High-Speed Bus System Design Challenges

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Agenda

- Introduction
- HFSS (High Frequency Modeling, High-order modes)
- Impacts of High Frequency Modeling on Interconnections
- Time & Frequency Domain Simulations
  - S-parameters (Return loss and Insertion loss analyses)
    - Tapered line
    - Split Plane
    - Return Path Discontinuities
      - Chang reference planes
      - Reference power plane
    - Socket
- 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
  - Quasi-TEM dominant mode
  - 3D effect (Discontinuity, Split, non-uniformity) not considered
  - Radiation loss not captured
  - Low frequency approximation in extraction
  - No dielectric material (velocity of light C=300,000 km/s)
- High-order mode
  - Group velocity not-equal to phase velocity
  - C = sqrt(V_g . V_p), {V_g = group velocity & V_p = phase velocity}
  - Non-smooth or non-monotonic S-parameters data
  - Impact on the interconnect model
  - How to improve the performance of interconnect
  - Understanding the impact on timing and noise margins

HFSS

- It is a supplementary tool for understanding in advance the new signal integrity issues such as:
  - Split plane,
  - Reference planes (power ←→ ground)
  - Return path discontinuity: (changing of reference plane)
  - Impedance mismatches,
  - Resonance peaks
  - Socket and connector effects
- Goal is to optimizing the impact of the different issues on interconnect model

Impacts of High Frequency Modeling on Interconnections

Jan. 2002 Ansoft HFSS Users Workshop

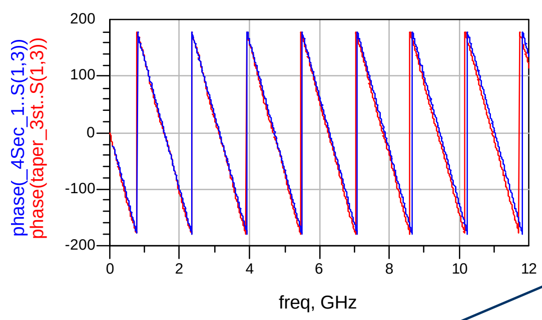
- Mismatches
- Delay
- Stored energy, Reactive Components, (E field and/or H field)
- Resonance peaks
- Unstable responses (Time domain issues)
- Non-passive (frequency domain)

Time & Frequency Domain Simulations

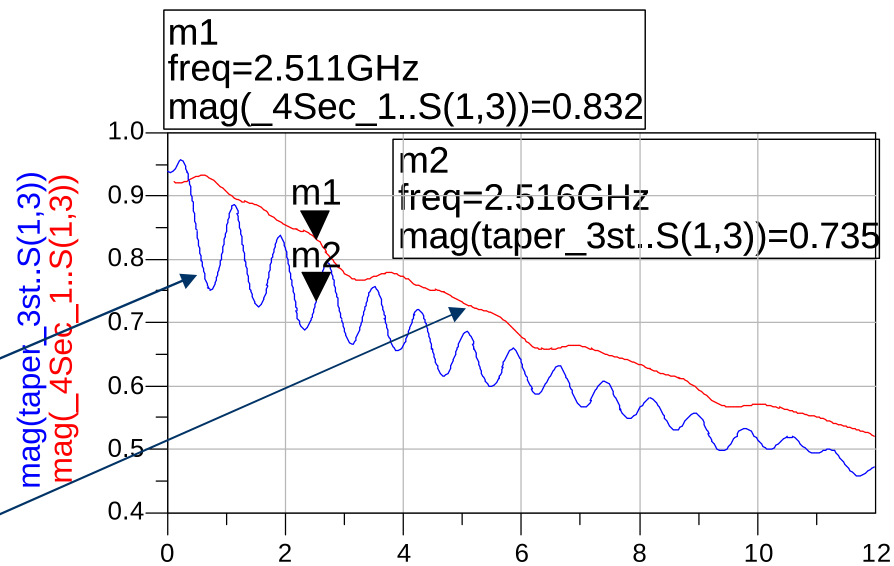
- Time domain parameters (transient simulation)
  - T_co, T_hld, T_su, Jitter & Skew, Characteristic impedance, Cross-talk
- Frequency domain parameters (frequency domain simulation)
  - Near and far end cross-talks
  - Return losses
  - Insertion losses

