Proposal for Defining Material Loss

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Supporters

- Merrick Moeller – Amphenol
- Matt Brown – AppliedMicro
- Vittal Balasubramanian – FCI
- Dave Chalupsky – Intel
- Kent Lusted – Intel
- Rich Mellitz – Intel
- Adam Healey – LSI
- Liav Ben Artsi – Marvell
- Walter Katz – SiSoft
- Megha Shanbhag – TE connectivity
- Ziad Hatab – Vitesse

Problem Brought to Light

- Inconsistent loss numbers used in discussions
  - Improved FR4:
    - 38.2dB loss for 40in and 2 connectors (beukema_01_1111)
    - 1.04dB/in **w/o** surface roughness (kipp_01_1111, originally goergen_01_0911)
  - Megtron6:
    - 0.9dB/in (ghiasi_01_1111)
    - 0.65-0.68dB/in (kipp_01_1111)
    - 30.2dB for 1m and 2 connectors (meghelli_01_0911, originally patel_01_0911)
- Consensus group formed with goal:

  Create acceptable loss parameters (dB/length) for 802.3bj Task Force to use in discussions in order to avoid miscommunication due to varied assumptions.

What Do We Know?

- Definition of Improved FR-4
- Variation exists in many forms within the PCB
  - Design specifics - Trace width, stackup, etc
  - Surface roughness – Manufacturer, pre-lam adhesion treatment, etc.
  - Lamination – “Football effect”, temp., pressure, book size, etc.
  - Circuit tolerances – Line width control, dielectric thickness, trace cross section, etc.

Slide from goergen_01_0511:

Definition: “Improved FR-4” as defined by IEEE P802.3ap

- Improved FR-4 (Mid Resolution Signal Integrity):
  - 100Mhz: Dk ≤ 3.60; Df ≤ .0092
  - 1Ghz: Dk ≤ 3.60; Df ≤ .0092
  - 2Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 5Ghz: Dk ≤ 3.50; Df ≤ .0115
  - 10Ghz: Dk ≤ 3.40; Df ≤ .0125
  - 20Ghz: Dk ≤ 3.20; Df ≤ .0140
- Temperature and Humidity Tolerance (0-70degC, 10-90% non-condensing):
  - Dk:+/- .04
  - Df: +/- .001
- Resin Tolerance (standard +/-2%):
  - Dk:+/- .02
  - Df: +/- .0005

Assumptions

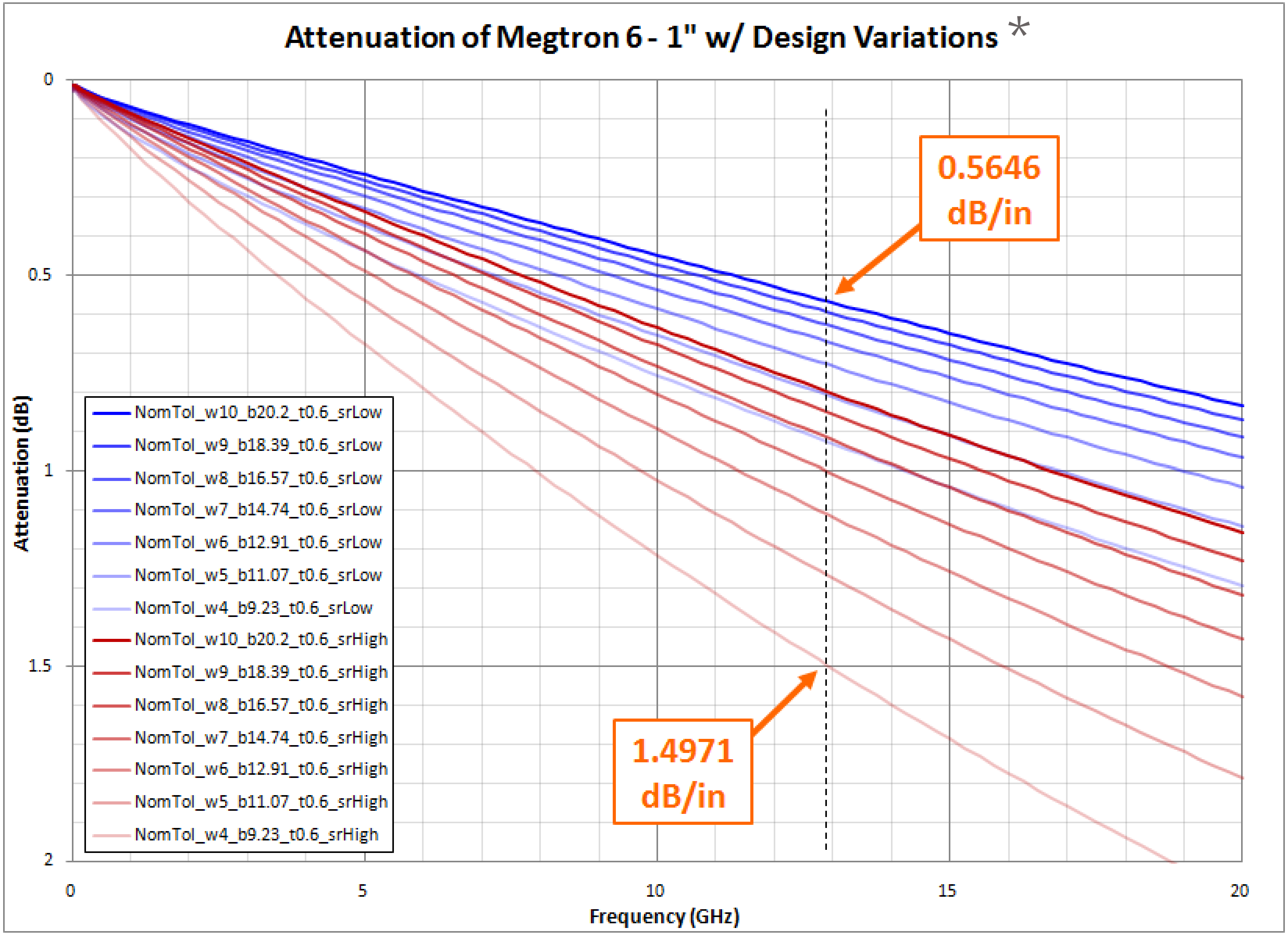
- NOTE: These assumptions are not limiting designers, only to select "typical" practices to understand loss variations.

