Crossing Transmission Line Modeling Using Two-Port Measurements

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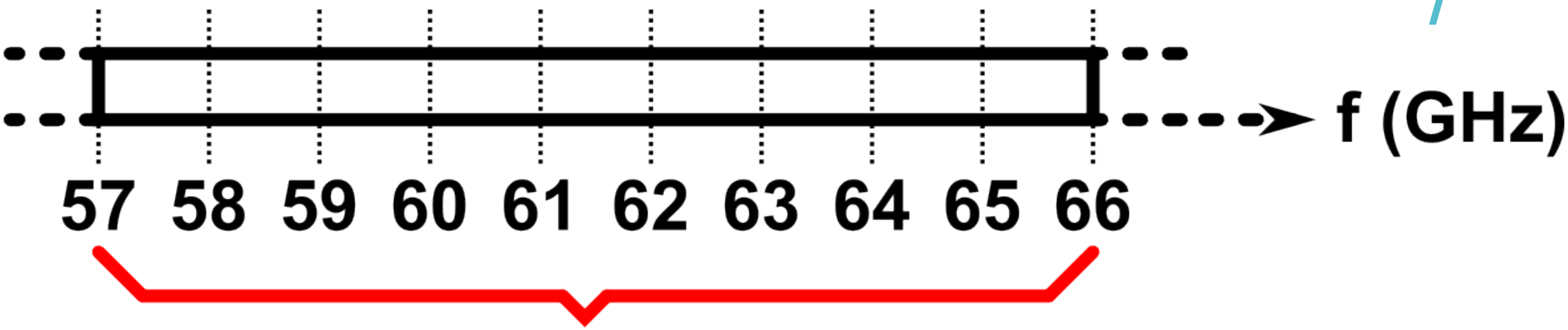
Outline

- Background
- Motivation
  - Importance of device modeling
  - Issues of Multi-Port Measurements
  - Previous Works
- Crossing Transmission Line
  - Methodology
  - Model
  - Results
- Conclusion

Millimeter-Wave Band: 60 GHz



*57-66 GHz Unlicensed Frequency Band

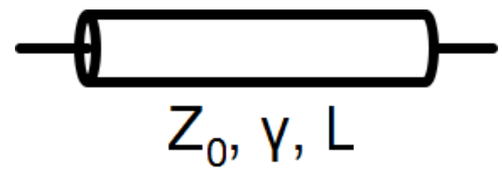
- Large atmospheric attenuation
  - ☺ Secure Communication
  - ☹ Limited Communication Range
- 9 GHz Unlicensed band
  - Data rates up to 40 Gbps (DVD under a second)
  - Real life wireless data rate:
    IEEE 802.11n standard, 400 Mbps

*http://www.tele.soumu.go.jp/resource/e/search/share/2008/t3.pdf

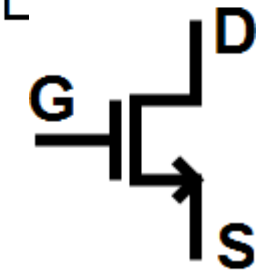
Importance of Device Modeling

- Foundry models not valid at mm-Wave
- Prediction of TRX Performance
- Devices To be modeled

