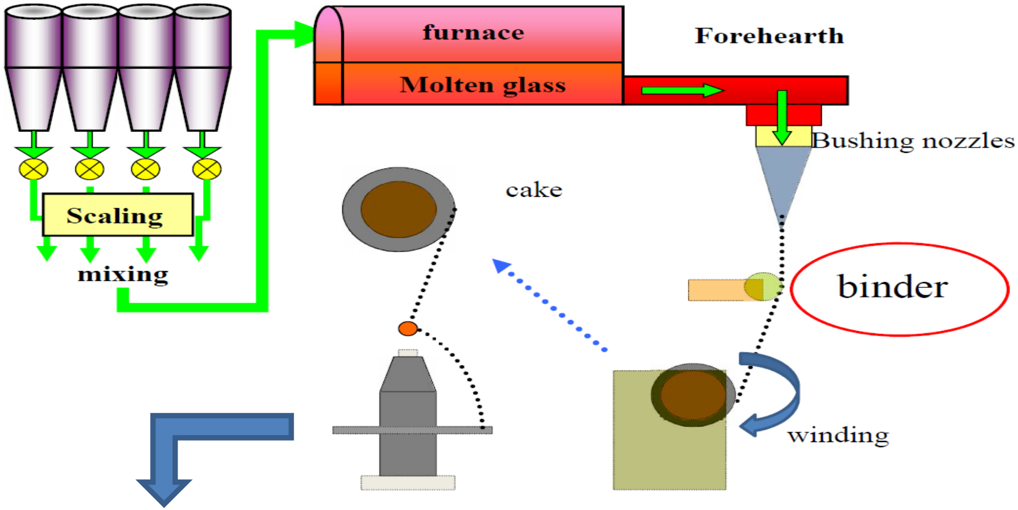


Prepreg or B-Stage

B-Stage + Foil = Laminate

Glass Fabric - Yarn

Glass Yarn



Finished glass
yarn bobbins

Critical Differences

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

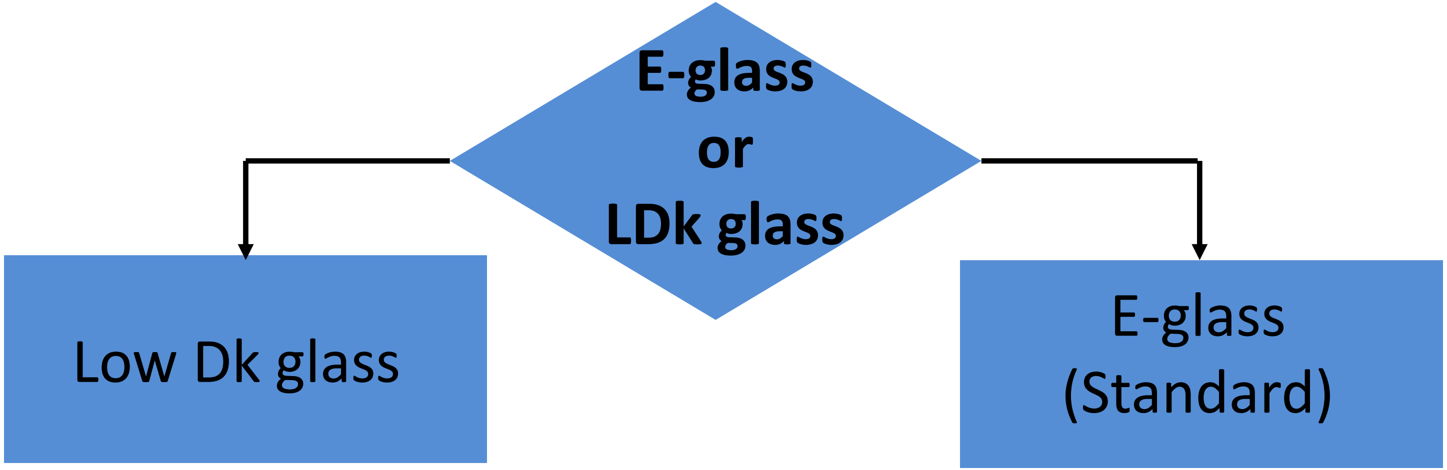
Glass Yarn Properties

	Property		E-Glass	Low Dk			Low CTE	
	Advantage	Disadvantage		D-Glass	L-Glass	NE-Glass	T-Glass	S-Glass
SiO_2	Dk, Df	Drillability	52-56%	72-76%	52-56%	52-56%	64-66%	64-66%
CaO		Dk	20-25%	0%	0-10%	0%	0%	0-0.3%
Al_2O_3		Df	12-16%	0-5%	10-15%	10-18%	24-26%	24-26%
B_2O_3	Dk, Dk		5-10%	20-25%	15-20%	18-25%	0%	0%
MgO	Meltability	Dk	0-5%	0%	0-5%	5-12%	9-11%	9-11%
Na_2O,K_2O		Dk, Df, Durability	0-1%	3-5%	0-1%	0-1%	0%	0-0.3%
TiO_2,LiO_2	Meltability		0%	0%	0-5%	0%	0%	0%

Property	Unit	E-Glass	Low Dk Glass	Low CTE Glass
Dk @ 1GHz	**Freq**	6.8	4.8	5.4
Df @ 1 GHz	**Freq**	0.0035	0.0015	0.0043
Tensile Modulus	**Gpa**	75	64	86
Thermal Expansion	**ppm/°C**	5.6	2.8	3.3

- **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

E-glass (Standard)

- Lower Dk & Df
- Increases glass cost ~5-6x
- Increases lead time

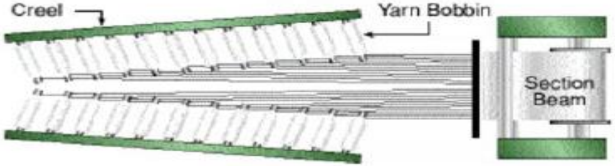
- Standard Dk & Df
- Low cost
- Readily available

Glass Fabric – Weaving

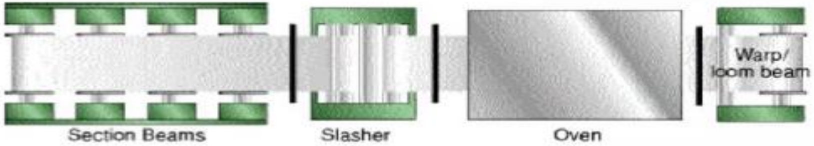
Fabric Weaving Process

Preparation

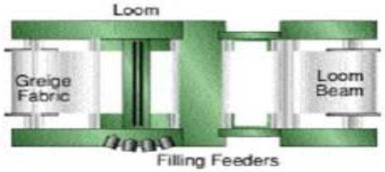
Warping

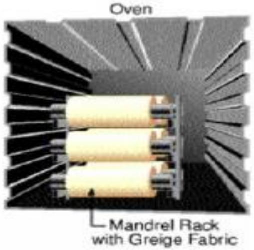


Slashing



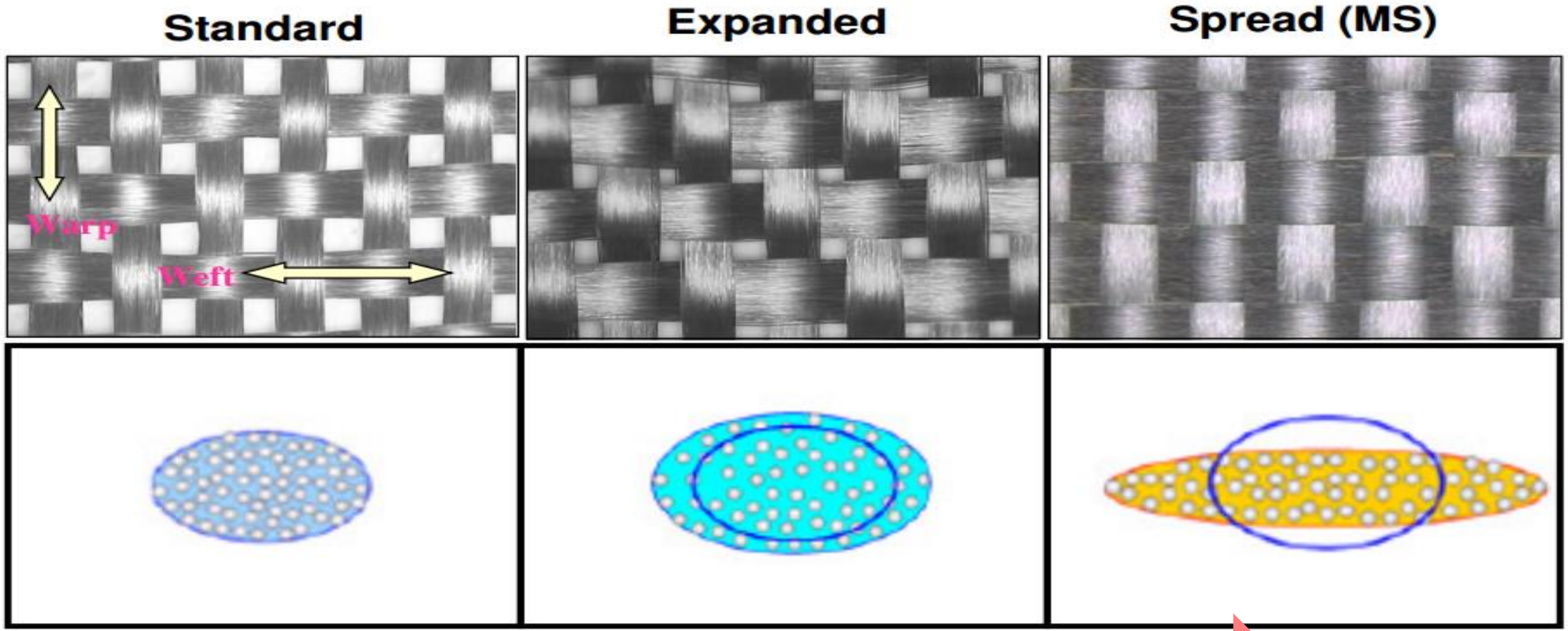
Weaving





Finishing

Glass Fabric Types

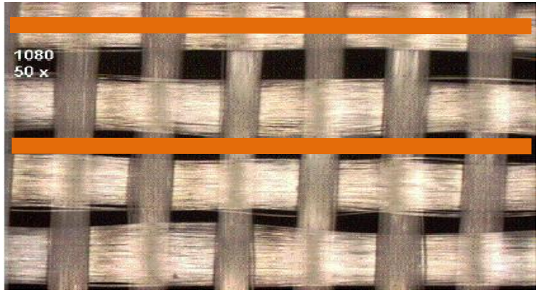


Less Skew or Fiber Weave Effect

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

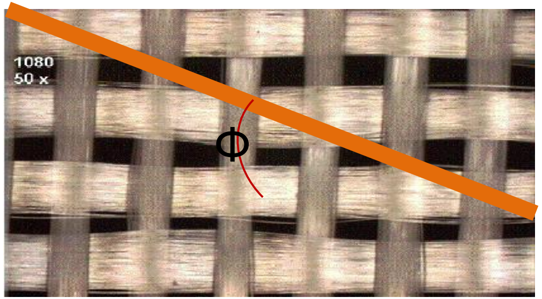
Two Main Fiber Weave Effects

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

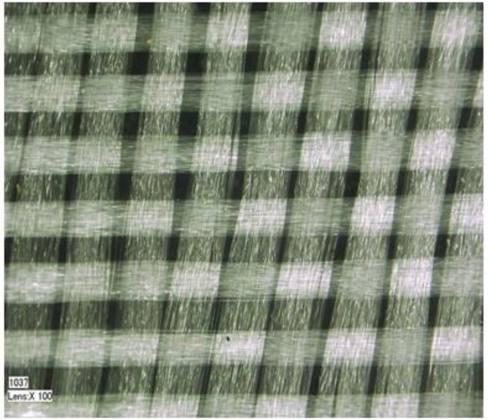


High Er;
Low Zo
Low Er;
High Zo

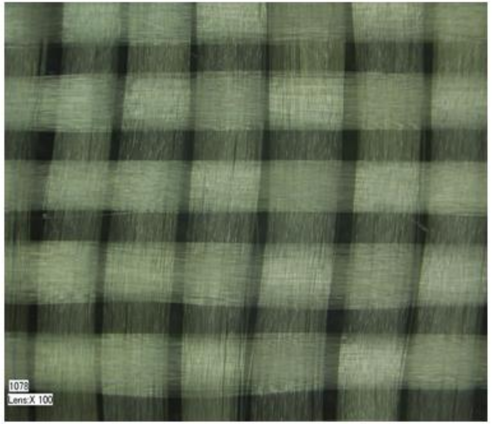
2. **Effects due to periodic loading of trace by fiber weave bundles – resonance**