- $Z_{0O} = Z_{0E}$*
- Characteristic Impedance: ~50Ω as "design target"
- Trace width: 4-10 mil
- Dielectric spacing**: ≤ 25

* Inherent assumption of the tool: loosely coupled. This validates single-ended stripline calculations for loss.

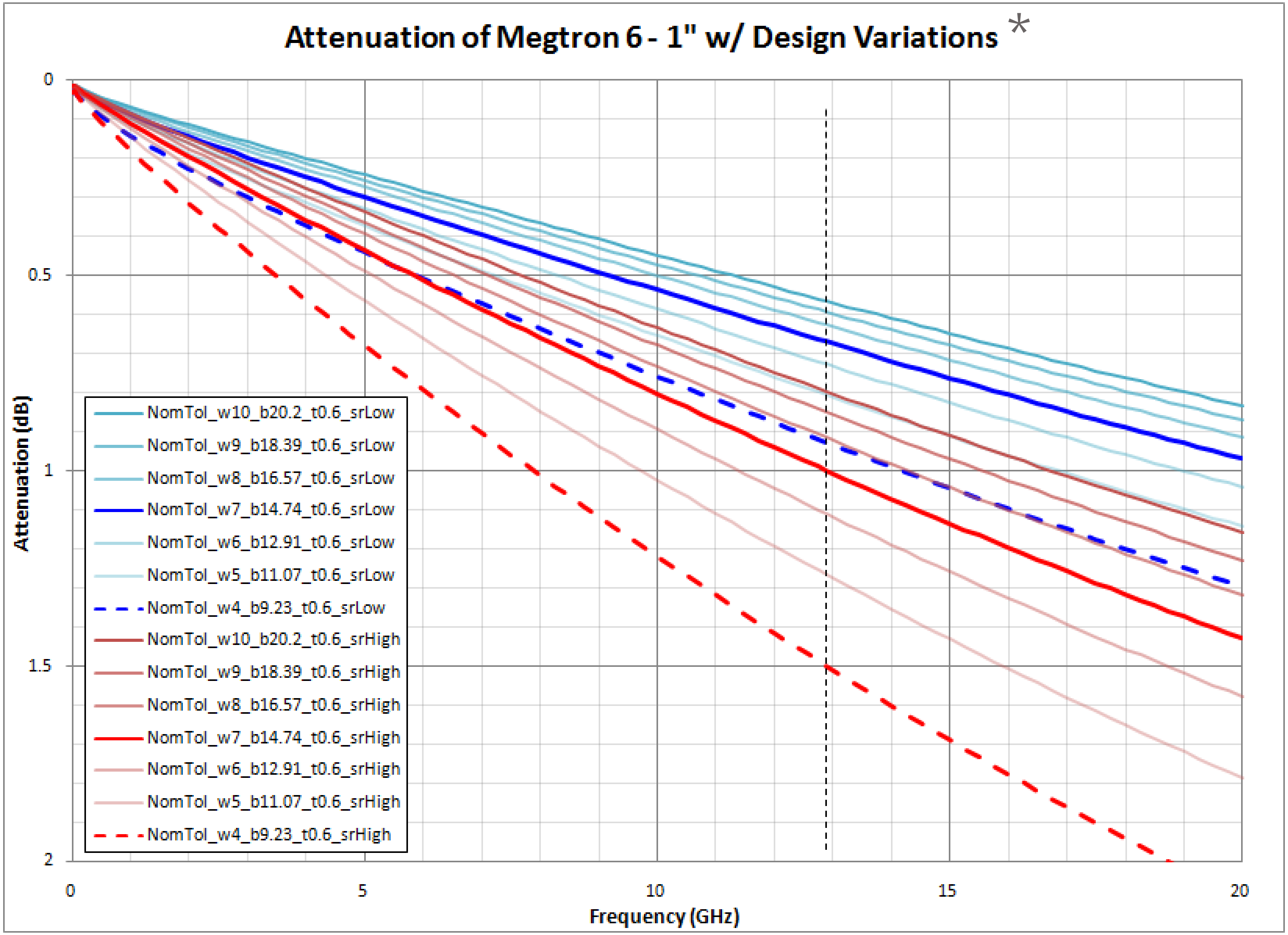
** Dielectric spacing used will be determined given the characteristic impedance and trace width

