Discussion regarding Insertion loss Variation

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Introduction

- The Purpose of this presentation is to describe the state of the art with regard to PCB processing factors that effect signal integrity variation.
- Many sources of variation highlighted (previous IEEE session) have been significantly improved in their manner of control over the last ten years.
- Follow up to IEEE request by Pravin Patel of IBM

Error in Insertion Loss

- Flow dam control* → "football effect"

  *one of the biggest contributors to loss variation
- Surface roughness/Micro Etch
- Glass weave
- Resin content
- Cu density in 3D
- B-stage variance
- Core variance
- Line width tolerance
- Plating/flash
- Moisture content (resonating at 13-15GHz)
- Temperature
- Panel Press (book size, books per press)

Note: this list taken from Beth Kochuparambil - Cisco, and previously documented

Source of Variation - "Football Effect"

Flow Dam control – "Football effect"

Panel Press (book size, books per press)

- These two are added together because they relate.

- "Football effect" is related to the edges of the working panel are thinner than the middle

Source of Variation - "Football Effect" Control Factors

- Control of press time temperature and pressure
- Vacuum lamination
- Understanding and control of lagging
  - Proper use of Kraft paper and loading
  - Appreciation of "thermal mass" (loading is adjusted as a function of thickness)
- Understanding of melt viscosity curves of each material type as a function of time, temperature and pressure
- Proper maintenance of all elements of the lamination process
  - Separator plates
  - Tooling fixtures
  - Lamination press calibration
  - Verification of software control for each press load

Source of Variation - “Surface Roughness”

- **Surface roughness**
- High speed traces can be significantly effected by copper roughness
- The variety of purchased foils has been well documented for some time. In 2005, “Non-classical Conductor Losses due to Copper Foil Roughness and Treatment” was published by Brist, Clouser and Liang at the ECWC 10 Conference at IPC printed circuit expo. Line below
- http://www.ticertechnologies.com/tech_papers/05_CopperSurfaceLoss.pdf

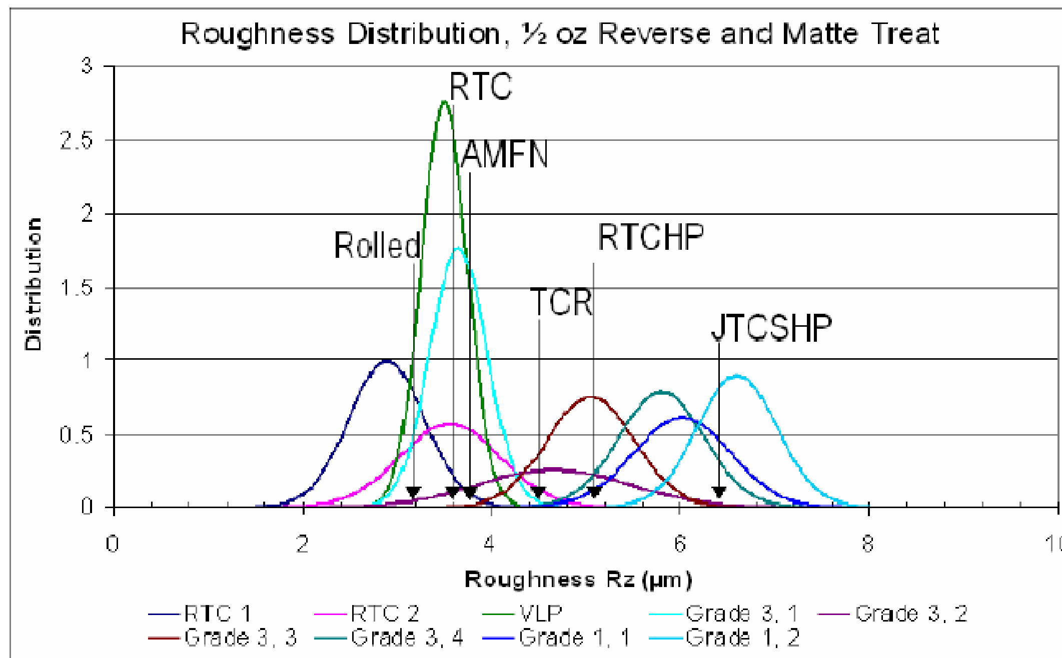


Figure 6 - Comparison of 0.5 oz Foils Produced Globally and This Study

Source of Variation - “Surface Roughness”