Ultra Thin Glass



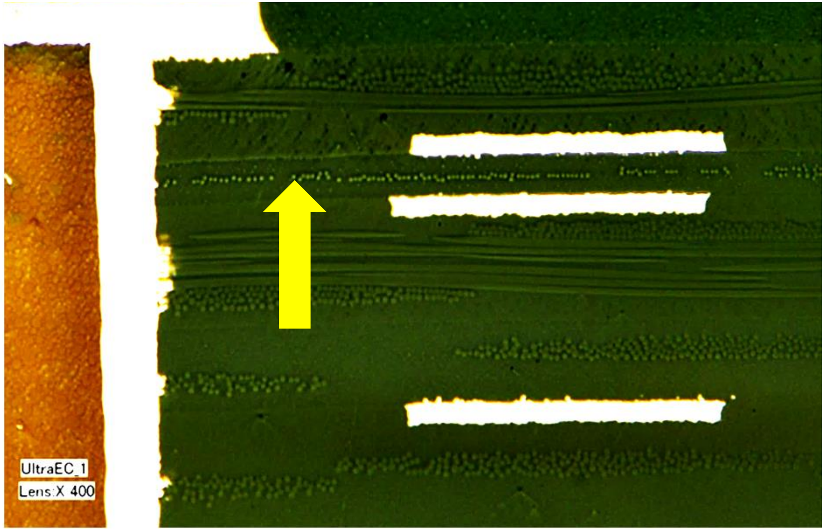
1037
Warp & Fill Count: 70 x 73 (ends/in)
Thickness: 0.0011” / 0.030 mm



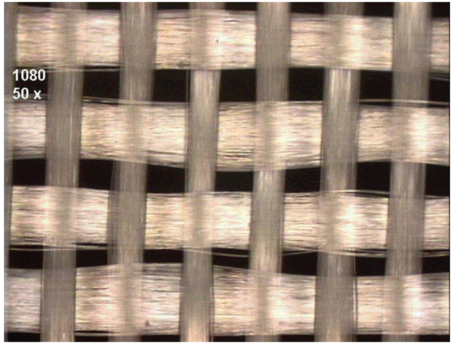
1078
Warp & Fill Count: 54 x 54 (ends/in)
Thickness: 0.0017” / 0.040 mm

IPC SPEC (excerpt)	Thickness (mm)	Weight (g/m^2)	count /25mm Warp	Fill	Weave
1037	0.025	24	69	72	Plain
1027	0.020	19	74	74	Plain
1017	0.015	13	95	95	Plain

The above data are examples of actual measured values and not standard values.



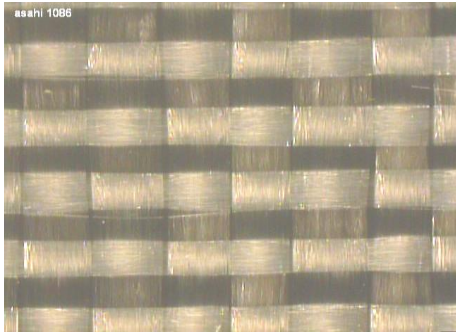
Open vs Spread Weave



1080

Warp & Fill Count: 60 x 47 (ends/in)

Thickness: 0.0021” / 0.064 mm



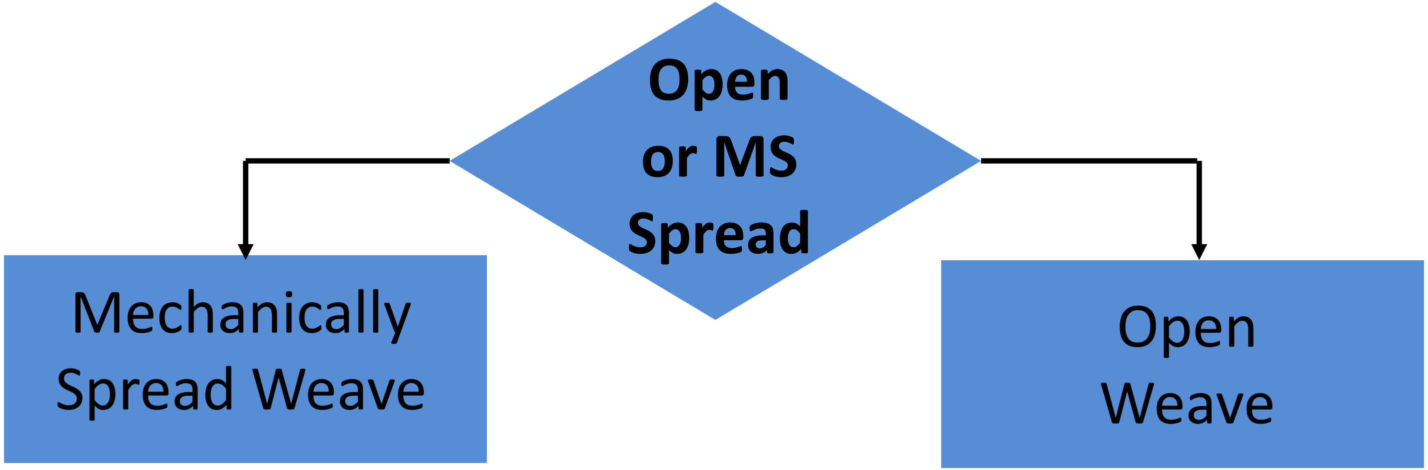
1086

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



Open or MS Spread

Mechanically Spread Weave

Open Weave

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

- Low cost
- Notable FWE (Fiber Weave Effect)
- Readily available
- **Through glass resin flow**

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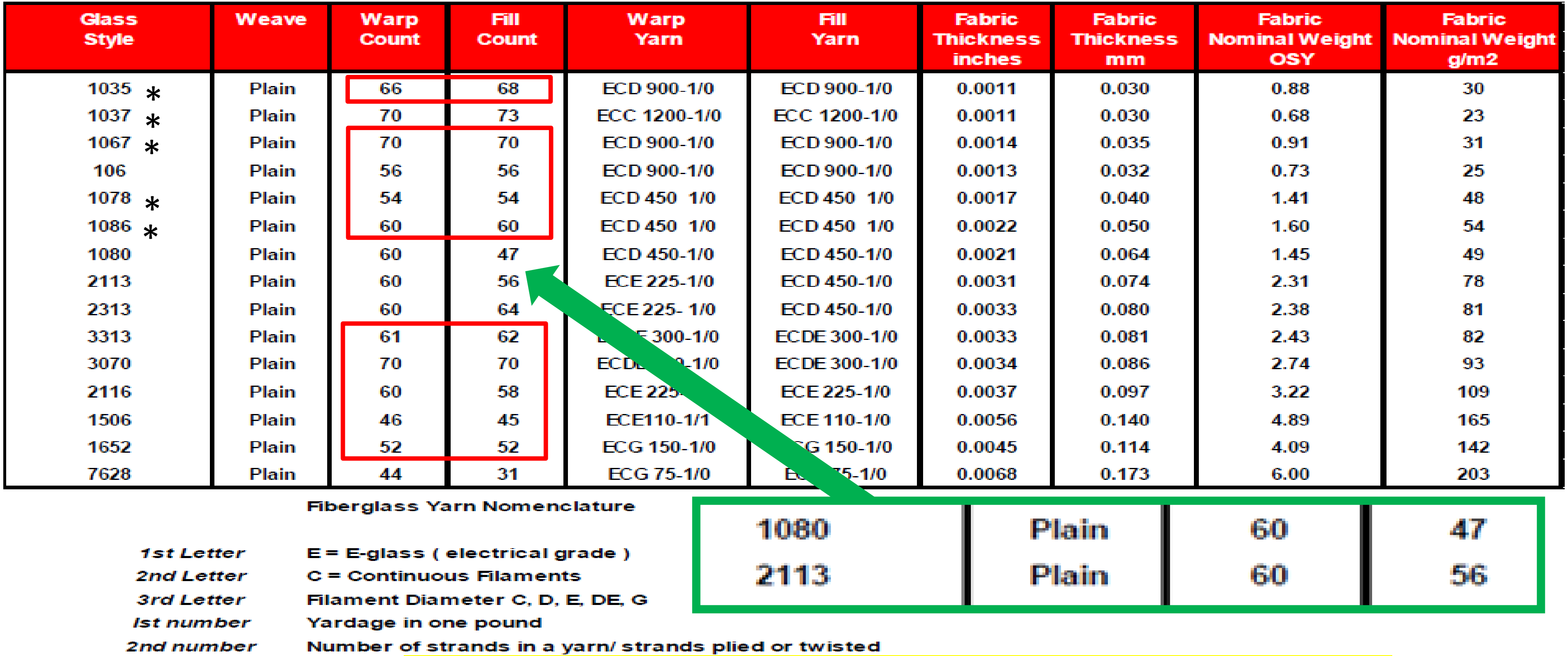
Glass Fabric - Style

Glass Styles



Glass Style	Weave	Warp Count	Fill Count	Warp Yarn	Fill Yarn	Fabric Thickness inches	Fabric Thickness mm	Fabric Nominal Weight OSY	Fabric Nominal Weight g/m2
1035 *	Plain	66	68	ECD 900-1/0	ECD 900-1/0	0.0011	0.030	0.88	30
1037 *	Plain	70	73	ECC 1200-1/0	ECC 1200-1/0	0.0011	0.030	0.68	23
1067 *	Plain	70	70	ECD 900-1/0	ECD 900-1/0	0.0014	0.035	0.91	31
106	Plain	56	56	ECD 900-1/0	ECD 900-1/0	0.0013	0.032	0.73	25
1078 *	Plain	54	54	ECD 450 1/0	ECD 450 1/0	0.0017	0.040	1.41	48
1086 *	Plain	60	60	ECD 450 1/0	ECD 450 1/0	0.0022	0.050	1.60	54
1080	Plain	60	47	ECD 450-1/0	ECD 450-1/0	0.0021	0.064	1.45	49
2113	Plain	60	56	ECE 225-1/0	ECD 450-1/0	0.0031	0.074	2.31	78
2313	Plain	60	64	ECE 225- 1/0	ECD 450-1/0	0.0033	0.080	2.38	81
3313	Plain	61	62	[illegible]E 300-1/0	ECDE 300-1/0	0.0033	0.081	2.43	82
3070	Plain	70	70	ECD[illegible]0-1/0	ECDE 300-1/0	0.0034	0.086	2.74	93
2116	Plain	60	58	ECE 225[illegible]	ECE 225-1/0	0.0037	0.097	3.22	109
1506	Plain	46	45	ECE110-1/1	ECE 110-1/0	0.0056	0.140	4.89	165
1652	Plain	52	52	ECG 150-1/0	[illegible]G 150-1/0	0.0045	0.114	4.09	142
7628	Plain	44	31	ECG 75-1/0	E[illegible]5-1/0	0.0068	0.173	6.00	203

Fiberglass Yarn Nomenclature

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

1080	Plain	60	47
2113	Plain	60	56

Square Weave

E-glass and Low Dk glass nominal weights are not equal

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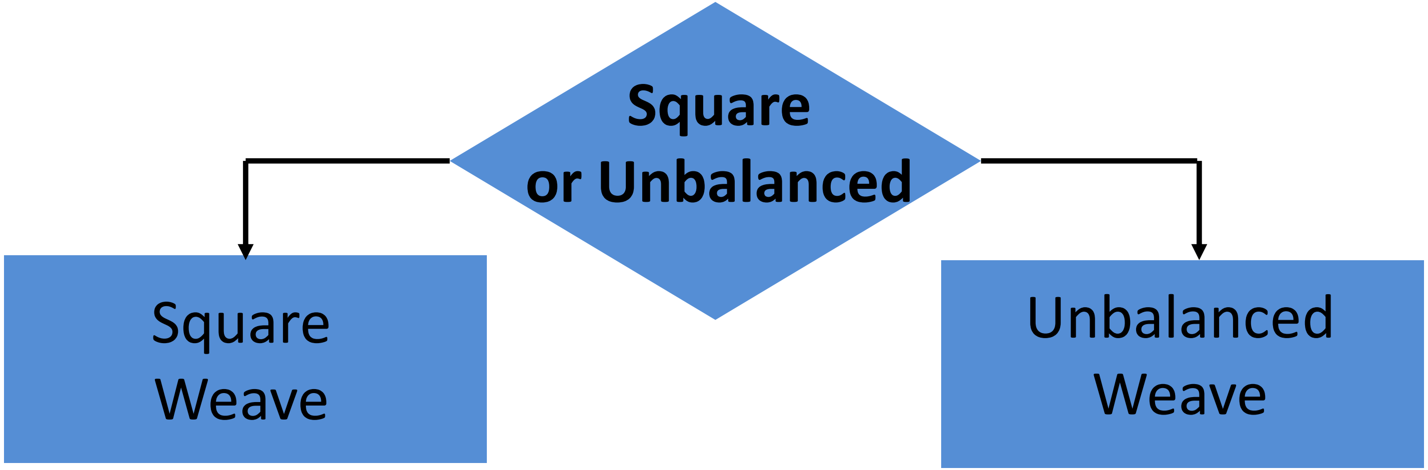
Glass Style Decision Tree



