DESIGNCON® 2019
WHERE THE CHIP MEETS THE BOARD

112 Gbps

In and Out of Package Challenges

Design insights from electromagnetic analysis

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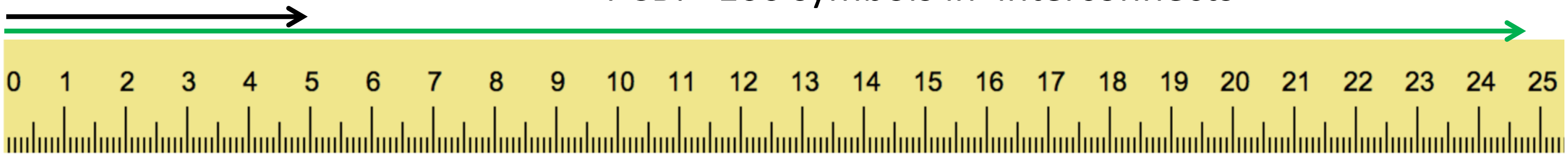
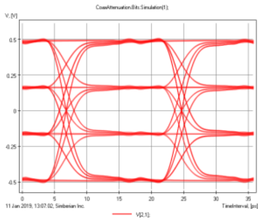
Package and PCB scales in symbol time for 112 Gbps PAM4



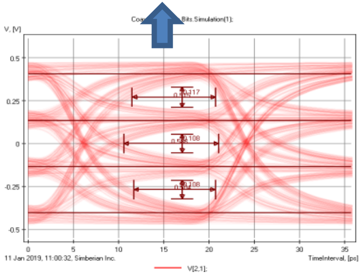
Package: ~20 symbols in interconnects

PCB: ~100 symbols in interconnects

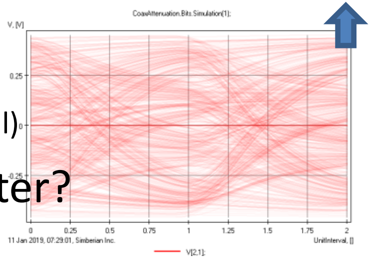
112 Gbps PAM4, symbol 17.857 ps, good package



12.5 cm of strip line on Meg7



25 cm of strip line on Meg7 (computed with data for actual material)



Can we do better?

What we have on PCB today will eventually happen at the package (20 bits on PCB were at about 14 Gbps NRZ)

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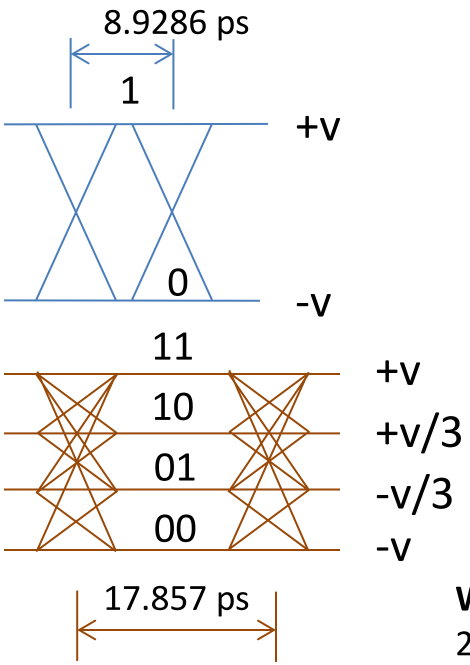
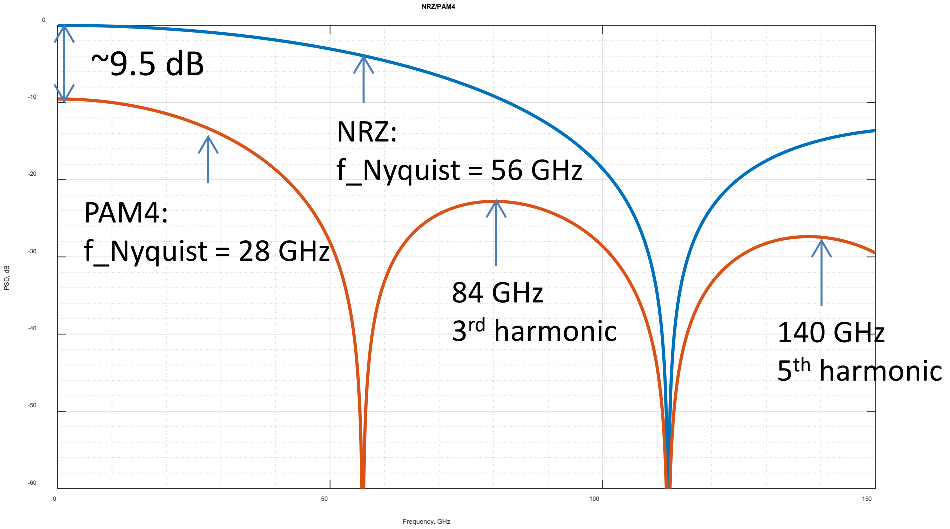
Bandwidth for 112 Gbps NRZ and PAM4

