Crossing Transmission Line Modeling Using Two-Port Measurements

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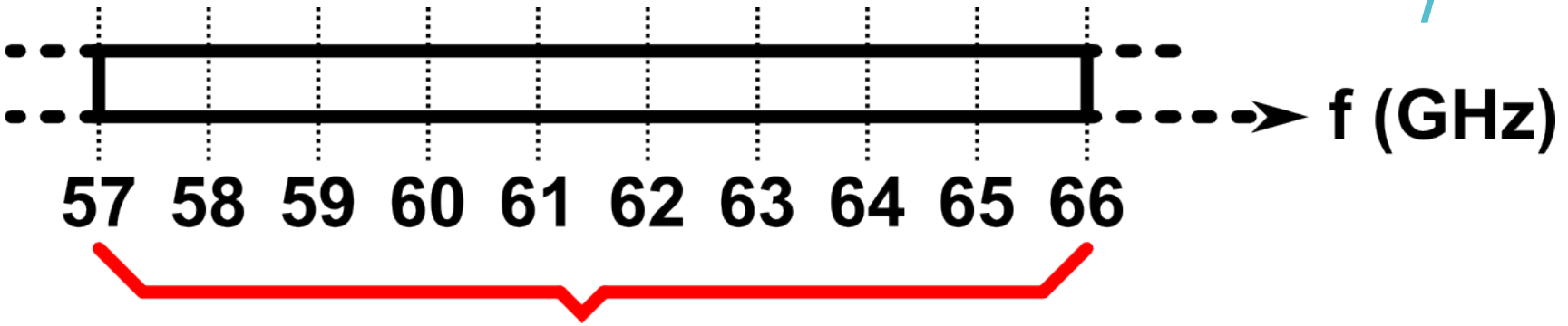
Outline

- 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



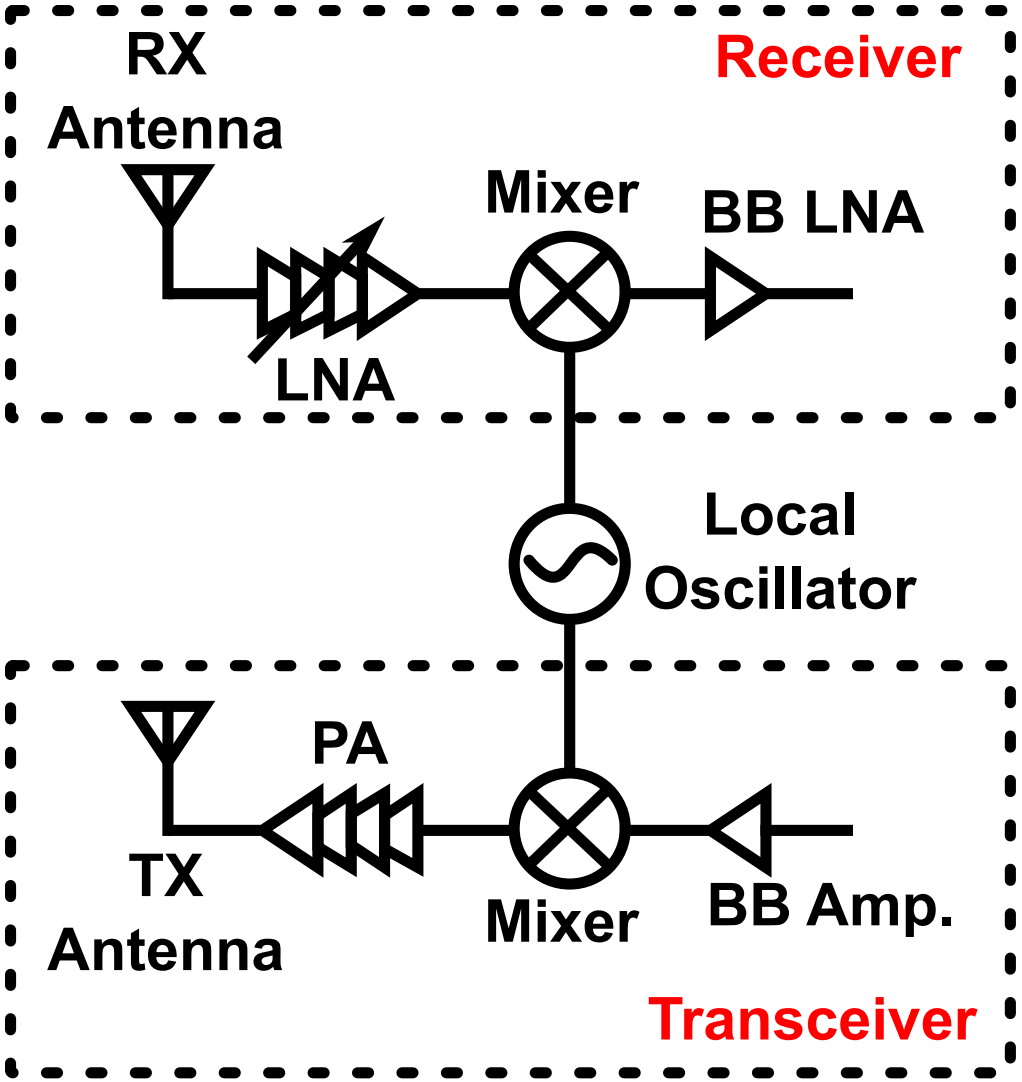
*57-66 GHz Unlicensed Frequency Band

- 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
- Large atmospheric attenuation
  - ☺ Secure Communication
  - ☹ Limited Communication Range

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

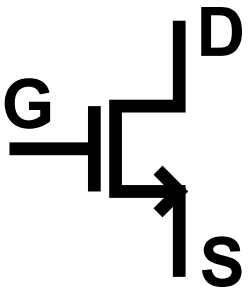
Why CMOS?