Design Affects Loss – Ex: Megtron 6



*using Algebraic Tool v2.02a – see backup slides for nominal Meg6 Dk/Df values

Reasonable Designs – Nominal Material

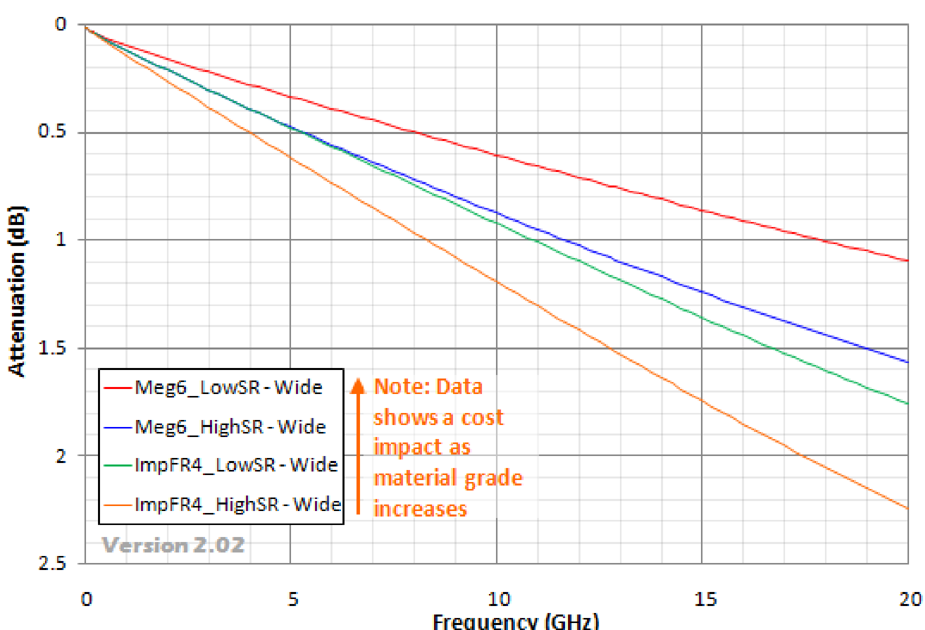


*using Algebraic Tool v2.02a – see backup slides for nominal Meg6 Dk/Df values

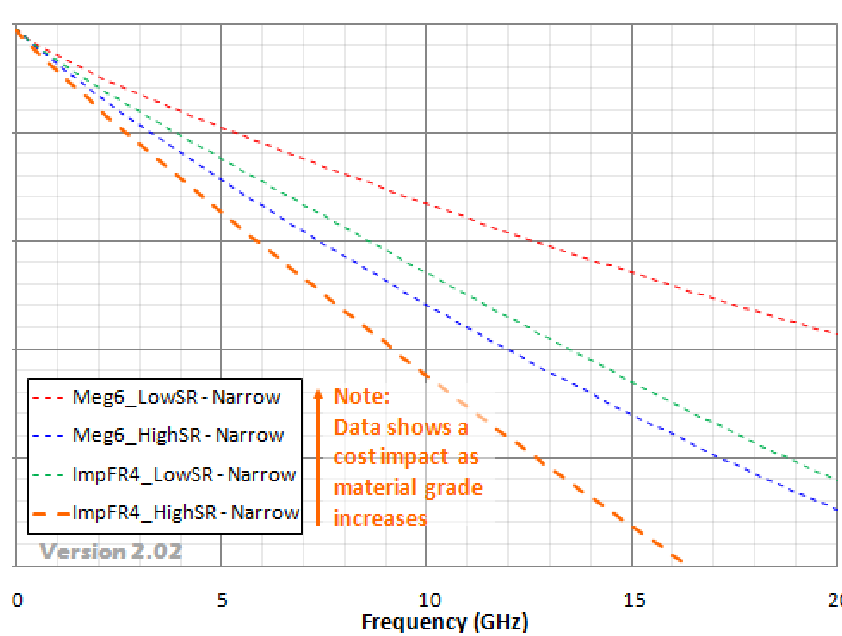
Put a Stake in the Ground

- Proposed Loss parameters ***include*** reasonable margin/tolerance
  - Vary Dk/Df based on defined tolerances (goergen_01_0511)
  - Gives ~0.1-0.15 dB/in
- Design constraints vary
  - BGA/connector fields, board thickness , tolerable loss, etc.
  - Tendency: Linecards → Narrow traces & Backplane → Wid**er** traces

Attenuation of Improved FR4 and Megtron 6, WIDE traces - 1 inch



Attenuation of Improved FR4 and Megtron 6, NARROW traces - 1 inch



PROPOSED PARAMETERS; NUMBERS ON NEXT SLIDE

*using Algebraic Model v2.02a – see backup slides for values entered in Model

Put a Stake in the Ground

- How should parameters be used?
  - Single parameter – quick calculation
  - Advanced simulation - ballpark check
- Suggest using the Algebraic Model for channel exploration
  - Compared to measurement by multiple companies
  - Ver. 2.02 includes surface roughness and A+B+C architecture

Attenuation* (dB/in) at:	1 GHz	6.5 GHz	7 GHz	12.89 GHz	14 GHz
Meg6_LowSR – Wide	0.0951	0.4159	0.4433	0.7562	0.8127
Meg6_LowSR – Narrow	0.1466	0.5849	0.6205	1.0152	1.0847
Meg6_HighSR – Wide	0.1175	0.5960	0.6367	1.0891	1.1688
Meg6_HighSR – Narrow	0.1856	0.8971	0.9557	1.5924	1.7020
ImpFR4_LowSR – Wide	0.1202	0.6096	0.6541	1.1772	1.2734
ImpFR4_LowSR – Narrow	0.1717	0.7794	0.8323	1.4410	1.5512
ImpFR4_HighSR – Wide	0.1427	0.7904	0.8484	1.5158	1.6367
ImpFR4_HighSR – Narrow	0.2106	1.0930	1.1692	2.0283	2.1813

PROPOSED PARAMETERS;
GRAPHS ON PREVIOUS SLIDE

*using Algebraic Model v2.02a – see backup slides for values entered in Model

Thank you for your attention!

Questions?

Backup Slides

Model Entries used: Megtron 6

Nominal Megtron 6		
Freq	Dk	Df
1.00E+08	3.67	0.0039
1.00E+09	3.65	0.004
2.00E+09	3.59	0.0043
5.00E+09	3.576	0.0049
1.00E+10	3.3494	0.0055
2.00E+10	3	0.0065

Low Tol. Meg6		
Freq	Dk	Df
1.00E+08	3.61	0.0024
1.00E+09	3.59	0.0025
2.00E+09	3.53	0.0028
5.00E+09	3.516	0.0034
1.00E+10	3.2894	0.004
2.00E+10	2.94	0.005

High Tol. Meg6		
Freq	Dk	Df
1.00E+08	3.73	0.0054
1.00E+09	3.71	0.0055
2.00E+09	3.65	0.0058
5.00E+09	3.636	0.0064
1.00E+10	3.4094	0.007
2.00E+10	3.06	0.008

- Slides 8/9: “Putting a Stake in the Ground”
  - Meg6_LowSR – Wide
    - High Tol. Meg6, w = 7, b = 14.74, t = 0.6, L = 1, SR = Low (20x0.6μm)
  - Meg6_LowSR –Narrow
    - High Tol. Meg6, w = 4, b = 9.23, t = 0.6, L = 1, SR = Low (20x0.6μm)
  - Meg6_HighSR – Wide
    - High Tol. Meg6, w = 7, b = 14.74, t = 0.6, L = 1, SR = High (65x0.6μm)
  - Meg6_HighSR – Narrow
    - High Tol. Meg6, w = 4, b = 9.23, t = 0.6, L = 1, SR = High (65x0.6μm)

Model Entries used: Improved FR4

Nominal Imp. FR4		
Freq	Dk	Df
1.00E+08	3.6	0.0092
1.00E+09	3.6	0.0092
2.00E+09	3.5	0.0115
5.00E+09	3.5	0.0115
1.00E+10	3.4	0.0125
2.00E+10	3.2	0.014