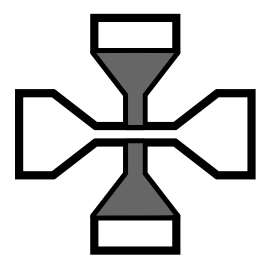
  - Transmission Lines



  - 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

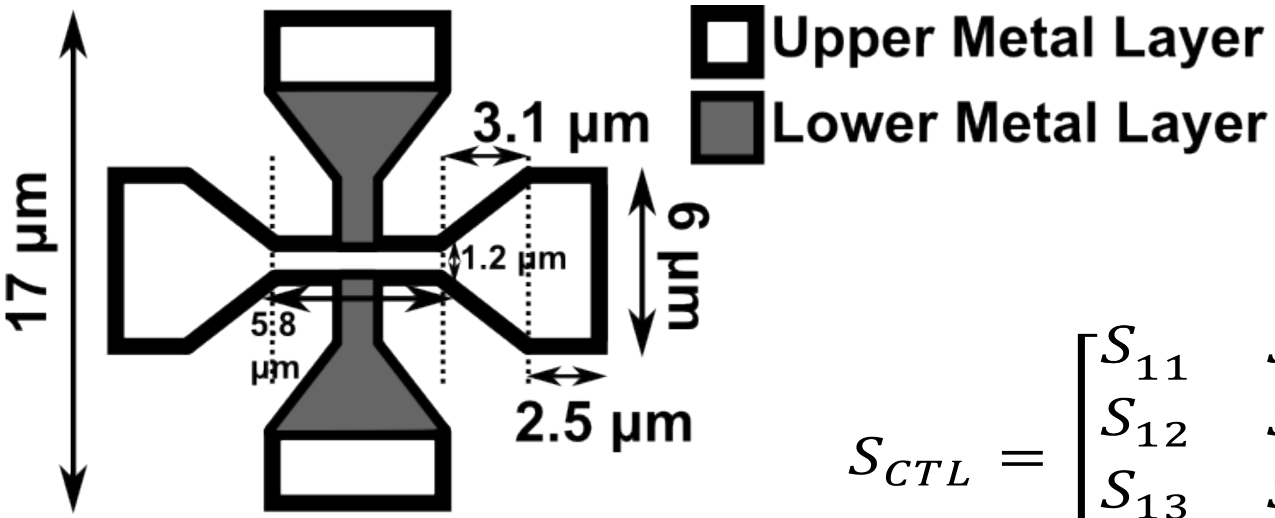
☺ Without terminations of other ports

☹ Optimized S-parameters for four different loads

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

*Chen and Chu, MTT 2007

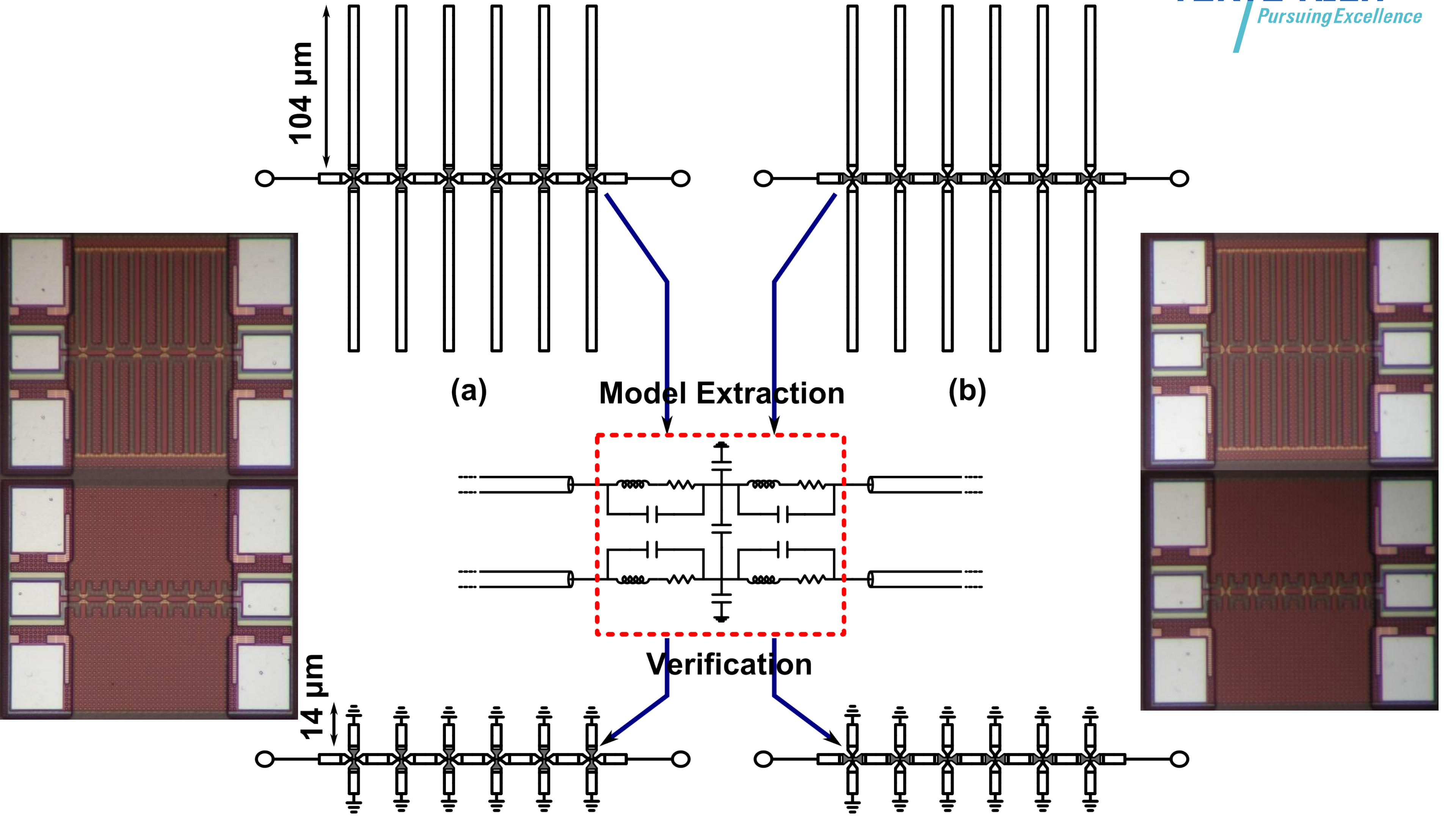