Square or Unbalanced

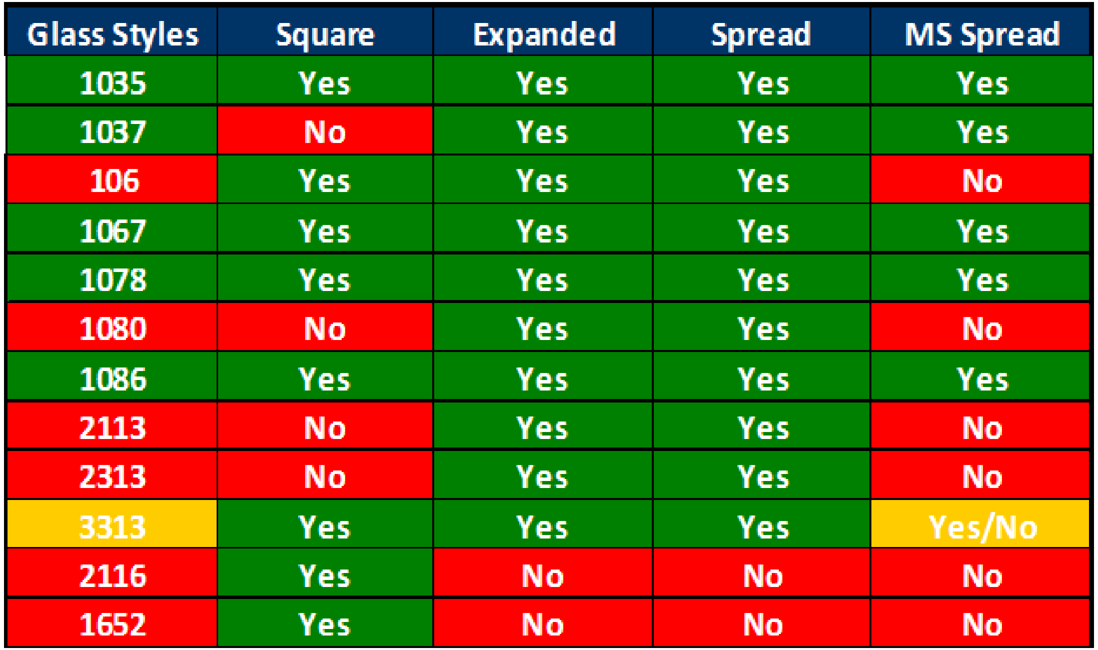
Square Weave

Unbalanced Weave

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

- Low cost
- Notable FWE (Fiber Weave Effect)
- Variation in x-y periodicity

Guide to Selecting Glass



Glass Styles	Square	Expanded	Spread	MS Spread
1035	Yes	Yes	Yes	Yes
1037	No	Yes	Yes	Yes
106	Yes	Yes	Yes	No
1067	Yes	Yes	Yes	Yes
1078	Yes	Yes	Yes	Yes
1080	No	Yes	Yes	No
1086	Yes	Yes	Yes	Yes
2113	No	Yes	Yes	No
2313	No	Yes	Yes	No
3313	Yes	Yes	Yes	Yes/No
2116	Yes	No	No	No
1652	Yes	No	No	No

- 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

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Resin

Resin Technology

- **Base Resin Components**
  - Difunctional & Tetrafuntional 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!"

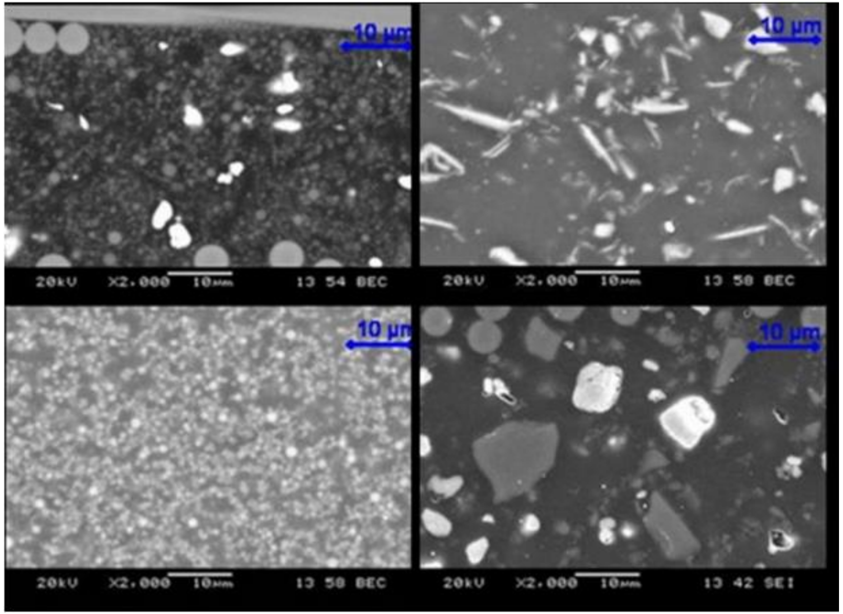
Next generation of non-PTFE laminate is expected to have

D_k < 3.0 Dk

D_f < 0.001

Resin Technology

- **Fillers - *'Components'*** *w*hich 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



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Resin Technology

- **Flame retardants**
  - Brominated – TBBPA Tetrabromobisphenol-A
  - Halogen Free
    - Phosphorus based
    - Aluminum hydroxide
    - Magnesium hydroxide
    - Nitrogen based
  - Solid vs reacted