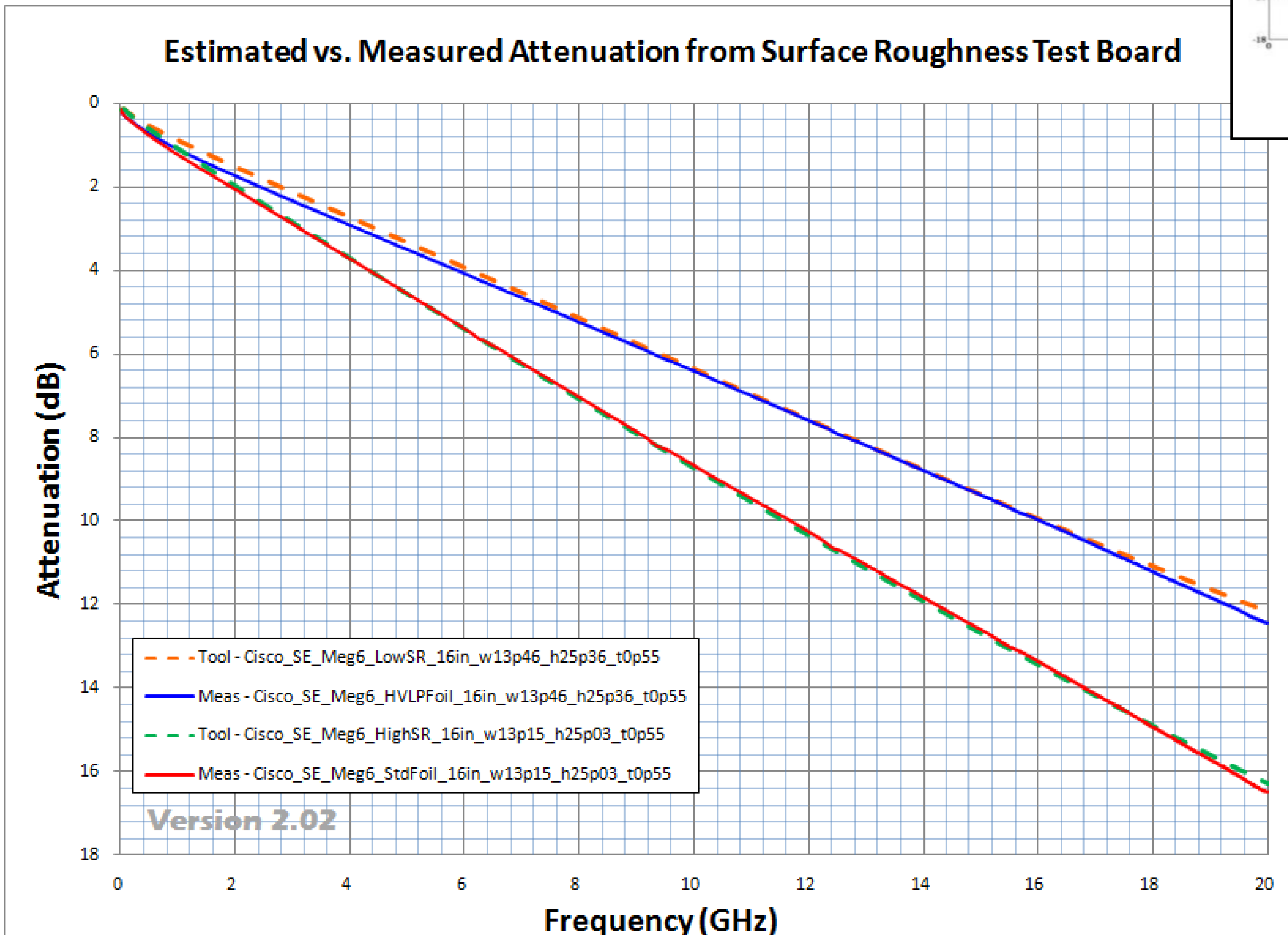
Low Tol. Imp FR4		
Freq	Dk	Df
1.00E+08	3.54	0.0077
1.00E+09	3.54	0.0077
2.00E+09	3.44	0.01
5.00E+09	3.44	0.01
1.00E+10	3.34	0.011
2.00E+10	3.14	0.0125

High Tol. Imp FR4		
Freq	Dk	Df
1.00E+08	3.66	0.0107
1.00E+09	3.66	0.0107
2.00E+09	3.56	0.013
5.00E+09	3.56	0.013
1.00E+10	3.46	0.014
2.00E+10	3.26	0.0155

- Slides 8/9: “Putting a Stake in the Ground”
  - ImpFR4_LowSR – Wide
    - High Tol. ImpFR4, w = 7, b = 14.59, t = 0.6, L = 1, SR = Low (20x0.6µm)
  - ImpFR4_LowSR –Narrow
    - High Tol. ImpFR4, w = 4, b = 9.13, t = 0.6, L = 1, SR = Low (20x0.6µm)
  - ImpFR4_HighSR – Wide
    - High Tol. ImpFR4, w = 7, b = 14.594, t = 0.6, L = 1, SR = High (65x0.6µm)
  - ImpFR4_HighSR – Narrow
    - High Tol. ImpFR4, w = 4, b = 9.13, t = 0.6, L = 1, SR = High (65x0.6µm)

