Effective data transmission at Extremely High Frequency (EHF) bands on printed circuit boards

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TestConX™
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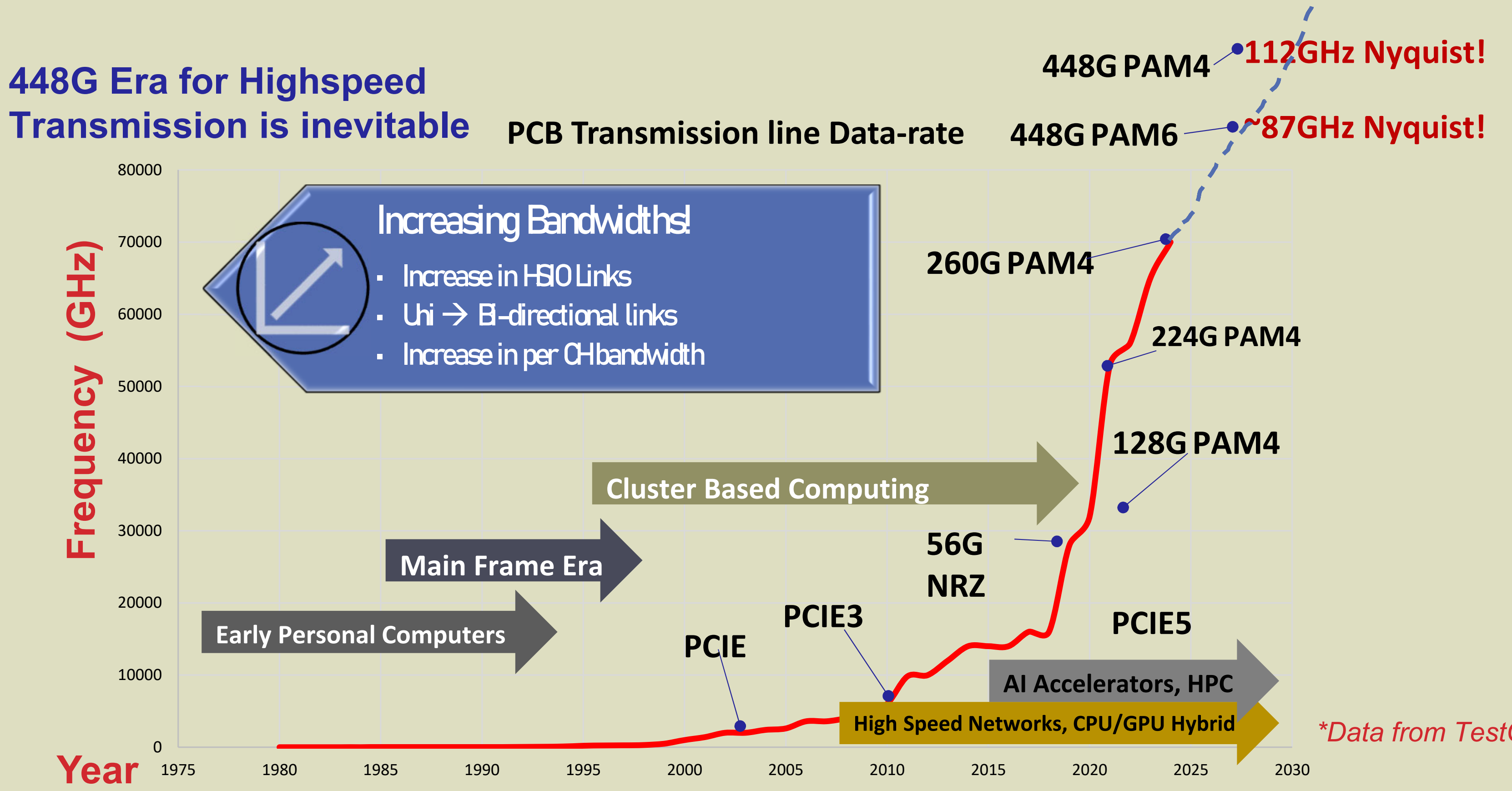
R&D Altanova® ADVANTEST® Group

Agenda

- Age of the high-speed data transfer
- Socket technology overview
- Board design solutions for extremely high frequency data transfer
- Important design choices and considerations
- Summary and Conclusion

High Speed Bandwidth Requirements

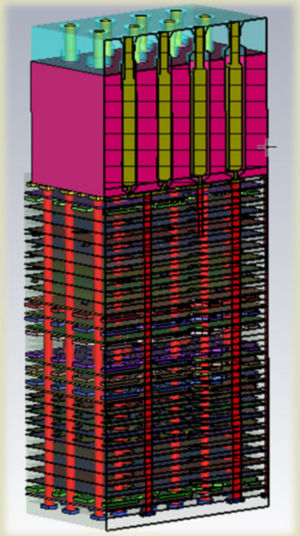


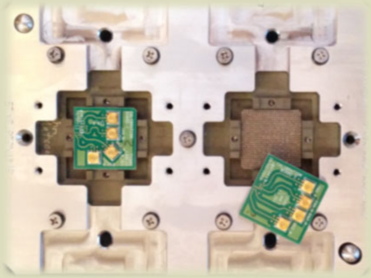
*Data from TestConX 2024

Integration of Socket Design in Simulations

Integration of Socket Modeling with Board Level Simulations will be critical for Next Gen Speeds

- Full channel performance guaranteed by including the socket 3D models in the board 3DFS simulations
- Non-optimized socket is a major contributor for impedance discontinuities at higher frequencies
- Socket model integration ensures that the parasitic elements are captured in simulation
- Device simulators or "Surrogates" ensure the socket & board measured performance correlates with full channel simulations

