Characterization of Cross-Line up to 110 GHz Using Two-Port Measurements

Korkut Kaan Tokgoz, Shotaro Maki, Kenichi Okada, and Akira Matsuzawa

Matsuzawa & Okada Lab.

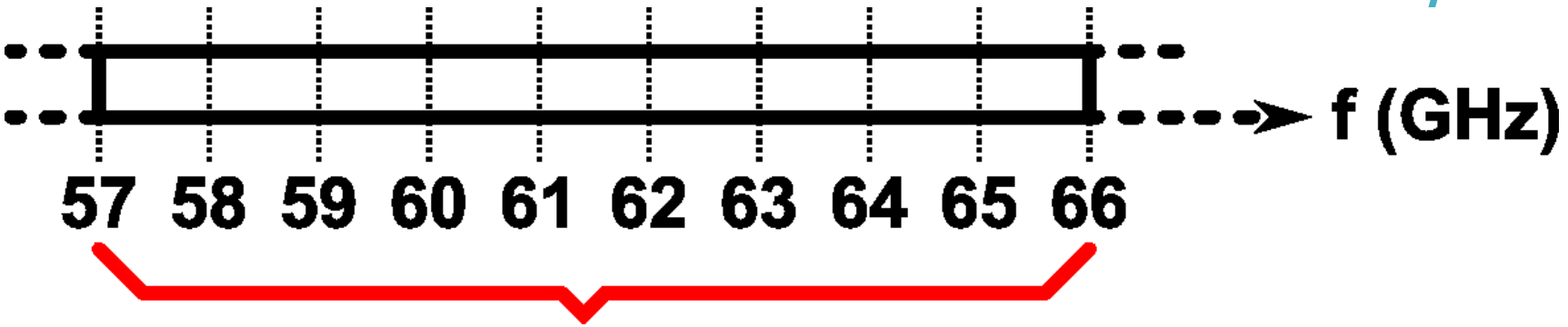
Tokyo Institute of Technology, Japan

Outline

TOKYO TECH
Pursuing Excellence

- Background
- Motivation
- Differential Cross-Coupled Amplifiers
- Cross-Line
- Issues of multi-port measurements
- Two-port characterization method
- Results
- Conclusion

Millimeter-Wave Band: 60 GHz



*57-66 GHz Unlicensed Frequency Band

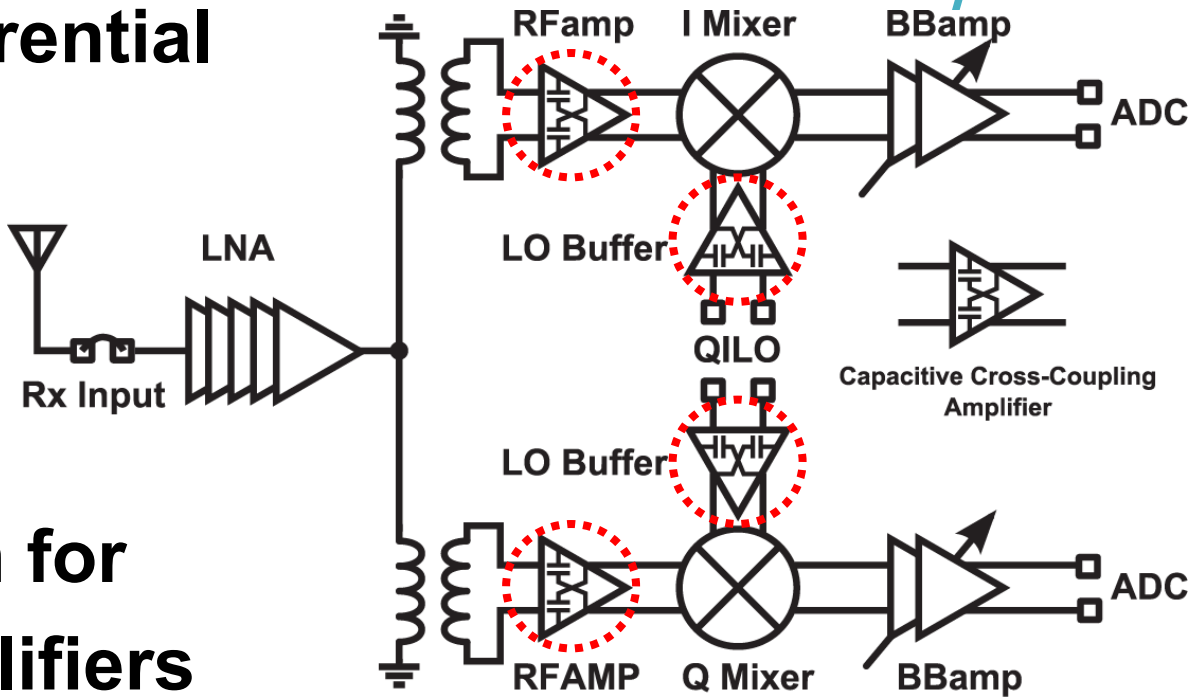
- 9 GHz Unlicensed band
  - Data rates up to 40 Gbps
- Large atmospheric attenuation
  - ☺ Secure Communication
  - ☹ Limited Communication Range