- Cost
- Monolithic Implementation
- Well-Known Technology
- Continuous Advancements

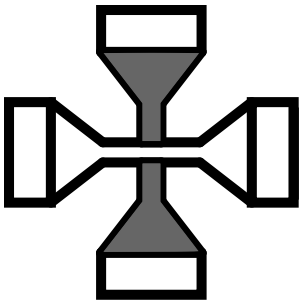


Importance of Device Modeling

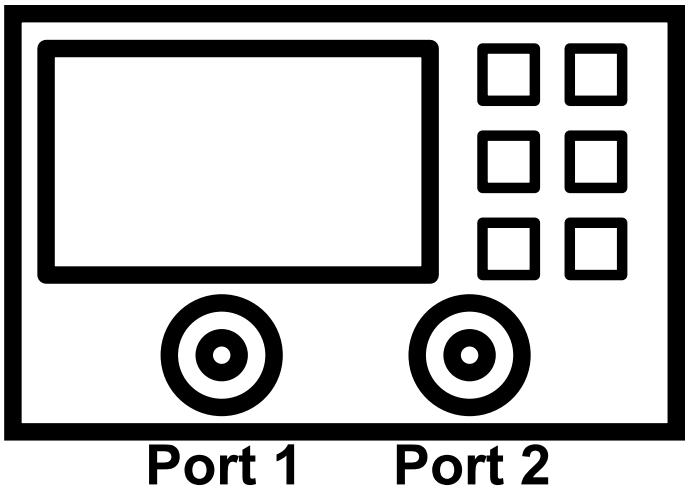
- Foundry models not valid at mm-Wave
- Prediction of TRX Performance
- Devices To be modeled
  - Transmission Lines
  - Capacitors, Inductors, Resistors
  - Transistors, Tee-junctions
  - Baluns, couplers, crossing TLs

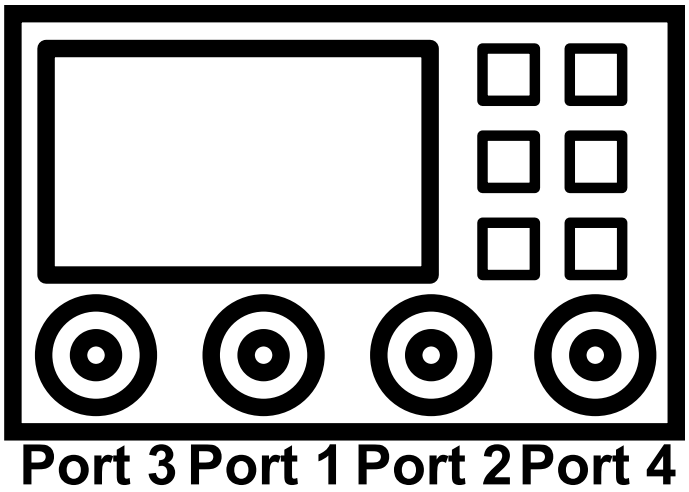


Z_0, γ, L



Issues of Multi-Port Measurements – I

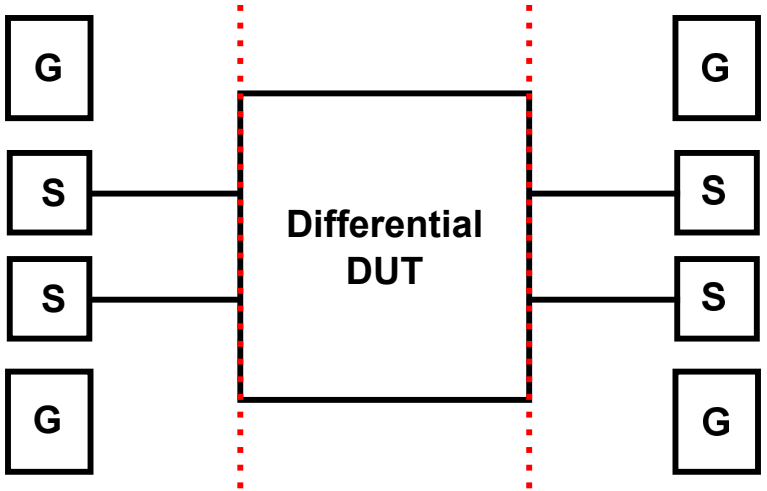




- Most common VNAs Two-Port
- Four-Port Measurements
  - Decreased Dynamic Range of Instrumentations*
    - Two-port→110 to 120 dB Dynamic Range up to 110 GHz
    - Four-port→80 dB after 67 GHz to 110 GHz

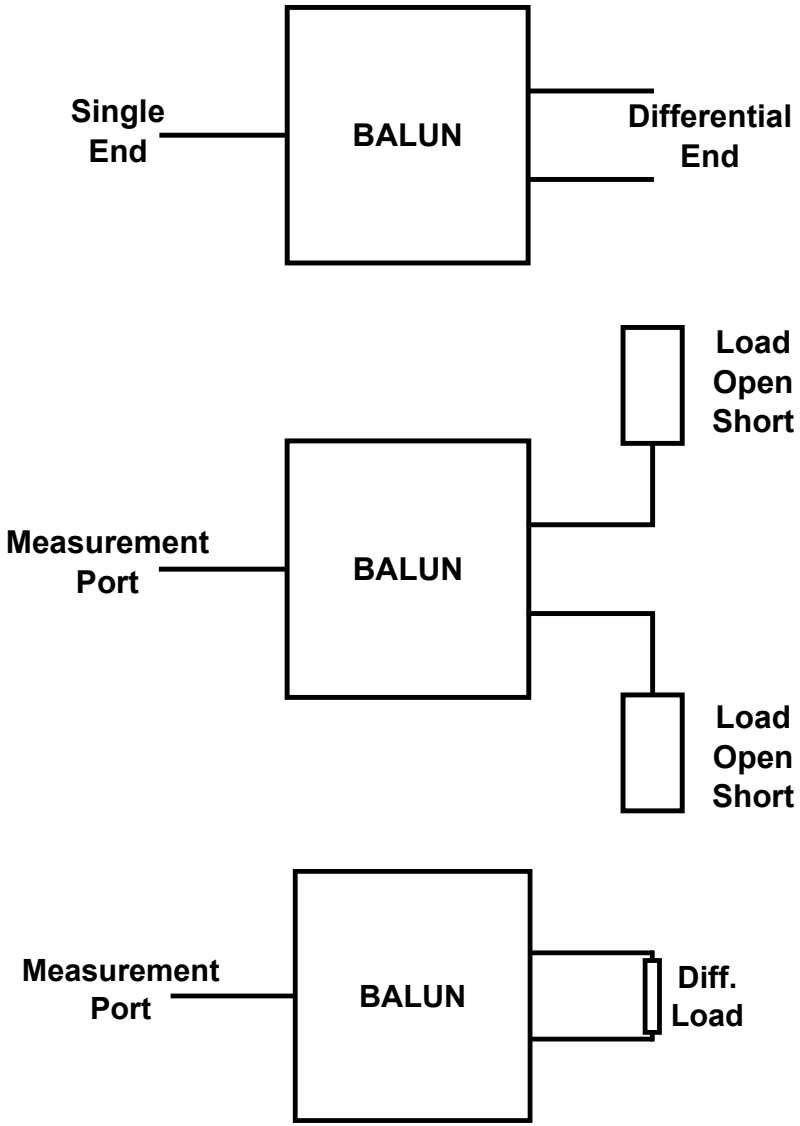
*Agilent Technologies, Network Analyzers' Data Sheets
http://www.home.agilent.com/agilent/