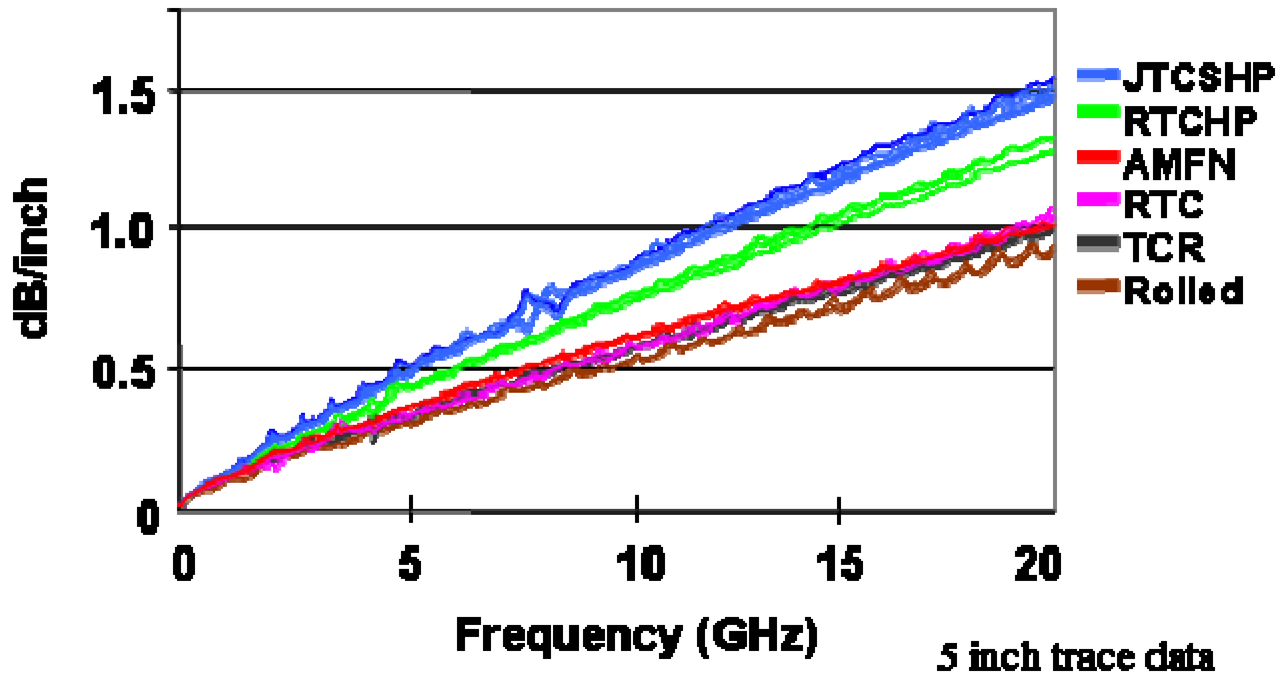


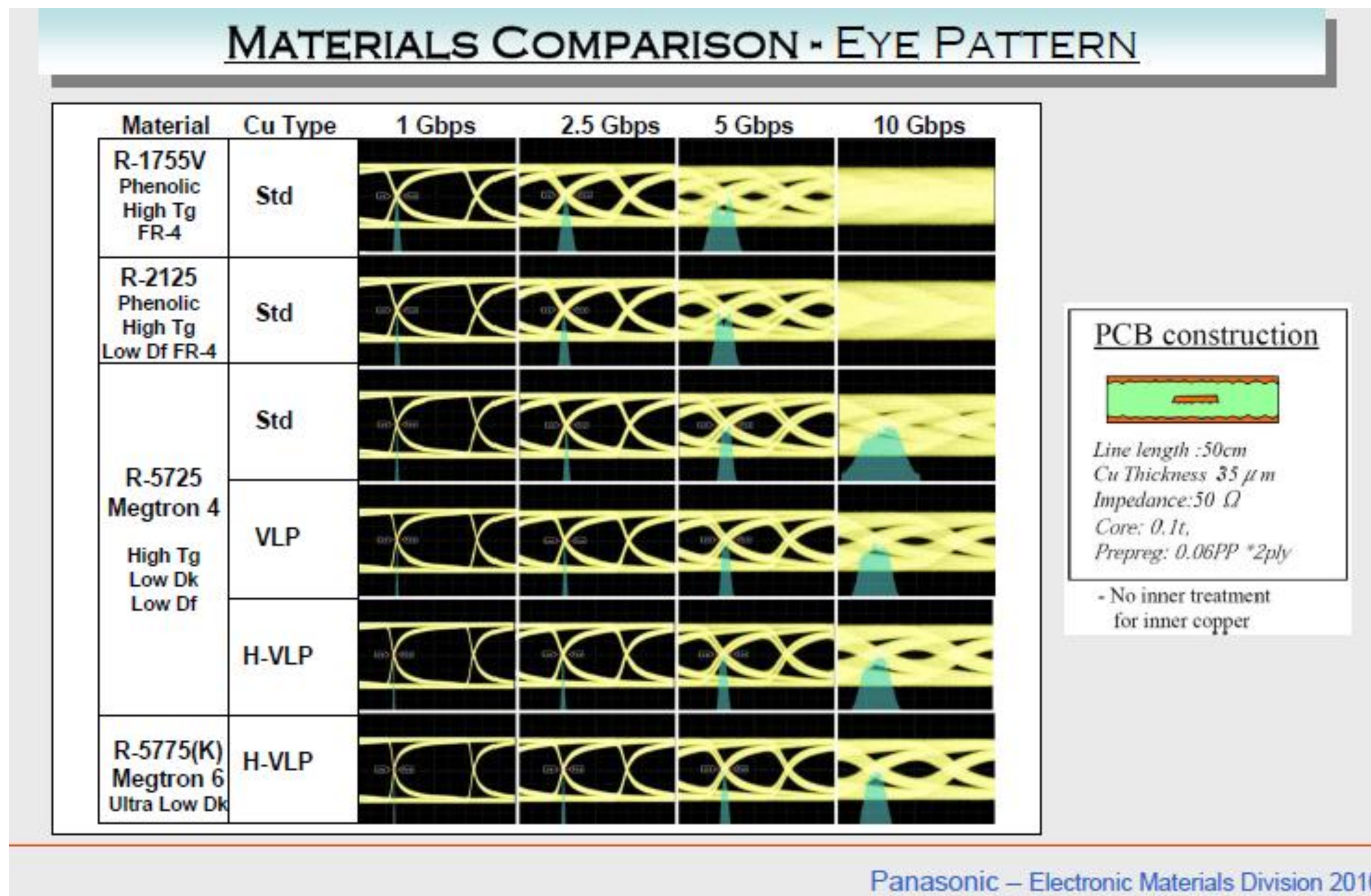
Figure 11 - Total Line Loss by Copper Type

Graph taken from same article mentioned on the previous page

Source of Variation - "Surface Roughness" Control Factors

- Proper copper foil type selection at stack up stage to match application
- Proper processing of core through process stages prior to lamination
  - No black oxide process
  - No micro etch prior to imaging
  - Use of Alternative oxide only
  - For outer layer processing, no brushing prior to solder mask stage