Tapered Line

- 1.1 dB difference between the two solutions at a particular frequency point (Magnitude)
- No phase disparity up to 8 GHz



HFSS versus ADS



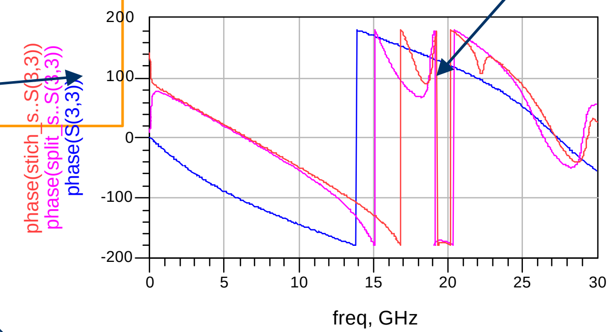
Split Plane

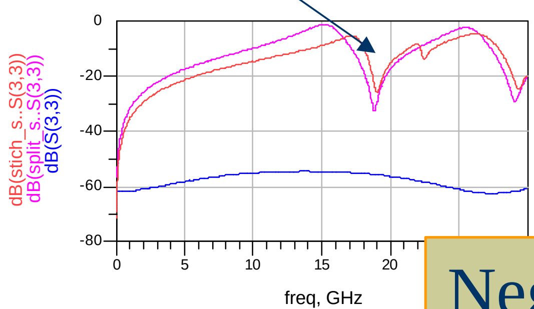
- Short line over split plane
  - Blue; no-split plane
  - Purple; split plane
  - Red; Stitching planes

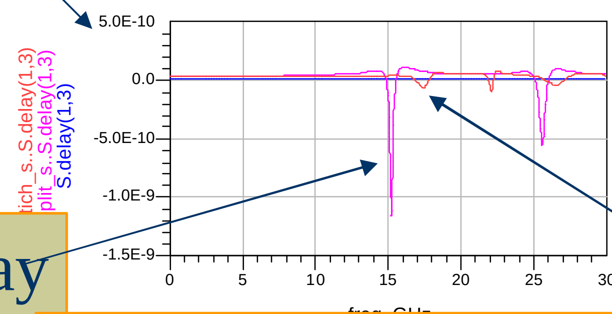
Phase Distortions

HFSS Sims.

Stored Energy







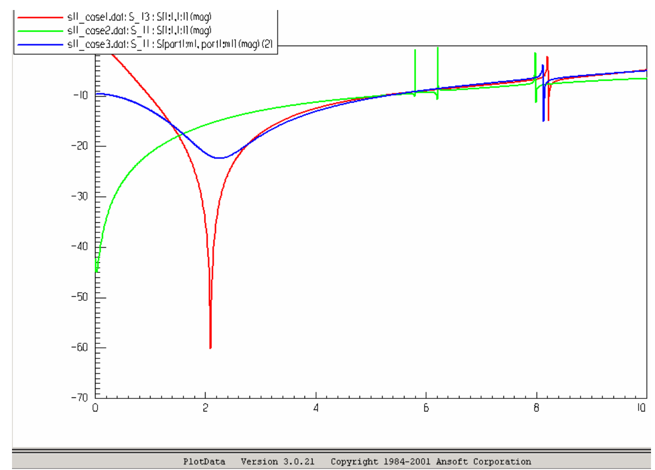
Negative Delay

Negative Delay Reduced by Stitching

Discontinuities

- Reference power plane
  - Notch filtering response at 2.1 GHz(energy is trapped)
  - De-grade the time domain responses
  - Different way of improving such as stitching the two ground planes
  - Number of stitching
  - Signal integrity issues are serious