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

Direct Conversion 60 GHz RX

TOKYO TECH Pursuing Excellence

- **Single & differential amplifiers**

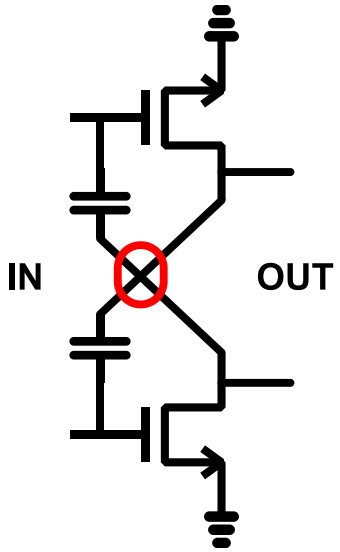


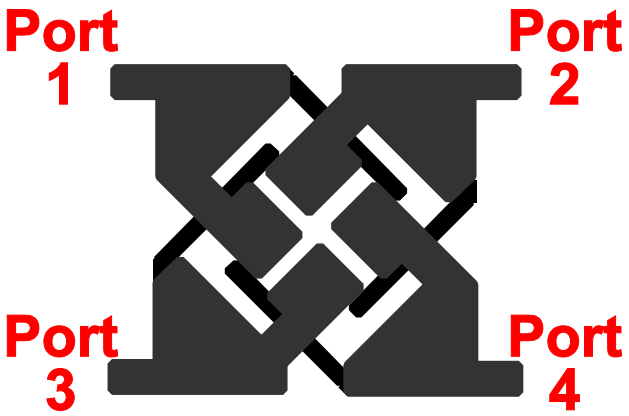
- **Neutralization for differential amplifiers**
  - **High gain**
  - **Lower power consumption**
  - **Less area**
- **Capacitive cross coupling amplifiers**

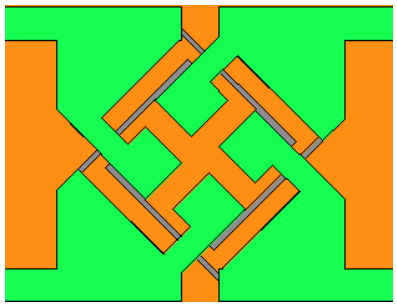
Capacitive Cross-Coupled Amps.

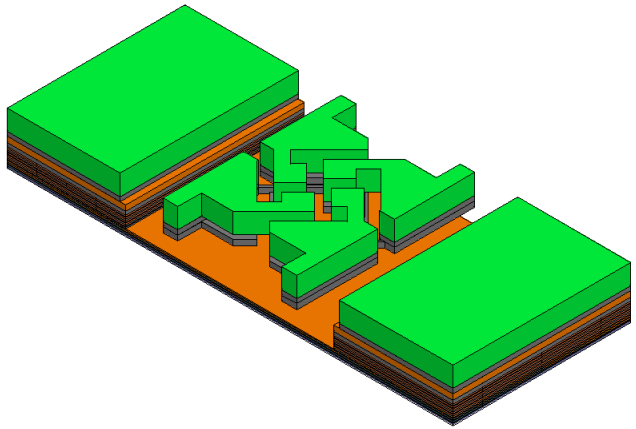
TOKYO TECH Pursuing Excellence

- Important characteristic: Symmetry
- Asymmetrical crossing part
  - Amplitude imbalance
  - Phase imbalance
  - Unwanted mode conversions
- ➢ SNDR and EVM degradation
- ➢ Electrically symmetric Cross-Line

