Challenges in Interconnect Channel with High-Bit Rates

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Agenda

- Introduction
- HFSS (High Frequency Structure Simulation)
- Why Full Wave Modeling and Simulation
- Challenges in Interconnect Channel
- Challenges in Package Modeling and Simulation
- Challenges in PCB Modeling and Simulation
- What are Discontinuities
- How does EMI Impact the Package and PCB
- Accuracy of HFSS (Interpolating Method)
- Frequency Domain Simulation
- Time Domain Simulation
- Back up Slides
    - S-parameters
    - RLCG to S-parameters
    - Attenuation (Losses)
    - High Order Mode (TEM & Full wave)
    - Cascading Networks
    - Power Spectrum Density

Introduction

- High Frequency bit rate about 2.5 to 10 GT/s
  - Mhz → Ghz
  - Lumped element → Partially Distributed → Fully distributed
- TEM mode (Traditional Simulator)
  - Quasi-TEM dominant mode
  - 3D effect (Discontinuity, Split, non-uniformity) not considered
  - Radiation loss not captured
  - Low frequency approximation in extraction
  - Losses are not accurately model
- Full Wave Model (High-order mode and Mode conversion)
  - Dispersion effect: Group velocity not equal to phase velocity
  - Resonances and/or non-monotonic S-parameters data
  - High loss limits the transfer bit rates
  - Radiation loss
  - Skin effect and proximity effect
  - Crosstalk, Coupling, and reflection
  - Impedance mismatches
  - Surface roughness
  - Fiber weave effects

Why HFSS

- It is a primary tool to investigate in advance the impacts of the following layout constrains to the interconnect channel including package, PCB, connector and so on:
  - Split plane,
  - Reference planes (power ←→ ground)
  - Return path discontinuity: (changing of reference plane)
  - Impedance mismatches,
  - Resonance peaks
  - Breakout,
  - Bends
  - Serpentines
- Goal is to optimize the impacts of the above issues on the time and noise margins of the high frequency buses.

Why Full Wave Modeling and Simulation ?

- Impedance Mismatches
- Discontinuities
- Mode conversions
- Dispersions
- Resonance structures
- Low pass filtering with high loss
- Impulse responses of channel (Time domain issues)
- Non-passivity
- Mode phase distortion (Frequency domain issues)

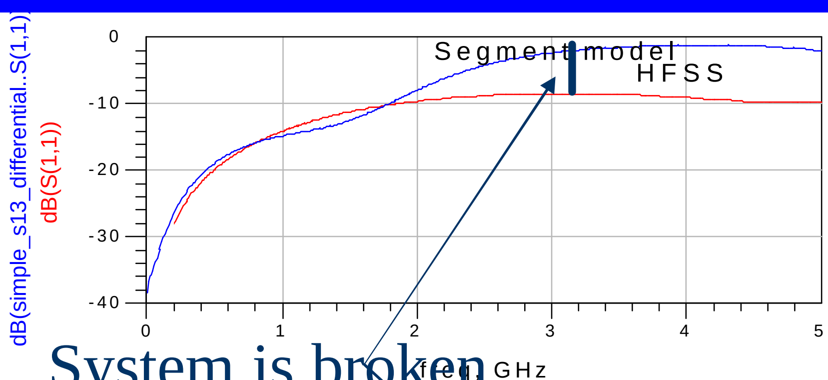
Challenges in Interconnect Channel

All these issues reduce the performance of the interconnect channel

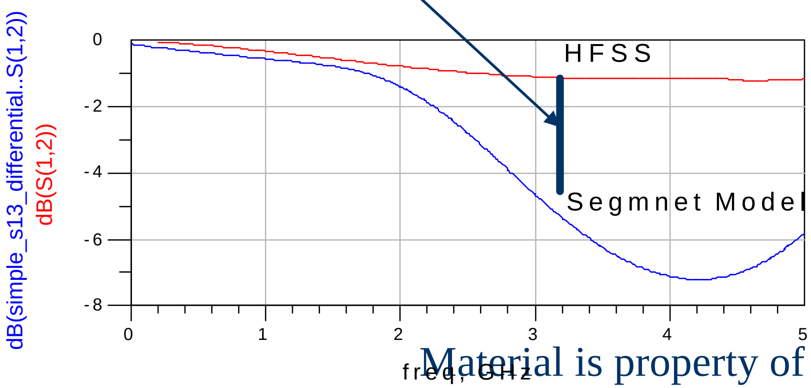
- Asymmetric differential pairs because of layout or non-uniform manufacturing tolerance
- Common Mode conversions (non-ideal differential mode)
- EMI (slot, breakout, via, connector)
- Power delivery and Ground Bounce issues (voltage fluctuations)
- Jitter, noise, and slew rate on the interconnect channel
- Resonances
- Discontinuities
- Impedance mismatches
- Buffer non-linearity

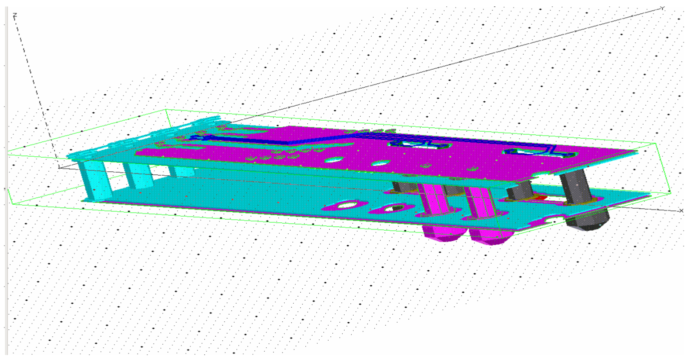
Challenges in Package Modeling and Simulation