Blue; improved by lumped cap
Red; reference to power
Green; Short-circuited

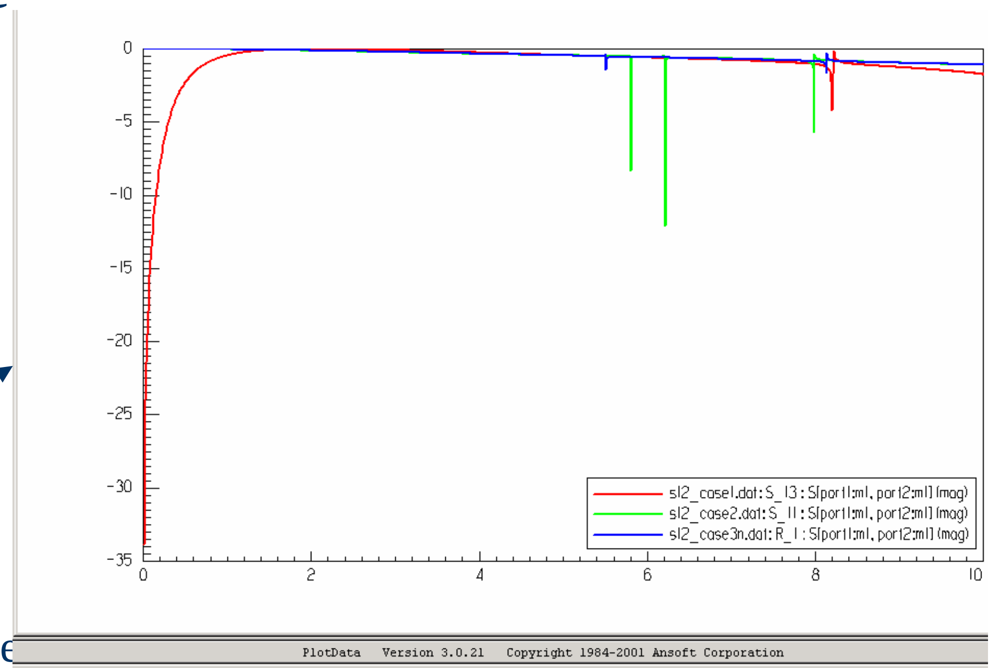


HFSS Sim.

Discontinuities

- Reference power plane
  - Not much effect on S_12
  - Relatively short-line

HFSS Sim.

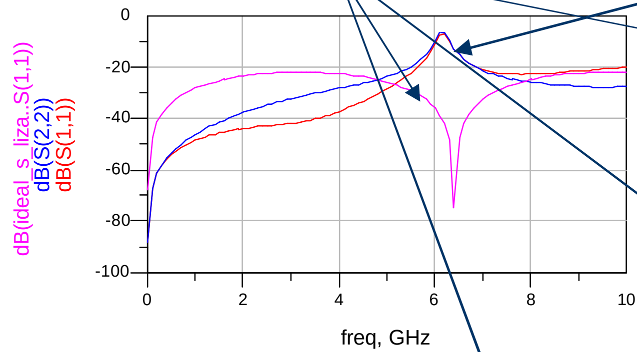


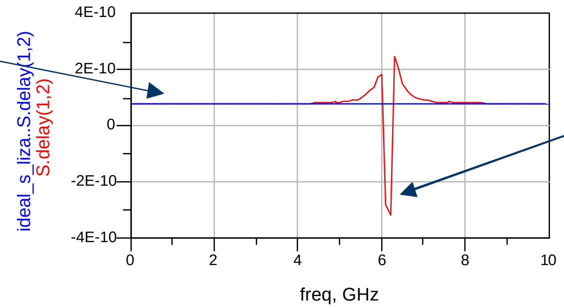
Discontinuities

- Change reference planes

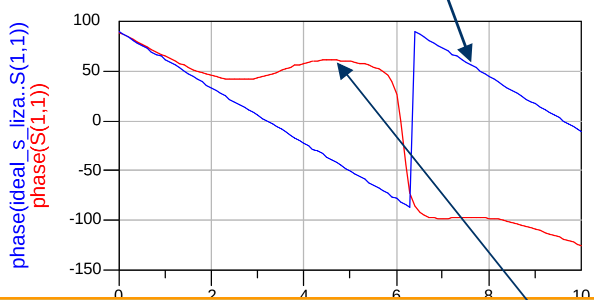
HFSS & ADS Sims.