Source of Variation - “Surface Roughness” Control Factors



- Combination of material type/foil type impact on signal integrity at increasing frequencies

Source of Variation - "Glass Weave"

- Glass weave
- Some woven glass types are asymmetrical resulting in resin rich areas and glass rich areas along the signal or trace length
- Lack of understanding and mitigation of these factors can increase variation in signal integrity especially for longer traces

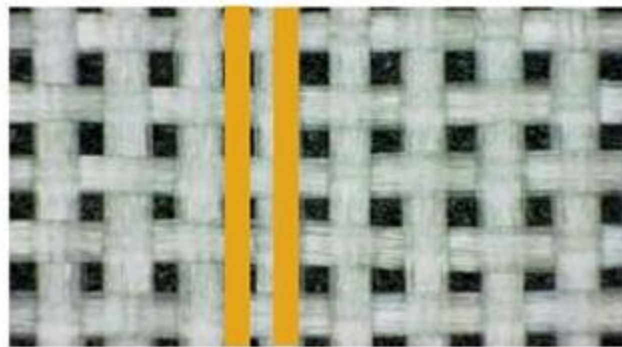
Source of Variation - "Glass Weave"

Spread Glass (Weave Effect)

- *Differences in propagation delay & loss are minimized with* *<u>Spread Glass</u>*

.005" LINES AND SPACES

Conventional



SS Fabric

→| |← .015" →| |← .015"