- 2-3 dB losses difference between the two models because of the non-ideal ground plane
- Introduce more jitter and noise on the receiver



System is broken



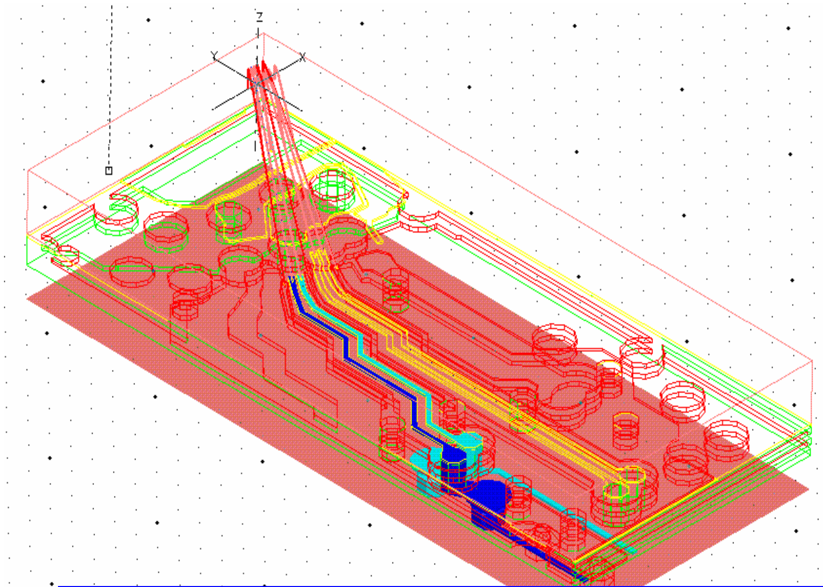


Up to 2 Ghz HFSS and Lumped+T_lines agree

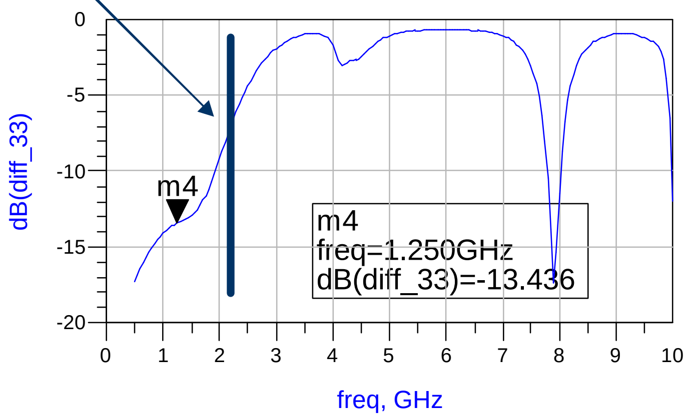
HFSS versus Segment Model

Challenges in Package Modeling and Simulation

Complex Wire-bond PKG Model with several impedance dis.



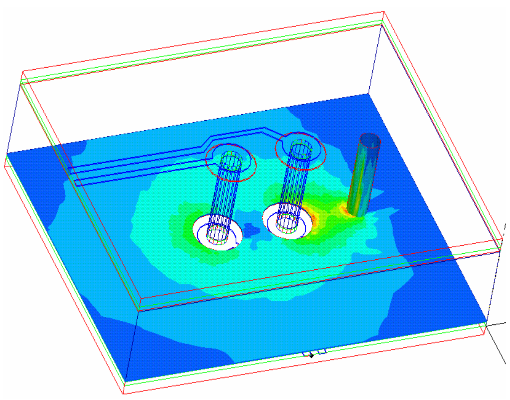
Package limitation

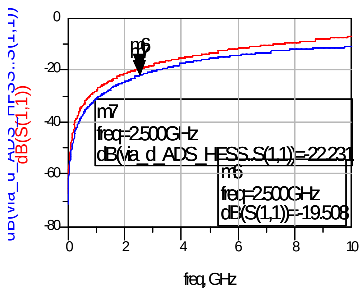


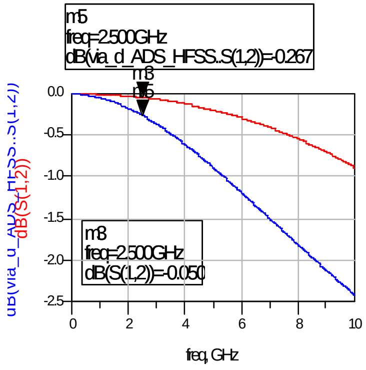
Goal is to reduce the impedance mismatch looking to the model impedance (TDR) using HFSS results