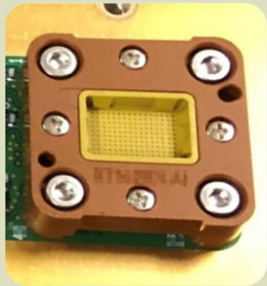




Standard Sockets

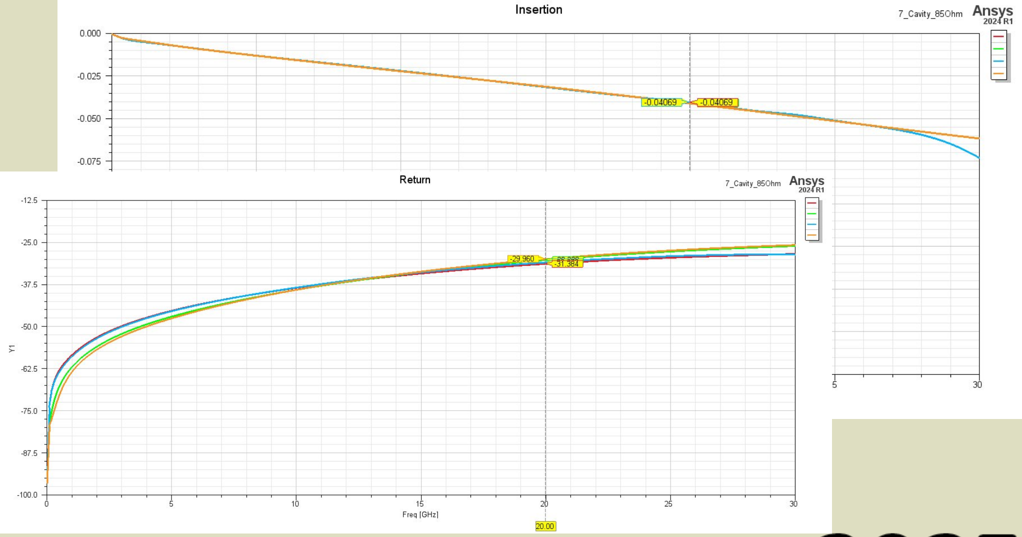
Standard sockets are constructed with ceramic / plastic body; typically, Vespel, Torlon, PEEK etc.

- Ball pitch 0.2mm or higher
- Good performance DC – 10GHz with impedance tuning
- Further performance improvement can be done by:
  - Shorter pin length
  - Better pin-out



Limitations:

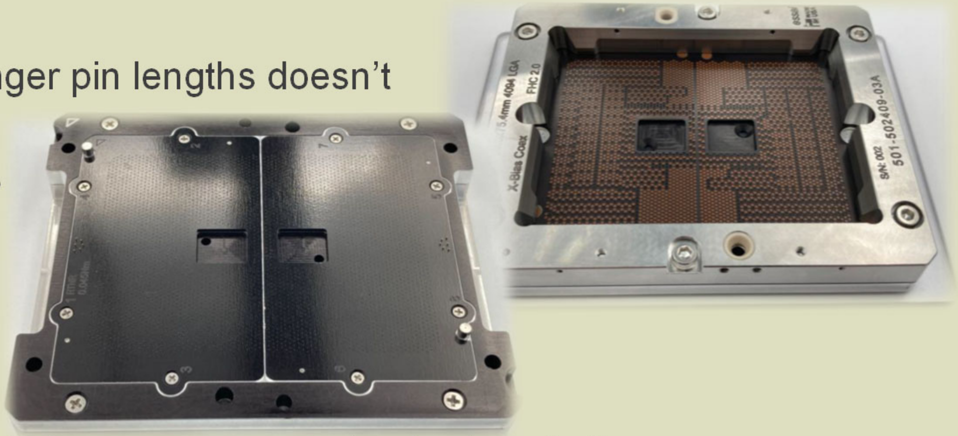
- Extremely High Frequency return loss
- Cross talk

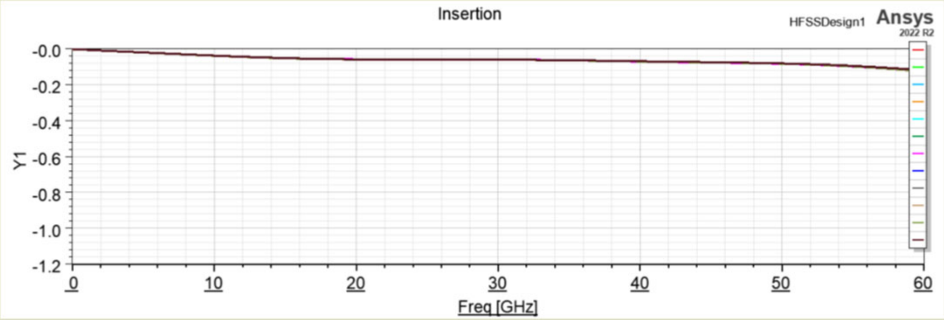


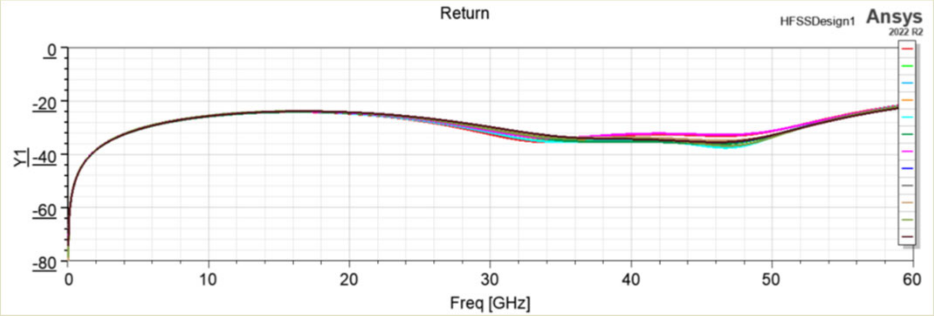
Coaxial Sockets

Socket constructed with metal body gives best performance for highspeed signaling and cross talk

- Great impedance tuning
- Full coax structure and tuned transmission line means longer pin lengths doesn't affect performance
- True Coax Socket is less sensitive to pin maps' variations
- Multi-Impedance matching feasibility per socket
- Can be tuned for DC – 100GHz+
- Difficult constructions for <0.5mm DUT pitch
- Excellent isolation specs
- A partial coax socket structure offers a good compromise between coax and standard socket!