Mixing & Blending Technology

Components

Resin

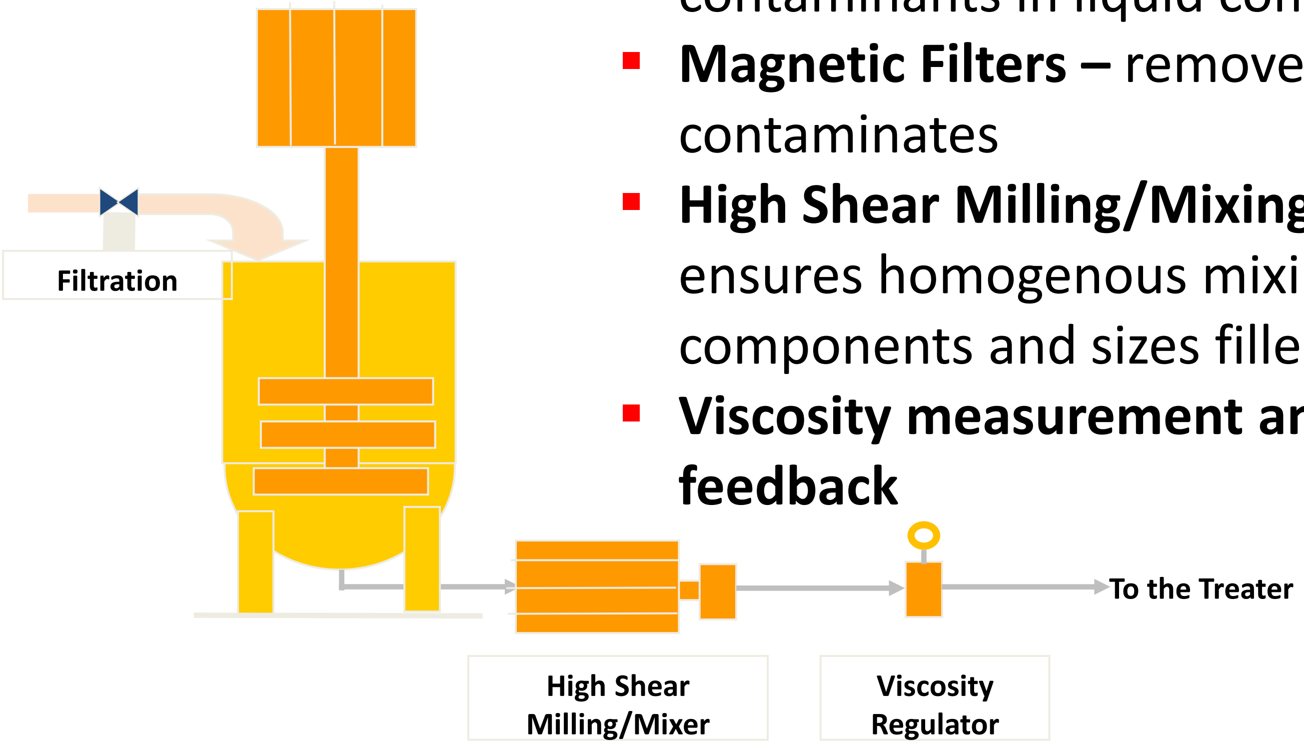
Solvent

Catalyst

Hardener

Fillers

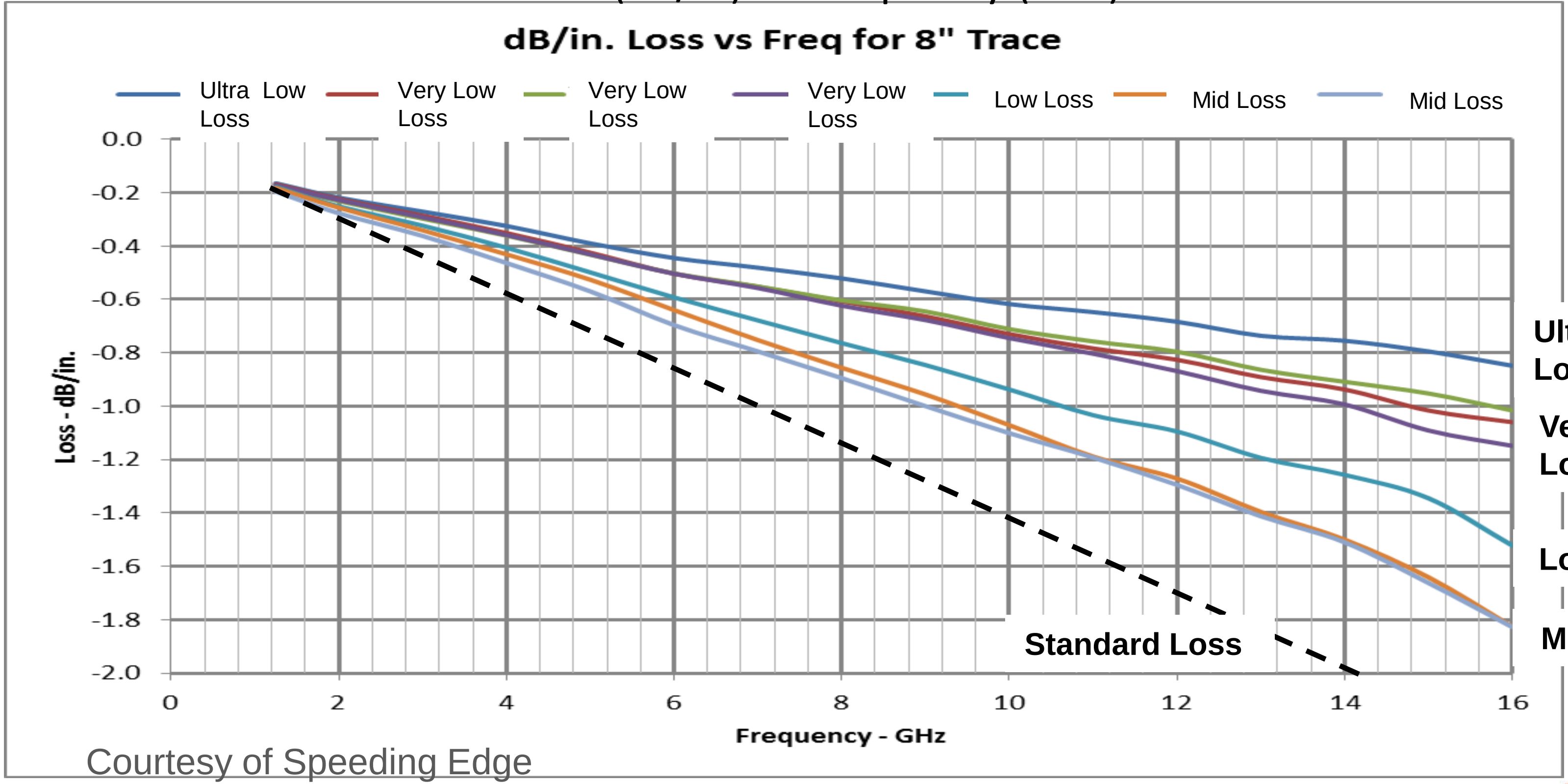
Flame Retardants



- **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**

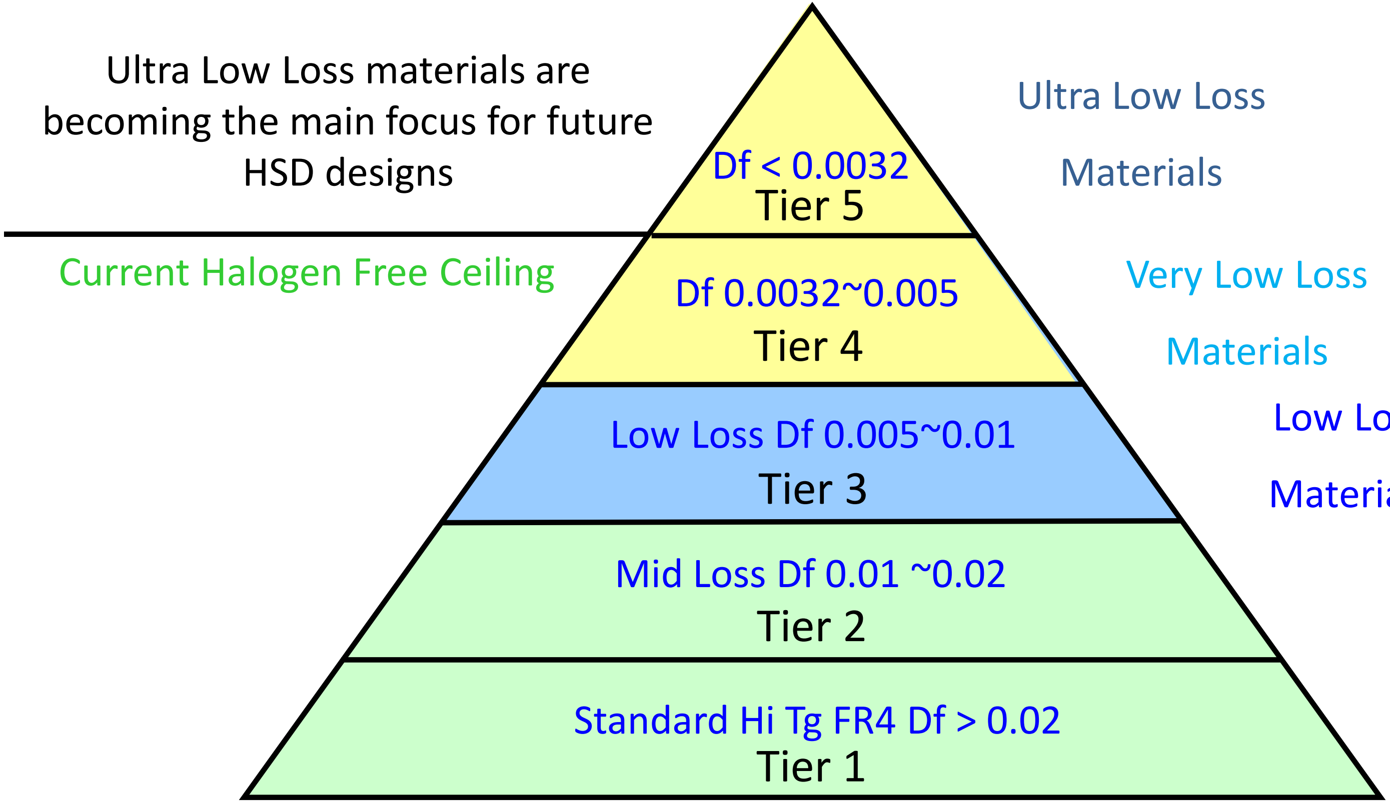
Comparing Resin Systems

Attenuation (dB/in) vs Frequency (GHz)



Courtesy of Speeding Edge

Material Loss Pyramid



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

Current Halogen Free Ceiling

Df < 0.0032
Tier 5

Df 0.0032~0.005
Tier 4

Low Loss Df 0.005~0.01
Tier 3

Mid Loss Df 0.01 ~0.02
Tier 2

Standard Hi Tg FR4 Df > 0.02
Tier 1

Ultra Low Loss Materials

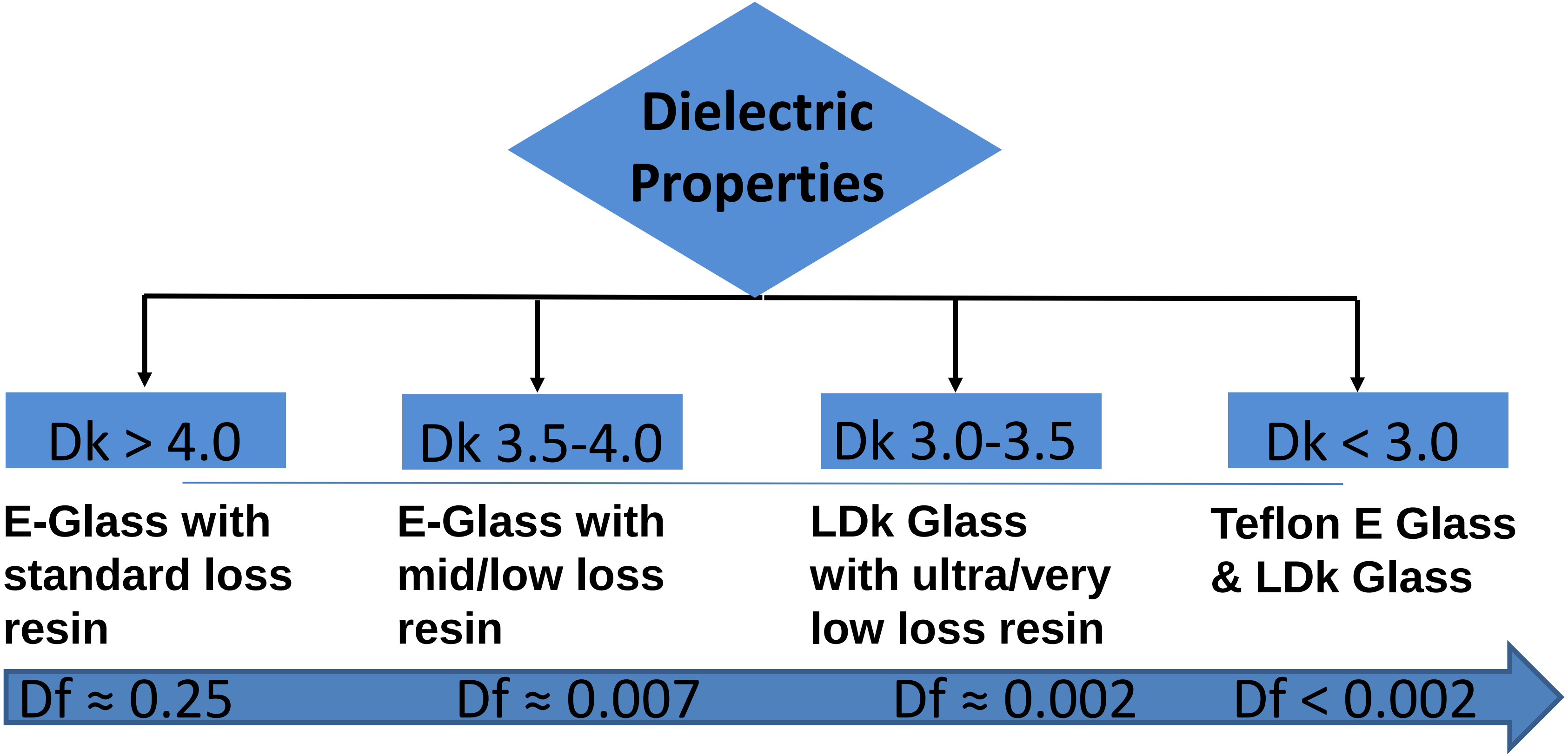
Very Low Loss Materials

Low Loss Materials

Standard Materials

Approximately 400 material offerings available today

Resin Decision Tree



Dielectric Properties

Dk > 4.0

E-Glass with standard loss resin

Df ≈ 0.25

Dk 3.5-4.0

E-Glass with mid/low loss resin

Df ≈ 0.007

Dk 3.0-3.5

LDk Glass with ultra/very low loss resin

Df ≈ 0.002

Dk < 3.0

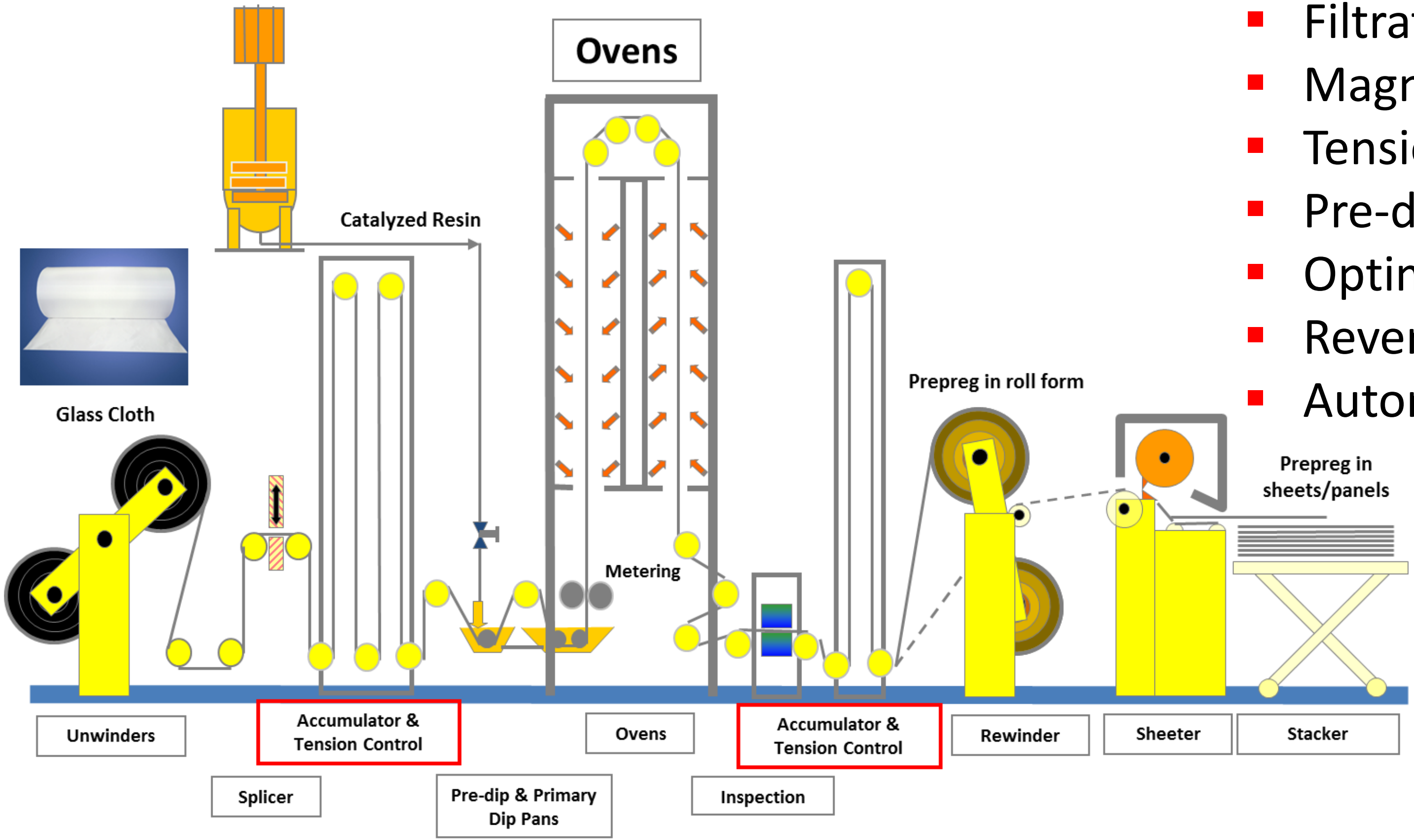
Teflon E Glass & LDk Glass

Df < 0.002

Where Dk is lower, Df tends to be slightly lower

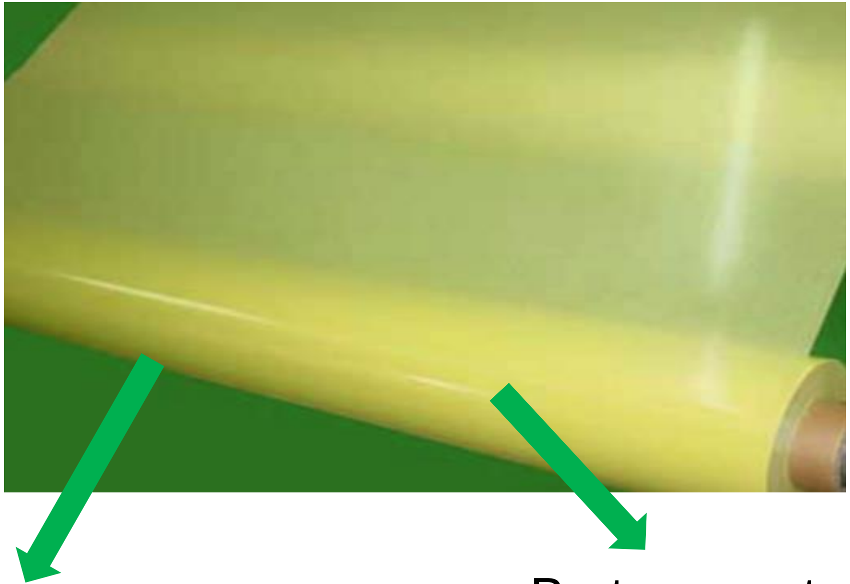
Glass Impregnation

Treating Technology

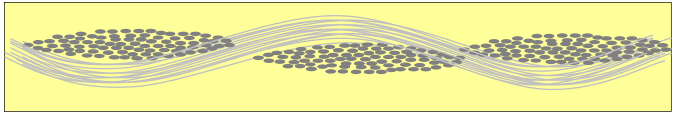


- Filtration
- Magnetic bars
- Tension controls
- Pre-dip
- Optimized primary dip
- Reversing metering rolls
- Automated inspection