Crossing Transmission Line



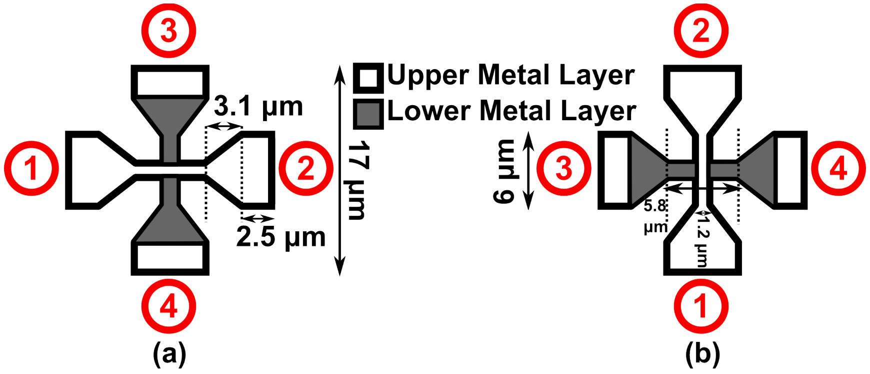
$$S_{CTL} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{13} \\ S_{12} & S_{11} & S_{13} & S_{13} \\ S_{13} & S_{13} & S_{33} & S_{34} \\ S_{13} & S_{13} & S_{34} & S_{33} \end{bmatrix}$$

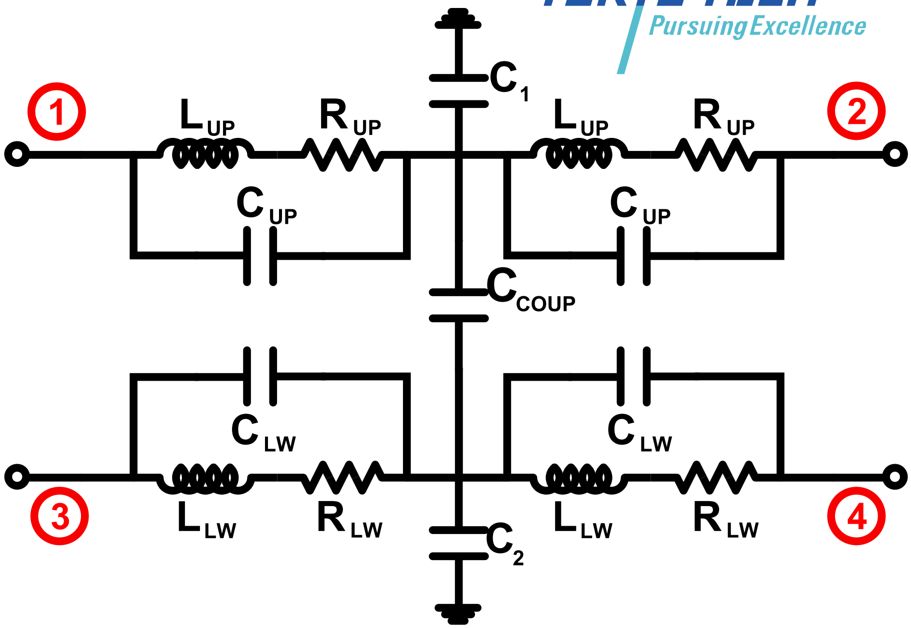
- Crossing area: 17 µm x 17 µm
  - Too small for measurement w/o cross-talk