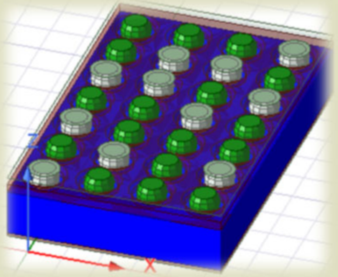






Elastomer Sockets

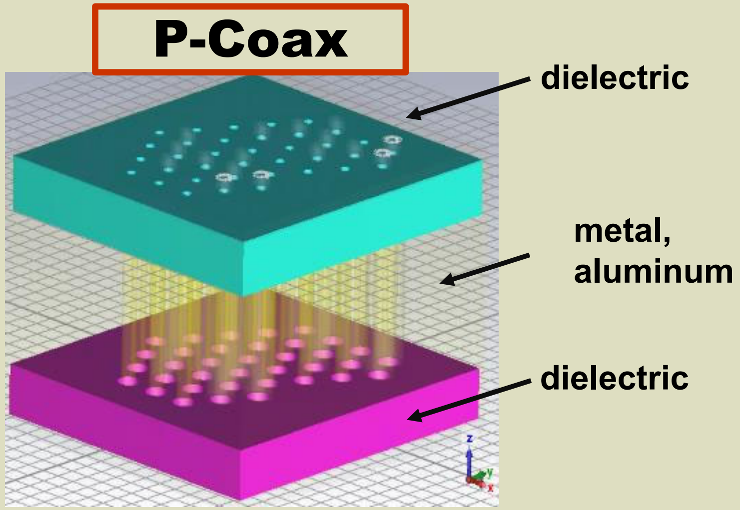
Excellent Performance due to near perfect cylinder design making easier to tune impedance

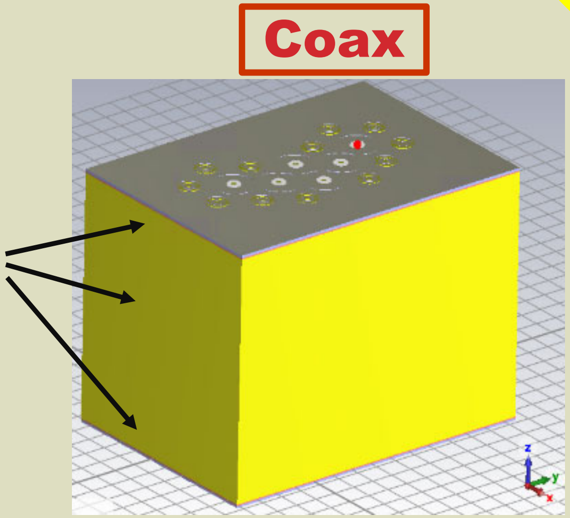


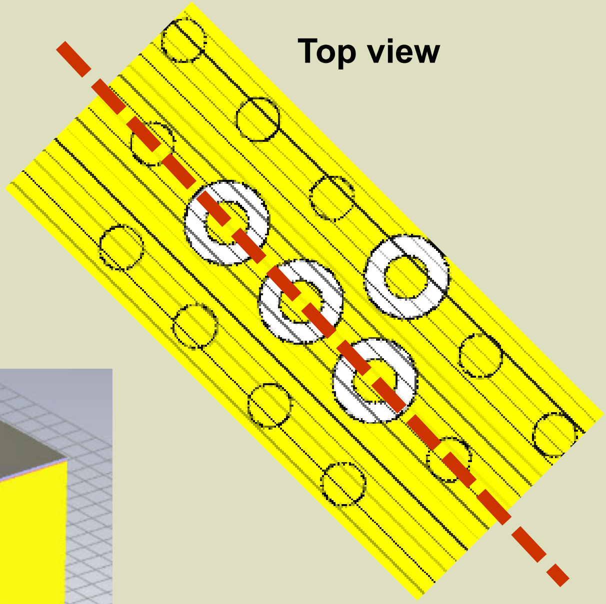
- Great return loss and high frequency performance
- Shortest test heights means reduced inductance and smaller cross talk
- Can be tuned for DC – 100GHz+
- Mediocre compliance, difficult to meet compliance for larger packages
- Limited cycling / insertions compared with pogo pins, although elastomers have gotten better over the years
- Cycle count vs. Performance is a compromise – but elastomers are getting better!
- Cross talk is subjective to height, construction and pin-map of elastomer columns

Modeling Details: Partial Coax Socket, True Coax Socket

- **Pin-map:** Imperfect grounding – see cut-plane, cross section
- **Sockets:** Partial Coax (**P-Coax**) vs. Coaxial
- **Frequency:** Nyquist = 32 GHz, example
- **Signaling:** e.g., 112Gbps PAM4