Challenges in PCB Modeling and Simulation

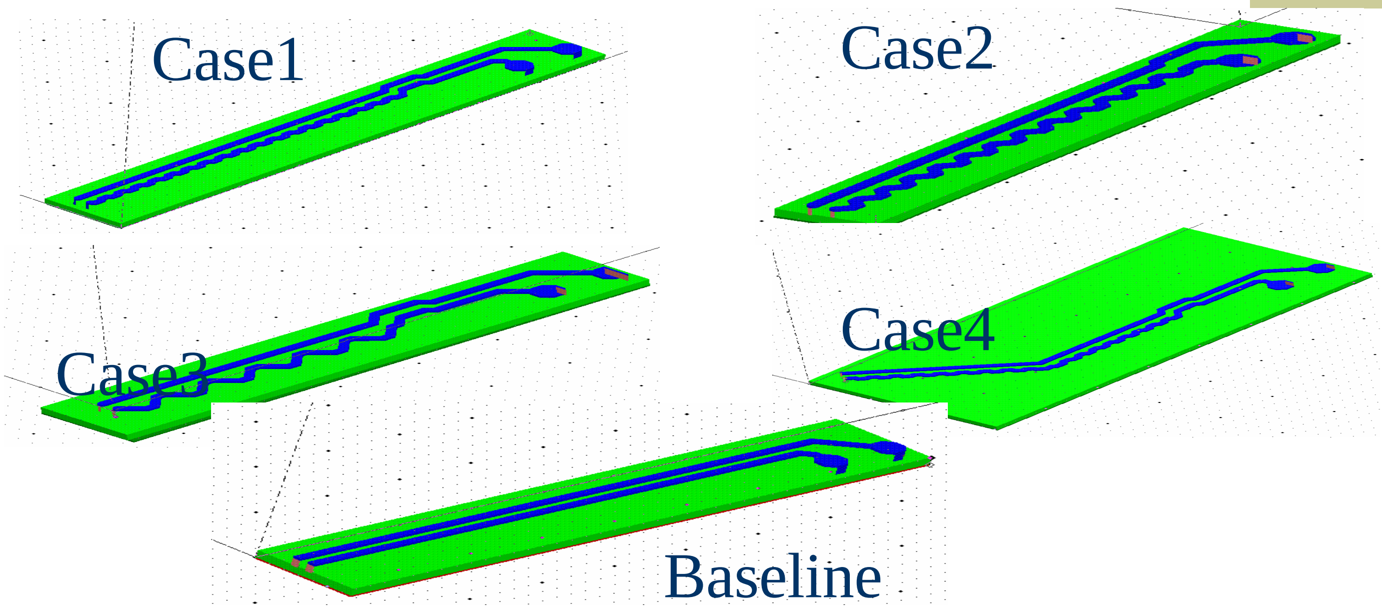
- Differential via radiation loss (HFSS model versus Q3D model)





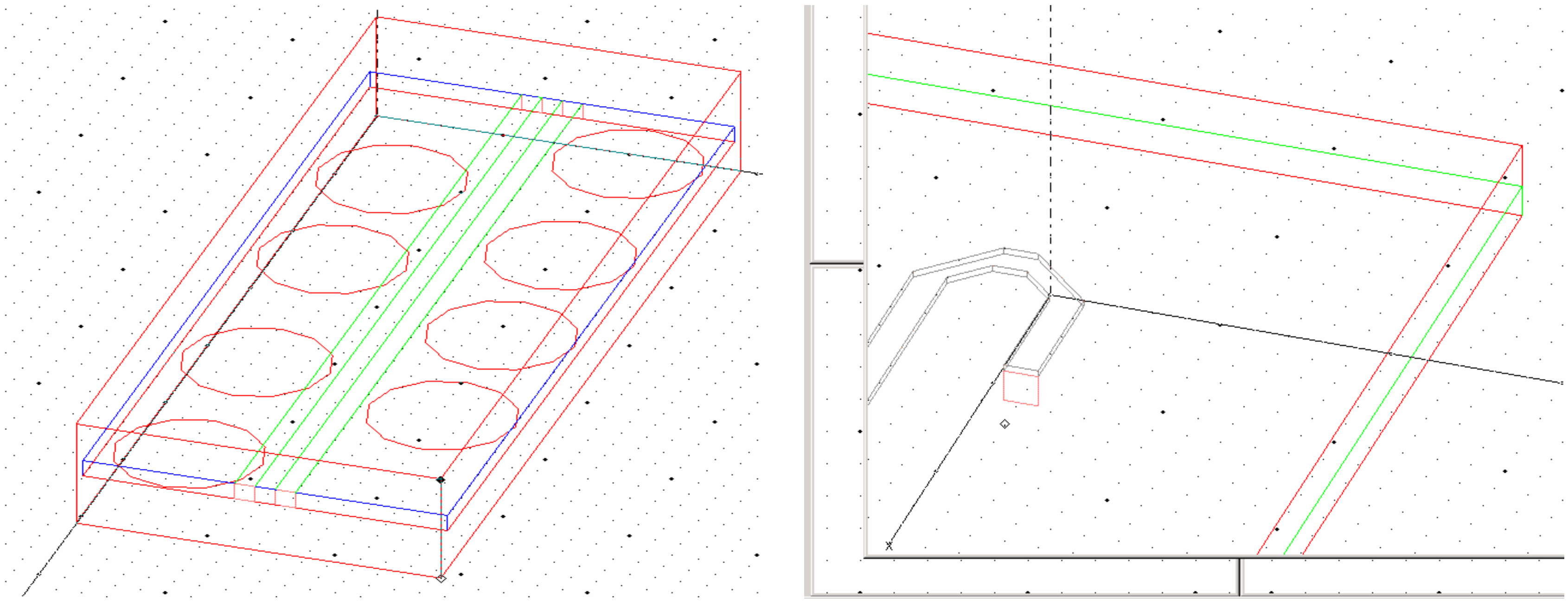


Challenges in PCB Modeling and Simulation



Variety of serpentines on the board needs accurate modeling computing the impacts on the RL and IR losses

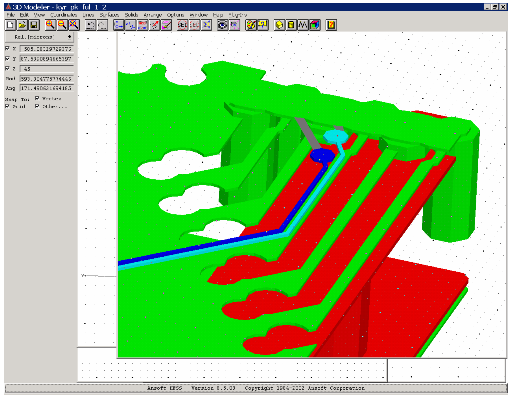
Challenges in PCB Modeling and Simulation