Issues of Multi-Port Measurements – II



- Differential Excitation Measurements
  - De-Embedding of GSSG pads: Hard Task
  - Unwanted crosstalk and coupling effects
  - Increased number of TEGs
- Possible Solution: Two-Port VNA Measurements
  - One-Port Measurements
  - Two-Port Measurements

Previous Work – I

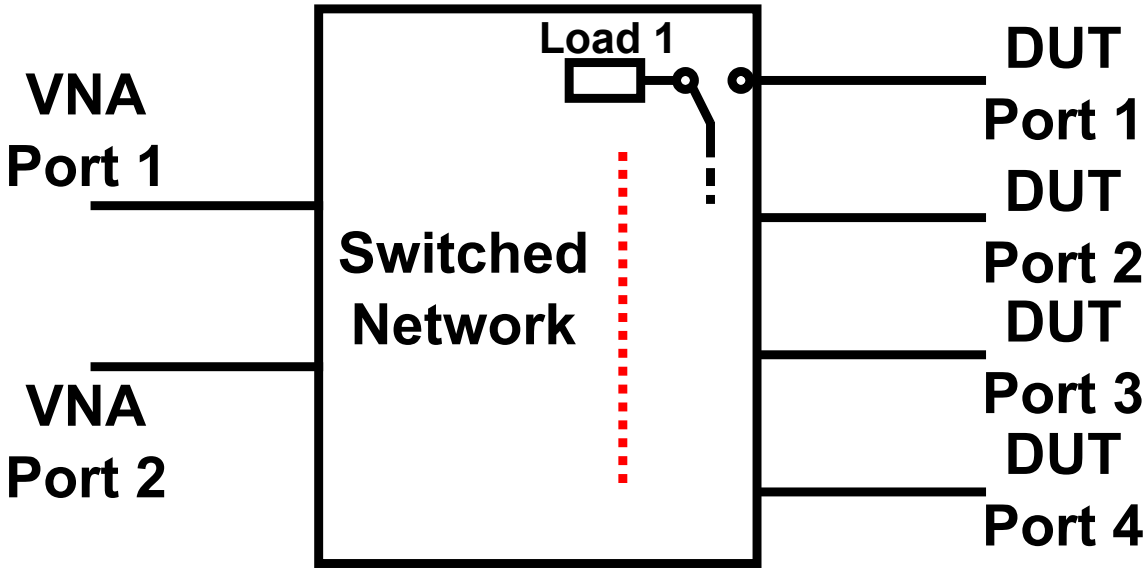


***Three-Port Balun Characterization**

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

*V. Issakov , European Microwave Conference 2011, p.305.

Previous Work – II

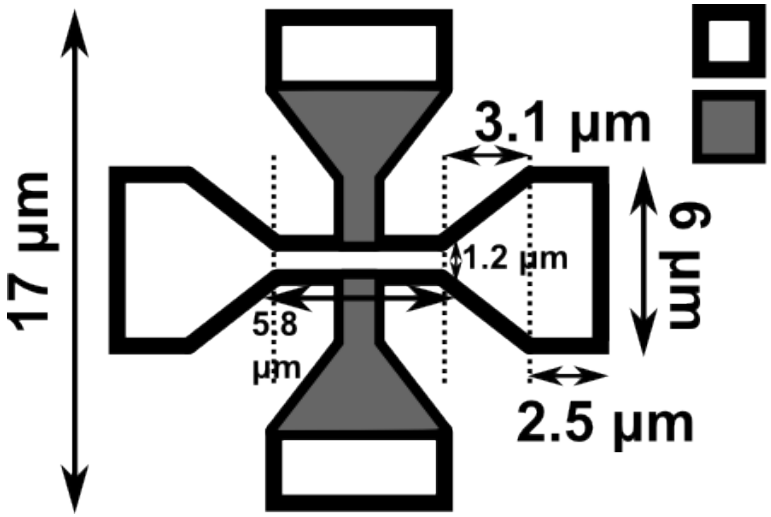


***Switching Network (SN): Four-Port**

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

*Rolfes and Schiek, IEEE Microwave Theory and Tech. **53** (2005) 1990.

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

Model and Method of Modeling

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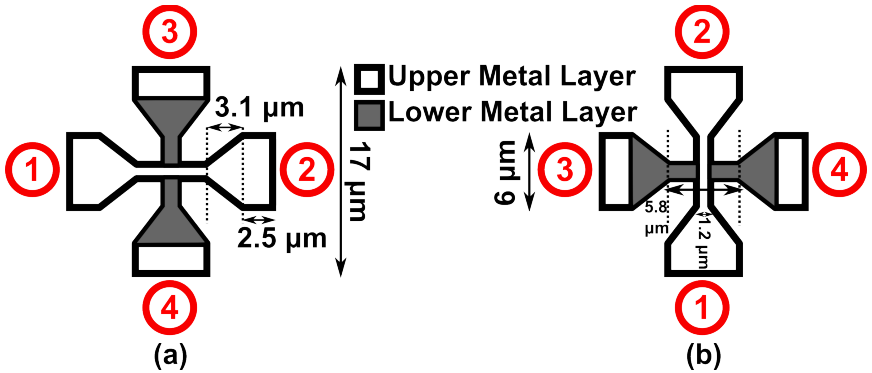