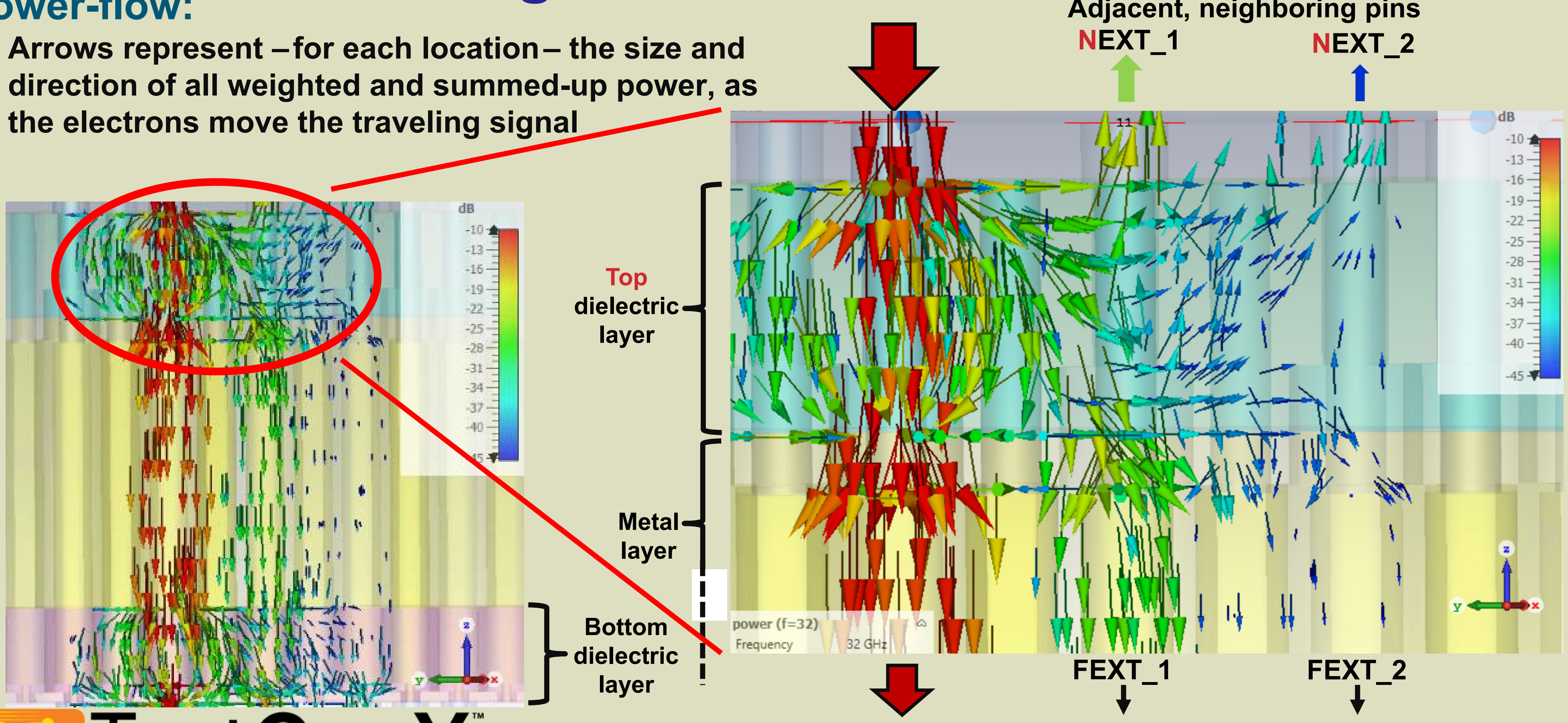




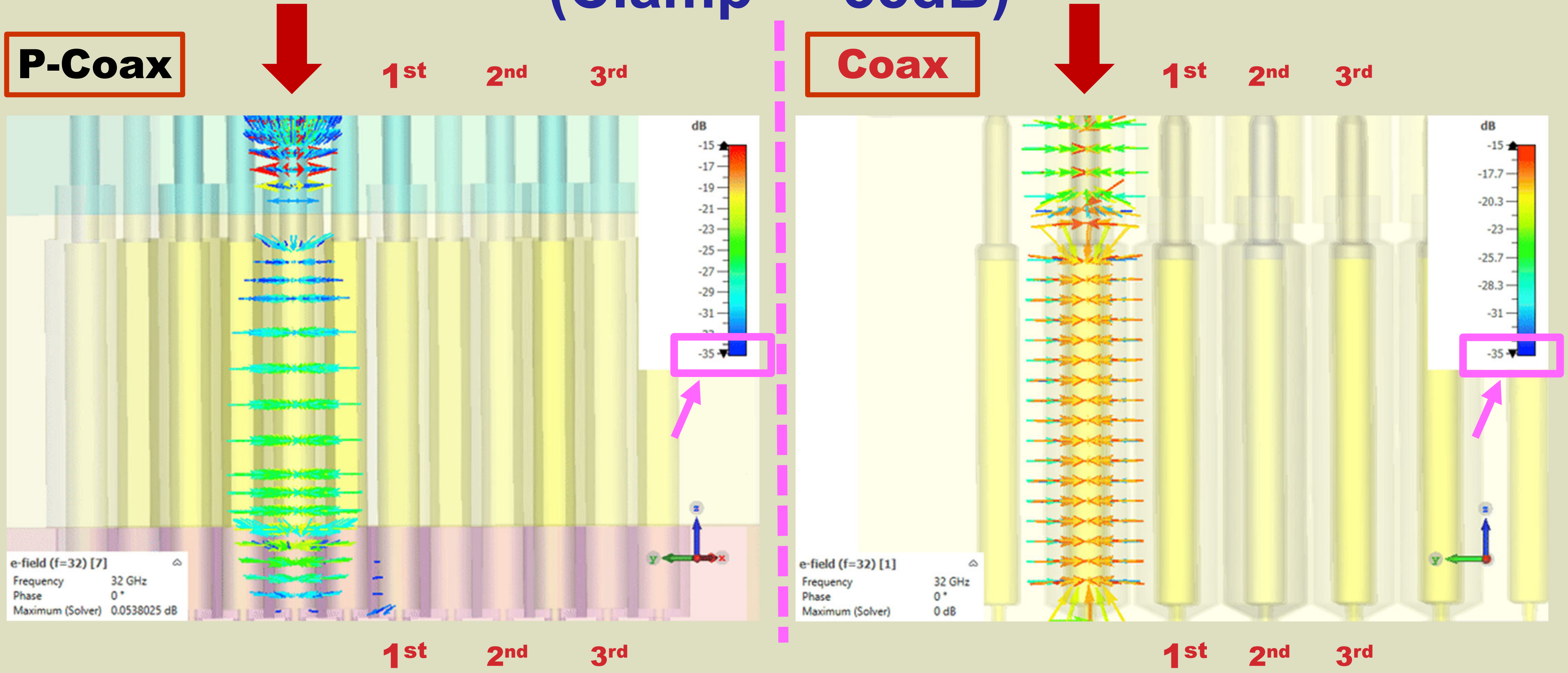
Visualizing Crosstalk on Socket Pins

Power-flow:

- Arrows represent – for each location – the size and
- direction of all weighted and summed-up power, as
- the electrons move the traveling signal



EM Field Propagation: P-Coax v.s. True Coax (Clamp = -35dB)



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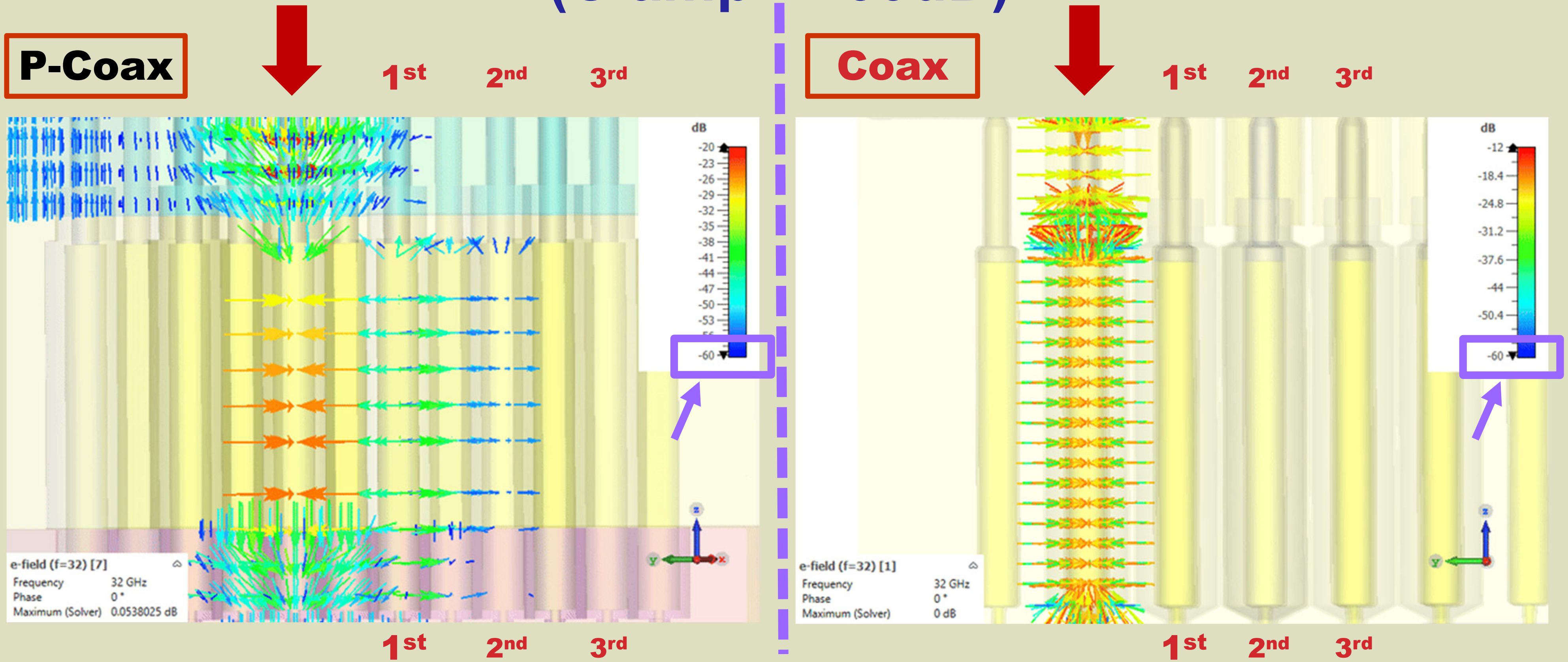
EM Field Propagation: P-Coax v.s. True Coax (Clamp = -60dB)