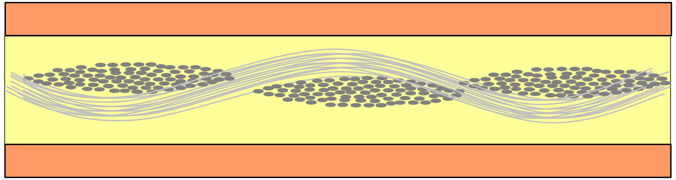
Finished B-Stage



B-stage material to be used as prepreg

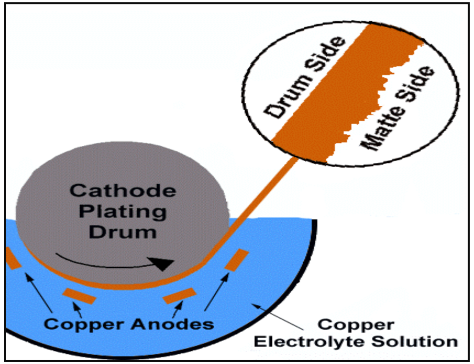


B-stage material to be used to make laminate

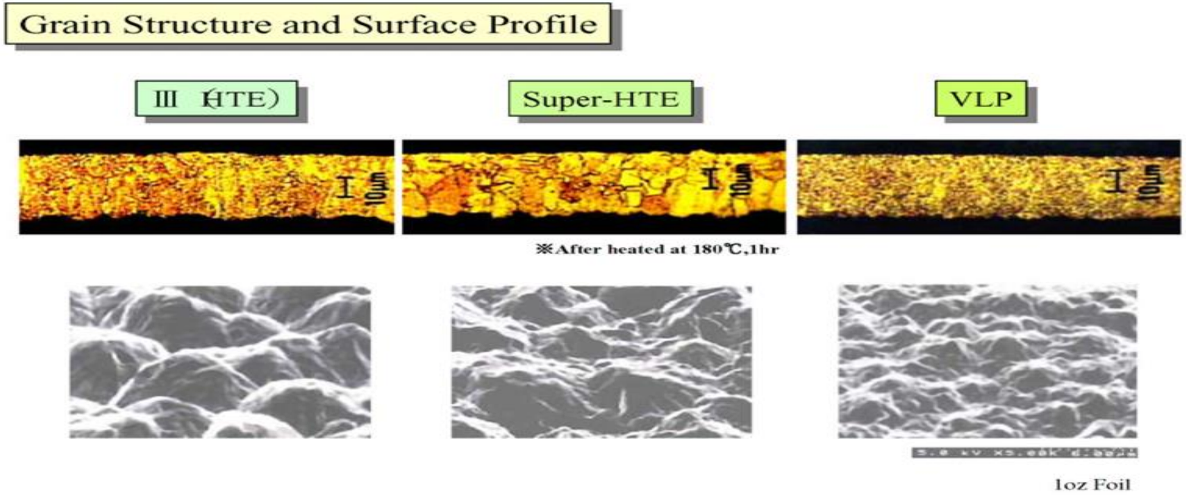


Copper

Copper Foil Plating



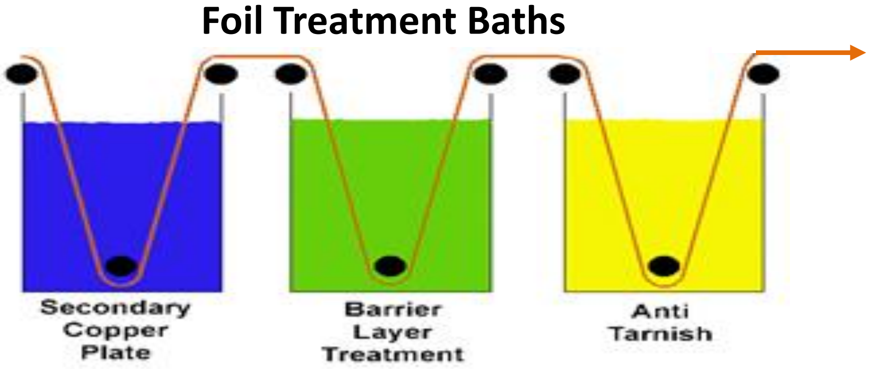
- **ED Copper Grain Structure determines:**
  - Surface roughness or profile
  - Physical properties of the copper
  - **Almost No Profile (ANP) – <2 µm**
  - Minimum thickness with carrier - 2,3, 5 µm

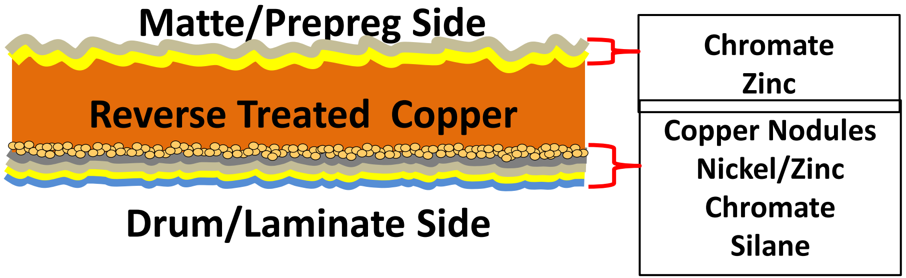


Warning:

- 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

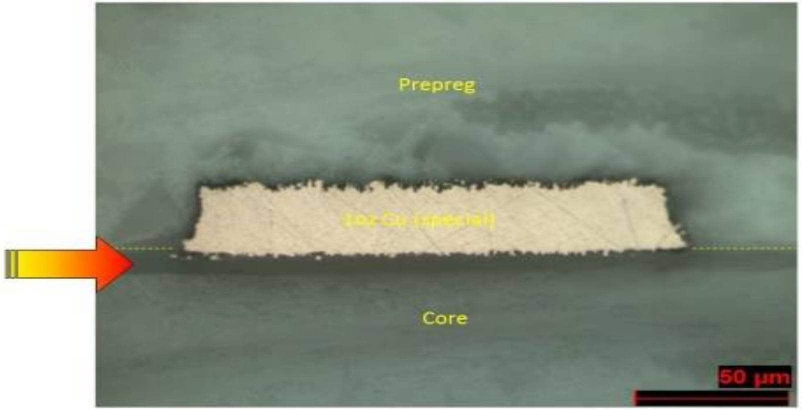
Copper Foil Treatment



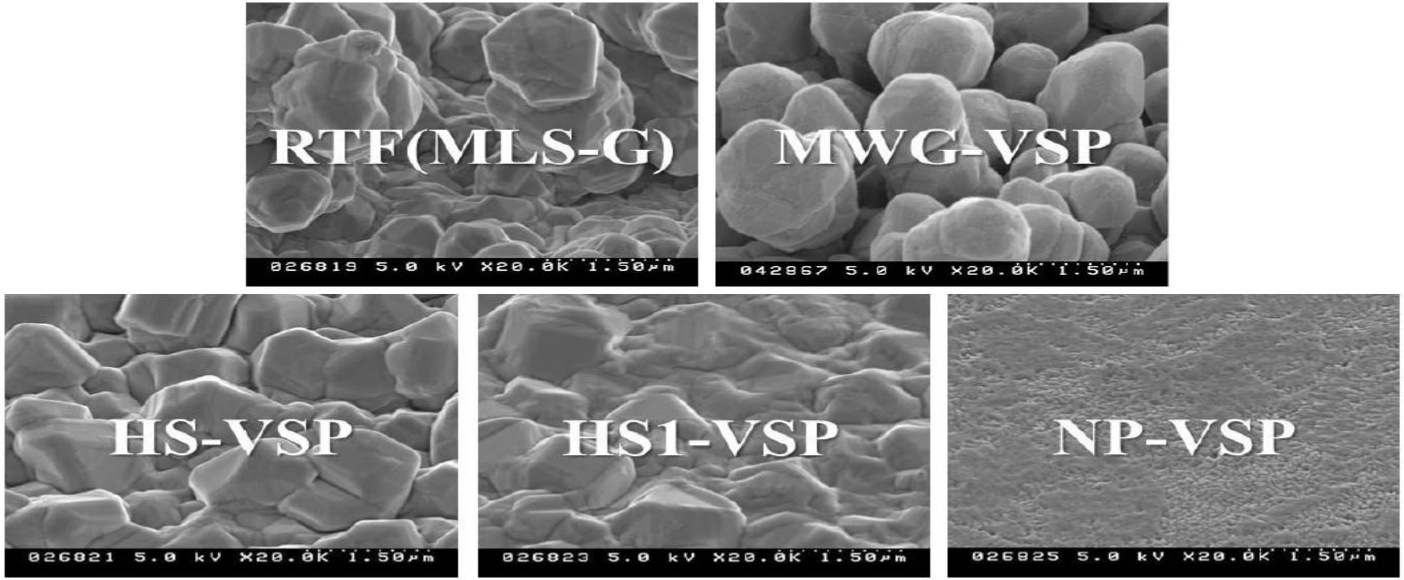


- **Secondary plating – Nodulation**
  - Reduction of conductor losses
  - Minimization of conductor path

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



Copper Surface Images

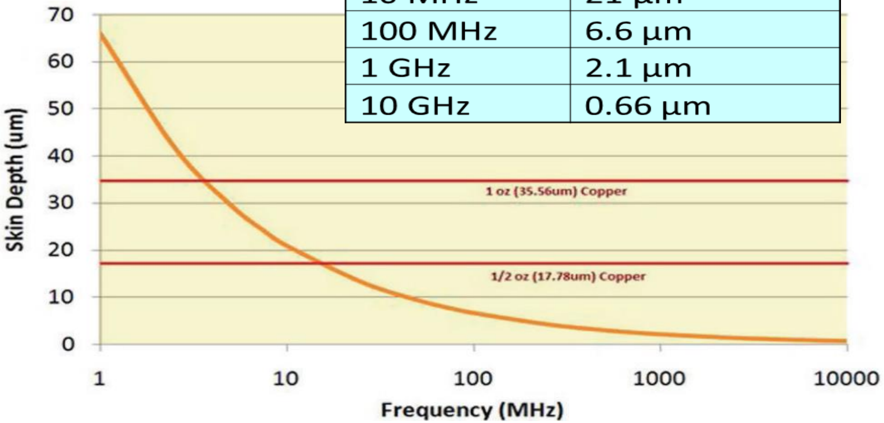


- **Smoother copper results in reduced conductor losses**

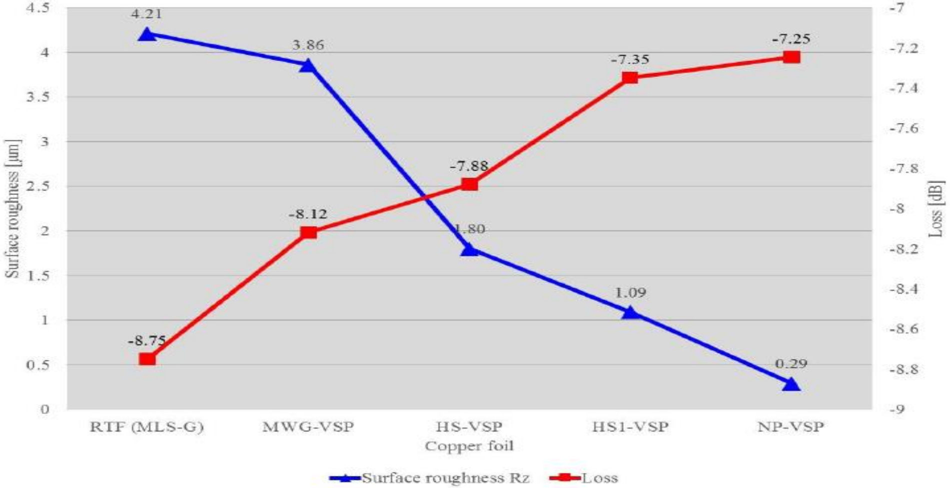
Courtesy Mitsui Copper Foil

Skin Effect

Frequency	**Skin Depth (Copper)**
50 Hz	9.3 mm
10 MHz	21 µm
100 MHz	6.6 µm
1 GHz	2.1 µm
10 GHz	0.66 µm