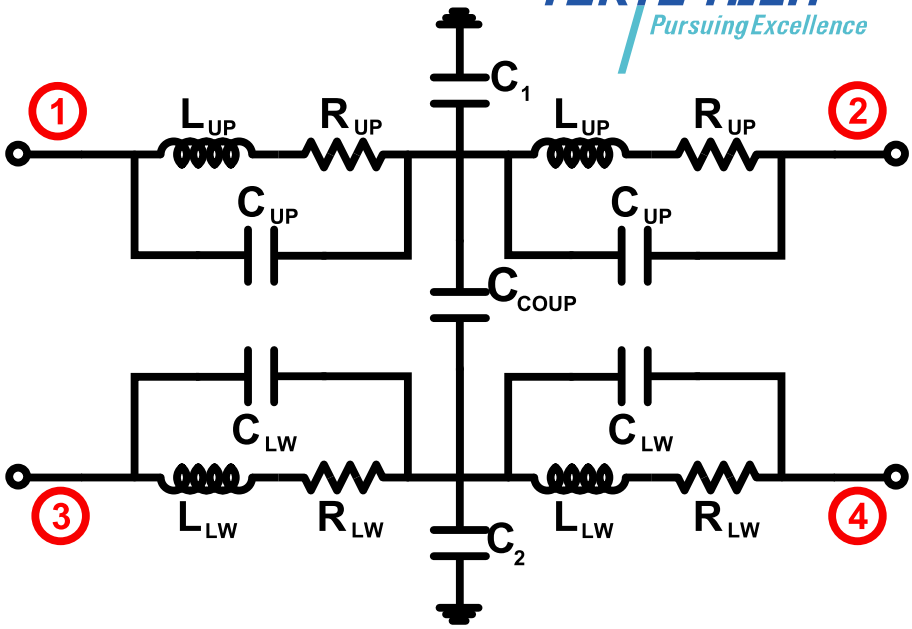

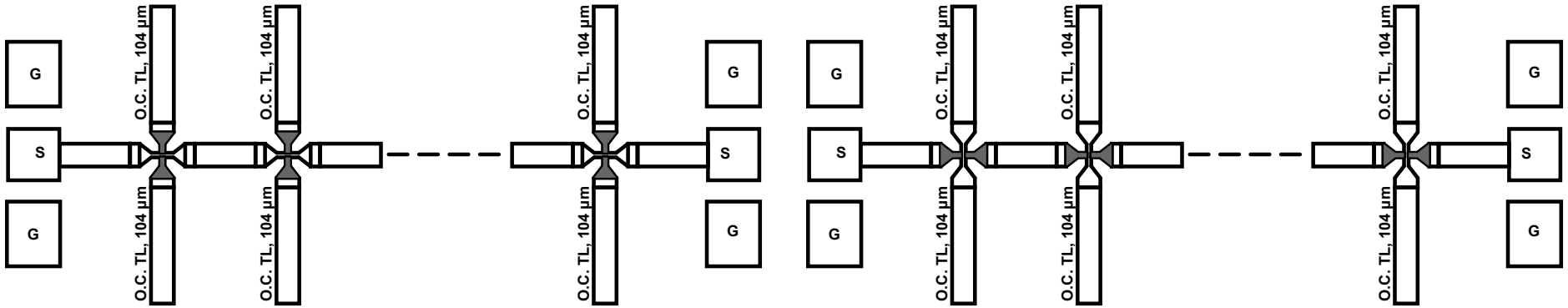

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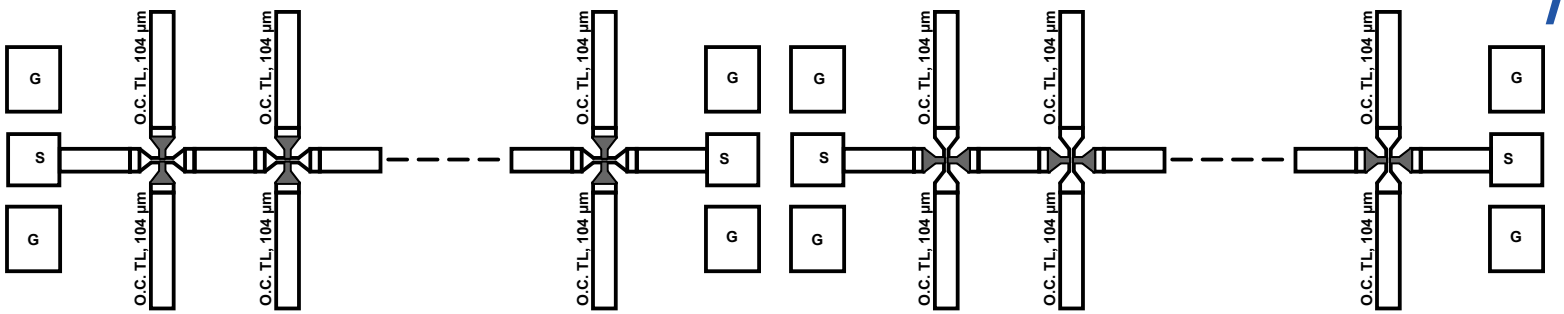
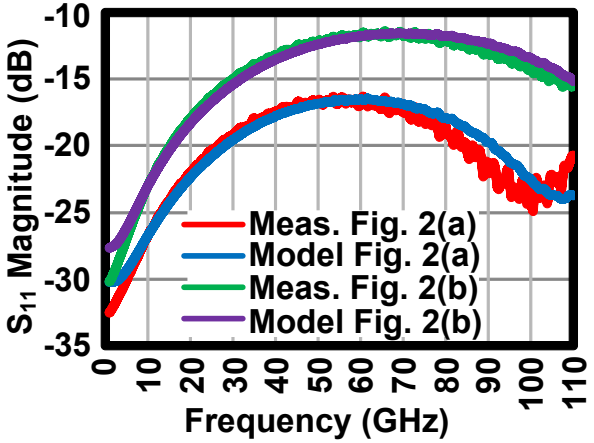
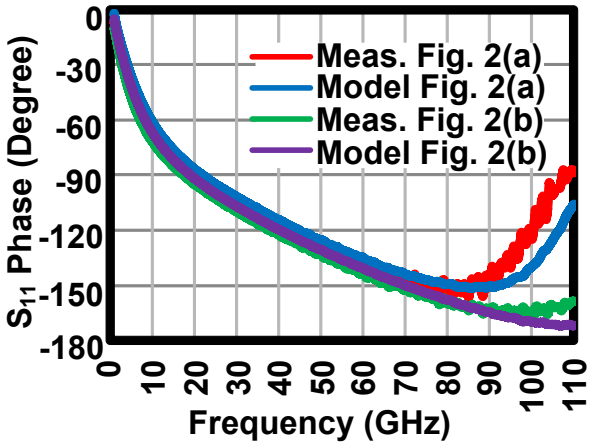
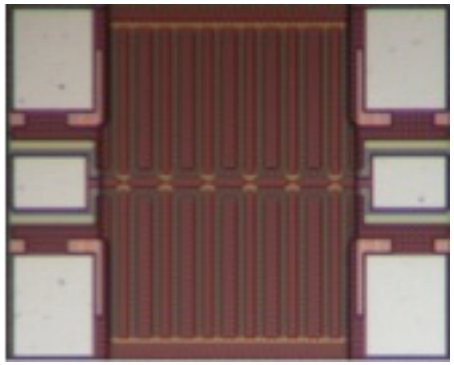
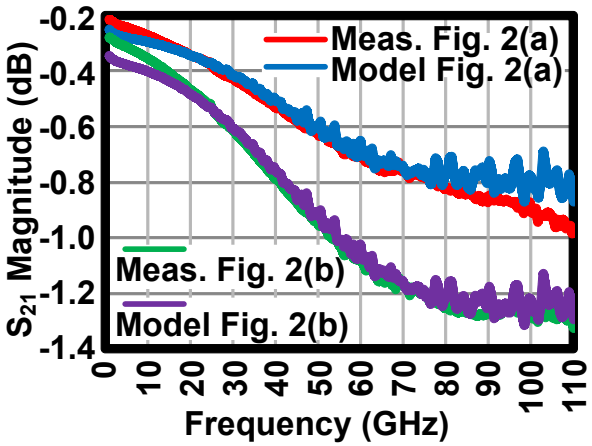
Results: Model Extraction