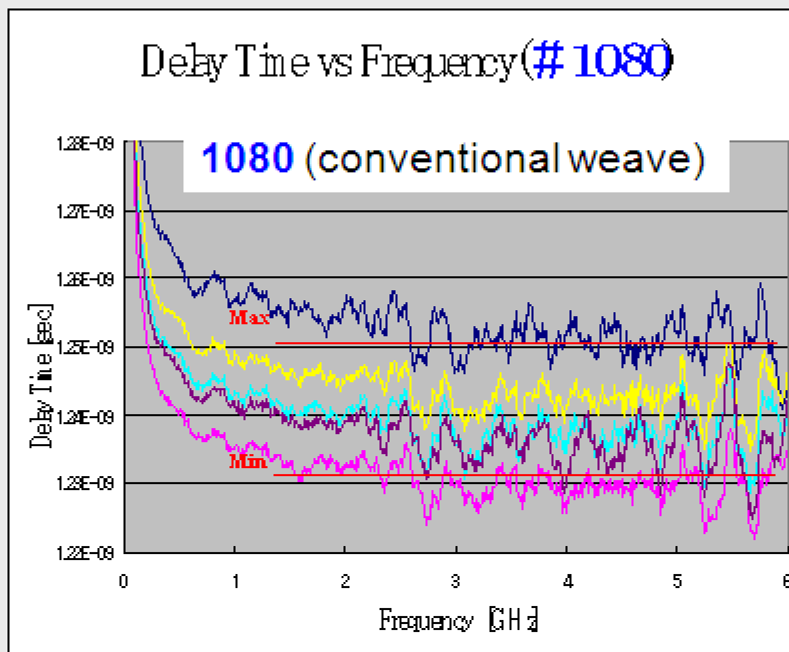
Image of cross section

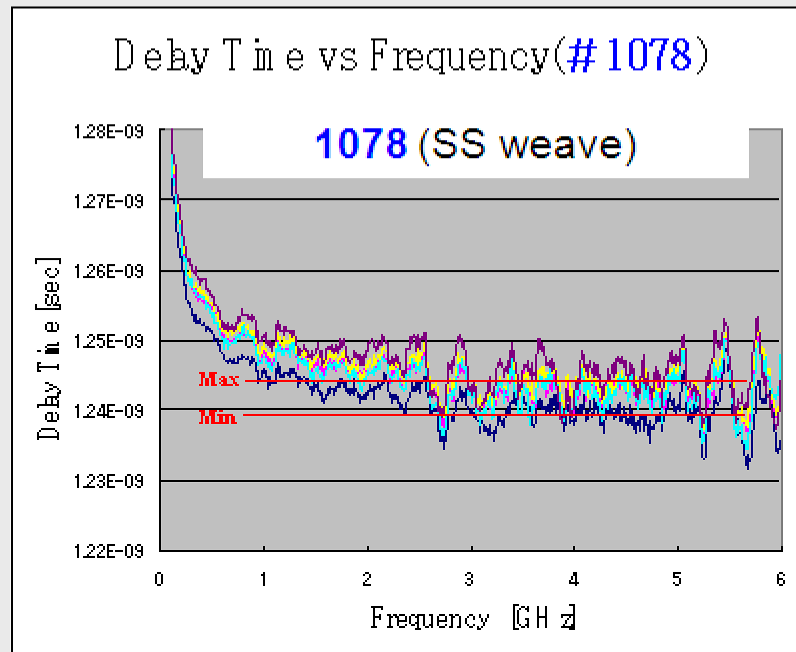
Source of Variation - "Glass Weave"

SPREAD GLASS (WEAVE EFFECT)

➢ CONVENTIONAL GLASS VS SPREAD GLASS

Delay Time vs Frequency





Variation in delay time can be decreased by incorporating SS cloth.

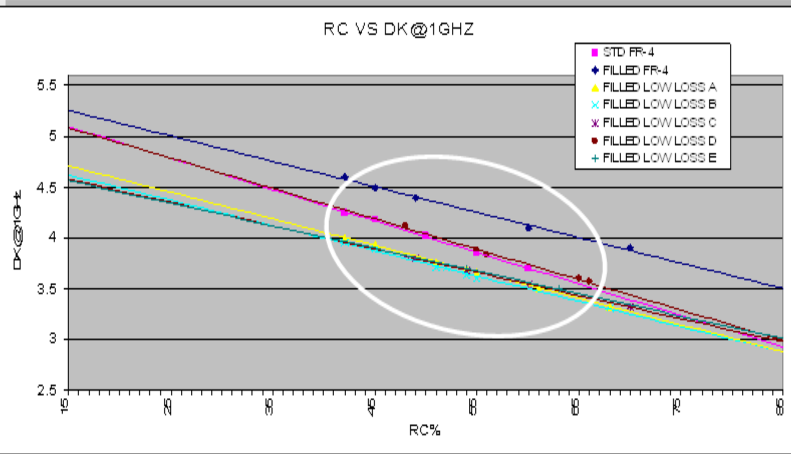
Source of Variation - “Glass Weave” Control Factors

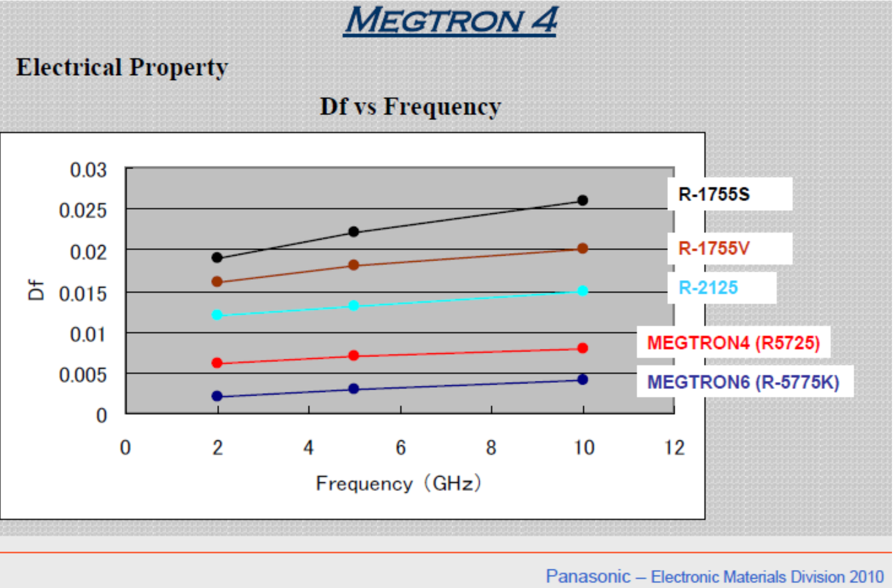
- The emergence of “square weave” is very compelling and in use today.
- 1080, 106 glass is replaced with 1087 and 1067 cloths.
- 1037 cloths to refine stack up control and impedance modeling emerging currently
- Further “thinner square glasses” planned
- These options are standard choices with most laminate fabricators