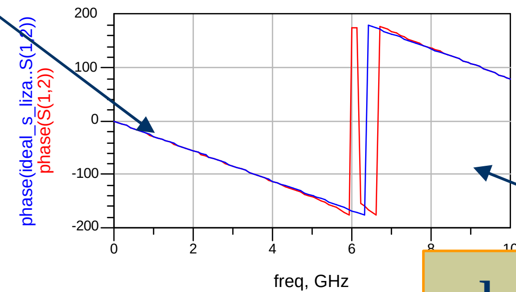
Stored energy (Reactive Component)





Negative Delay



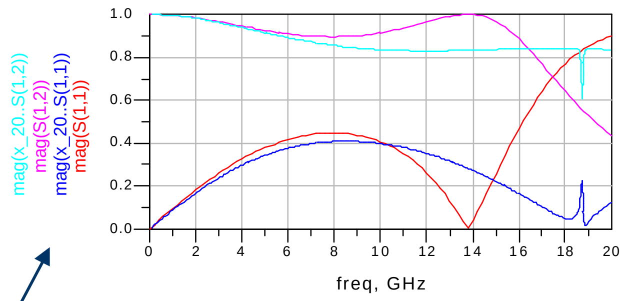


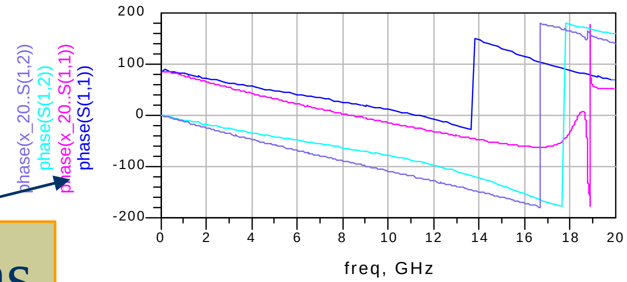
phase velocity Creates delay

Phase distortion (Non-monotonic phase)

Socket

- Lumped spice model is not adequate solution
- High frequency responses truncated
- Phase changes add skew
- Impedance mismatch is an issue