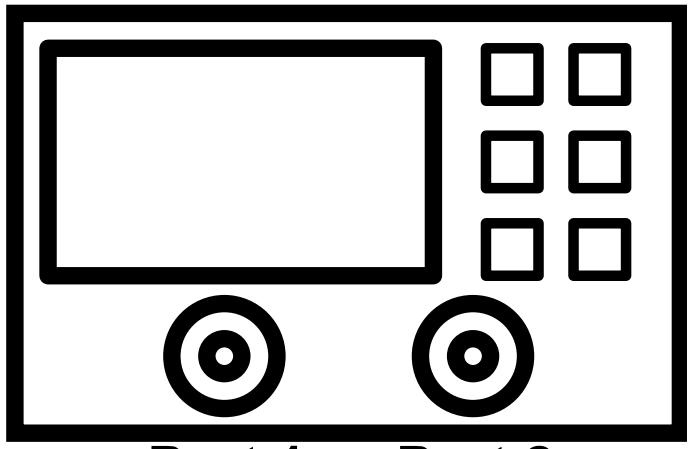


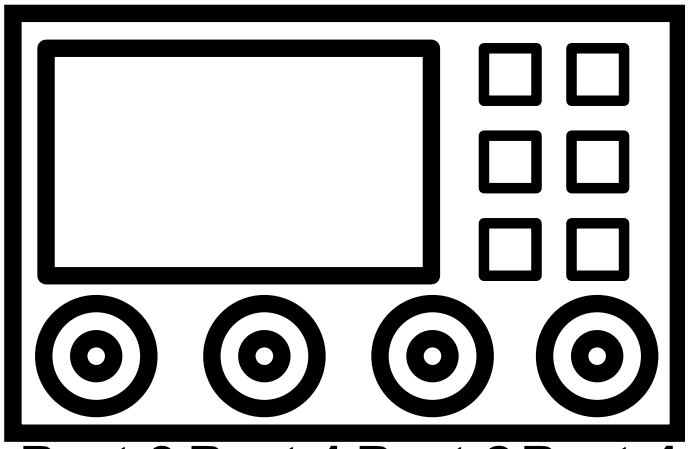






Issues of Multi-Port Measurements



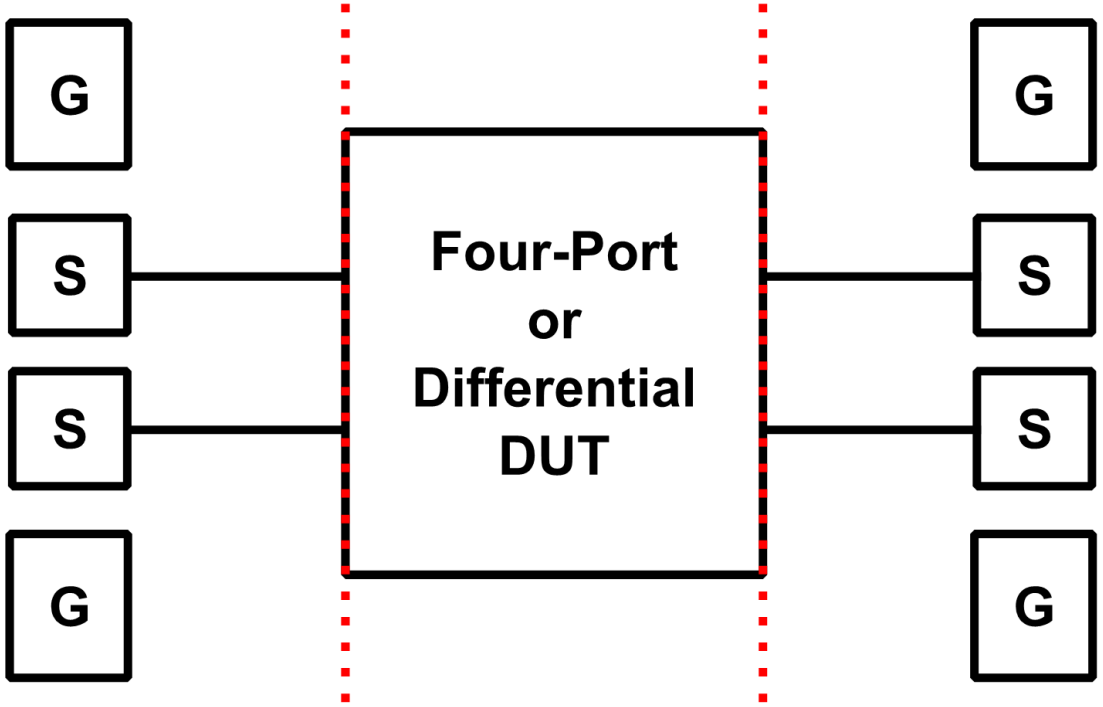


- Most common VNAs Two-Port
- Four-Port Measurements
  - Decreased Dynamic Range of Instrumentations*
    - Two-port→110 to 120 dB Dynamic Range up to 110 GHz
    - Four-port→80 dB after 67 GHz to 110 GHz