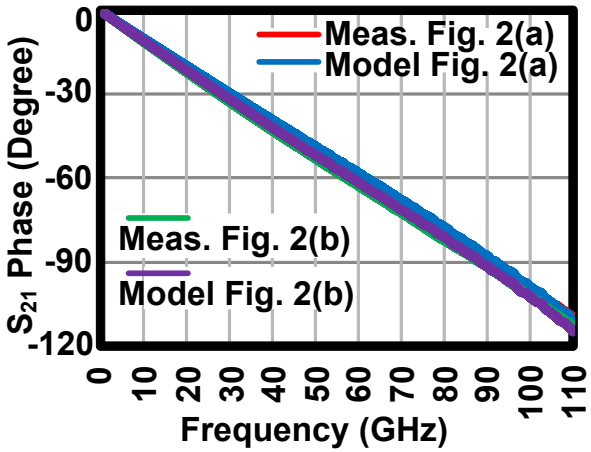


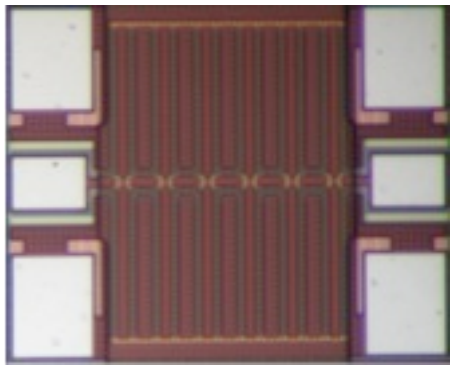












Lumped Equivalent Model

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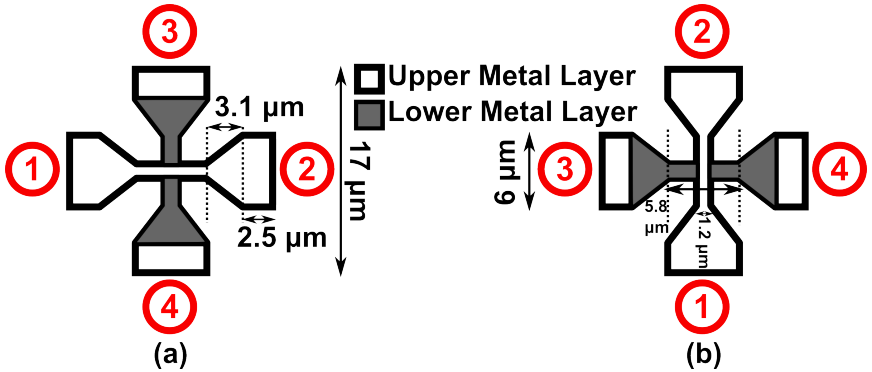