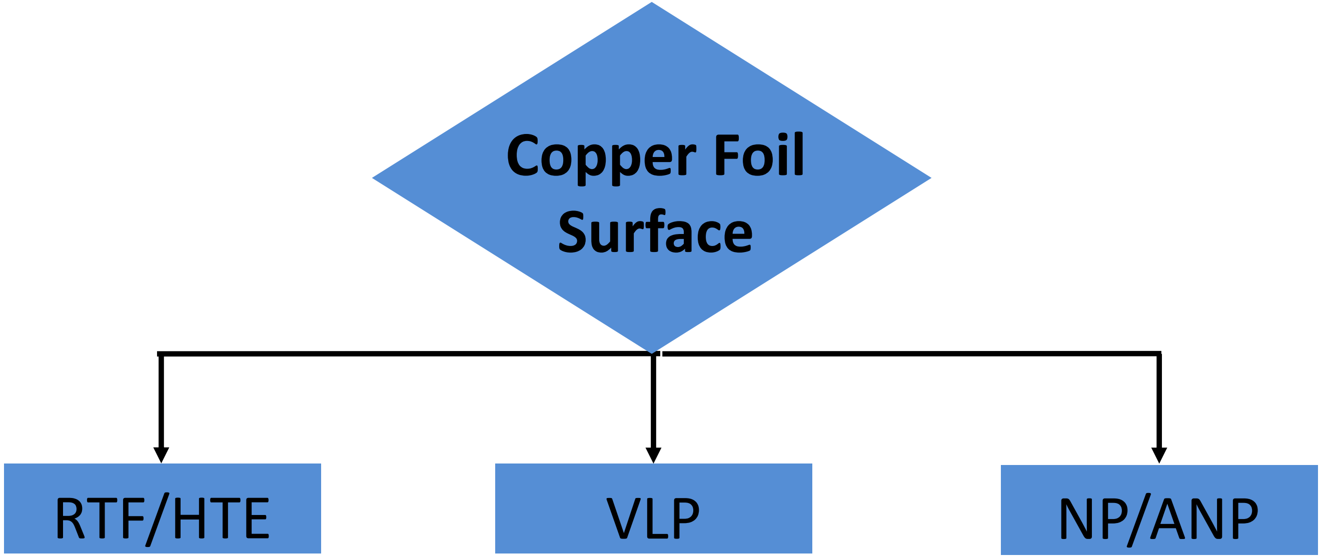


Courtesy Mitsui Copper Foil



- Skin depth decreases as frequency increases
- Conductor losses decrease as foil roughness decrease

Copper Foil Decision Tree



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

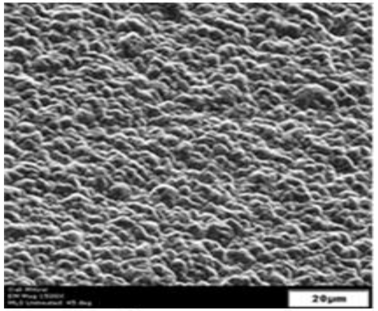
VLP
- 2-3 um
- Standard Availability
- Increased Cu Cost ~1.5x

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

Reduces conductor loss component

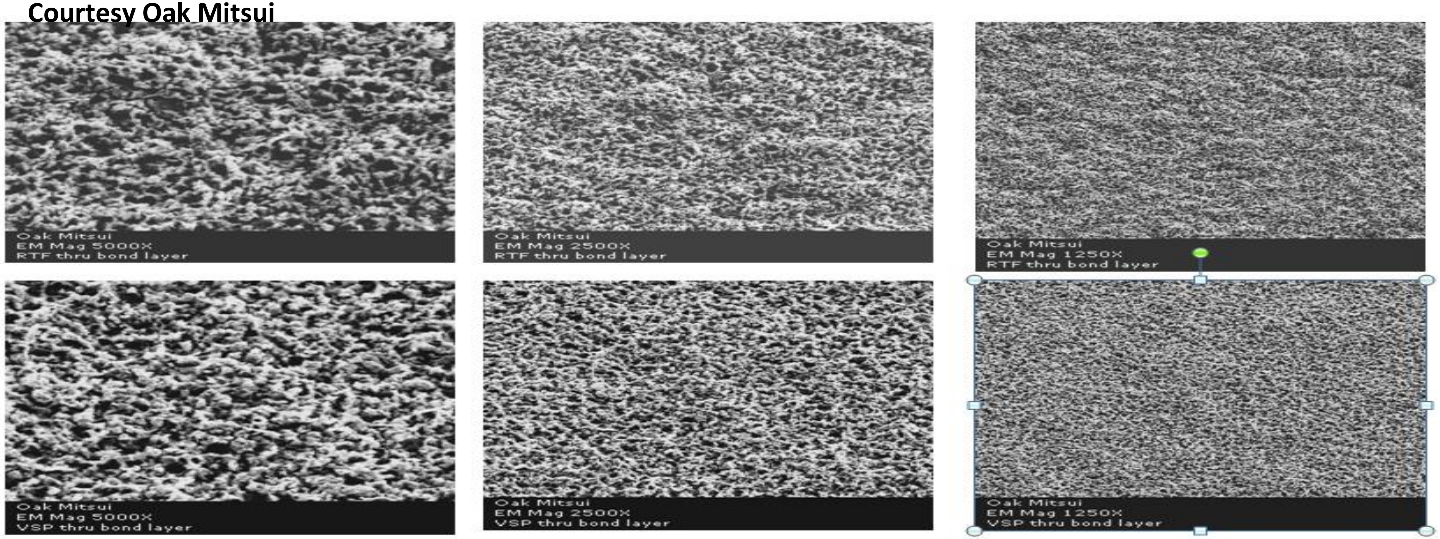
Inner Layer Bonding Treatment
(during PCB processing)

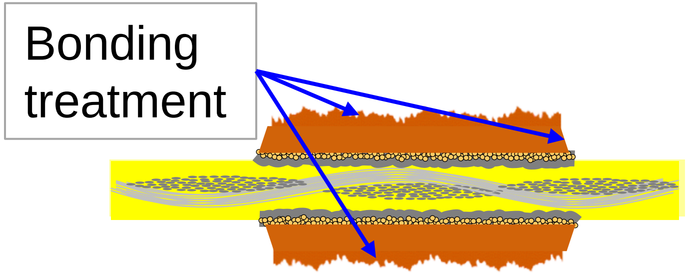
Cleaned
copper surface



Matte/Prepreg Side

Courtesy Oak Mitsui



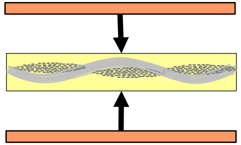


Bonding
treatment

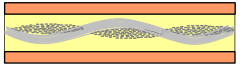
Warning:
Not all surface treatments are equal and result in significant variation from fab shop to fab shop

Lamination

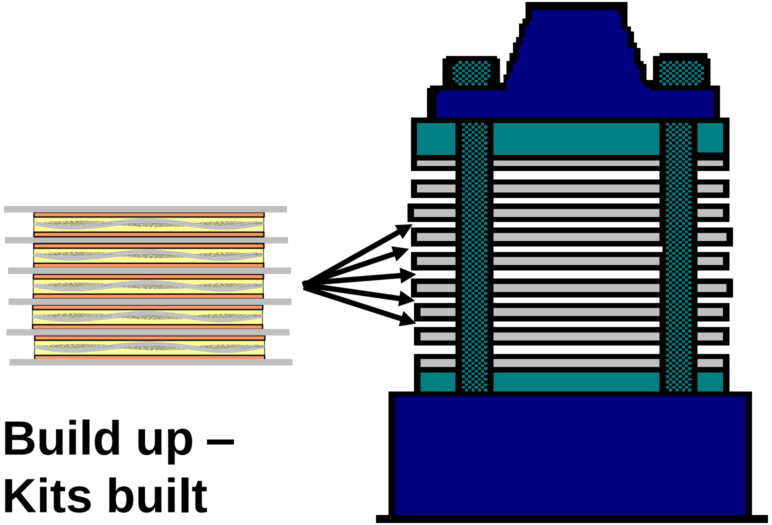
Lamination



Lay up - Copper foil applied to b-stage



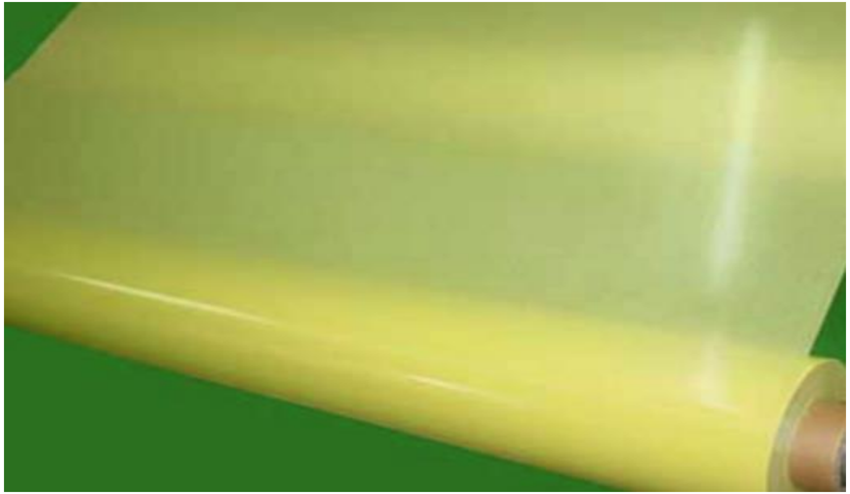
Laminate Kit



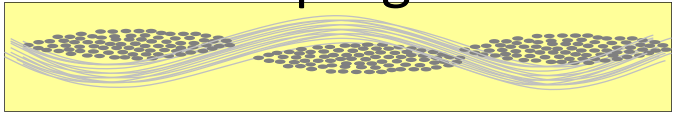
Build up – Kits built into a book

Master sheet lamination

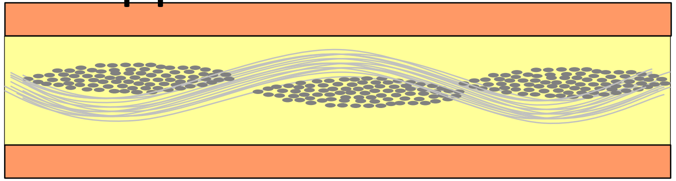
Finished Products



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**

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Selecting the Right Material

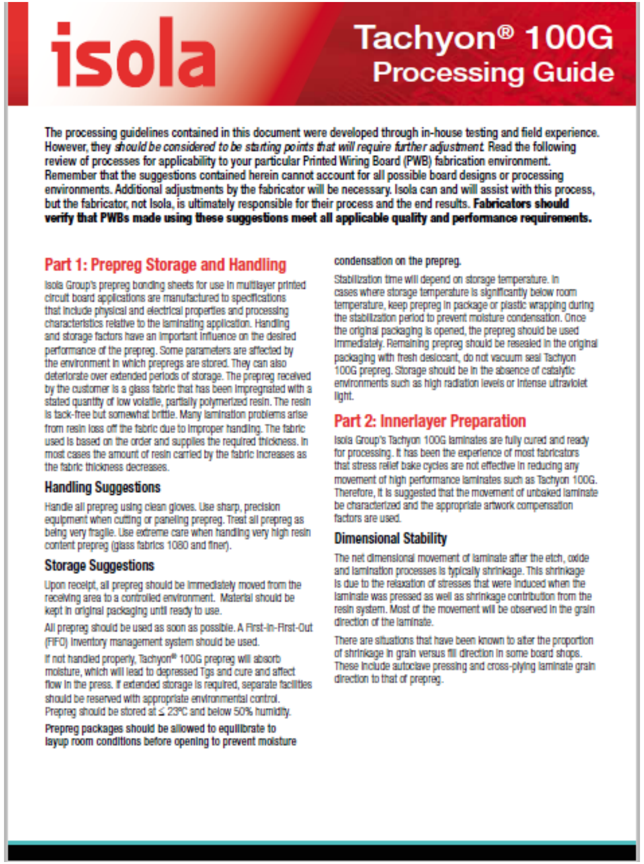
- Laminate material selection can not be condensed into a single page chart (Data sheet) for easy selection. More information is needed

- 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



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Tachyon® 100G Processing Guide

The processing guidelines contained in this document were developed through in-house testing and field experience. However, they *should be considered to be starting points that will require further adjustment.* Read the following review of processes for applicability to your particular Printed Wiring Board (PWB) fabrication environment. Remember that the suggestions contained herein cannot account for all possible board designs or processing environments. Additional adjustments by the fabricator will be necessary. Isola can and will assist with this process, but the fabricator, not Isola, is ultimately responsible for their process and the end results. Fabricators should verify that PWBs made using these suggestions meet all applicable quality and performance requirements.

Part 1: Prepreg Storage and Handling

Isola Group's prepreg bonding sheets for use in multilayer printed circuit board applications are manufactured to specifications that include physical and electrical properties and processing characteristics relative to the laminating application. Handling and storage factors have an important influence on the desired performance of the prepreg. Some parameters are affected by the environment in which prepregs are stored. They can also deteriorate over extended periods of storage. The prepreg received by the customer is a glass fabric that has been impregnated with a stated quantity of low volatile, partially polymerized resin. The resin is tack-free but somewhat brittle. Many lamination problems arise from resin loss off the fabric due to improper handling. The fabric used is based on the order and supplies the required thickness. In most cases the amount of resin carried by the fabric increases as the fabric thickness decreases.

Handling Suggestions

Handle all prepreg using clean gloves. Use sharp, precision equipment when cutting or paneling prepreg. Treat all prepreg as being very fragile. Use extreme care when handling very high resin content prepreg (glass fabrics 1080 and finer).

Storage Suggestions

Upon receipt, all prepreg should be immediately moved from the receiving area to a controlled environment. Material should be kept in original packaging until ready to use.

All prepreg should be used as soon as possible. A First-In-First-Out (FIFO) inventory management system should be used.