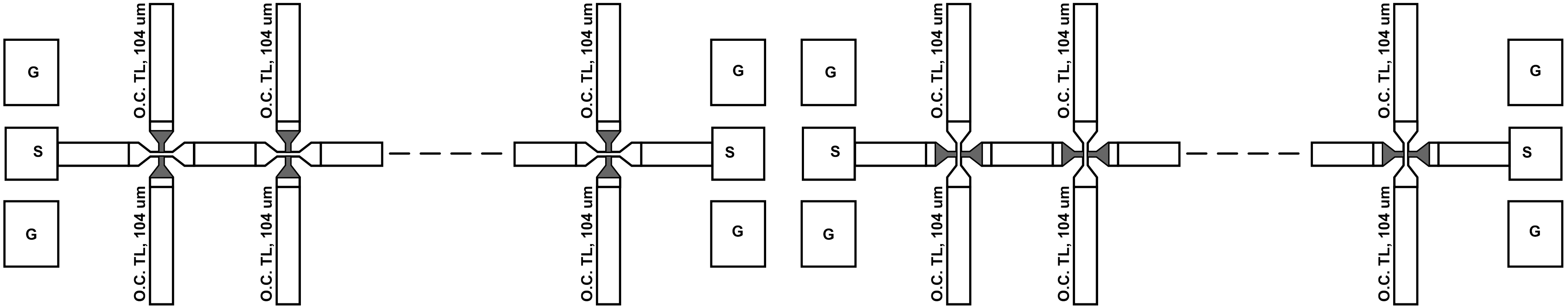
TEGs and Methodology



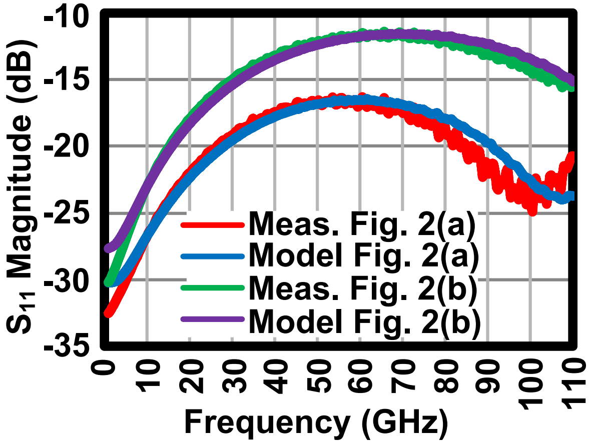
Model and Method of Modeling

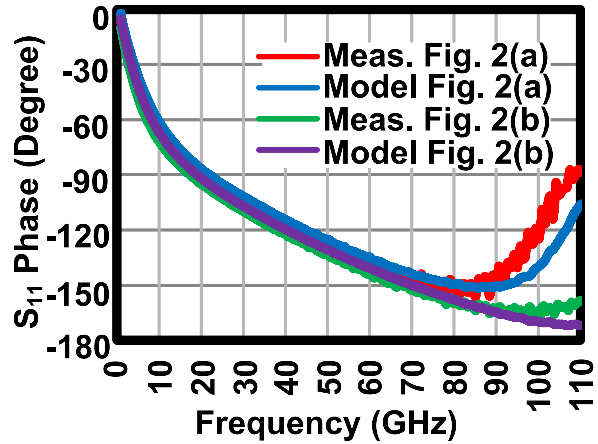


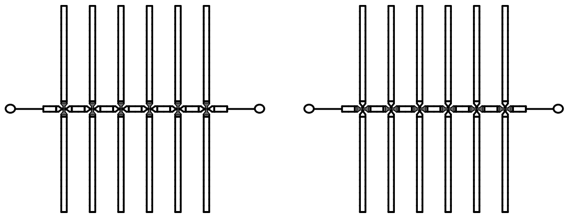




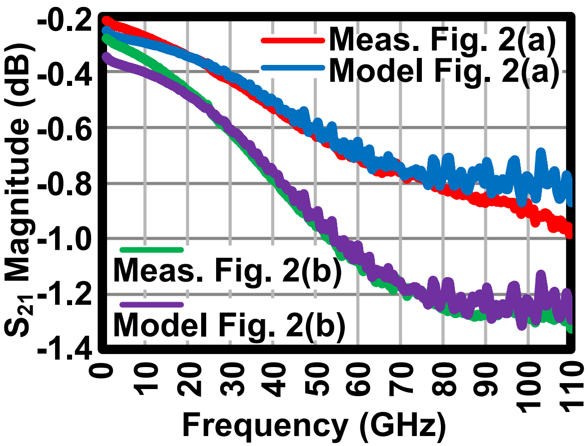
Results: Model Extraction

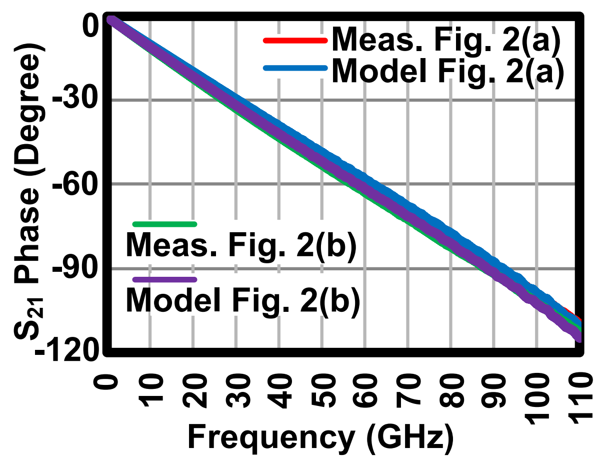




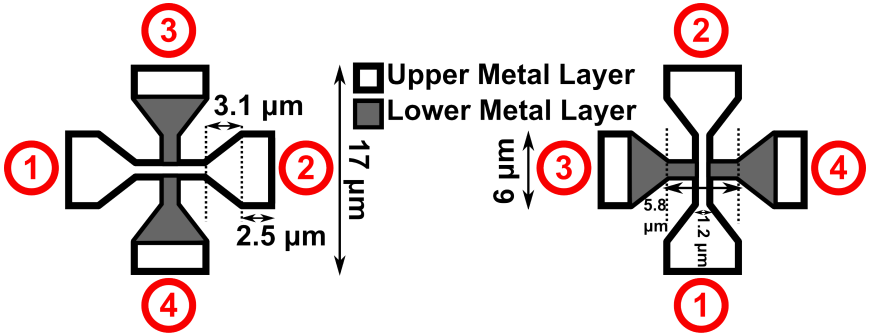


(a) (b)