AN 835: PAM4 Signaling Fundamentals, Intel





~9.5 dB

NRZ:
f_Nyquist = 56 GHz

PAM4:
f_Nyquist = 28 GHz

84 GHz
3rd harmonic

140 GHz
5th harmonic

What should be the bandwidth for electromagnetic analysis of interconnects? 28 GHz? 56 GHz? 84 GHz? 112GHz?...140? – it should be defined with numerical experiment and correlation with measurements. See simple case study at Simberian AN #2018_02, “Moving from 28 Gbps NRZ to 56 Gbps PAM4”, www.simberian.com ...

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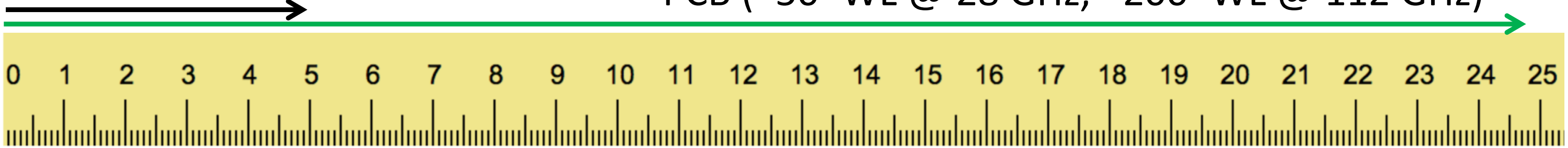
Package and PCB scales in wavelengths

Package (~10 WL @28 GHz, ~40 WL @112 GHz)

PCB (~50*WL @ 28 GHz, ~200*WL @ 112 GHz)



Dk=4

Frequency [GHz]	WL [mm], Air	WL [mm]	WL/2 [mm]	WL/4 [mm]	WL/8 [mm]
14	21.414	10.707	5.353	2.677	1.338
28	10.707	5.353	2.677	1.338	0.669
56	5.353	2.677	1.338	0.669	0.335
84	3.569	1.784	0.892	0.446	0.223
112	2.677	1.338	0.669	0.335	0.167

Dk=2

Frequency [GHz]	WL [mm], Air	WL [mm]	WL/2 [mm]	WL/4 [mm]	WL/8 [mm]
14	21.414	15.142	7.571	3.785	1.893
28	10.707	7.571	3.785	1.893	0.946
56	5.353	3.785	1.893	0.946	0.473
84	3.569	2.524	1.262	0.631	0.315
112	2.677	1.893	0.946	0.473	0.237

1 mm = 39.37008 mil
1 mil = 0.0254 mm

WL is wavelength in dielectric

$$\lambda = \frac{c}{f \cdot \sqrt{\varepsilon_r}}$$

Design Limits:
WL/2 - cutoff for SIW formed by via fences;
WL/4 - resonances, via localization (pass/fail);
WL/8 – via fence localization (bandgap structures if not possible);

We are deep into microwave and mm-wave territory

Waveguide Domain ruled by the Electromagnetic Analysis!

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Electromagnetic Analysis of Interconnects: Problem dimension and formulation

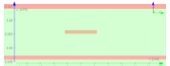
1D models or transmission line models – Telegrapher's equations

Modal or per unit length parameters for the Telegrapher's equations (Z, Y) are computed with static or quasi-static field solver (2D problems for Laplace's equations) or an electromagnetic fields solver (3D problems for Maxwell's equations)

Lines with coupling, multimodal waveguides, periodic structures can be accurately modeled

$$\frac{\partial V(x,t)}{\partial x} = -Z_\delta(t) * I(x,t)$$

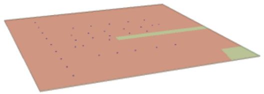
$$\frac{\partial I(x,t)}{\partial x} = -Y_\delta(t) * V(x,t)$$



2D models or transmission plane models - 2D Telegrapher's equations (Maxwell's equations for 2D TE problems)

Component to model power delivery processes in parallel plane PDNs

See more at Y. Shlepnev, ACES 2006, EPEPS 2012



$$\frac{\partial J_{sx}(t)}{\partial x} + \frac{\partial J_{sy}(t)}{\partial y} = -Y_{\square\delta}(t) * V(t) + J_z(t)$$

$$\frac{\partial V(t)}{\partial x} = -Z_{\square\delta}(t) * J_{sx}(t)$$

$$\frac{\partial V(t)}{\partial y} = -Z_{\square\delta}(t) * J_{sy}(t)$$

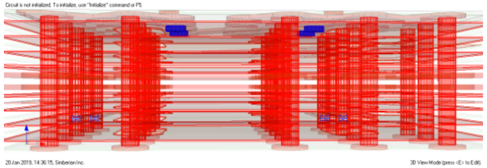
3D models or 3D full-wave models - everything described and solved with Maxwell's equations without any simplifications for 3D geometries or field components