If not handled properly, Tachyon® 100G prepreg will absorb moisture, which will lead to depressed Tgs and cure and affect flow in the press. If extended storage is required, separate facilities should be reserved with appropriate environmental control. Prepreg should be stored at ≤ 23°C and below 50% humidity.

Prepreg packages should be allowed to equilibrate to layup room conditions before opening to prevent moisture condensation on the prepreg.

Stabilization time will depend on storage temperature. In cases where storage temperature is significantly below room temperature, keep prepreg in package or plastic wrapping during the stabilization period to prevent moisture condensation. Once the original packaging is opened, the prepreg should be used immediately. Remaining prepreg should be resealed in the original packaging with fresh desiccant, do not vacuum seal Tachyon 100G prepreg. Storage should be in the absence of catalytic environments such as high radiation levels or intense ultraviolet light.

Part 2: Innerlayer Preparation

Isola Group's Tachyon 100G laminates are fully cured and ready for processing. It has been the experience of most fabricators that stress relief bake cycles are not effective in reducing any movement of high performance laminates such as Tachyon 100G. Therefore, it is suggested that the movement of unbaked laminate be characterized and the appropriate artwork compensation factors are used.

Dimensional Stability

The net dimensional movement of laminate after the etch, oxide and lamination processes is typically shrinkage. This shrinkage is due to the relaxation of stresses that were induced when the laminate was pressed as well as shrinkage contribution from the resin system. Most of the movement will be observed in the grain direction of the laminate.

There are situations that have been known to alter the proportion of shrinkage in grain versus fill direction in some board shops. These include autoclave pressing and cross-plying laminate grain direction to that of prepreg.

Laminate Thermal Performance

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

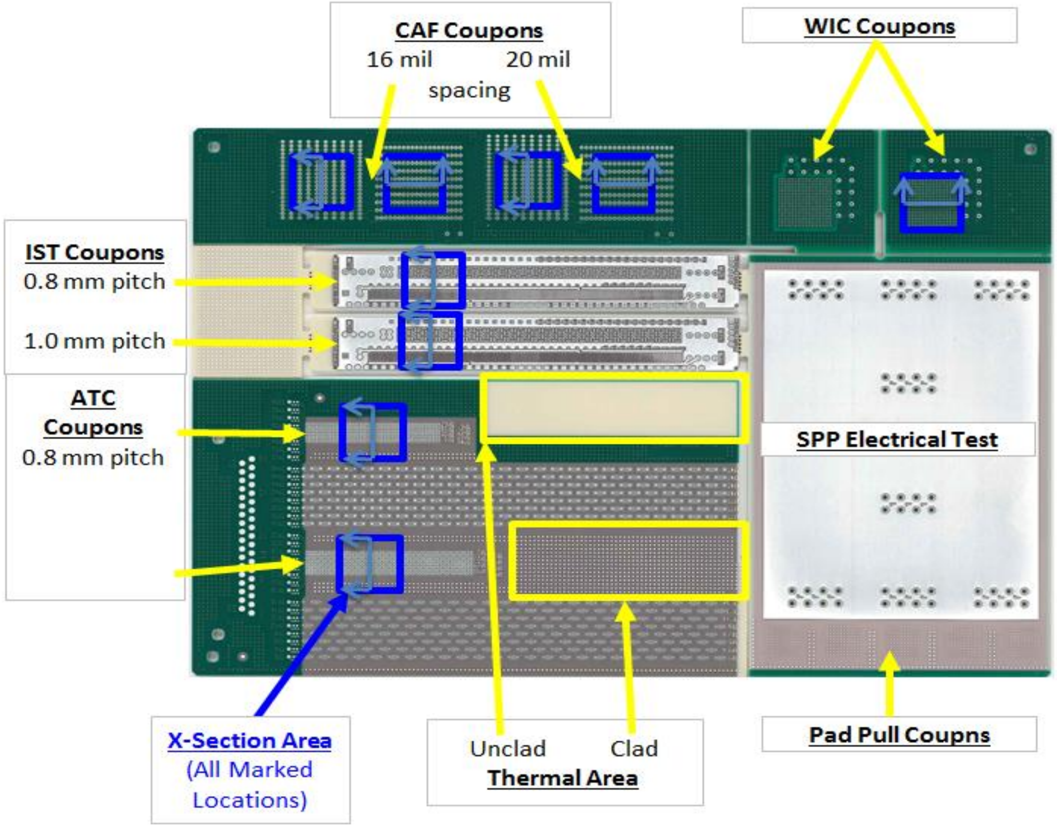
- **Assembly processing**
  - Multiple reflow cycles
  - Rework processing
  - Minimal moisture uptake
  - HDI Compatible – Stacked micro vias on blind

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**



CAF Coupons
16 mil 20 mil
spacing

WIC Coupons

IST Coupons
0.8 mm pitch
1.0 mm pitch

ATC Coupons
0.8 mm pitch

SPP Electrical Test

X-Section Area
(All Marked Locations)

Unclad Clad
Thermal Area

Pad Pull Coupns

TV created by members of HDPUG

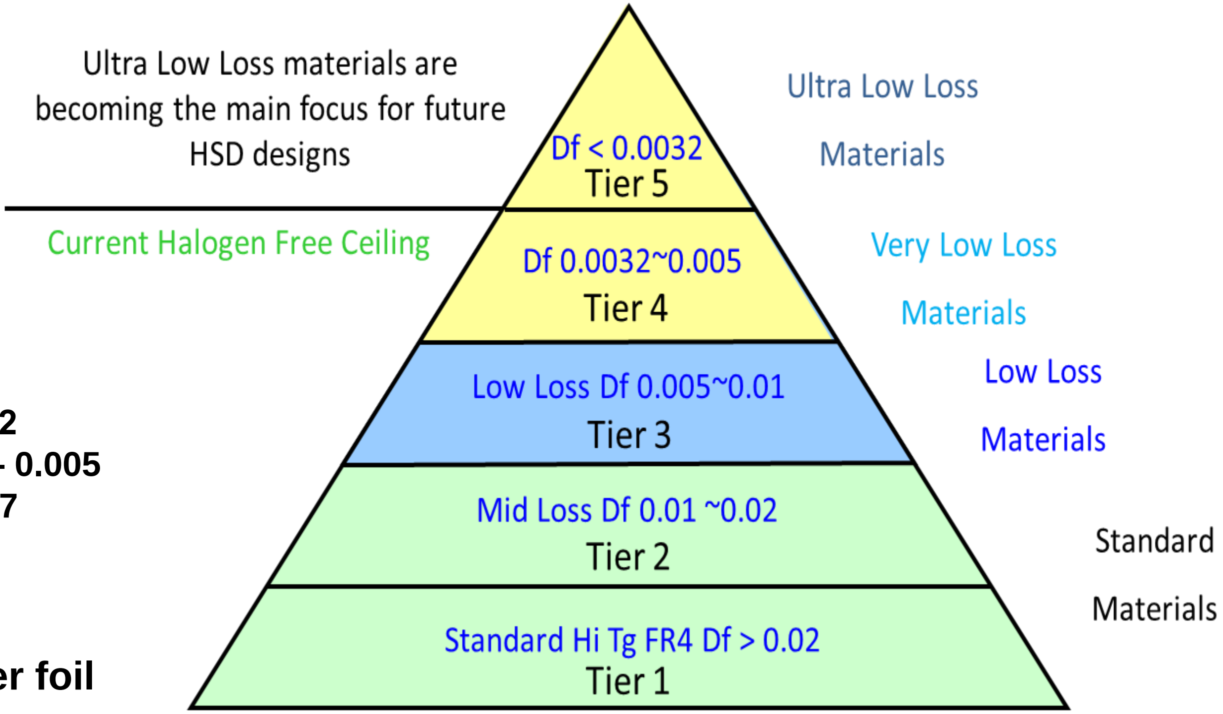
Laminate Electrical Properties

Basic Categories

- Dielectric Constant Dk
  - <u>Standard</u> Dk ≥ 4.0
  - <u>Mid</u> Dk: 3.5 – 4.0
  - <u>Low</u> Dk: 3.0 – 3.5
  - <u>Ultra Low</u>: ≤ 3.0

- Dissipation Factor Df
  - <u>Ultra</u> Low Loss Df ≤ 0.0032
  - <u>Very</u> Low Loss Df: 0.032 – 0.005
  - <u>Low</u> Loss Df: 0.005 – 0.007
  - <u>Mid</u> Loss Df: 0.010 – 0.02
  - <u>Standard</u> Df ≥ 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

Df < 0.0032
Tier 5

Ultra Low Loss Materials

Df 0.0032~0.005
Tier 4

Very Low Loss Materials

Low Loss Df 0.005~0.01
Tier 3

Low Loss Materials

Mid Loss Df 0.01 ~0.02
Tier 2

Standard Materials

Standard Hi Tg FR4 Df > 0.02
Tier 1

Approximately 400 material offerings available today

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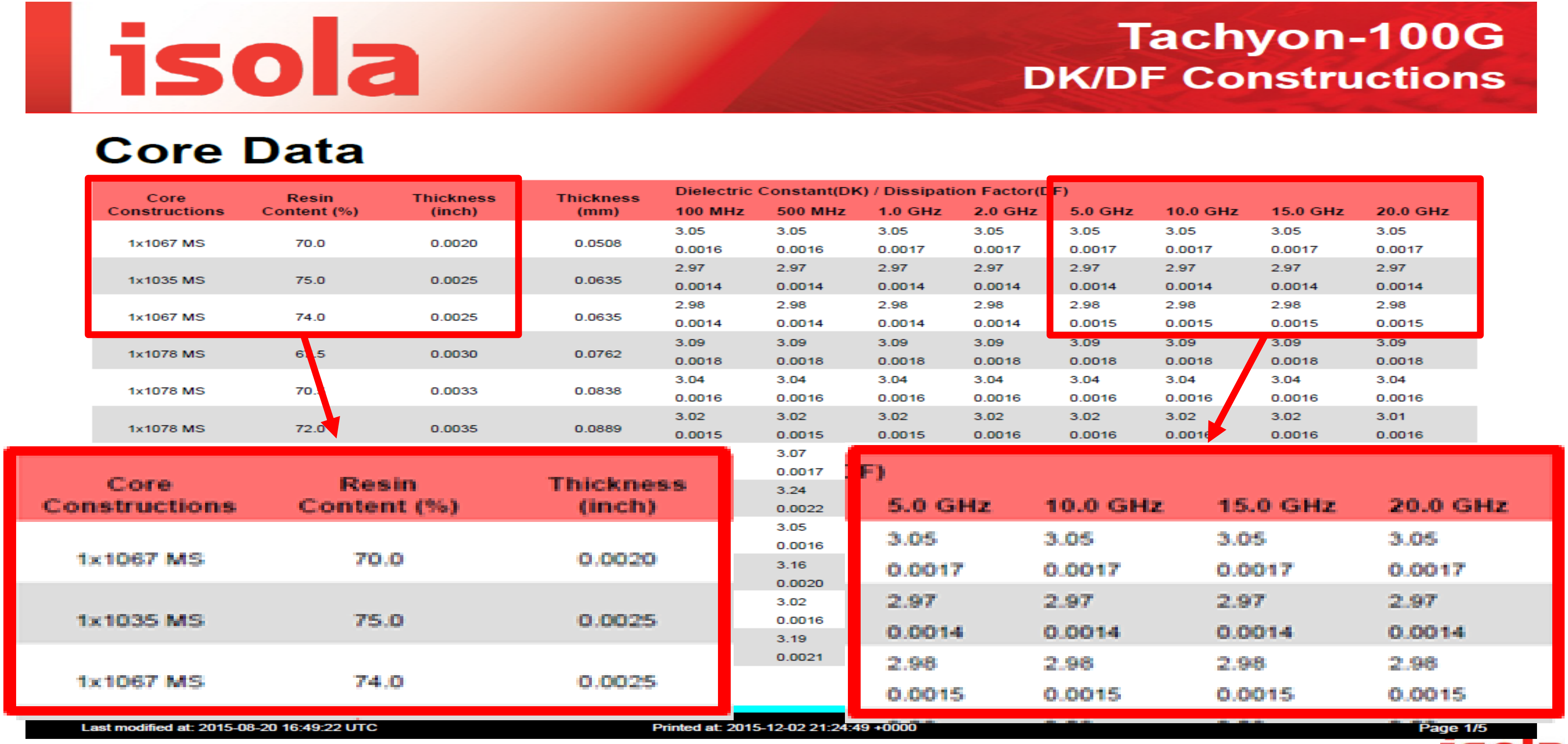
Data Sheet Laminate Properties