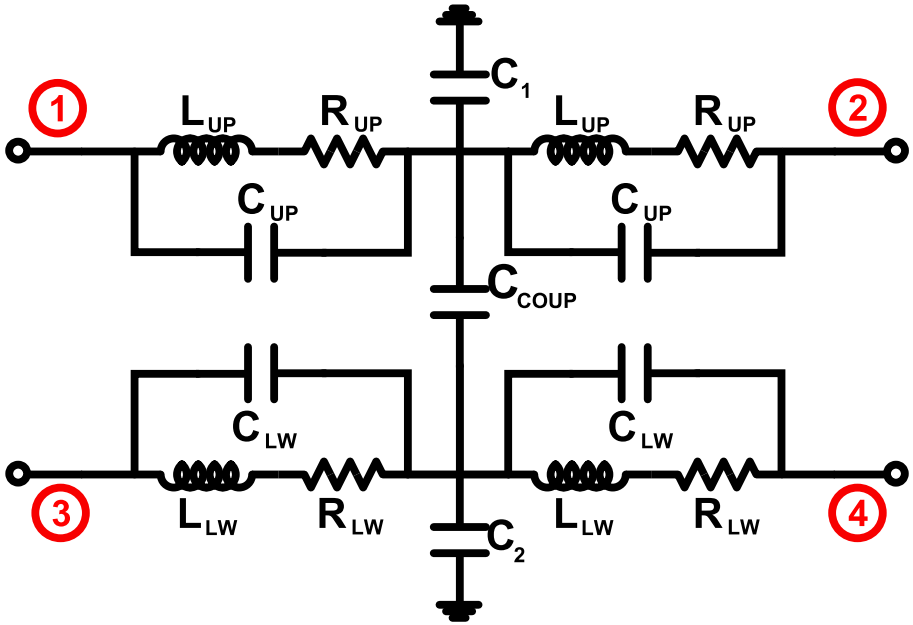

- L_{UP} = 2.86 pH
- R_{UP} = 0.18 Ω
- C_{UP} = 105 fF
- L_{LW} = 2.13 pH
- R_{LW} = 0.27 Ω
- C_{LW} = 175 fF
- C_1 = 2.05 fF
- C_2 = 0.05 fF
- C_{COUP} = 1.64 fF

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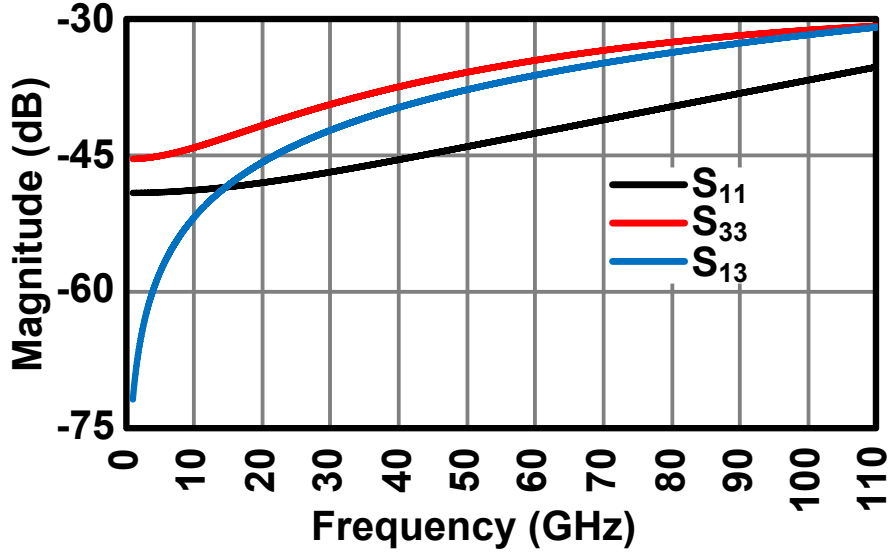
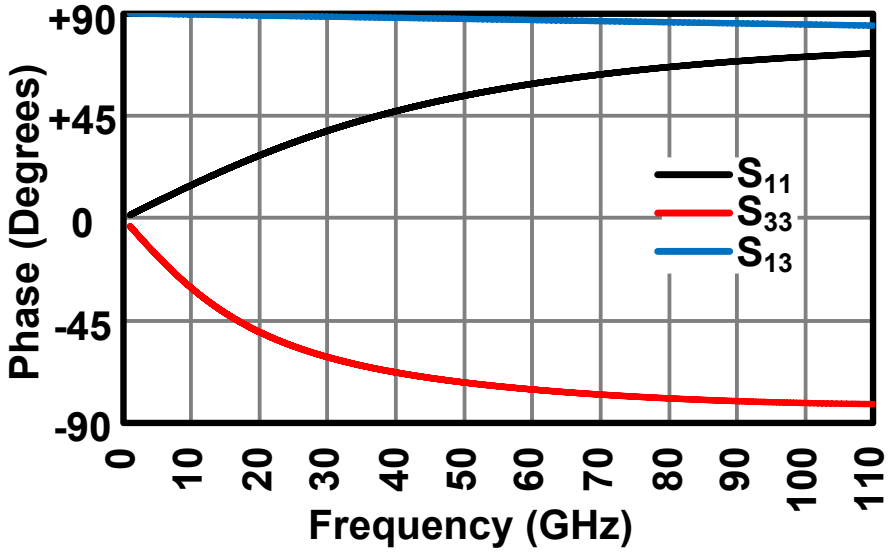
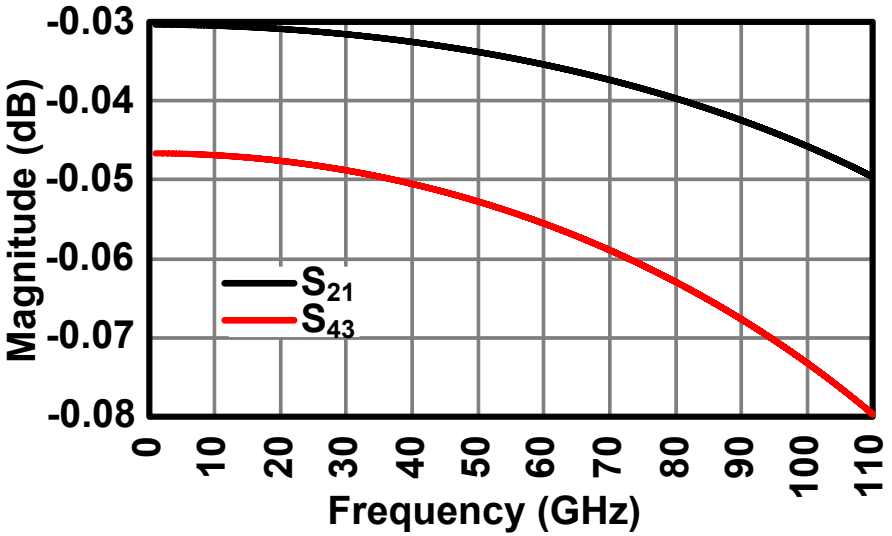
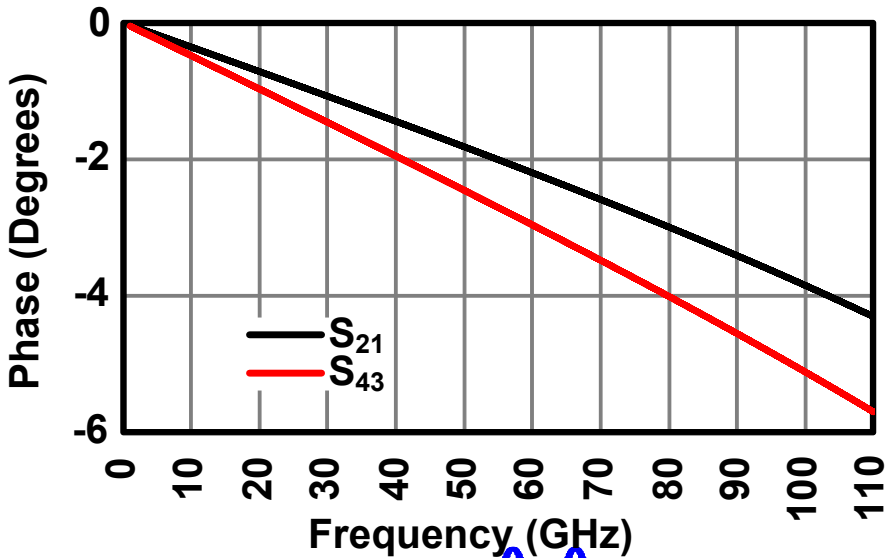
CTL S-Parameters Responses