Analysis of discontinuities such as via-holes, connectors or any type of transitions between uniform traces

Analysis of SI, PI or SI+PI with 3D models is possible with some tools, but may be not practical due to enormous complexity and accuracy issues

$$\nabla \times \vec{E}(\vec{r},t) = -z_\delta(\vec{r},t) * \vec{H}(\vec{r},t)$$

$$\nabla \times \vec{H}(\vec{r},t) = y_\delta(\vec{r},t) * \vec{E}(\vec{r},t) + \vec{J}$$



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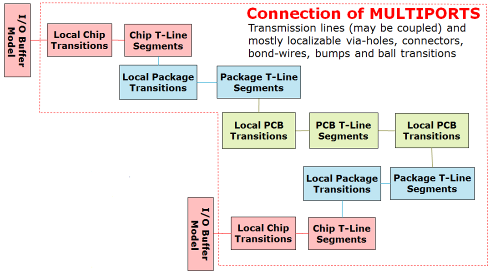
3D View Mode (press <E> to Edit).

Electromagnetic Analysis of Interconnects: Hybrid models



Connection of MULTIPORTS

Transmission lines (may be coupled) and mostly localizable via-holes, connectors, bond-wires, bumps and ball transitions

1D+3D: Hybrid de-compositional analysis with transmission line models for traces (1D) and 3D models for discontinuities or transitions

The best technique for the serial interconnects under the localization condition (Y. Shlepnev, EMC 2013)
This approach usually works for PCB and packaging problems with relatively long traces, but may fail if trace segments are too short - complete 3D analysis is required in this case

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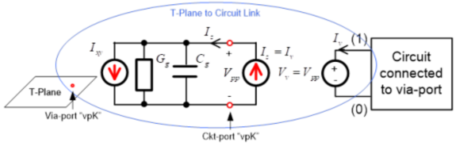
1D+2D: Hybrid analysis with transmission line models (1D) and the transmission plane models (2D) coupled at the via-holes (more at Y. Shlepnev, ACES 2006)

Such models are usually used to simulate SI + PI - even the whole board simulation is possible in many tools based on this technique, popular for solving un-localized problems
Though, the accuracy is severely limited due to via-hole models simplifications

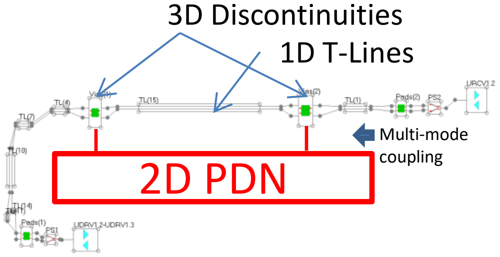


1D+2D+3D: Hybrid analysis with transmission line models (1D), transmission plane models (2D) with the coupling between two modeled simulated with 3D analysis

Advantage - fast algorithms of 1D+2D and accuracy of 3D at the discontinuities

Needed only in case if there is substantial coupling between 3D (via for instance) and 2D (PDN) models - **case of non-localized vias**, when energy from SI go to PI and the other way around

If you forced to use this approach, the alternative is to fix design – enforce the localization and simplify the problem back to 1D+3D



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Accuracy of 1D+3D de-compositional analysis

- Accuracy depends on proper **localization of every single element in the link**
  - Difficult in package and almost impossible on PCB for bandwidth of 112 Gbps signal
- **Broadband dielectric and conductor roughness models** are identified (with GMS-parameters or SPP Light)
  - About time to start doing it for packages, very important for PCB – models must be statistical (see more A. Manukovsky, Y. Shlepnev, DesignCon 2019)
- **Manufactured geometry adjustments** are identified
  - May be less important for packages, very important for PCB – models must be statistical
- **Electromagnetic solvers are formally validated with measurements** using systematic approach ("sink or swim" for instance)
  - This is not just getting the analysis matching the measurements by any means – see more at M. Marin, Y. Shlepnev, DesignCon 2018, EMC 2018
  - There are no data on solvers that are formally validated for 112 Gbps signal bandwidth (so far variations in geometry and materials technically prohibit this)
- Other considerations: Ports consistency and de-embedding, boundary conditions,…

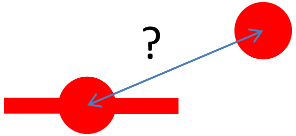
Only localized structures must be used to design PCB/Packaging interconnects – design only with predictable structures!