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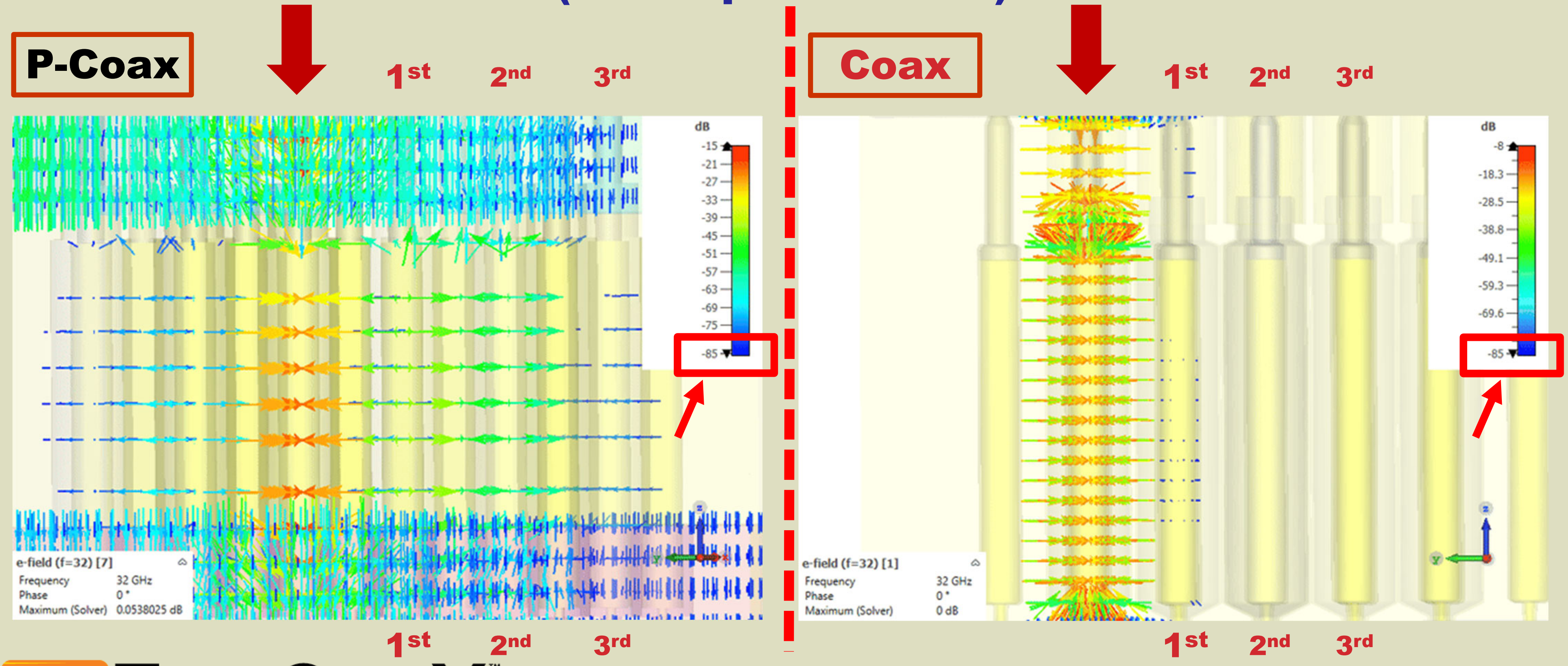
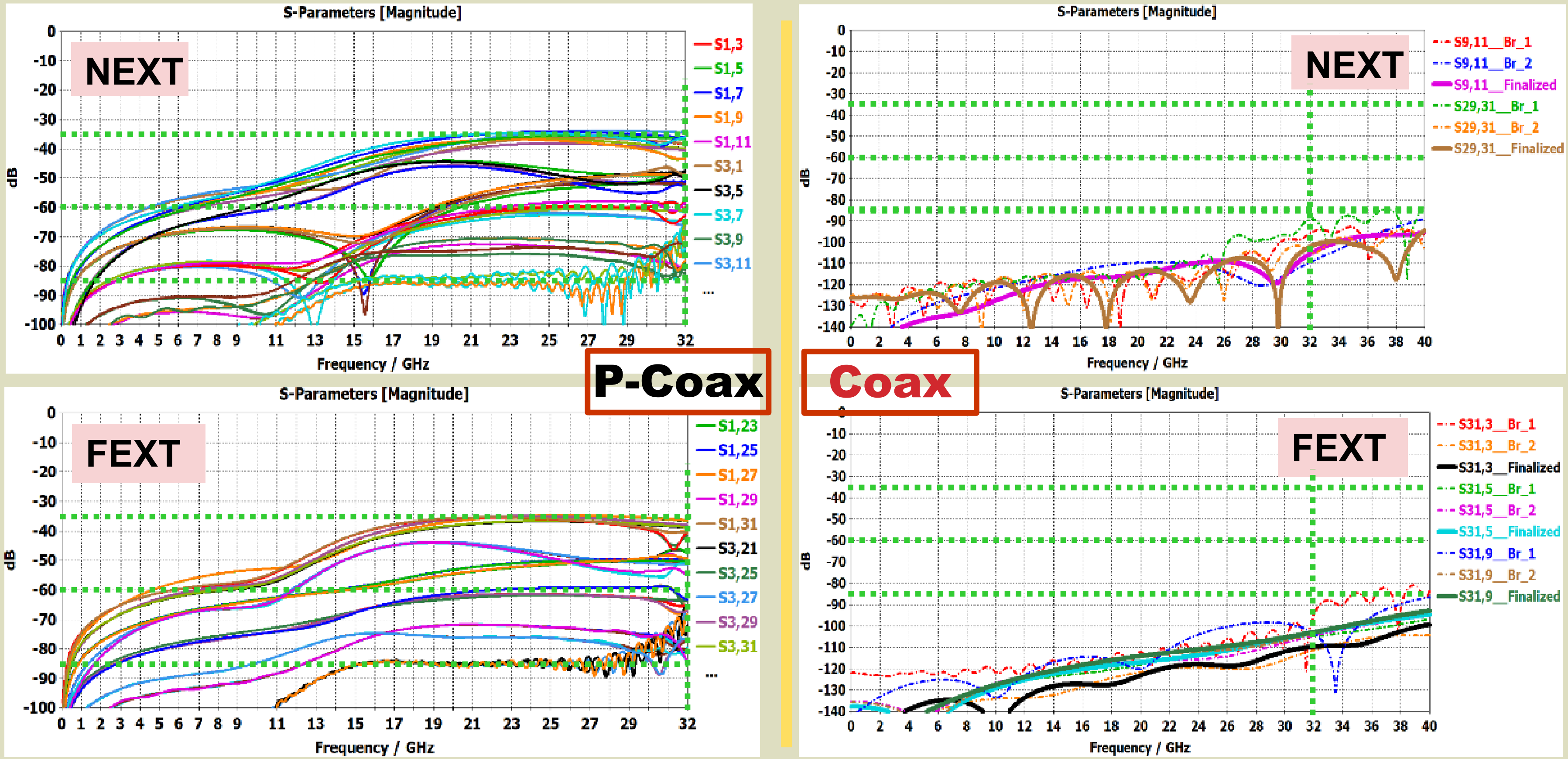
EM Field Propagation: P-Coax v.s. True Coax (Clamp = -85dB)