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

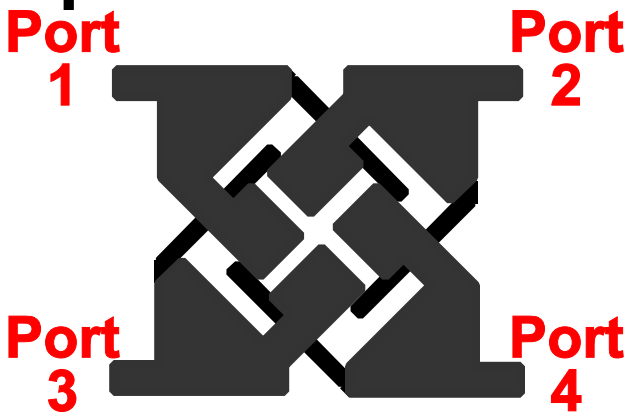
Issues of Multi-Port Measurements

- De-embedding of pad parasitics much harder than two-port
- Unwanted cross-talk and coupling between probes



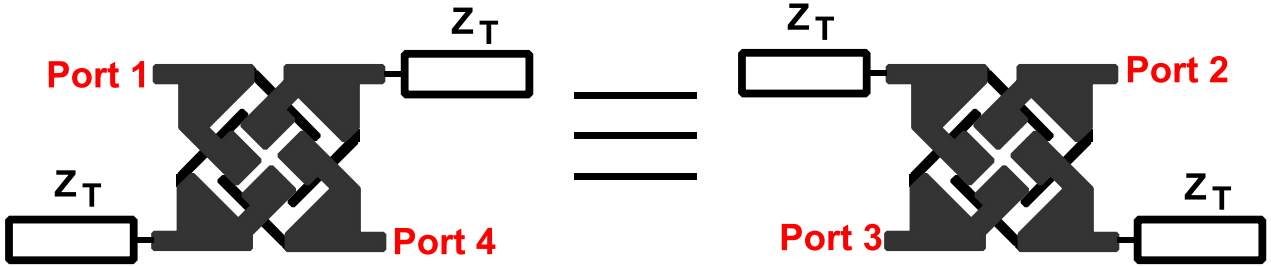
Characteristics of Cross-Line

- The structure is a four-port symmetrical and reciprocal one



$$S_{CCC} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{11} & S_{14} & S_{13} \\ S_{13} & S_{14} & S_{11} & S_{12} \\ S_{14} & S_{13} & S_{12} & S_{11} \end{bmatrix}$$

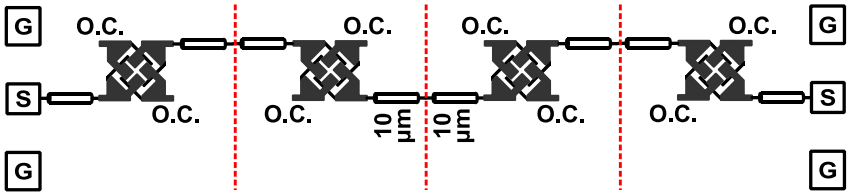
- Terminating port 2 and 3, or port 1 and 4 would result in same S-parameter response
  - Reciprocal and symmetrical