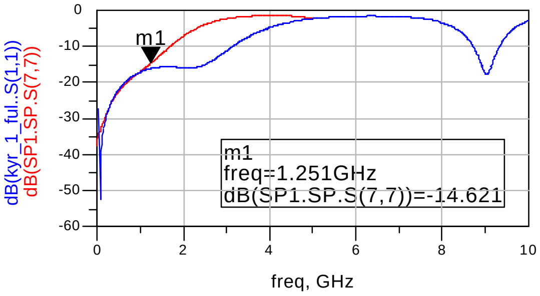


Voids and bends on the board with 0.5 to 1 dB impact
On the differential IL (who to come up with guideline)

What are Discontinuities

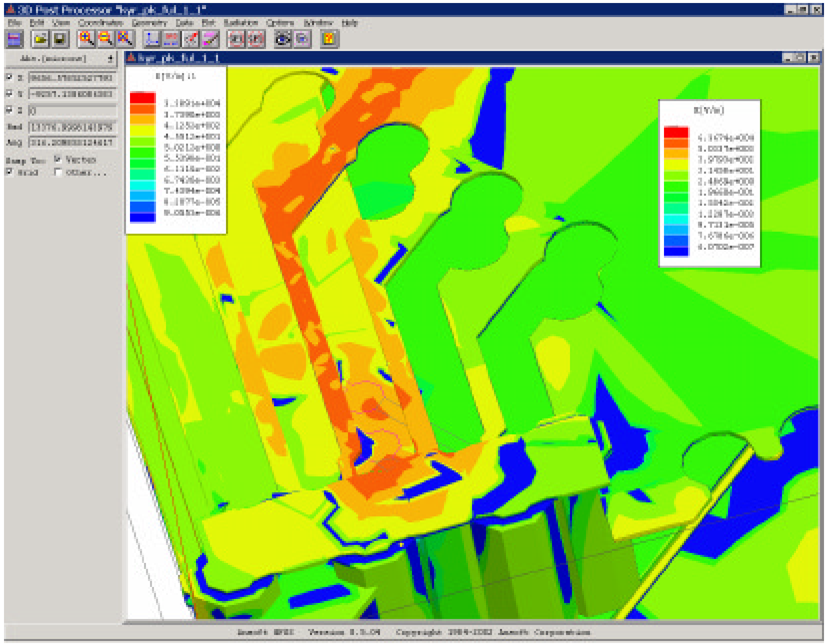
- Non-ideal reference plane
  - Low pass filtering (high capacitive parasitic)
  - Edge coupling effects
  - Asymmetric differential pair
  - RL is reduces by 2 to 3 dB depends on the length on the breakout area
  - Very large impact on the noise on the receiver





What are Discontinuities

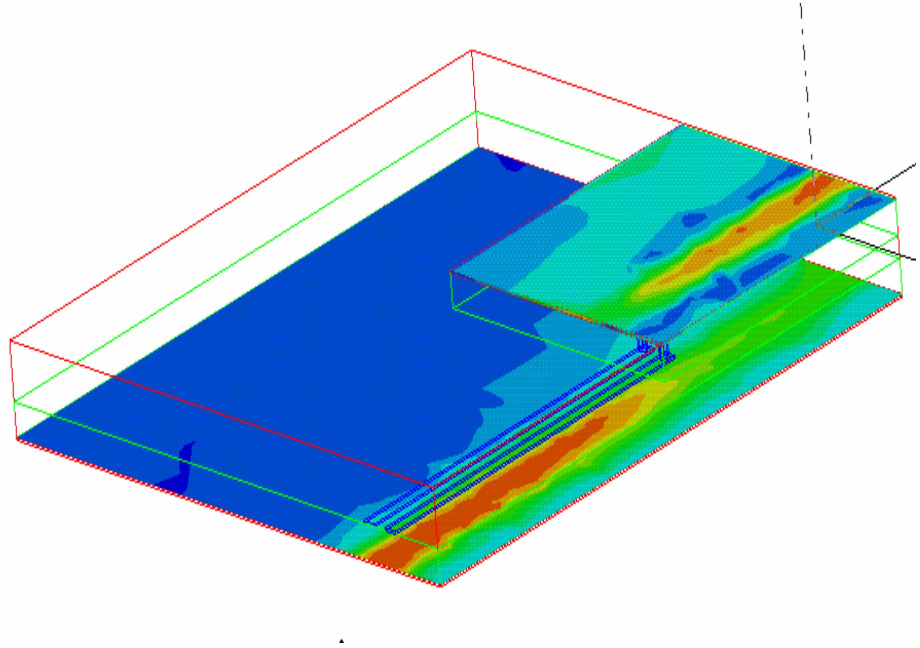
- Reference to power plane
  - Extra inductance in the power delivery loop
  - Edge Coupling
  - EMI issues



HFSS Sim.