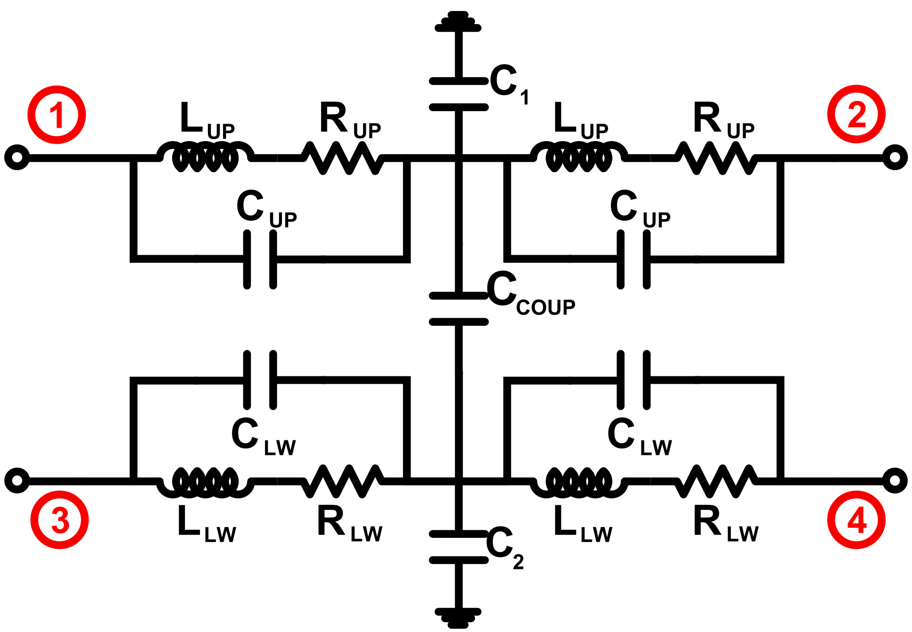




Lumped Equivalent Model

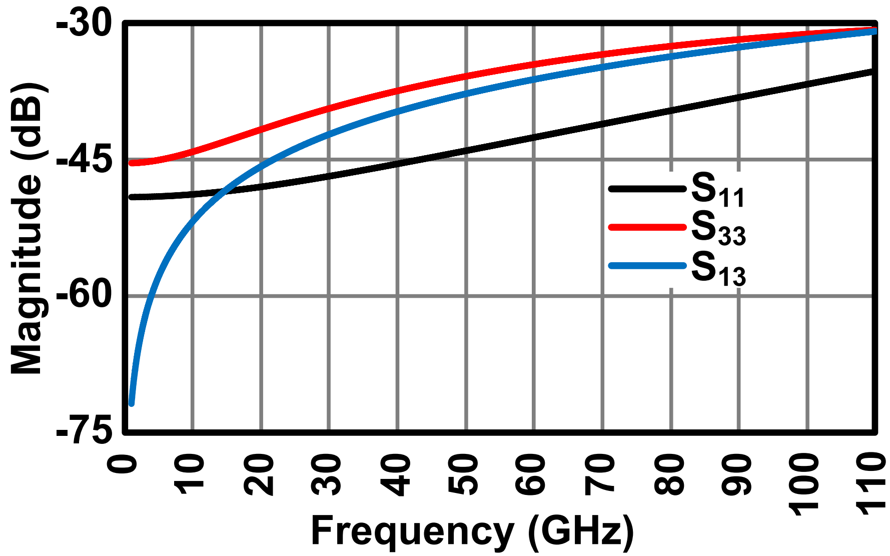


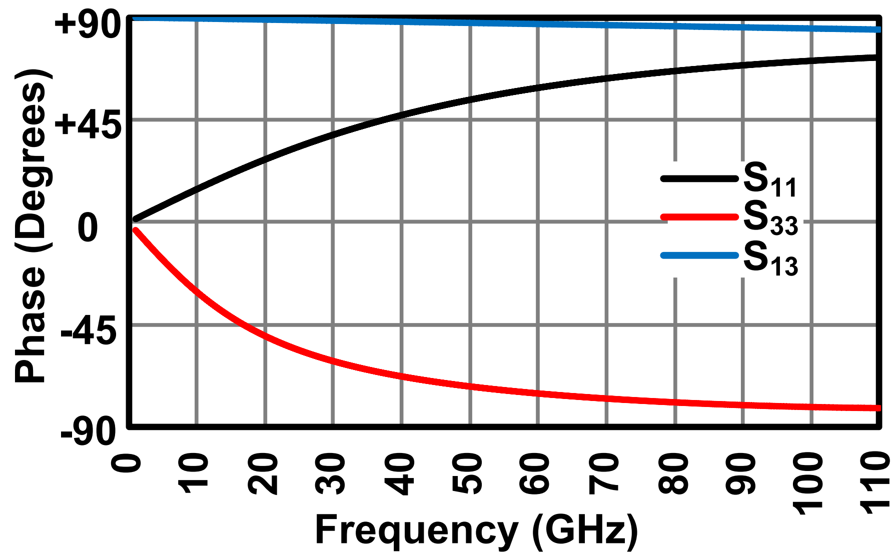
(a) (b)

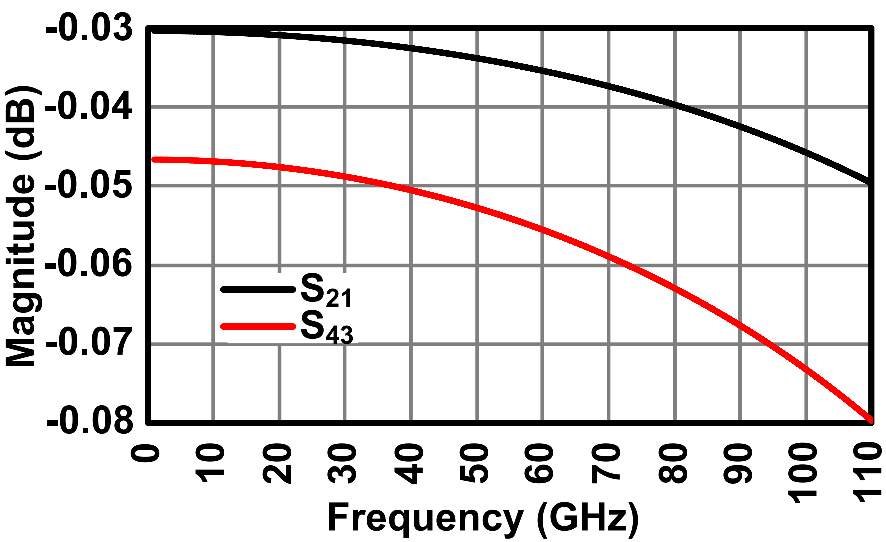