Model and Method of Verification

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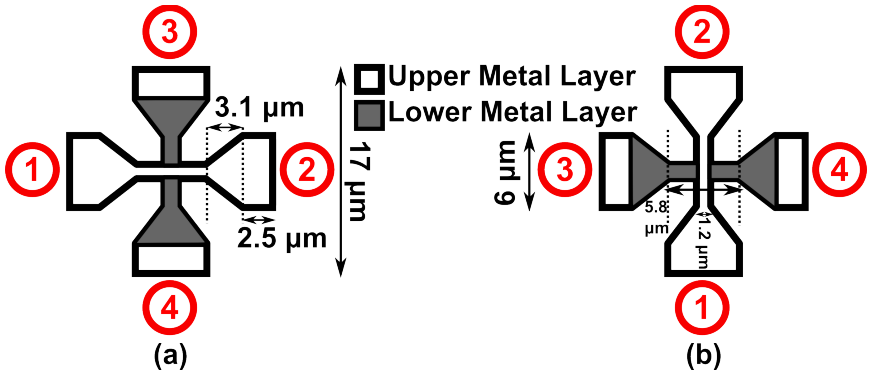

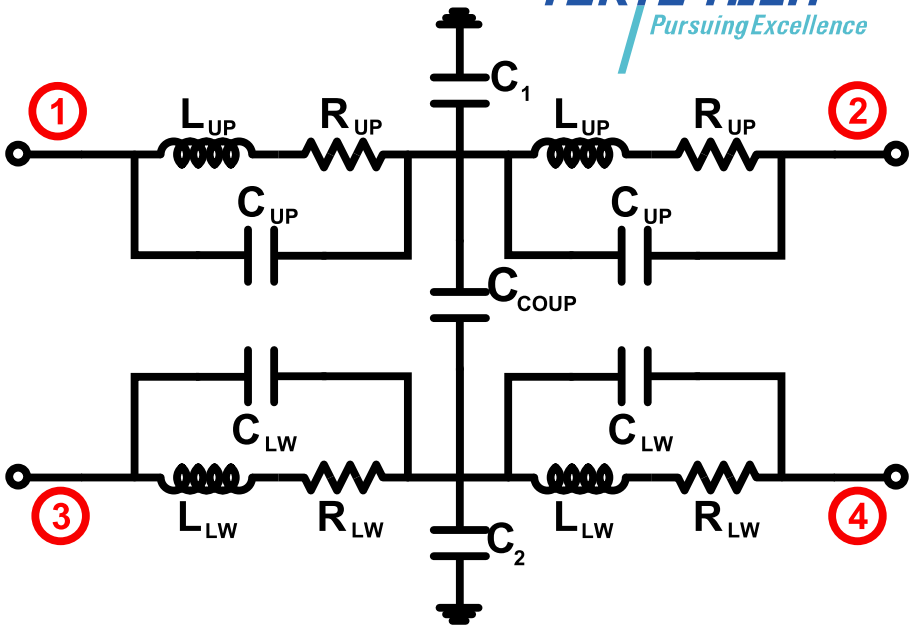

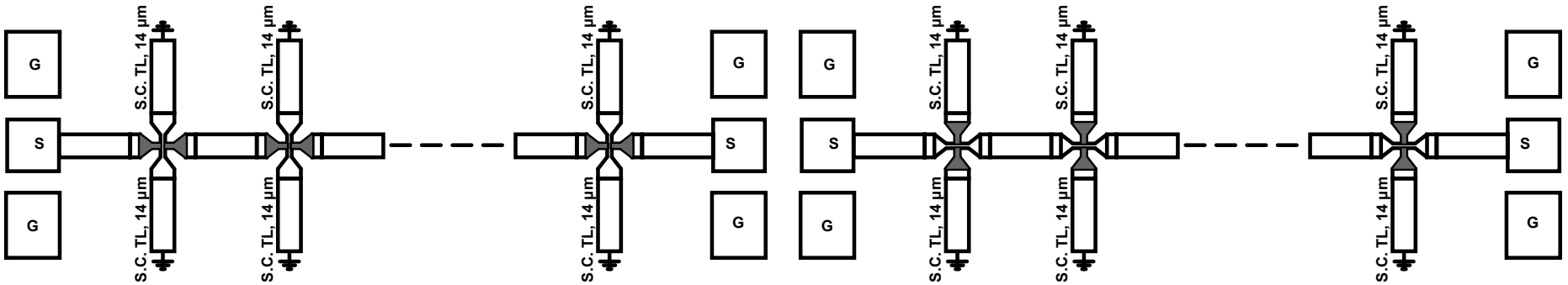

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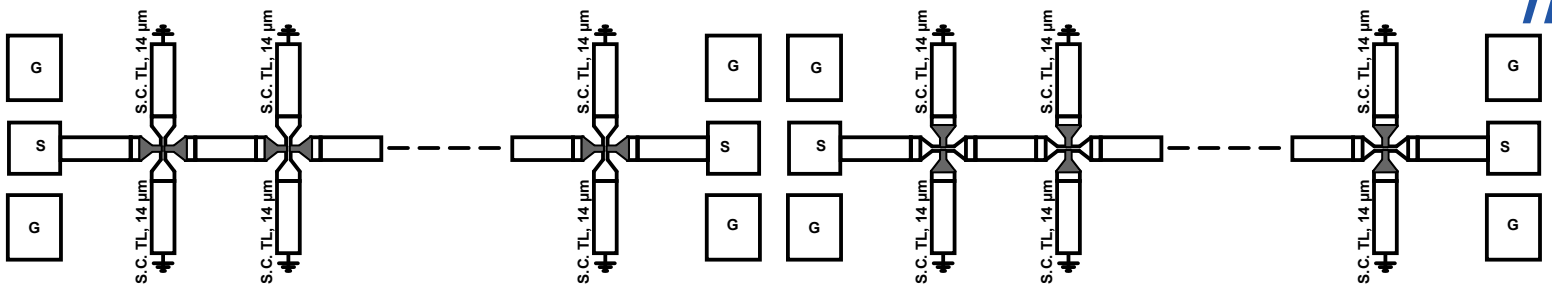
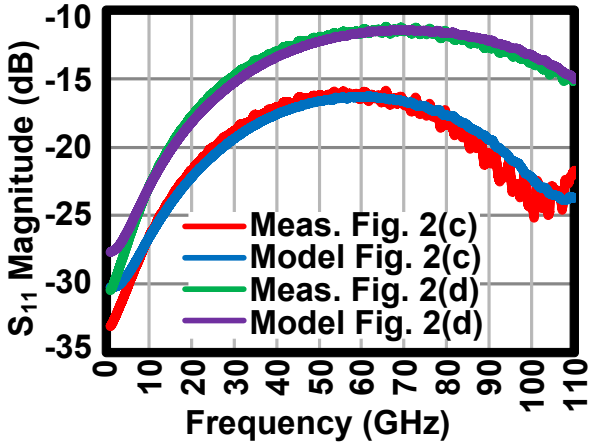