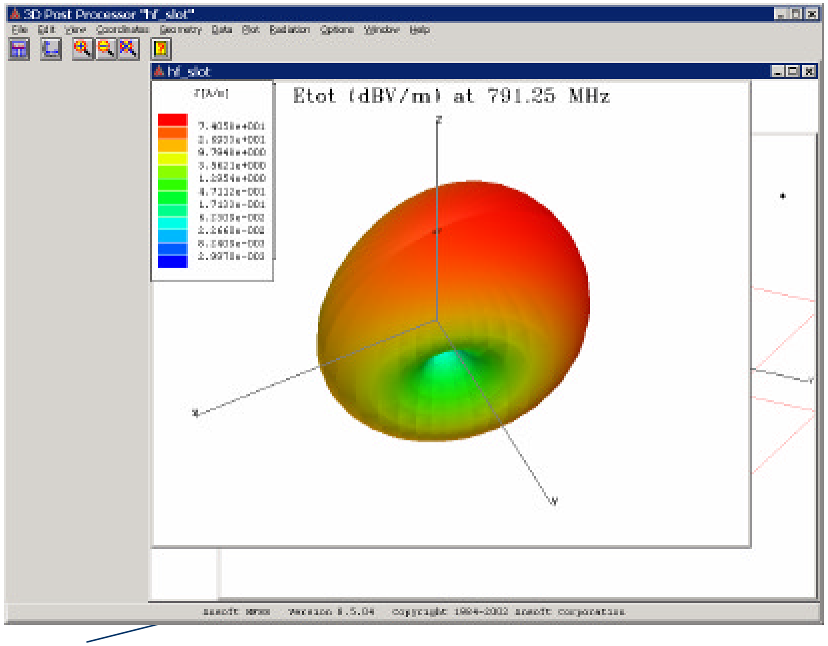
What are Discontinuities

- Mode conversion and common mode noise on the package
- High order mode propagate on the package plane
- Fringing field and EMI problems



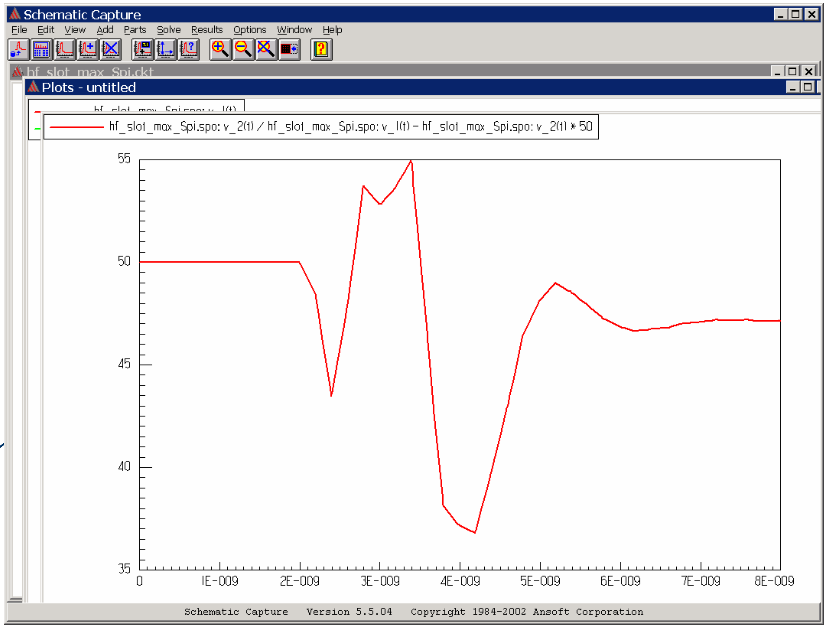
How does EMI Impact the Pkg and PCB

- Radiation due to the slot on the ground plane
- Effects the RF circuitry
- Noise immunity is not guarantee on the circuit
- Impedance mismatch is a challenge to fix



How does EMI Impact the Pkg and PCB

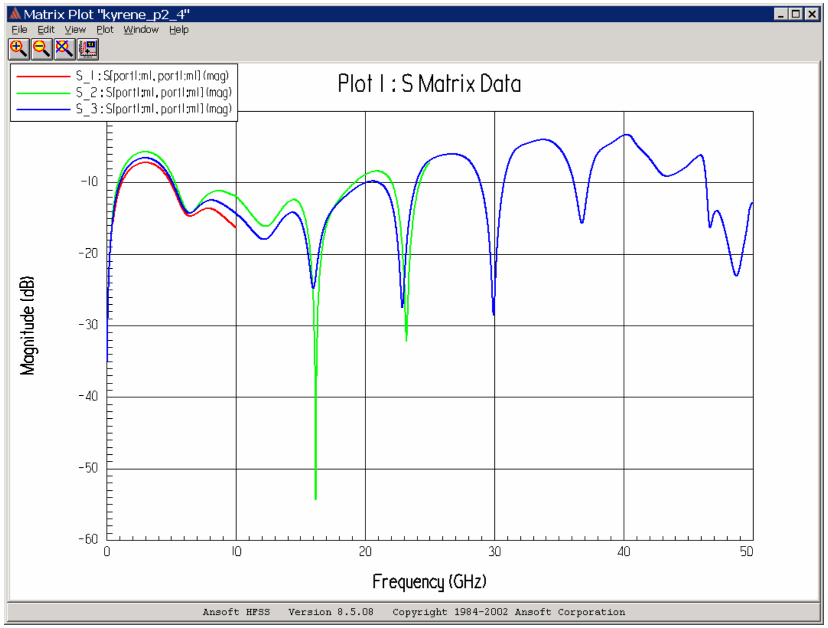
- Impedance mismatched on the differential signal
- Jitter and noise issues
- Impulse response and phase distortion issues on the signal integrity