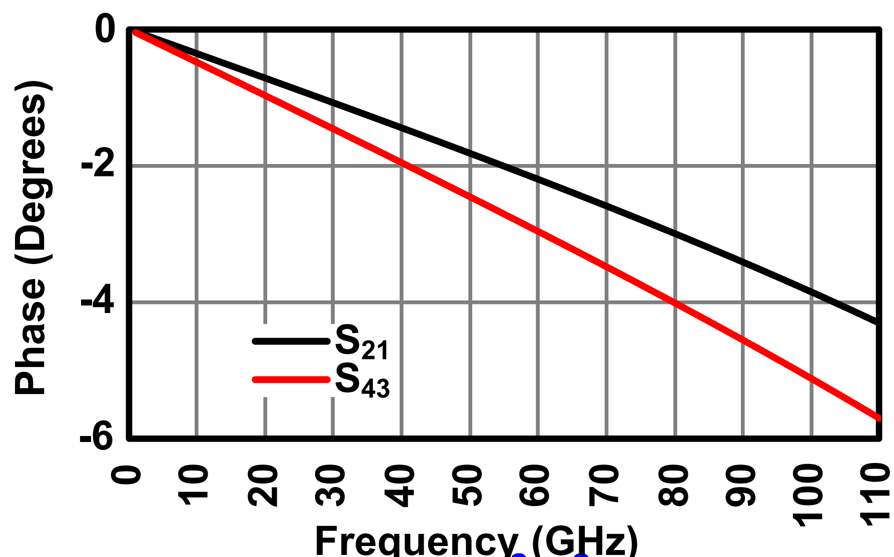
- L_{UP} = 2.86 pH
- R_{UP} = 0.18 Ω
- C_{UP} = 105 fF
- L_{LW} = 2.13 pH
- R_{LW} = 0.27 Ω
- C_{LW} = 175 fF
- C_1 = 2.05 fF
- C_2 = 0.05 fF
- C_{COUP} = 1.64 fF