Source of Variation - “Resin Content”

- Simply put, resin has a different Dk and Df when compared to the glass used.
- Prepregs with different % resin have a weighted impact on the resultant Dk and Df of the b-stage cloth used in the stack up
- The slope of change varies by material type and is now increasingly characterized at frequencies up to 20 GHz.
- Understanding this attribute is important at the material selection and stack up generation stage

Source of Variation - “Resin Content”





Megtron 6 – Dk /Df (2–10Hs)

1. R-5775K **Cores**

Nominal Thickness	Cloth Style	Typical Resin	ply	Typical Dk					Typical Df				
				2GHz	4GHz	6GHz	8GHz	10GHz	2GHz	4GHz	6GHz	8GHz	10GHz
0.05	1035	65%	1	3.4	3.4	3.4	3.4	3.4	0.002	0.003	0.003	0.004	0.004
0.06	1080	57%	1	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.10	3313	54%	1	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.10L	1035	65%	2	3.4	3.4	3.4	3.4	3.4	0.002	0.003	0.003	0.004	0.004
0.13	2116	54%	1	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.13L	1080	57%	2	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.15	1080	63%	2	3.4	3.4	3.4	3.4	3.4	0.002	0.003	0.003	0.004	0.004
0.20	3313	54%	2	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.25	2116	54%	2	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.30	3313	54%	3	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.40	3313	54%	4	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.50	2116	54%	4	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.56	7628	42%	3	4.0	4.0	4.0	4.0	4.0	0.002	0.003	0.003	0.004	0.004
0.63	2116	54%	5	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004
0.74	7628	42%	4	4.0	4.0	4.0	4.0	4.0	0.002	0.003	0.003	0.004	0.004
0.75	2116	54%	6	3.6	3.6	3.6	3.6	3.6	0.002	0.003	0.003	0.004	0.004

Copper : Std 12, 18, 35, 70μm
VLP 12, 18μm
H-VLP 12, 18, 35μm

Panasonic – Electronic Materials Division 2010

- This characterization is routinely provided by suppliers of laminate. Panasonic material used to demonstrate

Source of Variation - "Resin Content" Control Factors

- Understanding "slope of curve" for range of % resin content in all pre-pregs for good stack up modeling is critical today for each material being used
- This characterization is normal today, with measurement refinements at the PCB fabricator the key reason
- Proper selection at the stack up phase key to control
- With regard to processing:
  - See lamination control factors
  - PCB fabricators have closed loop verification system that is quite sophisticated to update model for predictable % resin result
  - A library by material type of predicted dielectric thickness and actual dielectric thickness is maintained by stack up and small updates to stack up modeling made as experience with a given material grows.