TDR Simulation

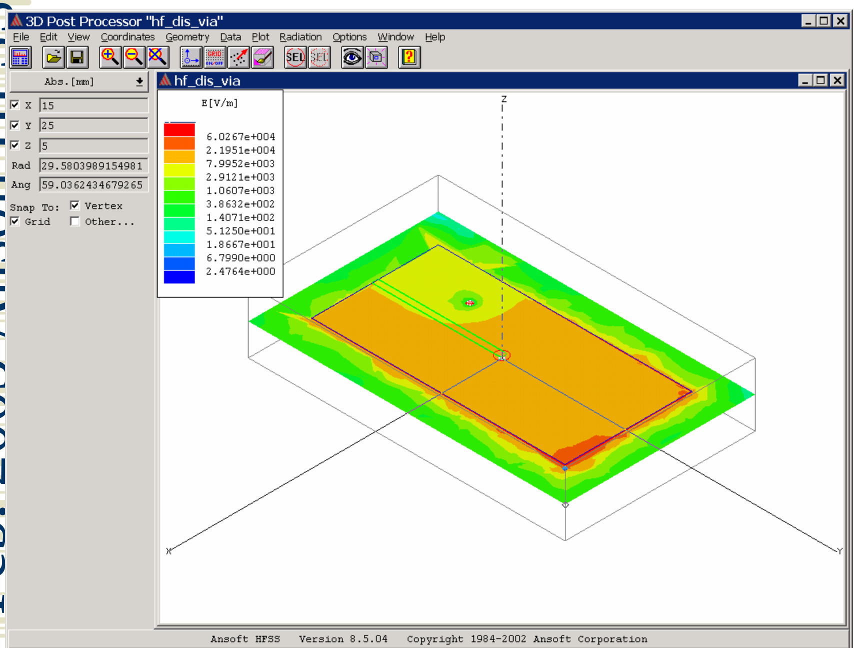
Accuracy of HFSS for different range of frequency using Interpolating

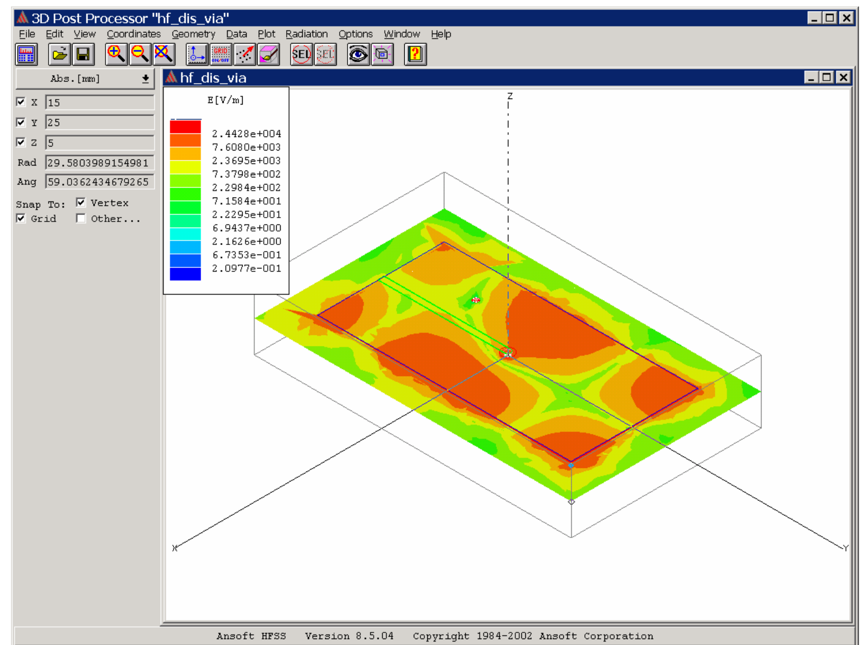
- Differential pairs
- S-parameters for 10 and 25 and 50Ghz
- Very good correlation for three different rang of frequency



Frequency Domain Simulations

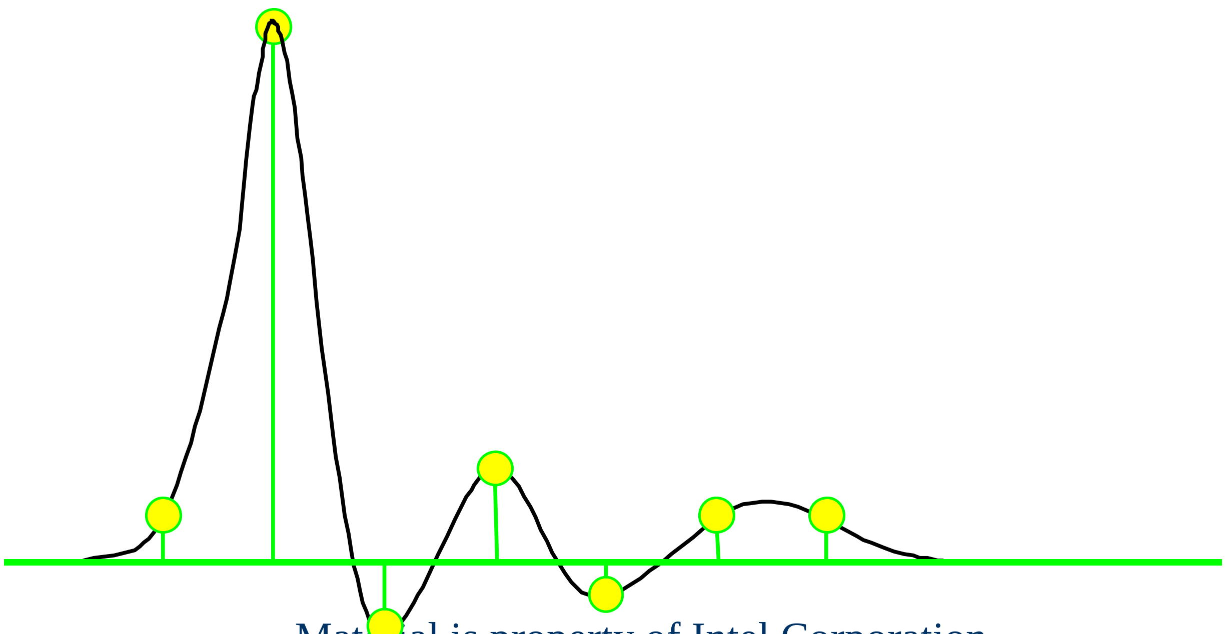
- Frequency domain simulation and resonances on the package structure
  - High current density spot needs on some part of package
  - Resonances can hurt the power delivery by creating high impedance profile





Time Domain Simulations

- Time domain parameters (Impulse responses)
  - Jitter & Skew, crosstalk and ISI can be characterize Characteristic by Impulse response (IFFT of S-parm.)