CTL S-Parameters Responses

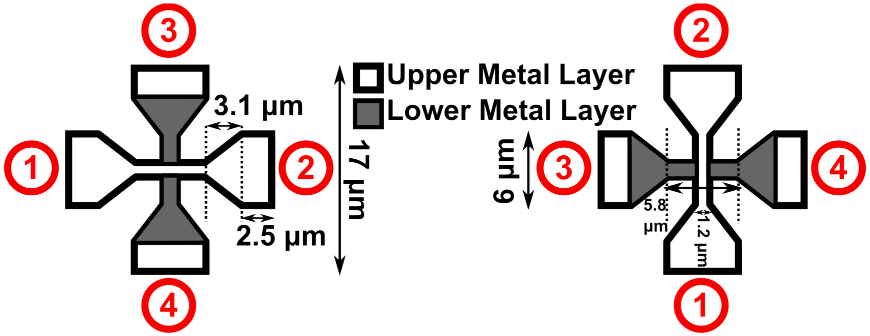




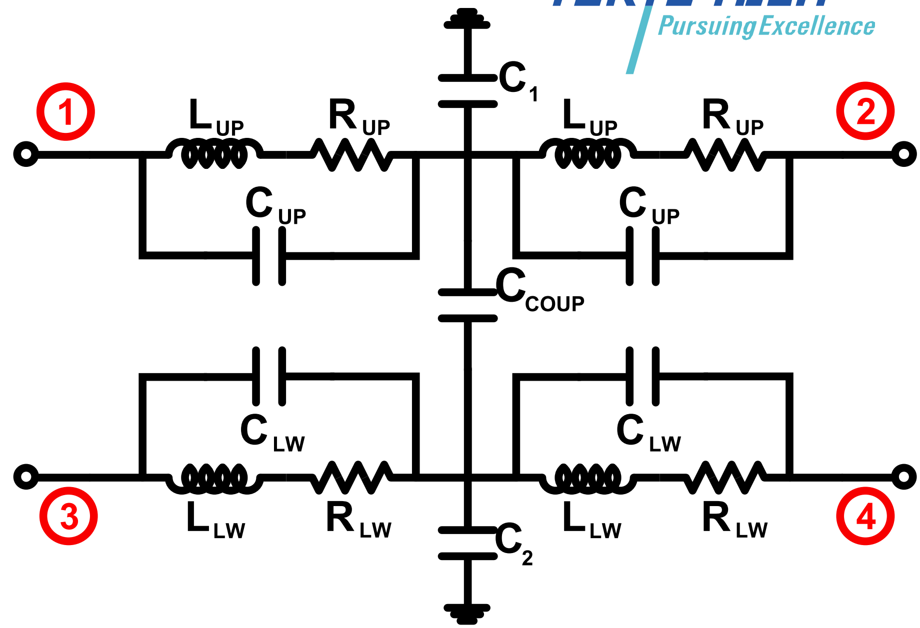


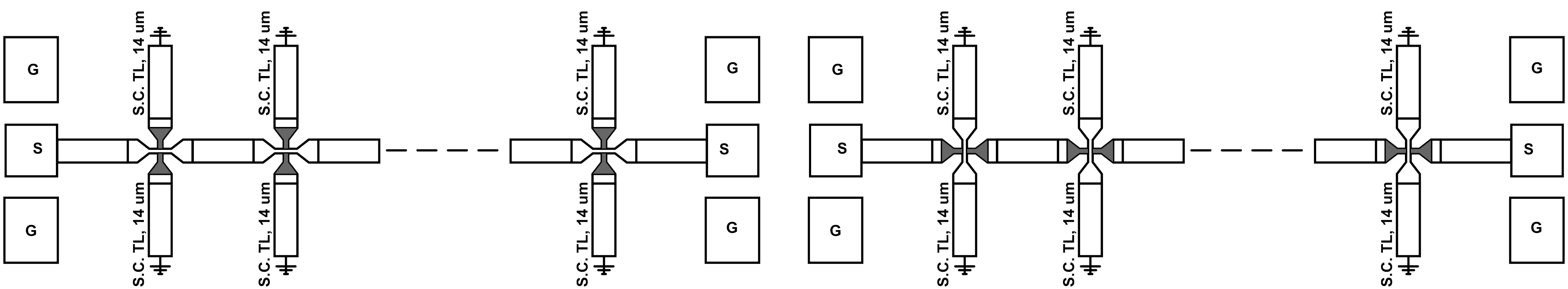


Model and Method of Verification

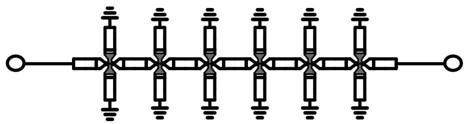


(a) (b)