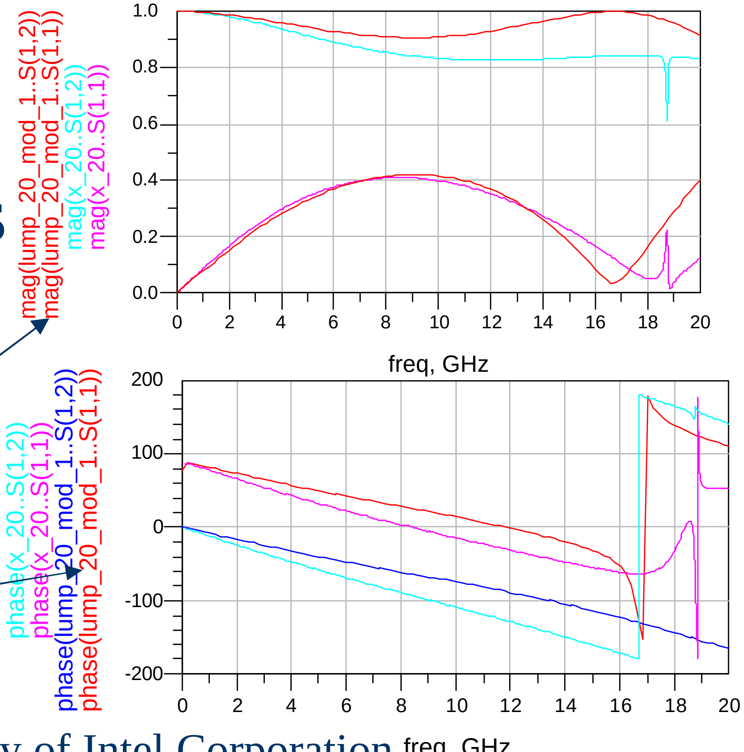


HFSS & ADS Sims

Socket

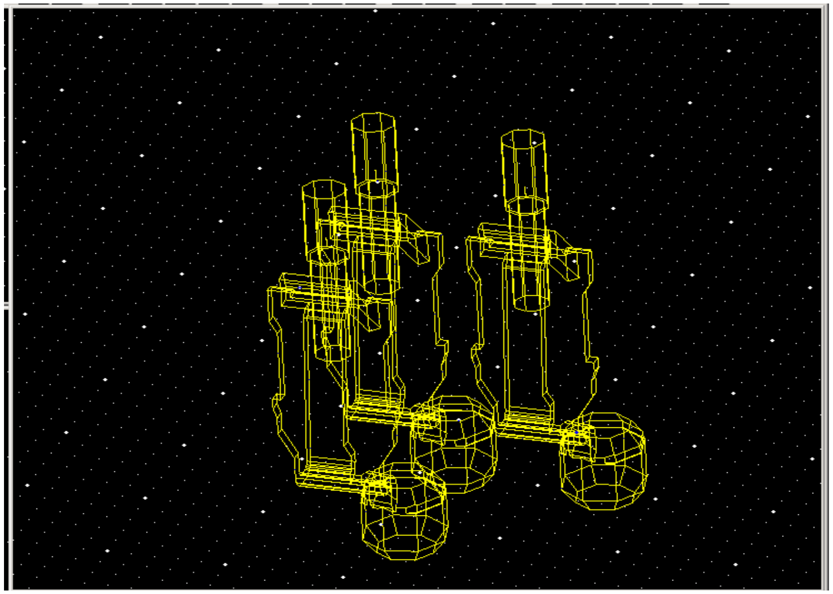
- High frequency solution comprehends all frequencies of interest
- Better phase response
- Low-order model works

HFSS & ADS Sims



Socket

- Two signal lines and one Ground
- Applying De-embedding method to extract S-parameters
- Simulate by HFSS



Conclusions

- In design of high-speed bus, the impacts of high frequency effects are substantial and must be modeled
- Time and frequency domain simulations are required
- Need high frequency modeling tool to understand the impact in advance for resolving non-physical behaviors
- HFSS has been used successfully (S-parameters data)
  - HFSS is not recommended for complete board modeling (very large data base and long simulation times)
- Design tools must evolve to identify high frequency specific failure mechanisms and permit the designer to avoid them

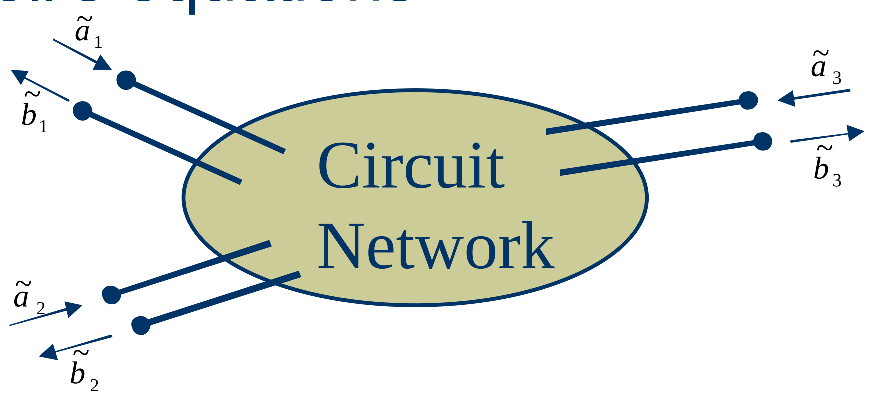
S-parameters

- 3D Full wave Solution

➢ Full-wave (S-parameter) extraction:

- requires no low frequency assumptions or geometry assumptions
- solves fully coupled Maxwell's equations

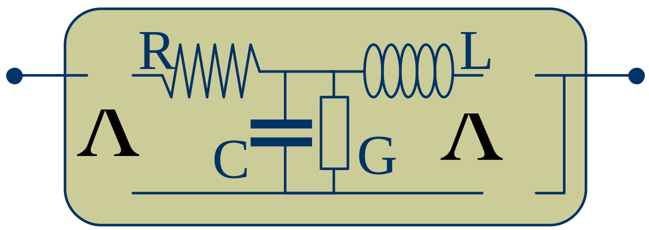
$$[b] = [S][a]$$



➢ Definition of S-parameters

RLCG to S-parameters

- RLCG to S-parameters



$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

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

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

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

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

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

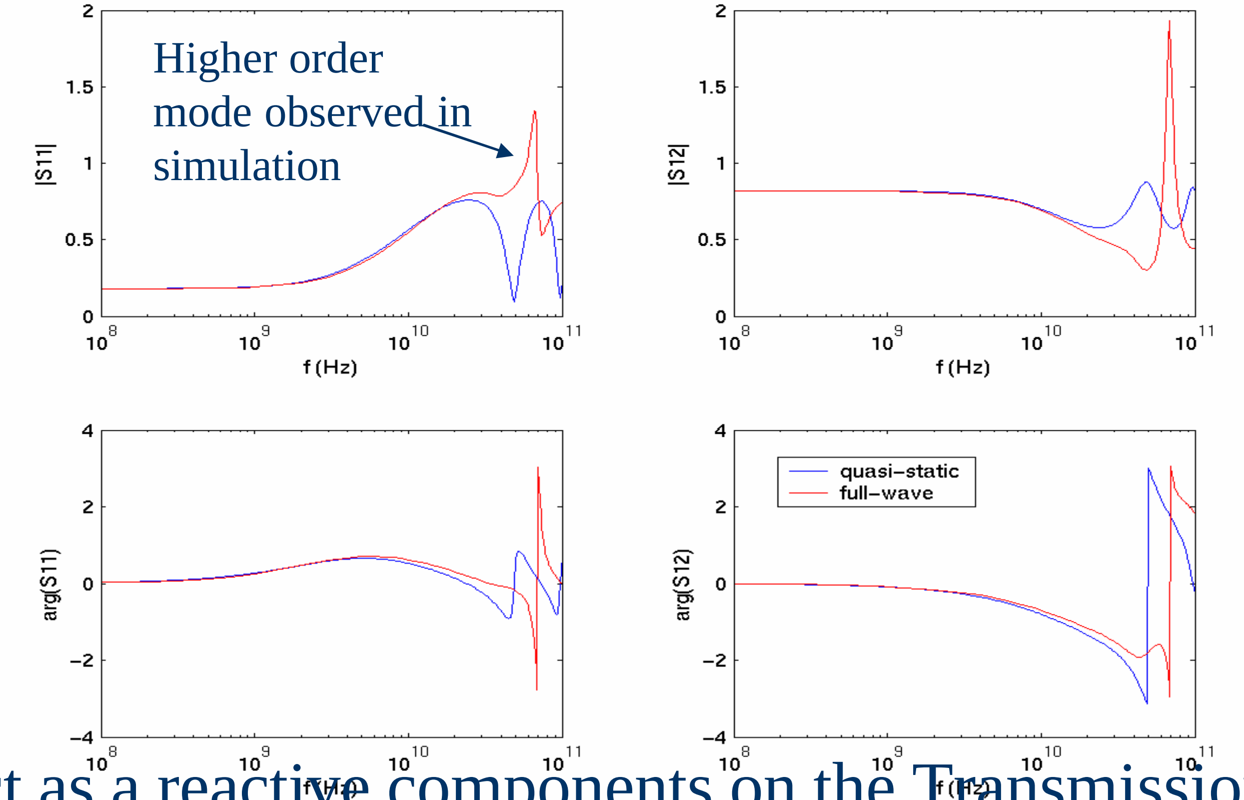
RLCG not uniquely defined in general
Breakdown regime can be identified from frequency-domain results
S-parameters magnitude are finitely bounded within [-1, 1]