Conclusions

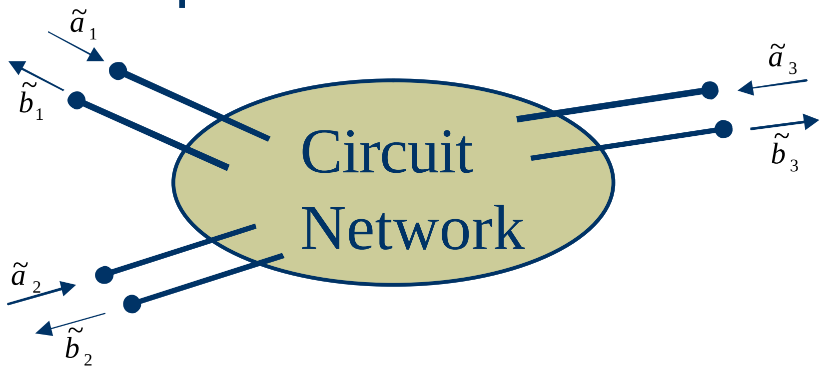
- Design of interconnect channel with high-bit rates, HFSS modeling is very critical to measure the impacts of mode conversions, dispersions, resonances, return path discontinues, and impedance mismatches on the package, PCB, connector, and so on.
- High frequency modeling and simulation give an indication into the model to improve the channel performance versus the layout constrains and issues
- The problems such as void, breakout, non-ideal ground, bend, serpentines, and so on are inevitable and need full wave modeling.
- HFSS has been used successfully to model and simulate the high-bit rates channel and also it has efficiently enhanced the channel model productively
- Design EDA tools must evolve to identify high frequency specific failure mechanisms and permit the designer to avoid them

S-parameters

- 3D Full wave Solution

➢ Full-wave (S-parameter) extraction:
  - requires no low frequency assumptions or geometry assumptions
  - solves fully coupled Maxwell's equations

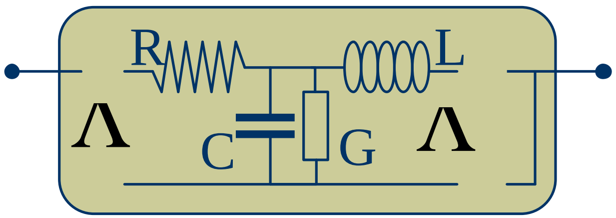
$$[b]=[S][a]$$

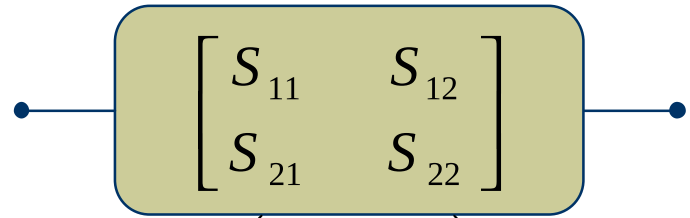


➢ Definition of S-parameters

RLCG to S-parameters

- RLCG to S-parameters





$$g = \sqrt{(R + jwL)(G + jwC)}$$

$$Z = \sqrt{\frac{R + jwL}{G + jwC}}$$

$$S_{11} = S_{22} = \frac{\left(Z^2 - Z_{ref}^2\right)sinh(?h)}{2ZZ_{ref}\ cosh(?h) + \left(Z^2 + Z_{ref}^2\right)sinh(?h)}$$

$$S_{12} = S_{21} = \frac{2ZZ_{ref}}{2ZZ_{ref}\ cosh(gh) + \left(Z^2 + Z_{ref}^2\right)sinh(gh)}$$

$$Z_{ref} = 50\Omega$$

RLCG not uniquely defined in general
Breakdown regime can be identified from frequency-domain results
S-parameters magnitude are finitely bounded within [-1, 1]