Tool Validation

Cisco – SR Test Board



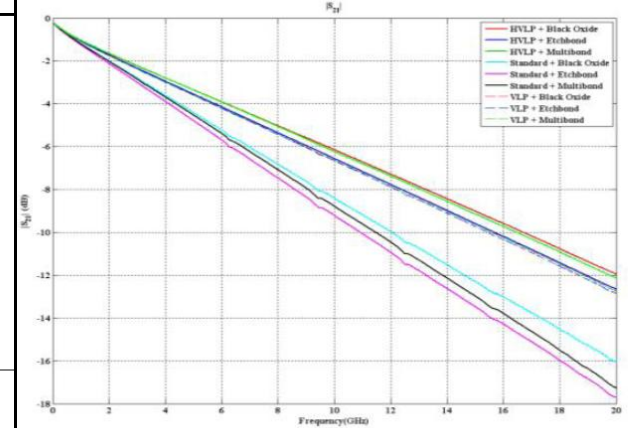


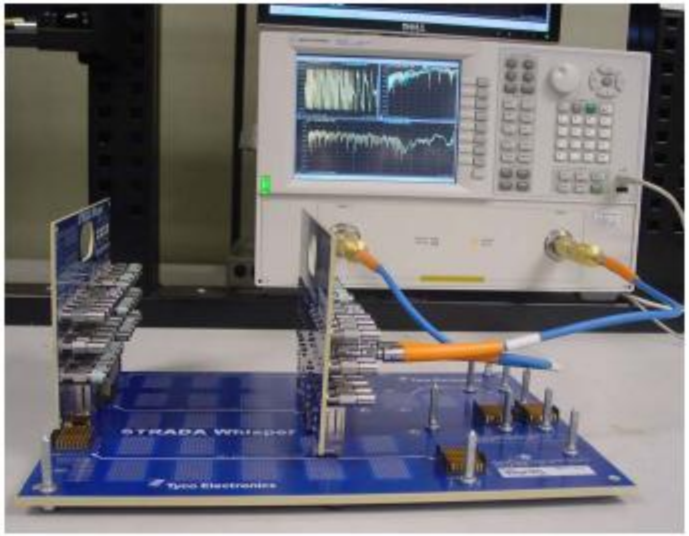
Figure 5
S21 measurements for the nine test vehicles

- Test boards are 16in length
- t, h, b, and w were taken from a cross-section measurement
- Single-ended measurement shown (data for differential not delivered to Beth)
- Graphs shown to the left are of Black Oxide process (above shows the variations due to process)

- Test boards used in surface roughness study, published in S. Hinaga, M. Koledintseva, P. Anmula, J. Drewniak, "Effect of Conductor Surface Roughness upon Measured Loss and Extracted Values of PCB Laminate Material Dissipation Factor," PCB007. Published 2010.

Tool Validation

TE Connectivity - 802.3bj submitted channel



DAUGHTER CARD
- Board Material = Megtron6 VLP
- Trace length = 5"
- Trace geometry = Stripline
- Trace width = 6 mils
- Differential trace spacing = 9 mils
- PCB thickness = 110mils, 14 layers
- Counterbored vias, 1 – 6mil stub
- Test Points = 2.4mm (included in data)

BACKPLANE
- Board Material = Megtron6 HVLP
- Trace length = 17"
- Trace geometry = Stripline
- Trace width = 8 mils
- Differential trace spacing = 13 mils
- PCB thickness = 200 mils, 20 layers
- Counterbored vias, 1 – 6mil stub

Snapshot from shanbhag_02_0511

- w and L given.
- t was assumed as ½ oz Cu
- b assumed to be calculated by
  $b = [(t_{Total} - 0.6*N_{lyrs})/(N_{lyrs}-1)] *2 + 0.6$

Backplane/Trace Material		
Length (inch)		17
Trace Width (mil)		8
Cu Thickness (mil)		0.6
Diel. Thickness (mil)		20.389
Freq	Dk	Df
1.00E+08	3.67	0.0039
1.00E+09	3.65	0.004
2.00E+09	3.59	0.0043
5.00E+09	3.576	0.0049
1.00E+10	3.3494	0.0055
2.00E+10	3	0.0065
Low Roughness	20	6.0E-07