- **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 Comstruction Data



Tachyon-100G
DK/DF Constructions

Core Data

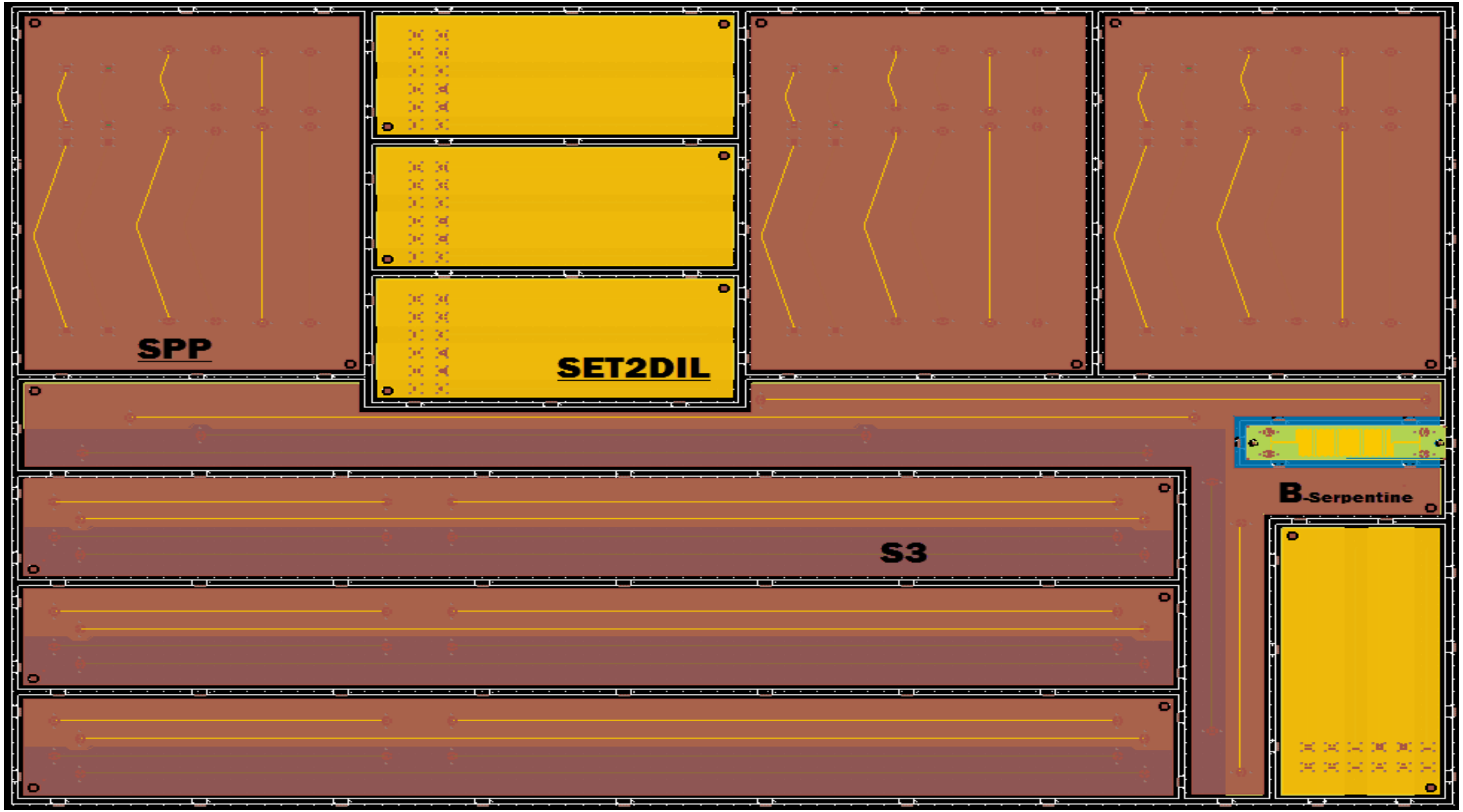
Core Constructions	Resin Content (%)	Thickness (inch)	Thickness (mm)	Dielectric Constant(DK) / Dissipation Factor(DF) 100 MHz	500 MHz	1.0 GHz	2.0 GHz	5.0 GHz	10.0 GHz	15.0 GHz	20.0 GHz
1x1067 MS	70.0	0.0020	0.0508	3.05 0.0016	3.05 0.0016	3.05 0.0017	3.05 0.0017	3.05 0.0017	3.05 0.0017	3.05 0.0017	3.05 0.0017
1x1035 MS	75.0	0.0025	0.0635	2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014
1x1067 MS	74.0	0.0025	0.0635	2.98 0.0014	2.98 0.0014	2.98 0.0014	2.98 0.0014	2.98 0.0015	2.98 0.0015	2.98 0.0015	2.98 0.0015
1x1078 MS	6[illegible].5	0.0030	0.0762	3.09 0.0018	3.09 0.0018	3.09 0.0018	3.09 0.0018	3.09 0.0018	3.09 0.0018	3.09 0.0018	3.09 0.0018
1x1078 MS	70.[illegible]	0.0033	0.0838	3.04 0.0016	3.04 0.0016	3.04 0.0016	3.04 0.0016	3.04 0.0016	3.04 0.0016	3.04 0.0016	3.04 0.0016
1x1078 MS	72.0	0.0035	0.0889	3.02 0.0015	3.02 0.0015	3.02 0.0015	3.02 0.0016	3.02 0.0016	3.02 0.0016	3.02 0.0016	3.01 0.0016
					3.07 0.0017						
					3.24 0.0022						
					3.05 0.0016						
					3.16 0.0020						
					3.02 0.0016						
					3.19 0.0021						

Core Constructions	Resin Content (%)	Thickness (inch)
1x1067 MS	70.0	0.0020
1x1035 MS	75.0	0.0025
1x1067 MS	74.0	0.0025

F)

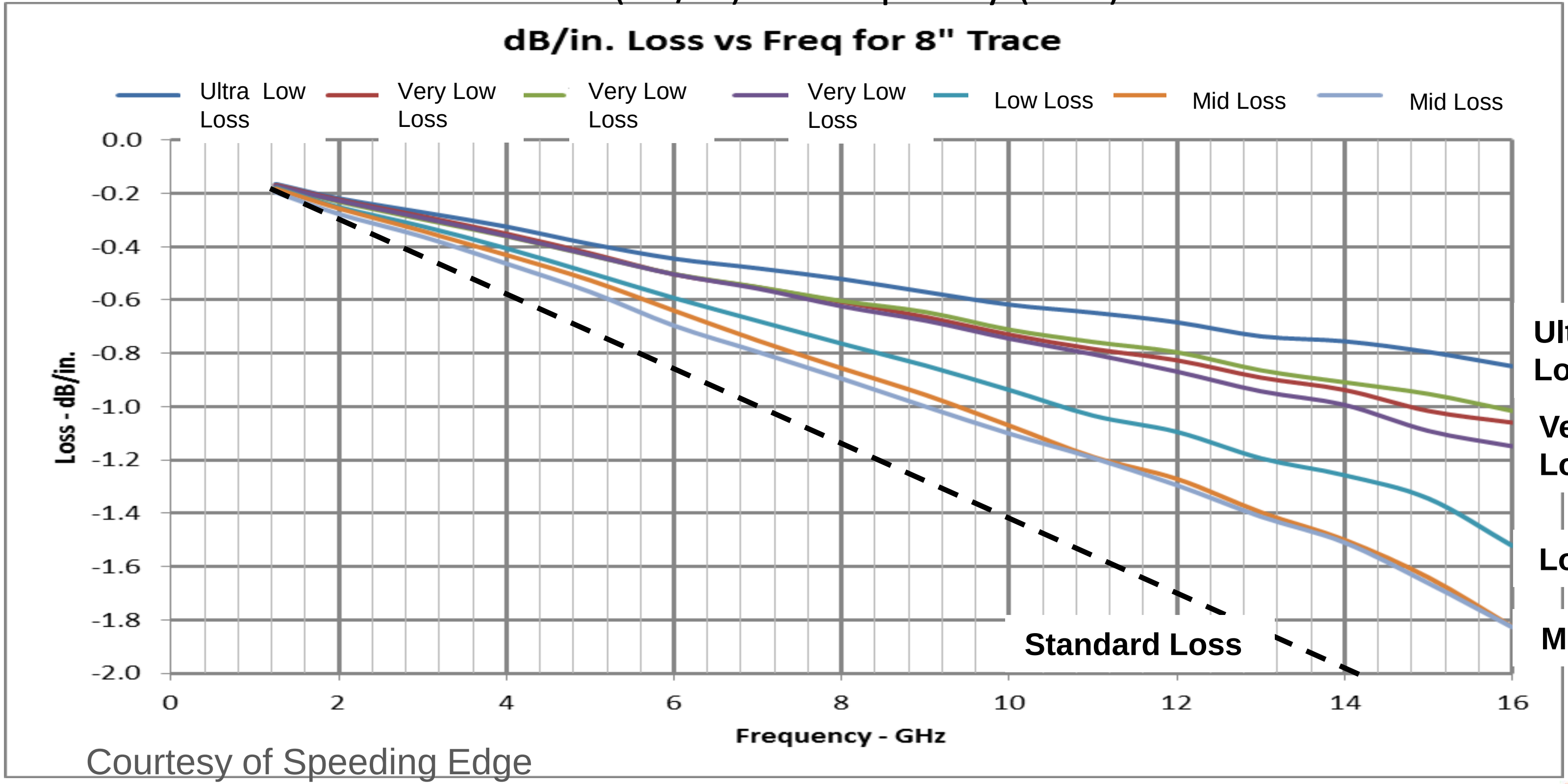
5.0 GHz	10.0 GHz	15.0 GHz	20.0 GHz
3.05 0.0017	3.05 0.0017	3.05 0.0017	3.05 0.0017
2.97 0.0014	2.97 0.0014	2.97 0.0014	2.97 0.0014
2.98 0.0015	2.98 0.0015	2.98 0.0015	2.98 0.0015

Typical Industry SI Test Vehicles



Comparing Resin Systems

Attenuation (dB/in) vs Frequency (GHz)

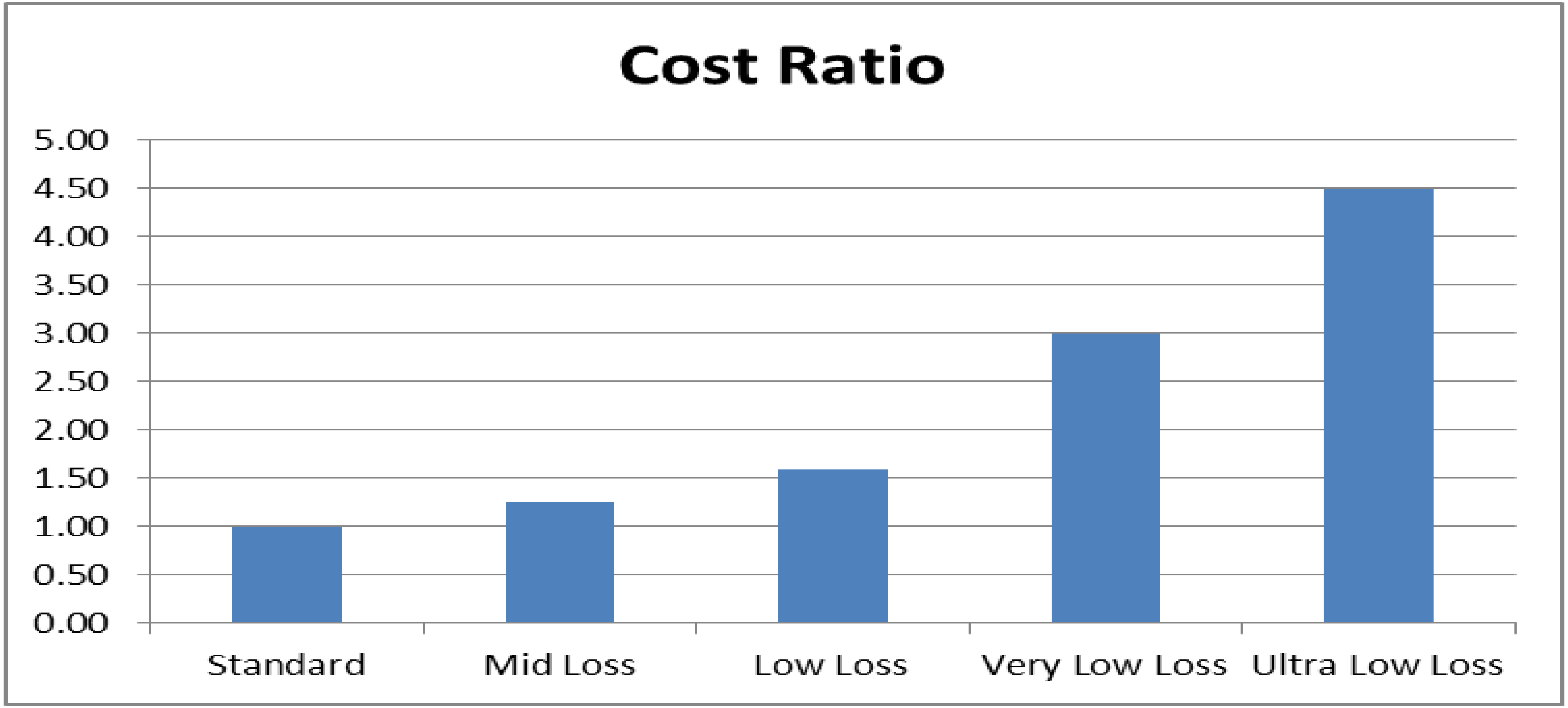


Courtesy of Speeding Edge

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



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The Base for Innovation

Thank You!