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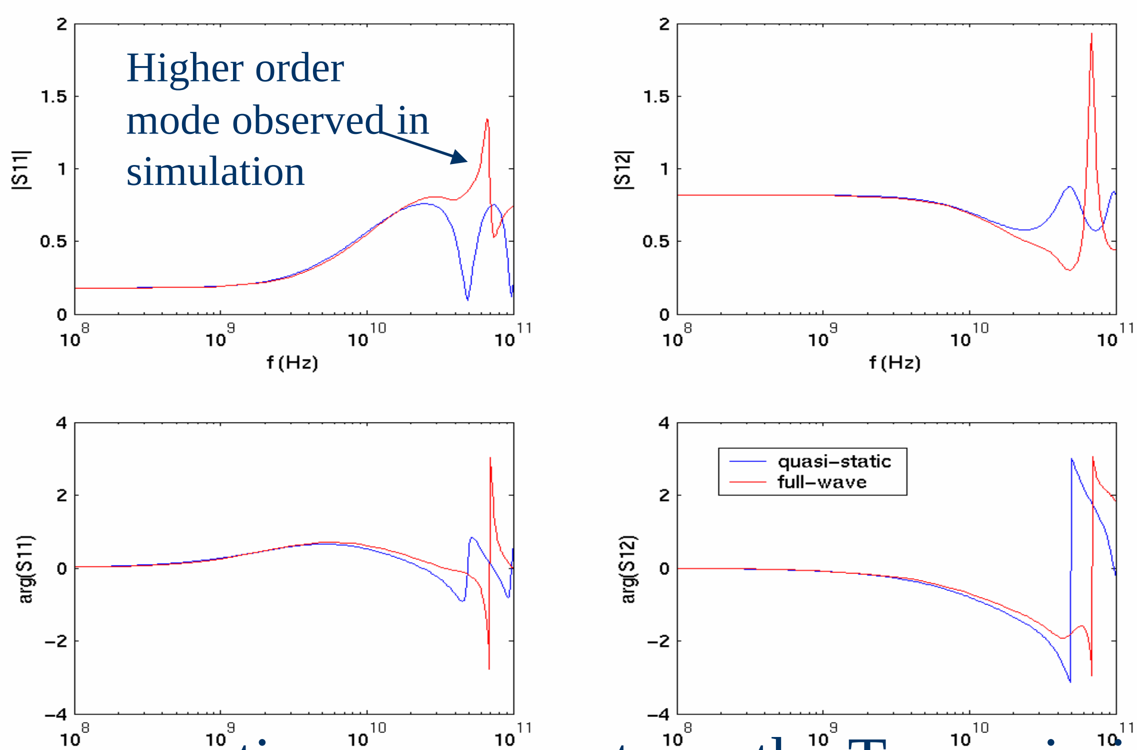
Attenuation (losses)

- Conductor losses (Skin Effect)
  - Dissipate energy
- Dielectric losses (depends on material)
  - Dissipate energy
- Mismatch losses (If dis. appears in the line or terminations)
  - More serious at high frequency than low frequency
  - Reflect and guide energy away from T.L.
- Radiation losses

High Order Mode (TEM & FULL Wave)

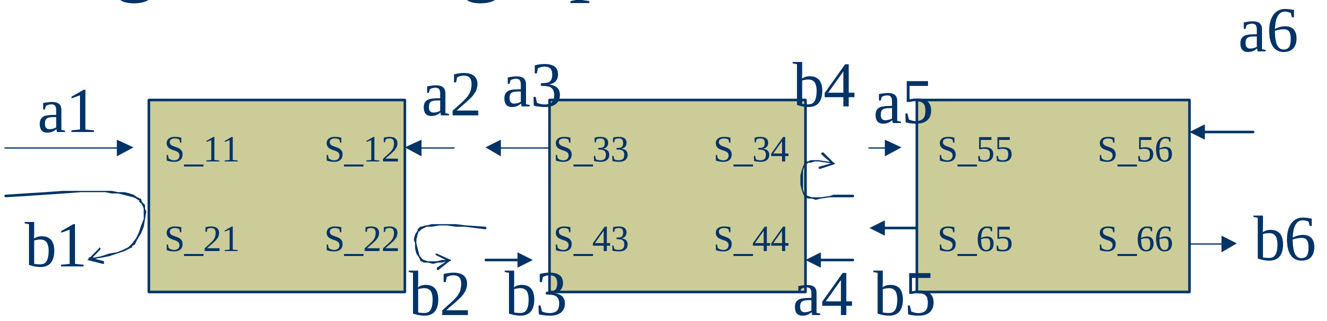
- S-parameters data TEM Model versus Full wave



Dis. act as a reactive components on the Transmission lines

Cascading Networks

- Signal flow graph

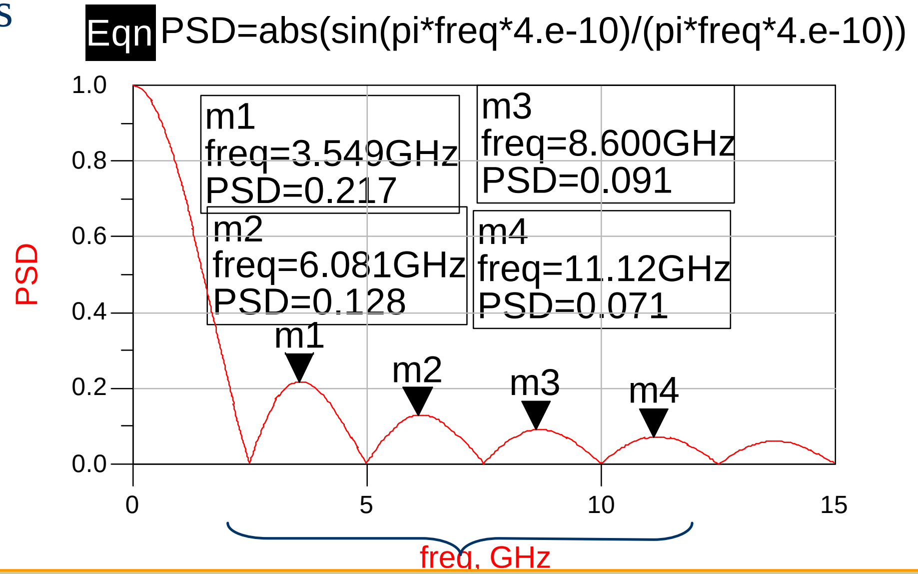


$$b6/a1 = \frac{S\_21.S\_43.S\_65}{1-(S\_22.S\_23+S\_44.S\_55+S\_43.S\_55.S\_34.S\_22+S\_22.S\_33.S\_44.S\_55)}$$

Depends on responses it could be simply add magnitude and phase

Power Spectrum Density

- For 2.5 GHz fundamental frequency
  - Up to fourth harmonic
  - Frequency response up to 11.12 GHZ
  - Safe for no filtering effects



Power band width (for not having serious attenuations)