Crossing Transmission Line Modeling Using Two-Port Measurements

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Outline

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Millimeter-Wave Band: 60 GHz

- Large atmospheric attenuation
  - Secure Communication
  - Limited Communication Range

- 9 GHz Unlicensed band
  - Data rates up to 40 Gbps (DVD under a second)
  - Real life wireless data rate:
    - IEEE 802.11n standard, 400 Mbps

*57-66 GHz Unlicensed Frequency Band

Importance of Device Modeling

- Foundry models not valid at mm-Wave
- Prediction of TRX Performance
- Devices To be modeled
  - Transmission Lines
  - Capacitors, Inductors, Resistors
  - Transistors, Tee-junctions
  - Baluns, couplers, crossing TLs
Issues of Multi-Port Measurements

- Most common VNAs Two-Port
- Differential Excitation Measurements
  - De-Embedding of GSSG pads cumbersome
  - Unwanted crosstalk and coupling effects
  - Increased number of TEGs
- Differential and Single Excitation Measurements
  - Decreased Dynamic Range of Instrumentations*
    - Two-port → 110 to 120 dB Dynamic Range up to 110 GHz
    - Four-port → 80 dB after 67 GHz to 110 GHz

Possible Solutions:
- One-Port Measurements
- Two-Port Measurements

*Agilent Technologies, Network Analyzers’ Data Sheets
http://www.home.agilent.com/agilent/
Previous Works – I

*Three-Port Balun Characterization

- One-Port Measurements
- Single End Measured
- Seven Structures
- Knowledge on Loads necessary

**Switching Network (SN): Four-Port

- Knowledge on one load
- All Two-Port Combinations with a SN
- Coaxial Applications
- Not cost effective for CMOS

*Issakov et al., EuMC 2011
**Rolfes and Schiek, MTT 2005
Previous Works – II

*Virtual Auxiliary Method:
TEG and Calibration Structures for non-coaxial applications

😊 Without terminations of other ports

😡 Optimized S-parameters for four different loads

😡 Several Data Manipulations: Glitch Removal, Fixing the ill-conditioned results

*Chen and Chu, MTT 2007
Crossing Transmission Line

Crossing area: 17 \( \mu \text{m} \times 17 \mu \text{m} \)
- Too small for measurement w/o cross-talk
TEGs and Methodology
Model and Method of Modeling
Results: Model Extraction

![Graphs showing comparison between measured and modelled results for S11 and S21 magnitudes and phases.](image)
Lumped Equivalent Model

- $L_{UP} = 2.86$ pH
- $R_{UP} = 0.18$ Ω
- $C_{UP} = 105$ fF
- $L_{LW} = 2.13$ pH
- $R_{LW} = 0.27$ Ω
- $C_{LW} = 175$ fF
- $C_1 = 2.05$ fF
- $C_2 = 0.05$ fF
- $C_{COUP} = 1.64$ fF
CTL S-Parameters Responses
Model and Method of Verification
Results: Verification

(c)

(d)

S\text{11} \text{Magnitude (dB)}

S\text{11} \text{Phase (Degree)}

S\text{21} \text{Magnitude (dB)}

S\text{21} \text{Phase (Degree)}
Conclusion

- Simple model
  - Ideal lumped components (all linear simple devices)
  - Can be used in SPICE environment
- Well-matched with measurement results
  - Error between measurements and model up to $110 \text{ GHz} < 1\%$
- Loose coupling: Coupling capacitor value around $1.6 \text{ fF}$