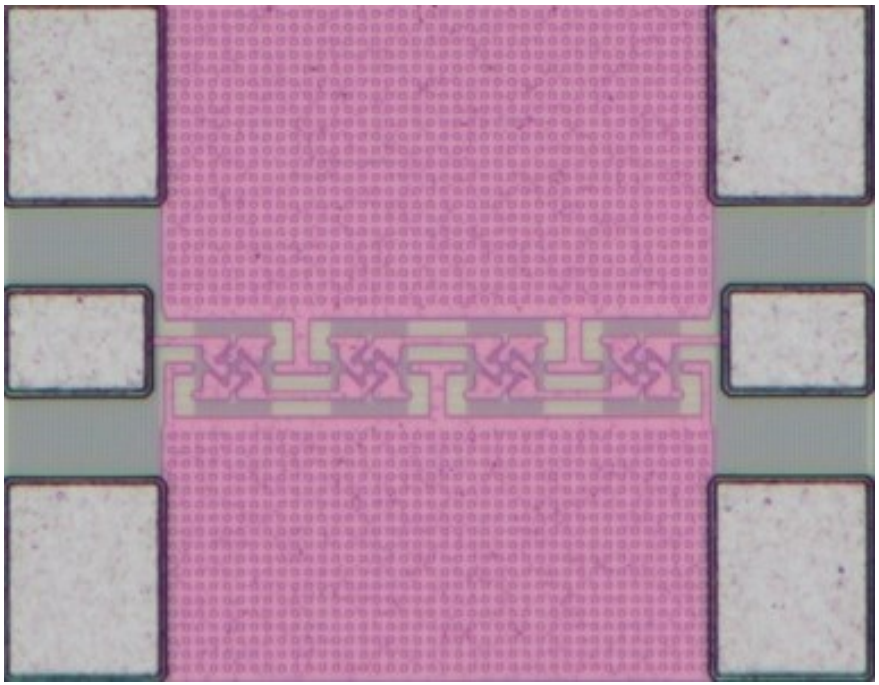


Two-Port Characterization Method

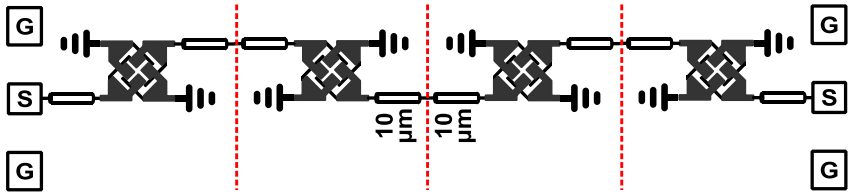
TOKYO TECH Pursuing Excellence

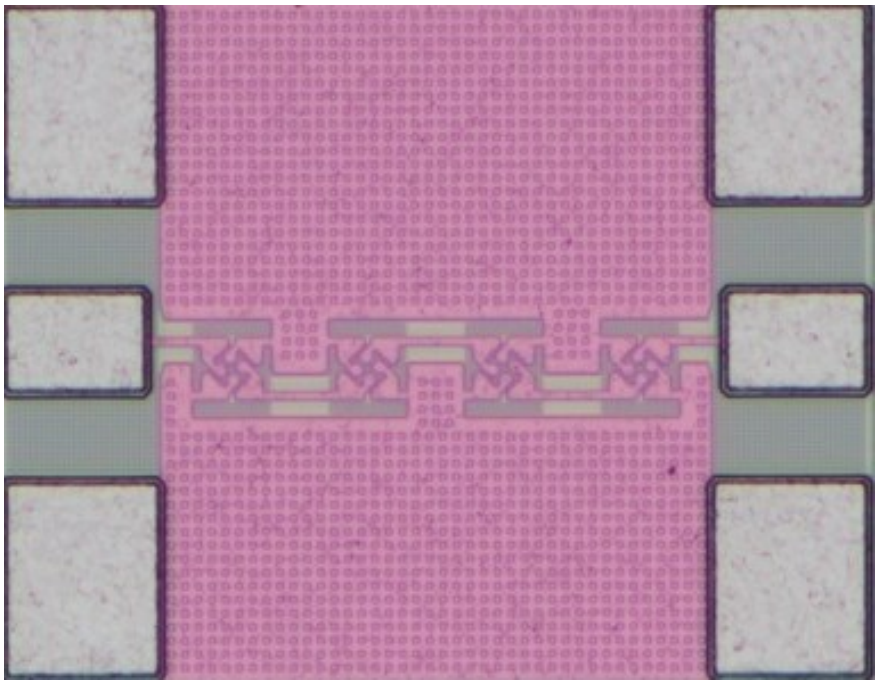
● Open Circuited





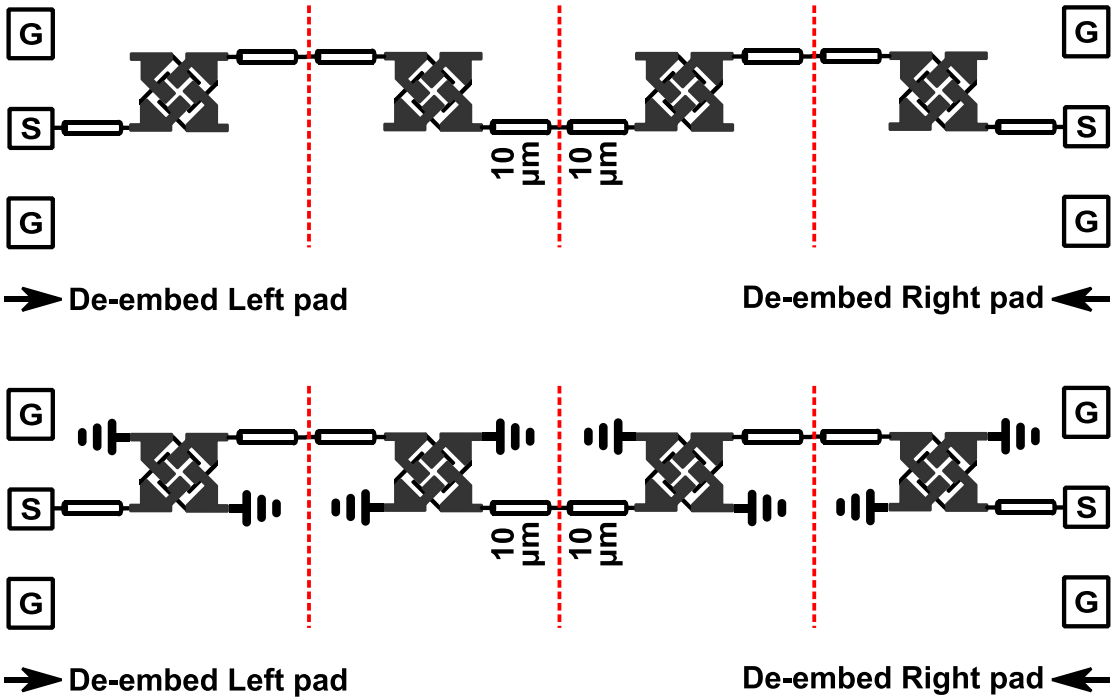
● Short Circuited





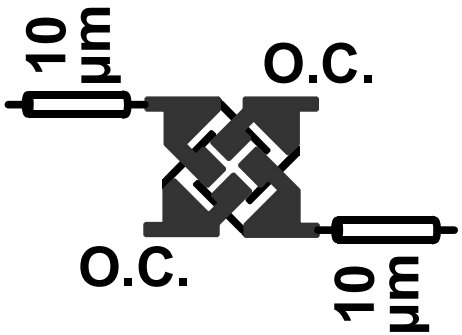
Method of Characterization

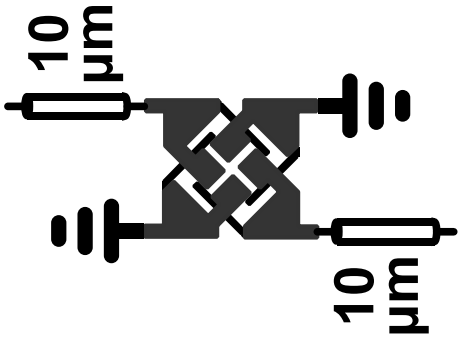
- GSG pads and transmission lines are readily characterized
- De-embedded pad parasitics from left and right hand side for the both structures



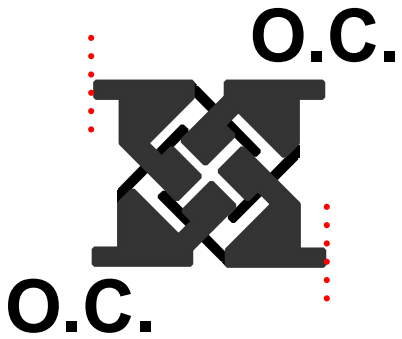
Method of Characterization

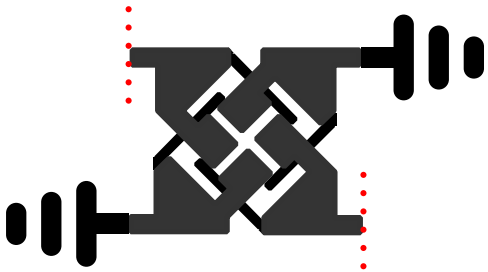
- Remaining is the four times cascaded same structure
- Can be solved for one for each case