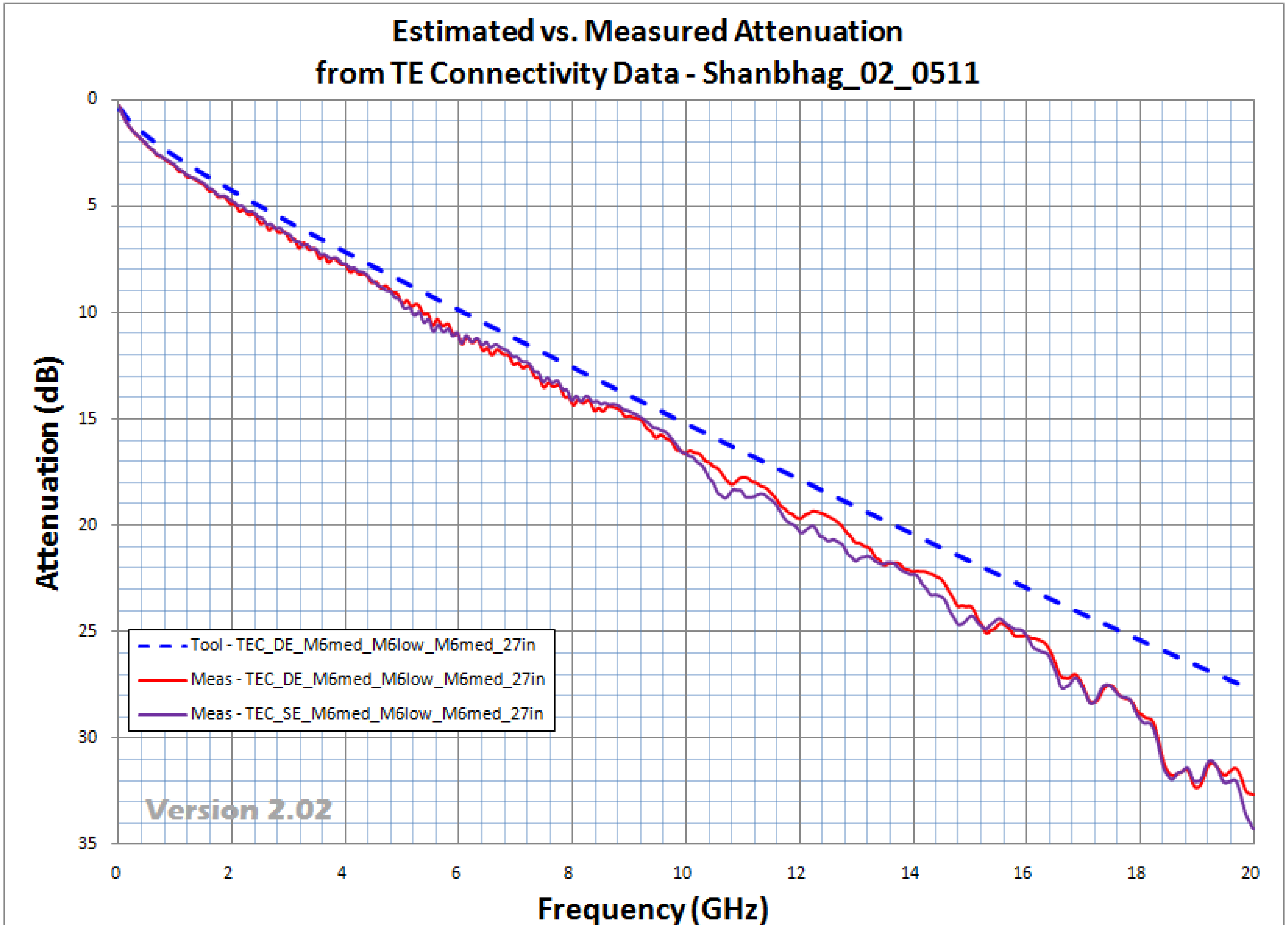
23dB loss at 12.75G - 1.21dB loss at 1

Linecard A Material		
Length (inch)		5
Trace Width (mil)		6
Cu Thickness (mil)		0.6
Diel. Thickness (mil)		16.231
Freq	Dk	Df
1.00E+08	3.67	0.0039
1.00E+09	3.65	0.004
2.00E+09	3.59	0.0043
5.00E+09	3.576	0.0049
1.00E+10	3.3494	0.0055
2.00E+10	3	0.0065
Medium Roughness	31	6.0E-07

Linecard B Material		
Length (inch)		5
Trace Width (mil)		6
Cu Thickness (mil)		0.6
Diel. Thickness (mil)		16.231
Freq	Dk	Df
1.00E+08	3.67	0.0039
1.00E+09	3.65	0.004
2.00E+09	3.59	0.0043
5.00E+09	3.576	0.0049
1.00E+10	3.3494	0.0055
2.00E+10	3	0.0065
Medium Roughness	31	6.0E-07

Tool Validation

TE Connectivity - 802.3bj submitted channel (cont)



- Test channel is 27in total (5" + 17" + 5") length
- Single-ended and differential measurements shown
- Remember measurements include the 2 launches (including SMA conn. and vias)

Tool Validation

Qlogic – e-mail of data given by Mike Dudek

E-mail states

- 100 ohm differential traces
- Measurement of 6.9mil w includes the 2 launches (including SMA conn. and vias)
- w, t, and L were given
- h was not given… model was used to calculate what h should be to give 50 ohms at 5G
- No control on the surface roughness for all 3 measurements
- Only a dB/in was given, not an s-parameter

Material	Megtron 4	Nelco 4000-13	Megtron 4
Geometry	4.5/7/4.5	4.5/7/4.5	6.9/8.6/6.9
Freq (GHz)	Loss dB/inch		
1	-0.173	-0.198049	-0.132662
6.5	-0.564	-0.68447	-0.52876
7	-0.609	-0.720855	-0.557981
12.89	-1.025	-1.071918	-1.002522
14	-1.190	-1.213834	-1.135518

Megtron 4

Backplane/Trace Material		
Length (inch)		9
Trace Width (mil)		4.5
Cu Thickness (mil)		0.65
Diel. Thickness (mil)		10.34
Freq	Dk	Df
1.00E+08	**3.59**	**0.005**
1.00E+09	**3.57**	**0.005**
2.00E+09	**3.56**	**0.006**
5.00E+09	3.54	0.0065
1.00E+10	**3.53**	**0.007**
2.00E+10	3.5	0.008
High Roughness	65	6.0E-07