Source of Variation - "Copper Density in 3D"

- With the closed loop feedback and "updating of stack up library by material type" mentioned previously, the reason this is needed on an ongoing basis, the actual copper pattern on each core adds "noise" to the predictability
- Actual copper "open area" as a function of half, one and two ounce foil heights is a significant variable that effects resultant dielectric thickness between layers

Source of Variation - "Copper Density in 3D "

Control Factors

- "Percent copper area" or "Fill" is now a routine element of PCB fabricators design rule check when reviewing gerber.
- Adjustment factors on % resin (up or down) are made to maintain "drawing thickness targets" based on this understanding of resin behavior by material type.
- Additional factors of control are:
  - Adjustment of lamination time, temperature and pressure to achieve necessary fill or flow
  - Manipulation of working panel border artwork to achieve predictable flow rates. (copper dummy patterns and panel orientation in press)
  - In some cases, copper thieving or dummy pads are requested during DFM stage to aid in this

Source of Variation - “B Stage/Core”

- B Stage and Core Variance
- B-stage is reasonably controlled and shelf life and storage factors are the largest factors to consider.
  - This effects flow and can “trip up” lamination models and previous controls mentioned
- Core variation is quite small with regard to thickness, resin % and dielectric control. Especially with the square weaves, which also allow more uniform resin %.

Source of Variation - “B Stage/Core” Control Factors

- Refrigerated delivery and storage are key b-stage control factors are implemented throughout the industry.
- Best results obtained with distances between PCB fabricator and material manufacturer are local or regional
- Proper FIFO control is very important
- Melt viscosity curves are best way to confirm impact of age on material flow property. Most companies either have this equipment or have an arrangement with their material suppliers to provide this service.
- Additionally, Incoming Quality Control is still important, especially with possible storage, environment or shelf life factors.

  In addition to melt viscosity, laboratory testing of thermal analysis properties (degree of cure, Tg, Td, CTE) serve well to assure material will perform as expected.

Source of Variation - "Line Width Tolerance"

- This effect on impedance is well characterized and understood at PCB fabricators and the controls applied to imaging and etching in this area also benefit signal integrity
- Actual geometry/design has an additional impact on how the etching mechanism works, when replenishment of fresh solution is challenged by tight spacing, lines can be wider.
- Conversely, individual lines without surrounding copper can be thinner.
- Further variation as a function of location on the working panel are possible
- With sub 0.8 mm pitch becoming mainstream, the need for continued focus here is evident
- Current "real" line width control varies from +/- 10% (quite good) to +/- 20% (standard or average)

Source of Variation - “Line Width” Control Factors

- Line Width Tolerance
- Etching machine state of the art has improved significantly in the last 10 years and continues to evolve/improve
  - Spray nozzle/impingement
  - Continuous chemical control
  - Oscillation of sprays and control of each nozzle
  - Line design/set up to reduce variation
- Quality systems do best to measure specific traces on the design the represent full range of variation, along with edge coupons at Set up and throughout the etching process to assure stable “lot” results.
- Imaging state of the art with regard to silver halide artworks/collimated printing is giving way to laser direct imaging for sub 75 micron lines with <10% variation achievable as a result

Source of Variation - “Plating”

- This applies to outer layer only or sub-layers that have been plated to achieve buried vias.
- Selection of plating line, parameters and sequence along with understanding of design factors are key to reduce plating variation.
- Plating variation in deposited thickness can result in signal integrity variation that is significant.