CST Swept Frequency Results: P-Coax v.s. True Coax



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Summary – Socket Selection

Socket Model Integration is key to achieve full channel HSIO performance

- Higher Performance can be achieved with standard, Elastomer and Partial coax when better signal / ground pin arrangements are available
- Losses and cross talk of standard socket can be improved closer to partial coax socket when using shorter pins

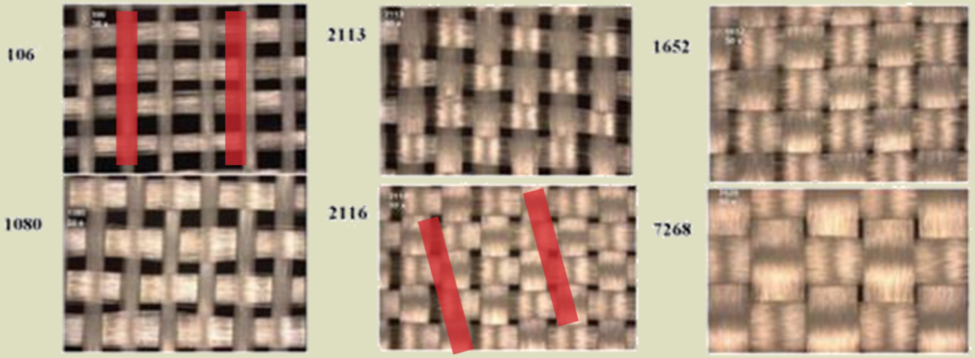
	Standard Socket	Partial Coaxial	Full Coaxial	Elastomer
Performance	DC – 20GHz	DC – 40GHz	DC – 100GHz+	DC – 100GHz+
Cross Talk	~ -20dB @ 20GHz *	~ -30dB @ 32GHz	~ -90dB @100GHz	~ -40dB @60GHz*
DUT pitch	0.2 mm and Higher	0.4 mm and Higher	0.5 mm and Higher	0.3 mm and Higher
Compliance	Good (Pogo pins)	Good (Pogo pins)	Good (Pogo pins)	Poor
Cycle Count	Good (Pogo pins)	Good (Pogo pins)	Good (Pogo pins)	Fair

**Depends upon construction*

Material Selection

Fiber Weave Effect!

- Glass Fiber vs. Resin (Epoxy)
- Materials like 2116 offer better impedance
- Rotation of design on the panel can help mitigate Fiber Weave Effect
- Rotation helps reduce impedance discontinuities and propagation delays on a differential line
- Tighter differential impedance control required!



	RTF2	RTF4*	HVLP	HVLP2	HVLP3	HVLP4	HVLP5*
Thickness (oz)	H / 1 / 2	H / 1 / 2	H / 1 / 2	H / 1 / 2	H / 1	H / 1	H / 1
Roughness, Sa (µm)	0.3	TBD	0.22	0.15	0.10	0.09	0.07

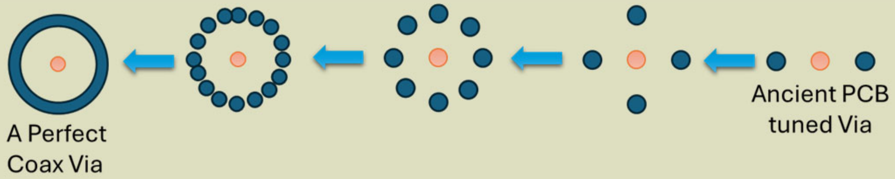
Surface Roughness

- RTF vs VLP/HVLP at higher frequencies
- Why surface roughness is important for Highspeed design and why you should care?
- Using surface roughness parameters in simulations

PCB Via Tuning!

Vias have same behavior for cross talk as with Socket pins (Coax vs. Std)

- More via → Structure goes closer to Coax via structure
  - True Coax vias are great due to less complex C-L-C structure
  - Challenge is layout and manufacturing



- Minimizing structure size by half would approximately double the bandwidth

Coaxial via tuning					
ID (d) [mil]	OD (D) [mil]	Dk	Z0 (Ohms)	Cut-off (GHz)	
4	19	3.5	49.91	174.62	GHz
5	23.5	3.5	49.57	140.92	GHz
7.9	38	3.5	50.31	87.50	GHz
9.8	47	3.5	50.22	70.71	GHz

$c \approx 300'000\ km/s$

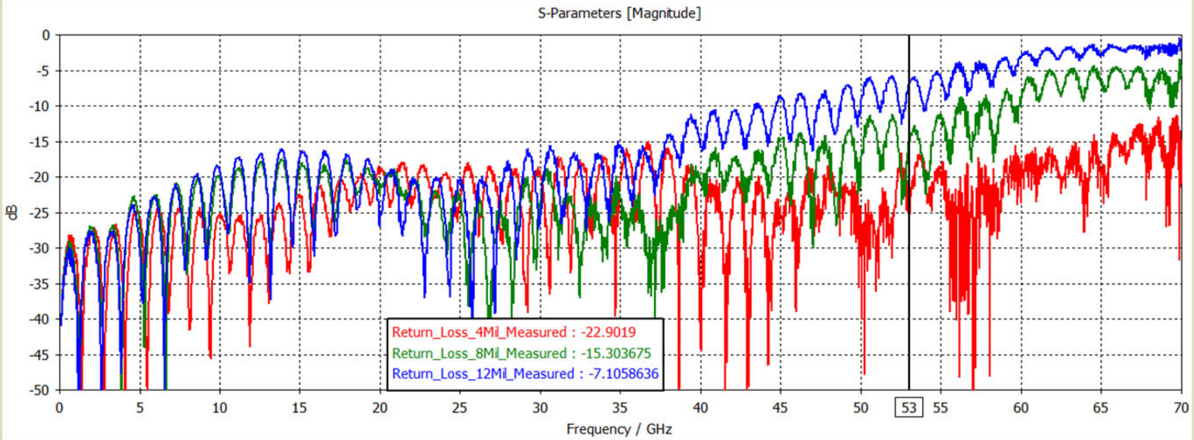
$$f_c \approx \frac{2 \times c}{(D + d) \times \pi \times \sqrt{\varepsilon_r}}$$

- Properly constructed coaxial vias can offer highest bandwidth available!