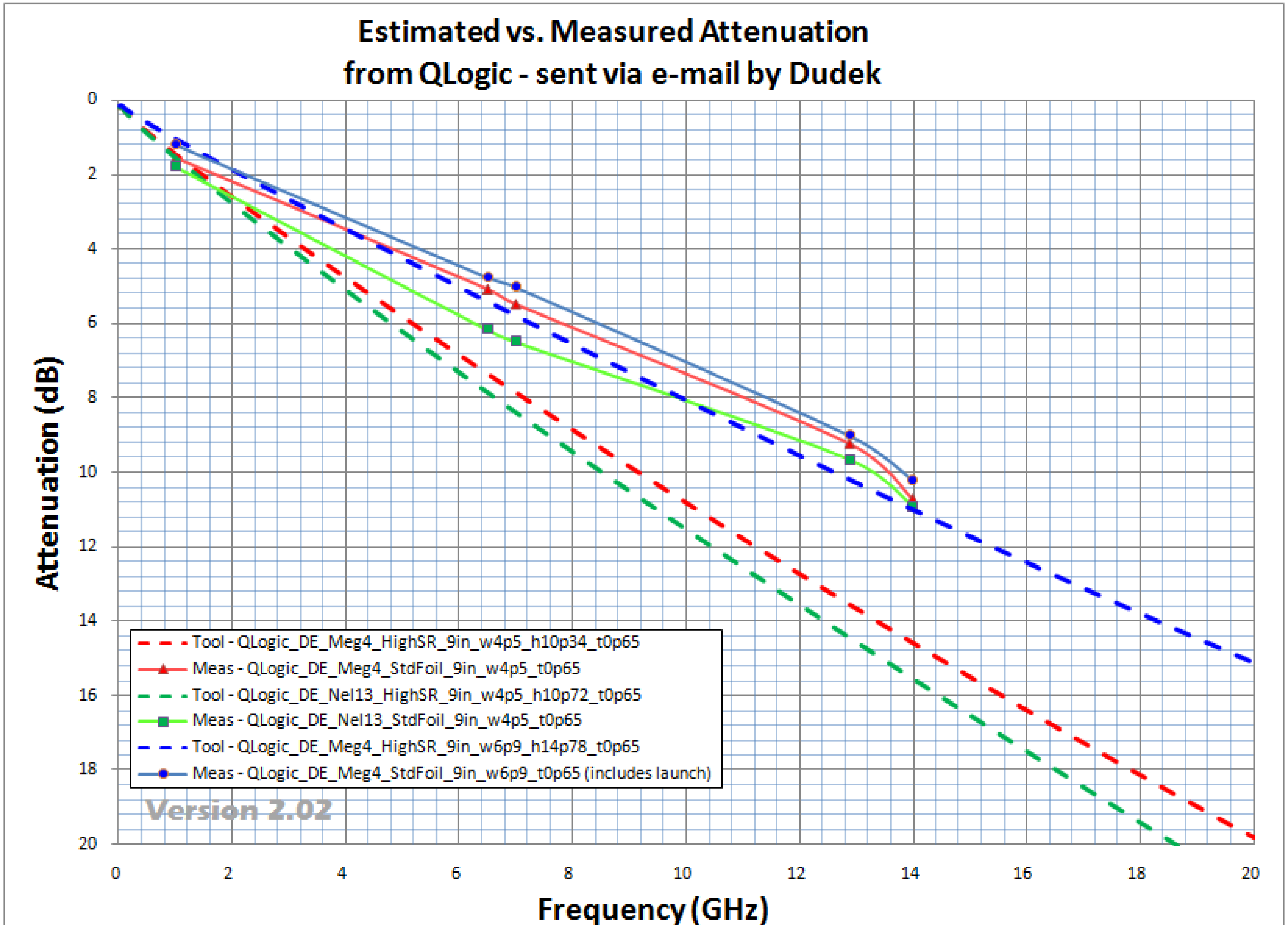
Nelco 4000-13

Backplane/Trace Material		
Length (inch)		9
Trace Width (mil)		4.5
Cu Thickness (mil)		0.65
Diel. Thickness (mil)		10.6
Freq	Dk	Df
1.00E+08	3.7	0.0075
1.00E+09	**3.7**	0.0075
2.00E+09	3.68	0.008
5.00E+09	3.65	0.0085
1.00E+10	**3.6**	**0.009**
2.00E+10	3.55	0.01
High Roughness	65	6.0E-07

Material Dk/Df values determined by datasheet: Numbers that are bolded were given in datasheet… other frequencies were filled in.

Tool Validation

Qlogic – e-mail of data given by Mike Dudek (cont)



- "Measured" data is drawn given 5 freq points of dB/in, NOT a s-parameter
- Measurement of 6.9mil w includes the 2 launches (including SMA conn. and vias)
- Note that h was not given

Tool Validation

Marvell – summary of validation by Liav Ben Artsi

Loosely Coupled Traces:

•Measurements of narrow traces of both HVLP and VLP had a good correlation to the calculated value (≤0.13dB)

•Measurements indicate that "normal" surface roughness loss may have high variance in relation to calculated loss (up to 0.3dB)

Tightly Coupled Traces:

•Measurements of narrow traces of meg6 and Nelco13SI with various surface roughness levels had a very good correlation (≤0.05dB) to the values suggested on slide 9 (which takes into account the tolerance).

Material / construction	Trace width (before etching)	Measured loss	Calculated loss	Difference to calculated loss
Megtron6 HVLP (tightly coupled)	5	1.04dB	0.8dB (slide 9 indicate 1.01dB) – 0.911 for VLP	0.204dB
Above is a Meg6 LowSR – Narrow: 0.03 difference from proposed parameter				
Megtron6 Normal (tightly coupled)	5	1.54dB	1.255dB (slide 9 indicate 1.5924)	0.19dB
Above is Meg6 HighSR – Narrow: 0.05 difference from proposed parameter				
Nelco-13SI Medium surface roughness (tightly coupled)	5	1.28dB	1.297dB	0.017dB
HQ FR4 – HVLP – Two width - Loosely coupled		Can't share due to vendor Confidential note		Calculated loss is higher by ~0.12dB
HQ FR4 – VLP – Two width - Loosely coupled		Can't share due to vendor Confidential note		Calculated loss is higher by ~0.13dB
HQ FR4 – Normal – Two width - Loosely coupled		Can't share due to vendor Confidential note		Calculated loss is higher by ~0.3

Tool Validation

Intel– comparison to validated 3D solver (Rich Mellitz)

setting	value	units
PCB: trace width sigma	0.2625	mils, 1 std dev
PCB: trace height sigma	0.03	mils, 1 std dev
PCB: dielectric height sigma	0.11875	mils, 1 std dev
PCB: er sigma	0.05	1 std dev
PCB: Er\tanD reference frequency	1	GHz
PKG: trace width sigma	1.67	um, 1 std dev
PKG: trace height sigma	1.67	um, 1 std dev
PKG: dielectric height sigma	2	um, 1 std dev
PKG: er sigma	0.07	1 std dev
PKG: Er\tanD reference frequency	5	GHz
Impedance measure frequency	1	GHz
dB/inch loss measure frequency	5	GHz
dB/inch reference impedance	lineZtarget	ohms
db/inch calculation (extra imap run)	disable	
IMAP accuracy	default	
Output filetype	sparam	
Solver IMAP/XFX	IMAP	
Model frequency steps linear/log	lin	
Model frequency steps linear/log	lin	
Frequency Begin	1.00E+08	Hz
Frequency End	20	GHz
Number of Points	2001	
min Smask on top of trace when tt>Sm	0.3	

Notice 1Ghz is the reference frequency for the Djordjevic Model

Using Intel Validated Field Solver to output .s2p

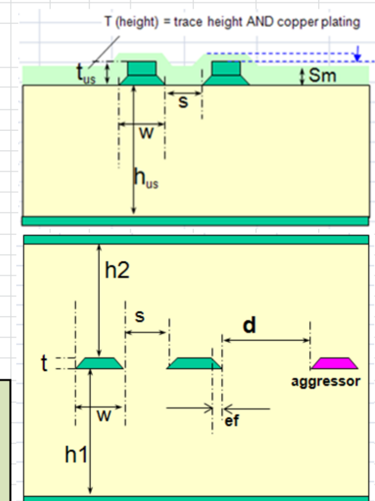
Predicted Impedance		50.29

param		nominal
signal mode		se
stripline or microstrip		sl
number of conductors		1
dielectric above	h2	7.37
width	w	7
dielectric below	h1	7.37
trace thickness	t	0.6
space (edge to edge)	s	7
space (pair to pair, edge)	d	7
dielectric constant (er)	er	3.65
loss tangent	tand	0.004
stack up units		mils
roughness and filename		
Roughness model	ver	3
Sphere Radius (um)		0.6
RMS peak width (um)	pw	9.4
RMS (hammerstad) (um)	srms	0.815
ref frequency	hz	1.00E+09
Number of Spheres		65
solve this model tab/lcf		tab
filename		Meg6_nomtol_w7_b14.74_h
Solder Mask		
solder mask dielectric	er	3.8
solder mask loss tand	tand	0.025
etch factor and conductivity		
etch factor		0
conductivity	; (S/m	5.96E+07