- Additional 10 μm transmission lines to be de-embedded



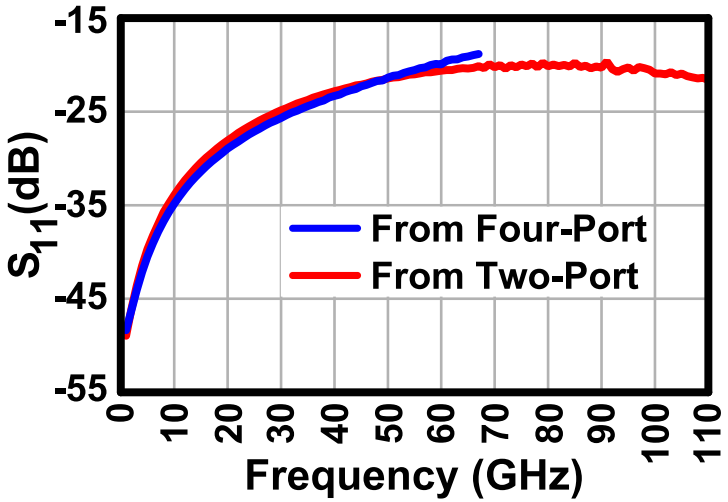


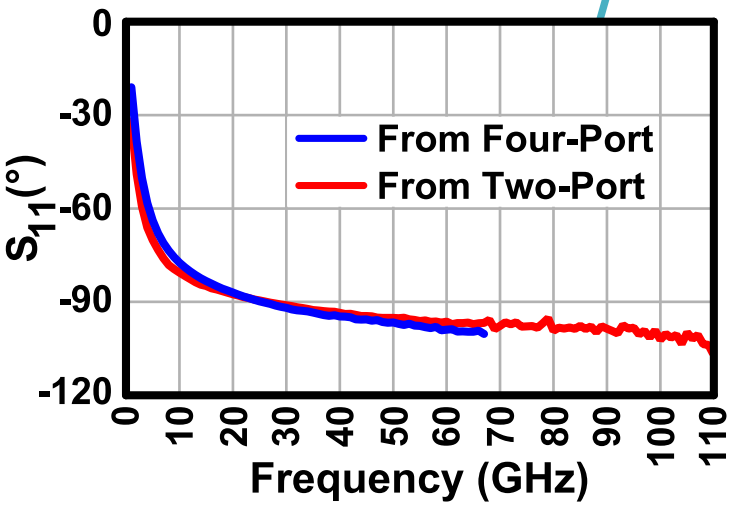
Reconstruction of four-port S-para.

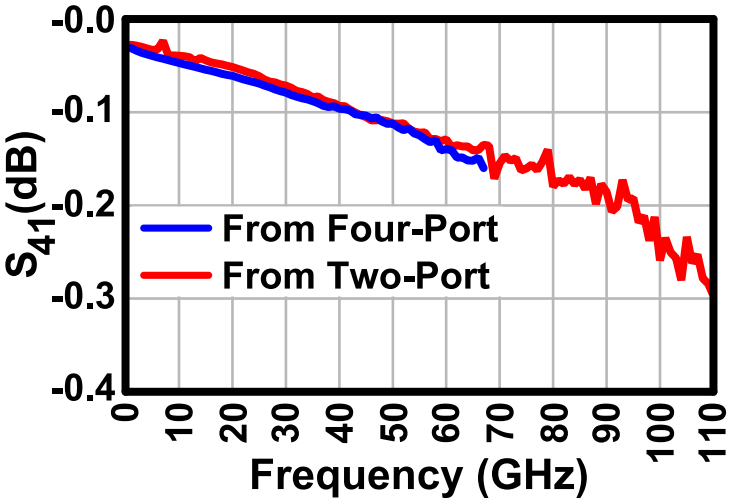
- From the two different two-port results
- Solve for four unknowns of the symmetrical and reciprocal four-port cross line
- Note that open and short circuit is assumed to be perfect

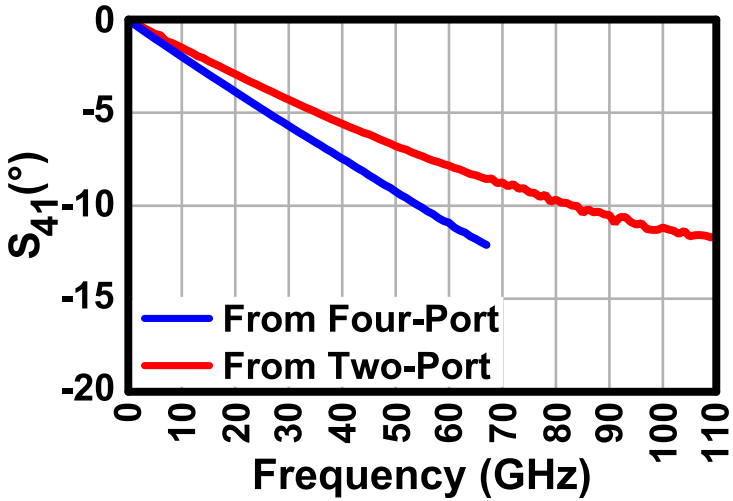
$$C_1 = (S_{CO,T} + S_{CS,T})/(2 + S_{CO,T} - S_{CS,T})$$
$$C_2 = (S_{CO,D} + S_{CS,D})/(2 + S_{CO,D} - S_{CS,D})$$
$$S_{11} = (C_1 + C_2)/2$$
$$S_{41} = (C_1 - C_2)/2$$
$$C_3 = \sqrt{(S_{CO,T} - S_{CS,T})(1 - C_1^2)/2}$$
$$C_4 = \sqrt{(S_{CO,D} - S_{CS,D})(1 - C_2^2)/2}$$
$$S_{21} = (C_3 + C_4)/2$$
$$S_{41} = (C_3 - C_4)/2$$