Not localized == not predictable!

Stripline

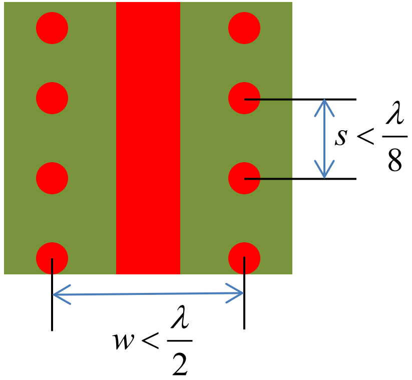
Microstrip

Via + stitching via(s) somewhere

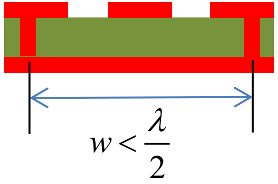


Predictable, conditionally localized, single-mode!

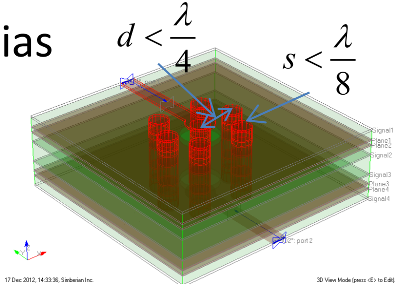
“Fenced” Stripline



CBCPW



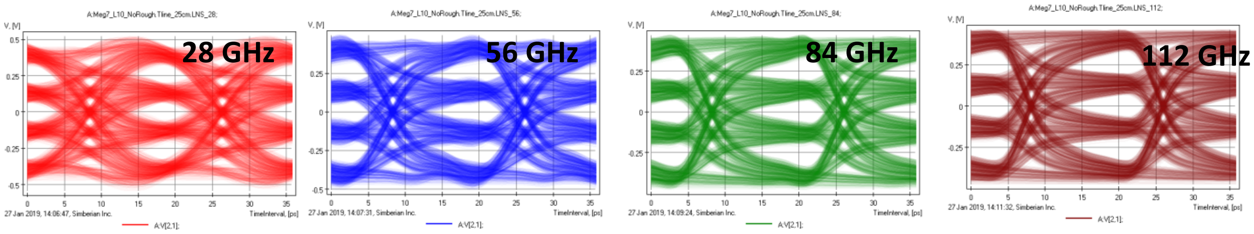
Localized Vias



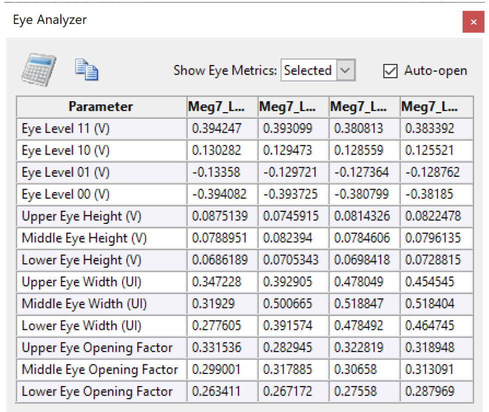
If not possible - use of bandgap structures for localization

Conclusion

- Understand the electromagnetic solver technology limitations by systematic validation over the target bandwidth (applicable to system-level simulators too)
- Define the target bandwidth by numerical experiment with identified material models, correlated with measurements



Effect of model bandwidth on eye diagram for 25 cm stripline segment in Meg7, flat copper



Parameter	Meg7_L...	Meg7_L...	Meg7_L...	Meg7_L...
Eye Level 11 (V)	0.394247	0.393099	0.380813	0.383392
Eye Level 10 (V)	0.130282	0.129473	0.128559	0.125521
Eye Level 01 (V)	-0.13358	-0.129721	-0.127364	-0.128762
Eye Level 00 (V)	-0.394082	-0.393725	-0.380799	-0.38185
Upper Eye Height (V)	0.0875139	0.0745915	0.0814326	0.0822478
Middle Eye Height (V)	0.0788951	0.082394	0.0784606	0.0796135
Lower Eye Height (V)	0.0686189	0.0705343	0.0698418	0.0728815
Upper Eye Width (UI)	0.347228	0.392905	0.478049	0.454545
Middle Eye Width (UI)	0.31929	0.500665	0.518847	0.518404
Lower Eye Width (UI)	0.277605	0.391574	0.478492	0.464745
Upper Eye Opening Factor	0.331536	0.282945	0.322819	0.318948
Middle Eye Opening Factor	0.299001	0.317885	0.30658	0.313091
Lower Eye Opening Factor	0.263411	0.267172	0.27558	0.287969

- Design only predictable localized interconnects with the identified material models and manufacturing adjustments and properly validated solvers!

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