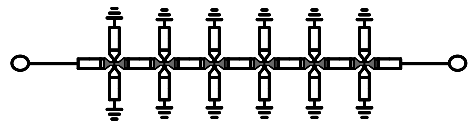




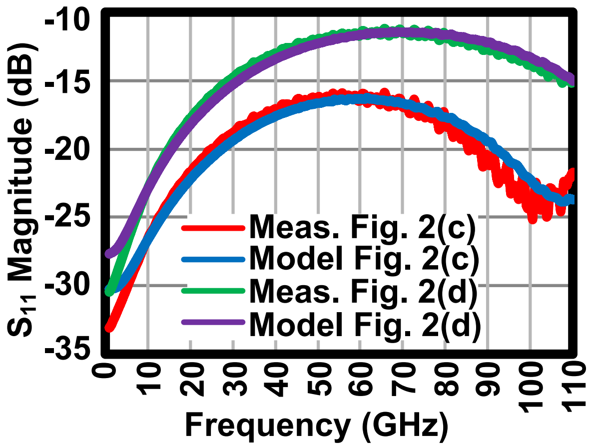
Results: Verification

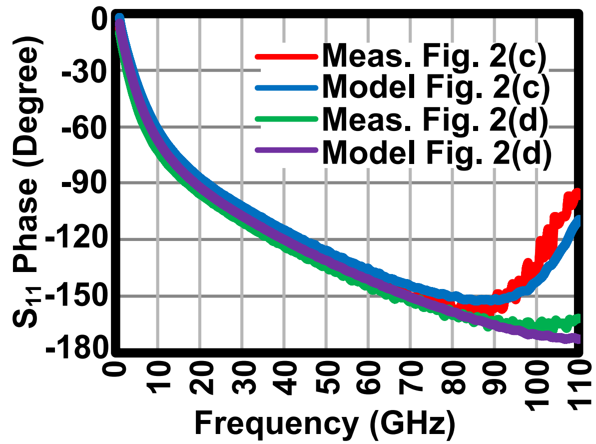


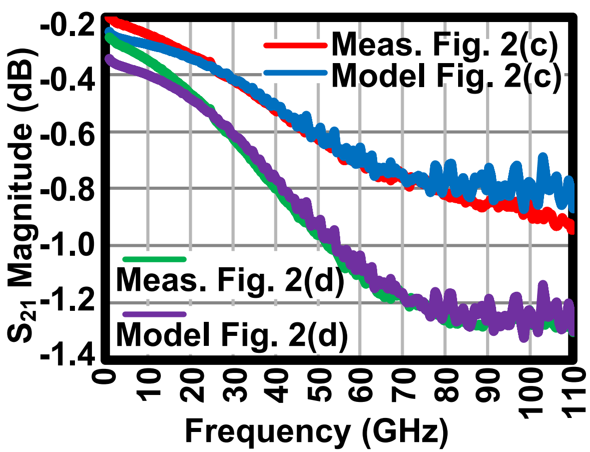
(c)

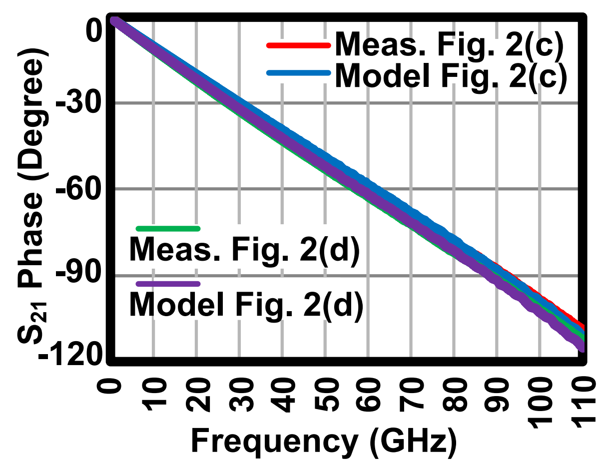


(d)









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 GHz < 1%
- Loose coupling: Coupling capacitor value around 1.6 fF