Solved Z0	
51.10	ohms
disabled\error	db/inch

SOLVE

Surface Roughness Key
No roughness: ver 0
Packages: ver 1 Hammerstand
Package 0.32/0.35 for sl/us
Board: ver 3 Hurray
sphere radius 0.5
RMS peak width 9.4
number spheres 64/79 for sl/us
use 50 spheres for stripline RTC



AlgebraicTool v2.02

Nominal Megtron 6

Freq	Dk	Df
1.00E+08	3.67	0.0039
1.00E+09	3.65	0.004
2.00E+09	3.59	0.0043
5.00E+09	3.576	0.0049
1.00E+10	3.3494	0.0055
2.00E+10	3	0.0065

Inputted Djordjevic model values into Algebraic Tool v2.02

Intel Validated Field Solver
… withDjordjevic model at 1Ghz

freq	dk	df
1.00E+08	3.6715	0.00398
1.00E+09	3.6499	0.00400
2.00E+09	3.6436	0.00401
5.00E+09	3.6351	0.00402
1.00E+10	3.6286	0.00402
2.00E+10	3.6222	0.00403

To match Algebraic 2.02 for high surface roughness (HSR) : sigma = 5.96e7, number of spheres = 65, sphere radius = 0.6

Caveat: Etch factor is set to 0.3 for Intel Validated Field Solver . For Algebraic tool, the etch factor is zero.

Tool Validation

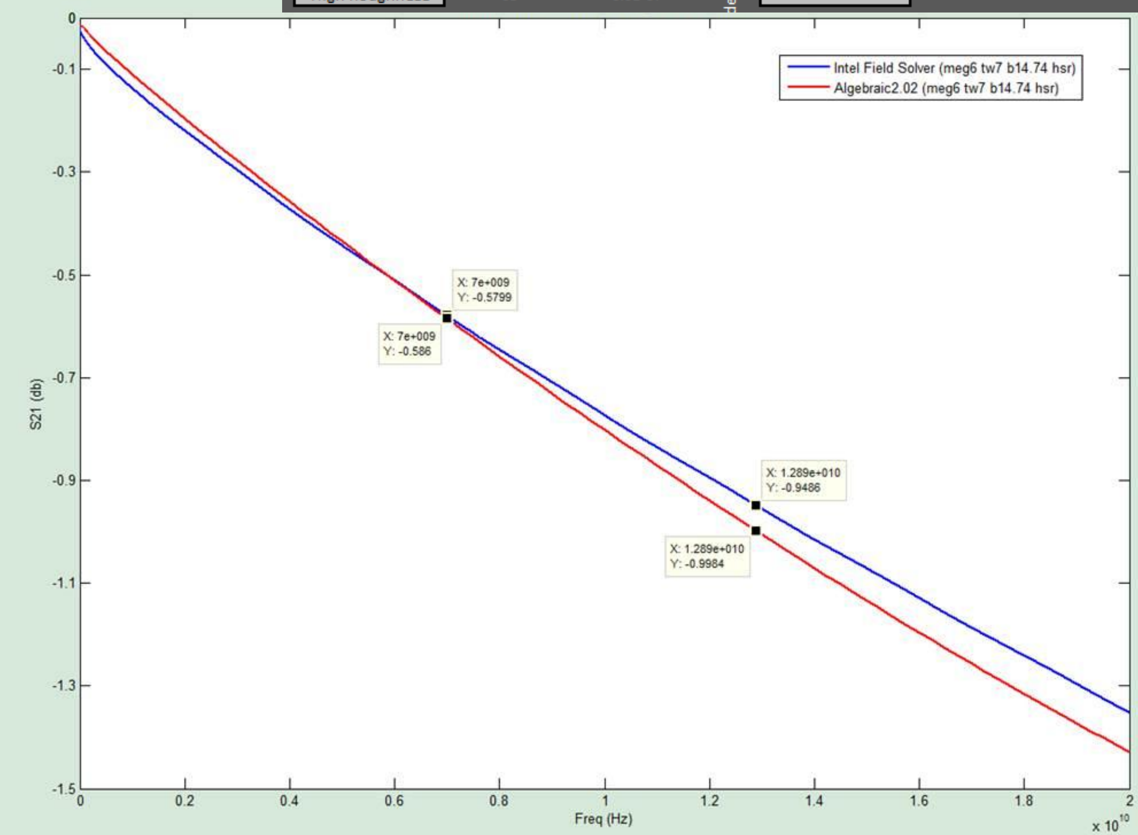
Intel– comparison to validated 3D solver (Rich Mellitz)

Version 2.02 LOSS SNAPSHOT: Loss at 5GHz: 0.42 dB Loss at 12.75GHz: 0.94 dB Loss at 14GHz: 1.01 dB

Backplane/Trace Material		
Length (inch)		1
Trace Width (mil)		7
Cu Thickness (mil)		0.6
Diel. Thickness (mil)		14.74
Freq	Dk	Df
1.00E+08	3.6715	0.00398
1.00E+09	3.6499	0.004
2.00E+09	3.6436	0.00401
5.00E+09	3.6351	0.00402
1.00E+10	3.6286	0.00403
2.00E+10	3.6222	0.00404
High Roughness	65	6.0E-07

Linecard A Material		
Length (inch)		0
Trace Width (mil)		
Cu Thickness (mil)		
Diel. Thickness (mil)		
Freq	Dk	Df
1.00E+08		
1.00E+09		
2.00E+09		
5.00E+09		
1.00E+10		
2.00E+10		

Linecard B Material		
Length (inch)		0
Trace Width (mil)		
Cu Thickness (mil)		
Diel. Thickness (mil)		
Freq	Dk	Df
1.00E+08		
1.00E+09		
2.00E+09		
5.00E+09		
1.00E+10		
2.00E+10		



Intel comments:

- AlgebraicTool v2.02 is with 5% for dB predictions upto 13 GHz.
- AlgebraicTool v2.02 is comparable to Intel Validated Field Solver for 7GHz.
- AlgebraicTool v2.02 is a good tool to quickly estimate dB per inch loss.