Back-drills & Stub Control!

Stub is a major contributor to reflections on highspeed lines!

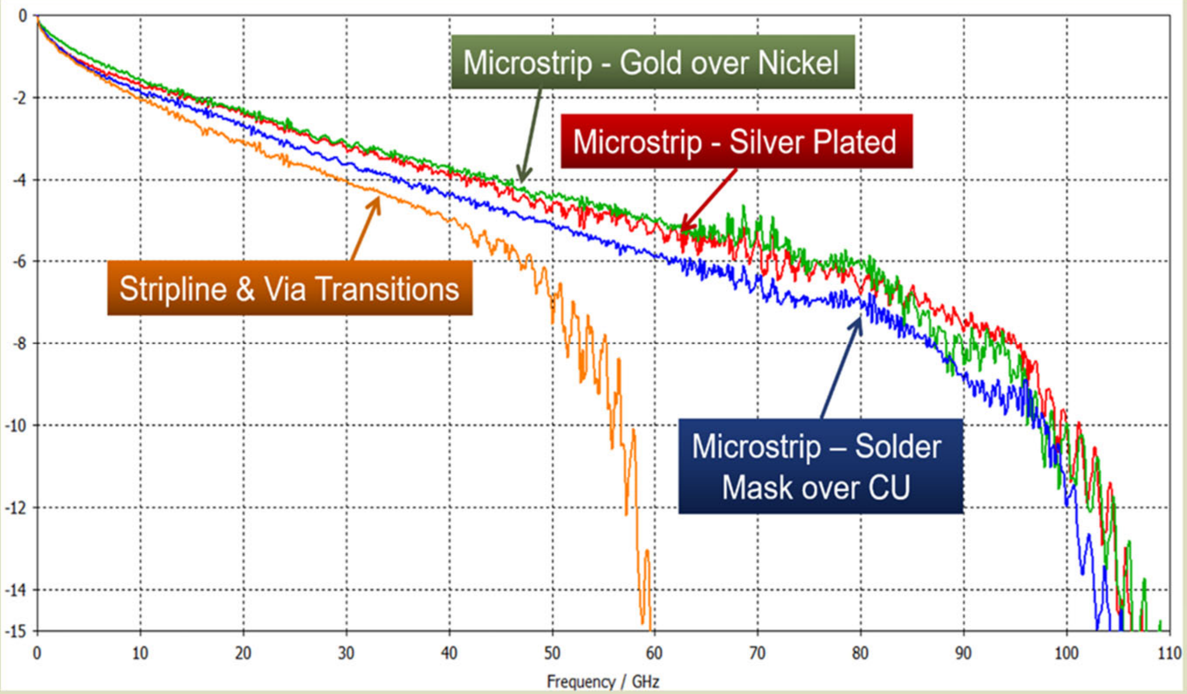
- Return loss is the most important parameter to understand link performance
- As speeds are pushed for 224G PAM4 and higher, back-drills stub needs to be kept less than 5 mils
- 448G designs will challenge the technologies further demanding a near-zero stub for a cleaner lines with smallest reflections to obtain an open eye!



PCB Trace Plating

Electroplated gold over nickel remains the choice of plating [No Solder mask!]

- CPW Considerations
  - Select a 0.75x – 1x spacing between Sig / GND
- Plating Undercut is undesirable!



Skin Loss

Skin Depth Calculations

- Signal energy should be contained in the material of least resistance
- Microstrip gold thickness >~1.5um [>5u”] ideally

	Resistivity (uW*cm)	Permeability
Copper	1.68	0.999994
Nickel	6.99	100
Gold	2.24	0.999998
Palladium	10.54	1.0008

	Skin Depth (um)			
Freq (GHz)	Copper	Nickel	Palladium	Gold
1	2.06 um	0.42 um	5.16 um	2.38 um
3	1.19 um	0.24 um	2.98 um	1.38 um
5	0.92 um	0.19 um	2.31 um	1.07 um
10	0.65 um	0.13 um	1.63 um	0.75 um
15	0.53 um	0.11 um	1.33 um	0.62 um
24	0.42 um	0.09 um	1.05 um	0.49 um
32	0.36 um	0.07 um	0.91 um	0.42 um
44	0.31 um	0.06 um	0.78 um	0.36 um
56	0.28 um	0.06 um	0.69 um	0.32 um

Equations for Calculating Skin Depth

$$\delta = \sqrt{\frac{\rho}{\pi f_o \mu_r \mu_o}}$$

Where:

δ = skin depth

ρ = resistivity

f_o = signal frequency

μ_r = relative permeability

μ_o = permeability of free space = $4\pi \times 10^{-7}$

Summary

- PCB Manufacturing parameters will affect high frequency behavior
  - Drill size accuracy and positional accuracy, feature control, and registration etc.
- Phase, return loss and cross talk dominate performance at higher frequencies – Socket modeling gets paramount!
- Design should make use of new fabrication technologies to guarantee performance
- A closed-loop work with design and fabrication engineering will be required to ensure best choices between technologies, feature control and manufacturing capabilities to achieve good fabrication yields

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