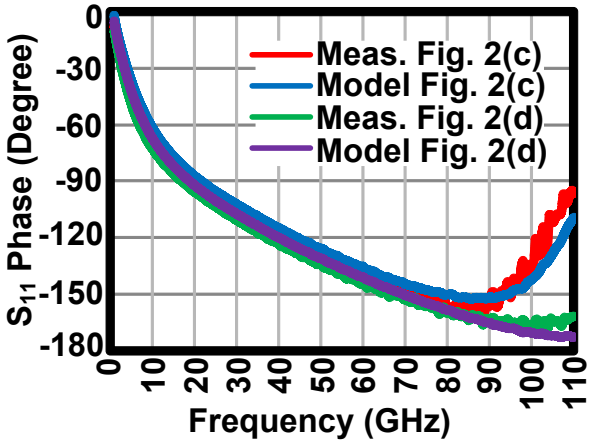
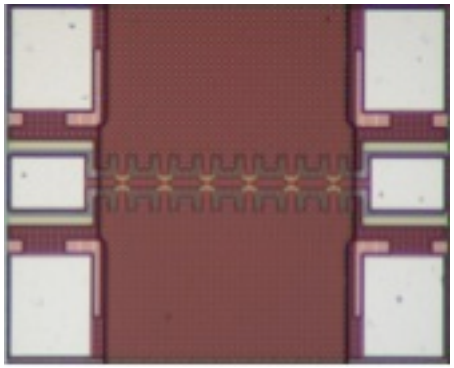
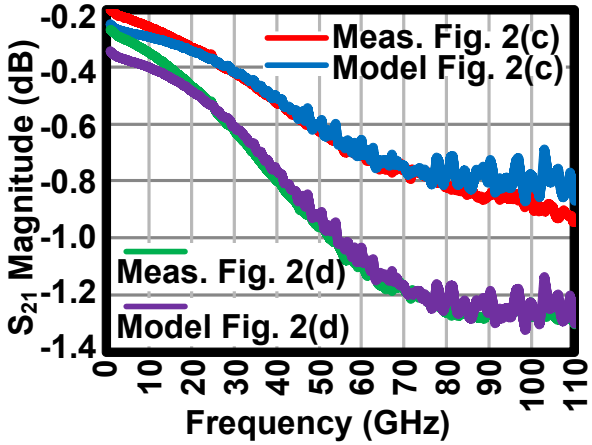
Results: Verification

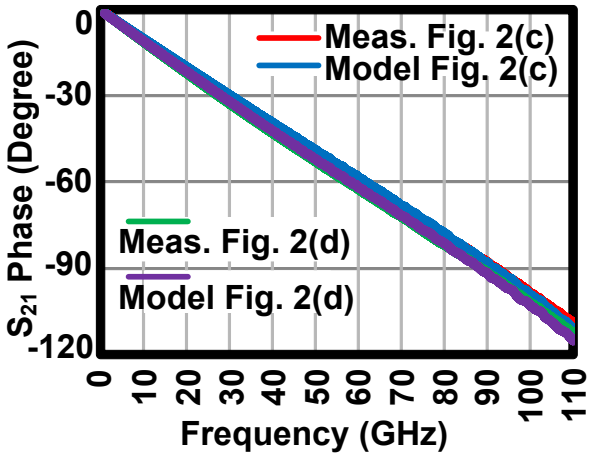


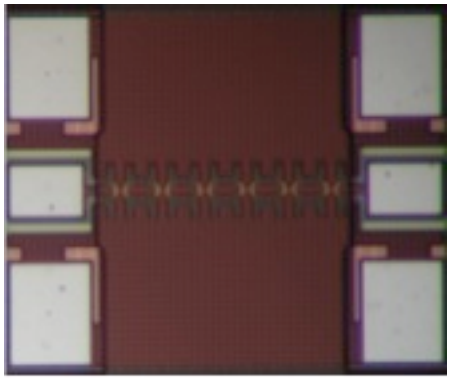












Conclusion

- 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