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)

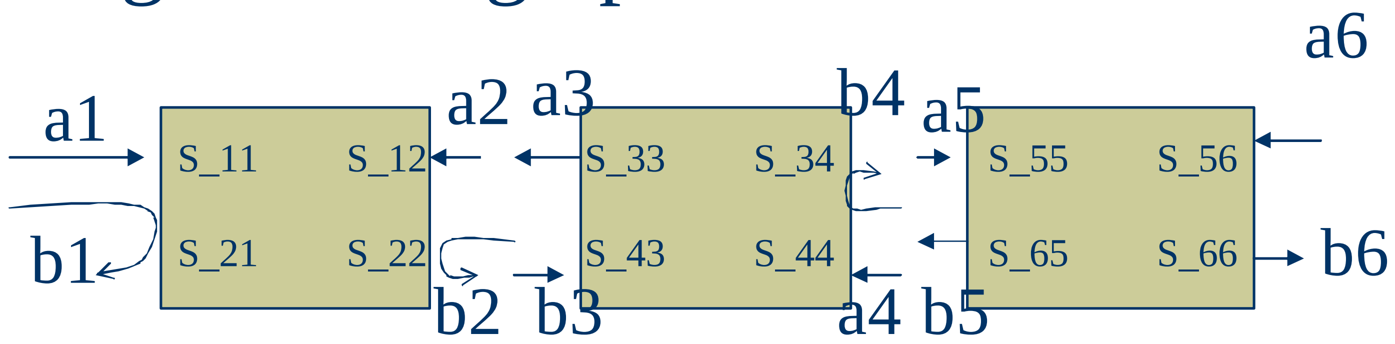
- S-parameters data TEM Model versus Full wave



Dis. act as a reactive components on the Transmission lines

Cascading Networks

- Signal flow graph



S_21.S_43.S_65

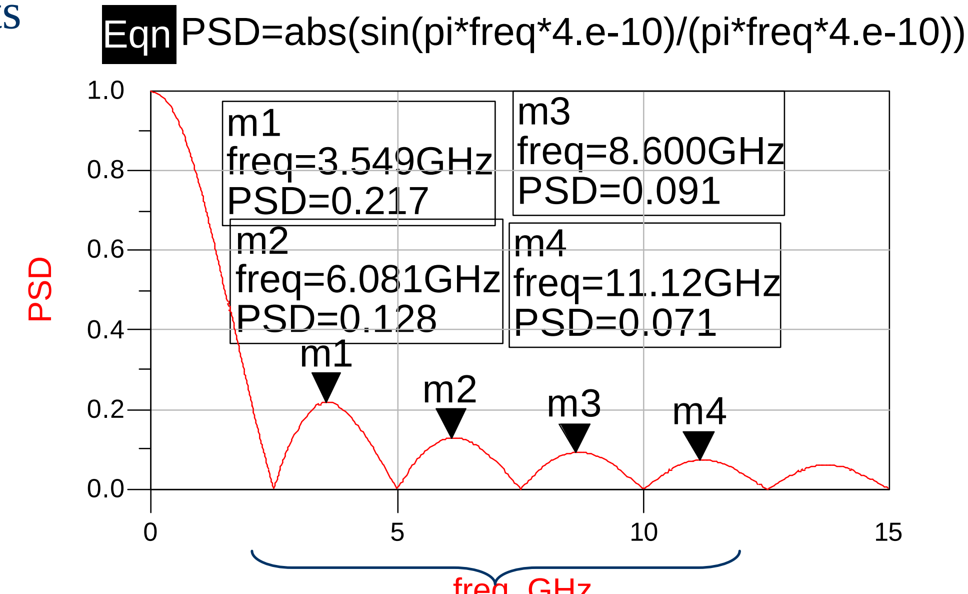
b6/a1 = --

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)