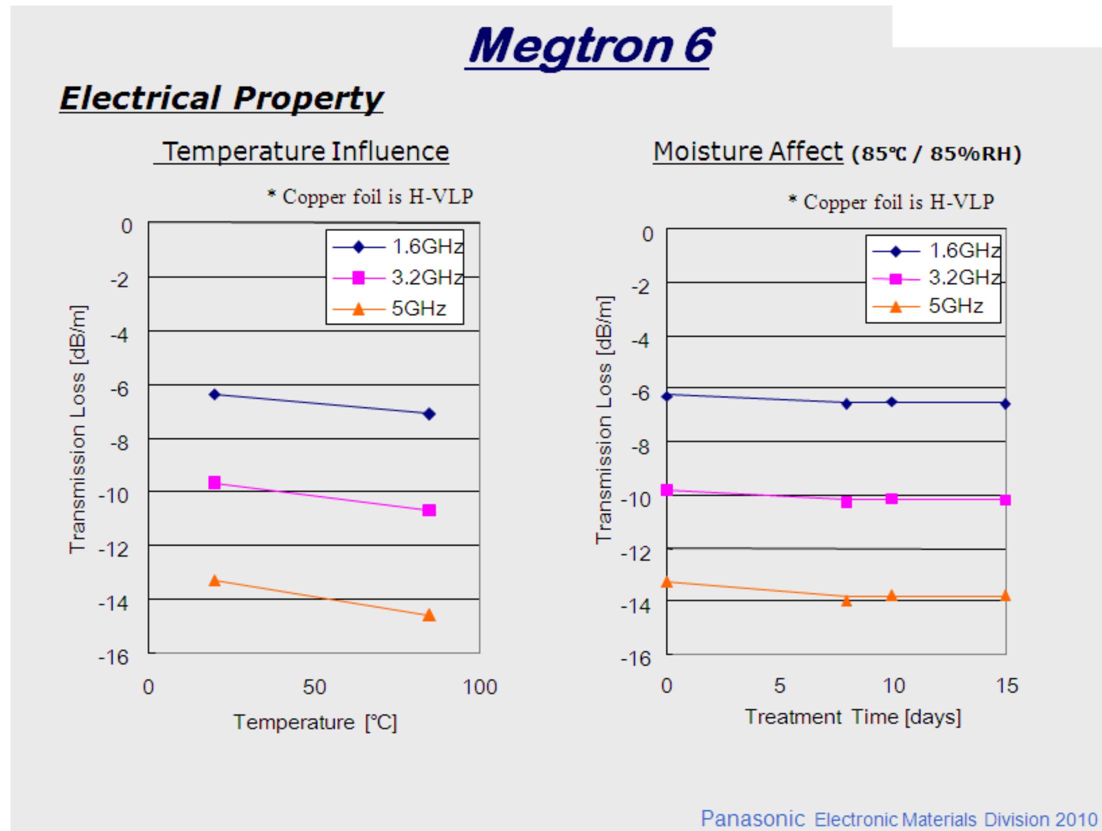
Source of Variation - “Plating” Control Factors

- Plating parameters
  - Rectification, current density, dwell time.
  - Understanding of plating tank variation and application of countermeasures. (circulation, shielding, anode/cathode design and control)
  - Chemical supplier namely leveling agents and brightener type and control
- At DFM stage, suppliers will suggest thieving or dummy pad methodologies to reduce impact of geometry on current density
- In addition, higher use of “panel plating” (no image) reduces impact on variation, so “pattern plate” total thickness tends to be smaller or in some cases, the selection of the “Etch resist” is manipulated to get the best result.

Source of Variation - “Temperature and Moisture”

- Temperature and moisture:
  - Understanding how a material behaves in different environments with respect to temperature and moisture is key to proper selection of materials
  - How much a given material can hold moisture varies a function of the resin formulation and curing.
  - Lower loss material formulations are more “non-polar” and tend to have less moisture pick up, however, even small amounts of moisture have an impact on Dk and Df since the Dk and Df of water are very high compared to the resin systems.

Source of Variation - “Temperature and Moisture”



- Working with laminate suppliers to understand specific and individual material type properties is critical to success

Source of Variation - “Temp/Moisture” Control Factors

- PCB Fabricators use of moisture barrier bags for all lead free shipments
- Selection of proper material and understanding of the moisture holding proper of that resin formulation
- Proper storage of B-Stage (previously mentioned) will allow for predictable degree of cure, which is good for moisture resistance.

Summary

- Signal integrity demand on the control of many factors continues.
- The PCB industry has and will continue to characterize, adapt and improve variation control to meet the requirement
- Strong communication and customer relationships help in this endeavor and can drive high yields if mutually applied