Return loss and Transmission



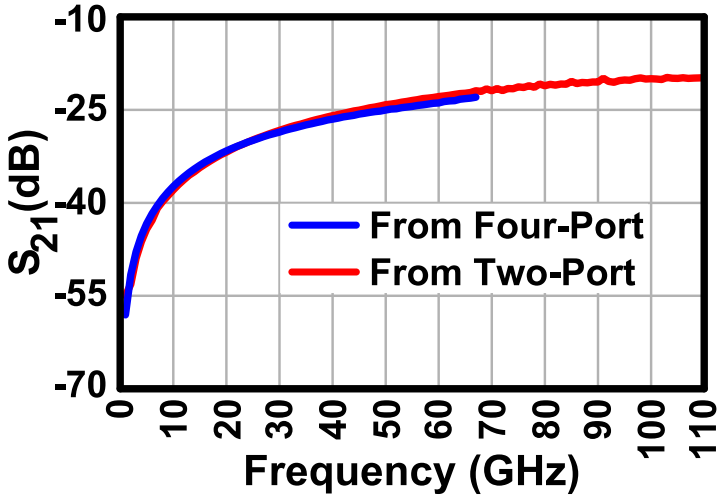


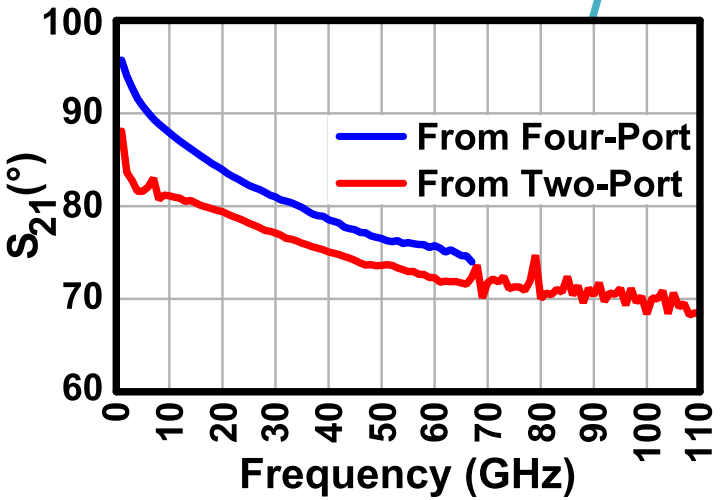


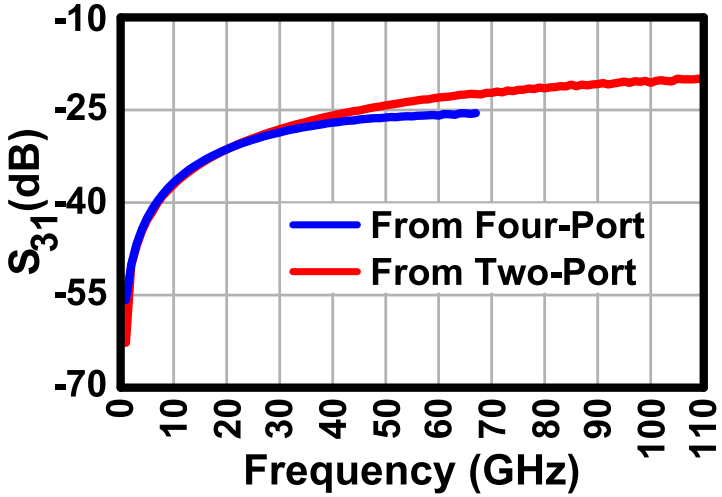


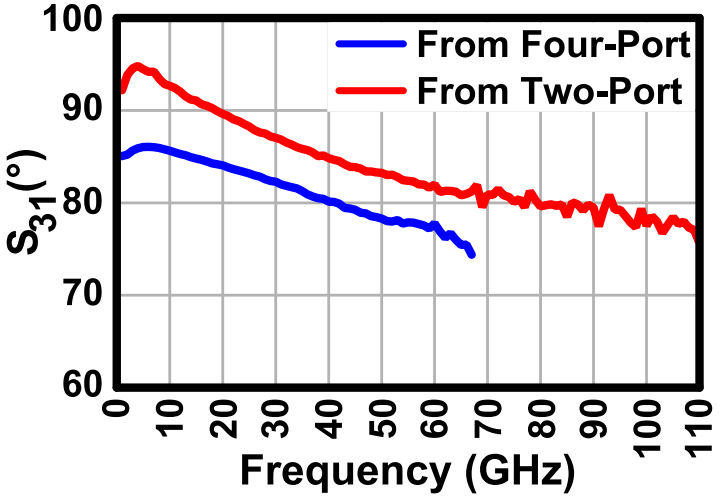
Four-port results: Tokgoz *et al.*, SiRF 2015

Isolation and Coupling









Four-port results: Tokgoz *et al.*, SiRF 2015

Conclusions

- Importance of symmetry for the cross-coupled amplifiers
- Issues of multi-port measurements
- Two-port characterization method for a four-port device
- Two compact characterization structures
- Results are obtained up to 110 GHz
- Well-matched with four-port measurement results up to 67 GHz

TOKYO TECH
Pursuing Excellence

THANK YOU VERY MUCH FOR YOUR ATTENTION!