Multilayered Substrate-Integrated Waveguide Couplers

Vladimir A. Labay
Department of Electrical and Computer Engineering
Gonzaga University, Spokane, WA 99258, USA
Jens Bornemann
Department of Electrical and Computer Engineering
University of Victoria, Victoria, BC V8W 3P6, Canada

Outline

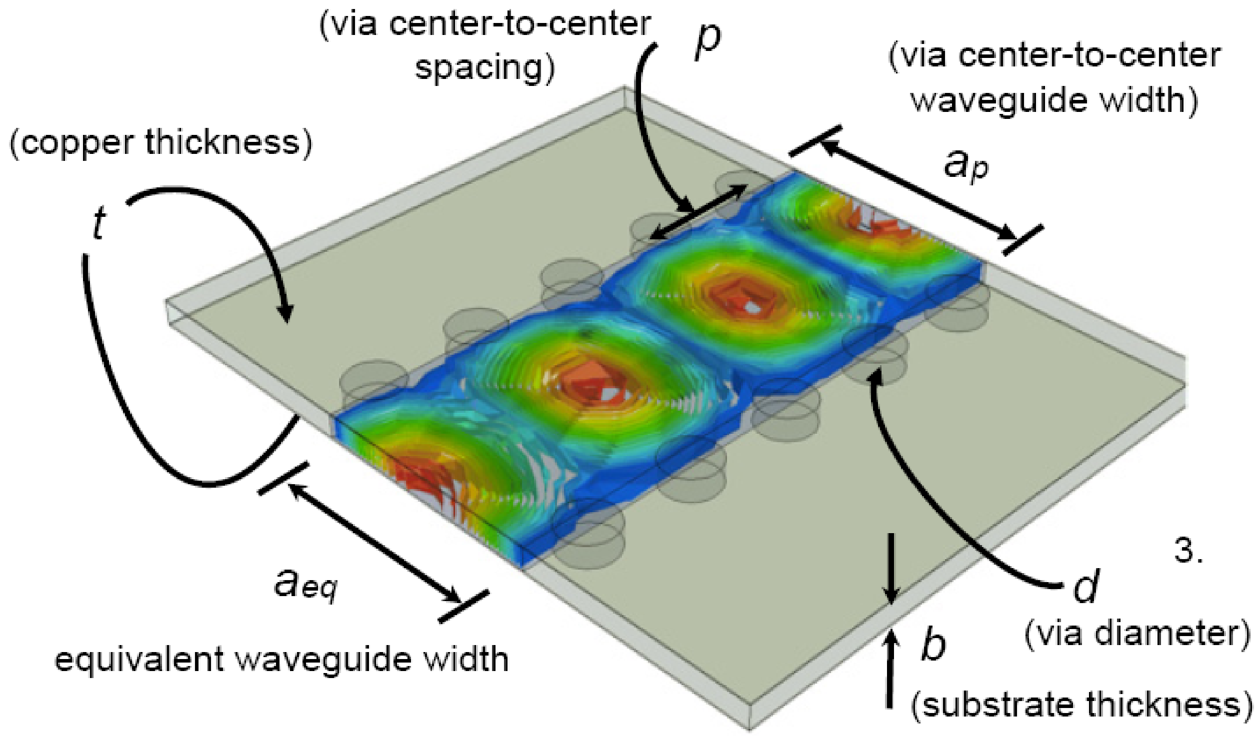
- Introduction
- SIW Parameters
- Modeling Tools
- Microstrip Ports vs All-Dielectric Waveguide Ports
- Multilayered SIW Directional Couplers

  - Dual-hole Couplers
  - Riblet-Saad Couplers
  - Moreno Cross-slot Couplers
  - Dual-band Couplers
  - Microstrip-to-SIW Couplers
- Conclusions

Introduction

- Substrate-integrated waveguide (SIW) components have mostly been implemented as H-plane waveguide components which is commensurate with their planar fabrication approach.
- In order to employ this technology for two-dimensional feed-system integration, however, power transfer between multiple layers of SIW circuits is mandatory. Such coupling is predominantly directional and can range from weak transfer (20 dB) to power trisection (4.78 dB) and division (3 dB).
- Therefore, this presentation discusses multilayered SIW directional couplers in various configurations such as dual-hole couplers, Riblet-Saad couplers, Moreno cross-slot couplers and for either wide-band or dual-band operation.
- Typical performance expectations of the respective coupler topology, including interface ports, are presented and discussed.

SIW Parameters



TE$_{10}$ dominant mode propagation

Guidelines (from [1]):

1. $$0.05 \le \frac{p}{\lambda_c} \le 0.25$$

2. $$0.50 \le \frac{d}{p} \le 0.83$$

3. $$0.7 \le \frac{a_p}{a_{eq}} \le 1.0$$

where the normalized width (a_p/a_{eq}) is calculated using empirical equation given in [2]

References:

[1] D. Deslandes and K. Wu, IEEE Trans, Microwave Theory Tech, June 2006.
[2] Y. Cassivi, L. Perregrini, P. Arcioni, M. Bressan, K. Wu, and G. Conciauro, IEEE Microw. Wireless Comp. Lett., Sep. 2002.

Modeling Tools

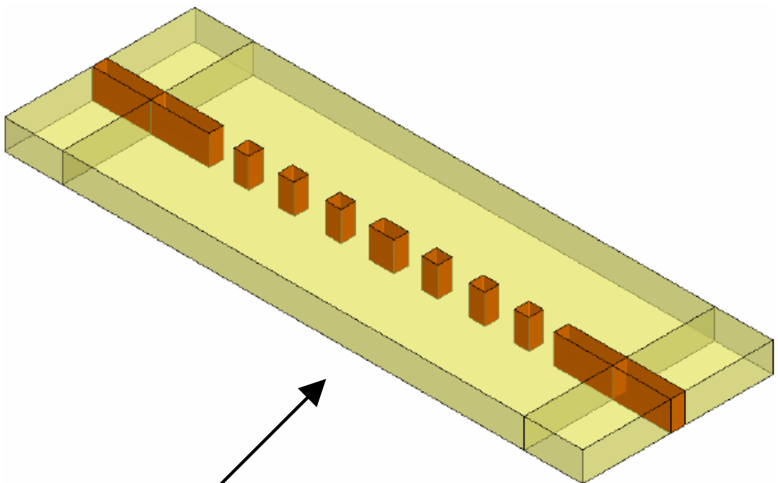
Several different modeling tools to design SIW couplers:

- Mode-matching technique (MMT) using an equivalent width and all-dielectric filled waveguides – for initial designs and rough optimization.

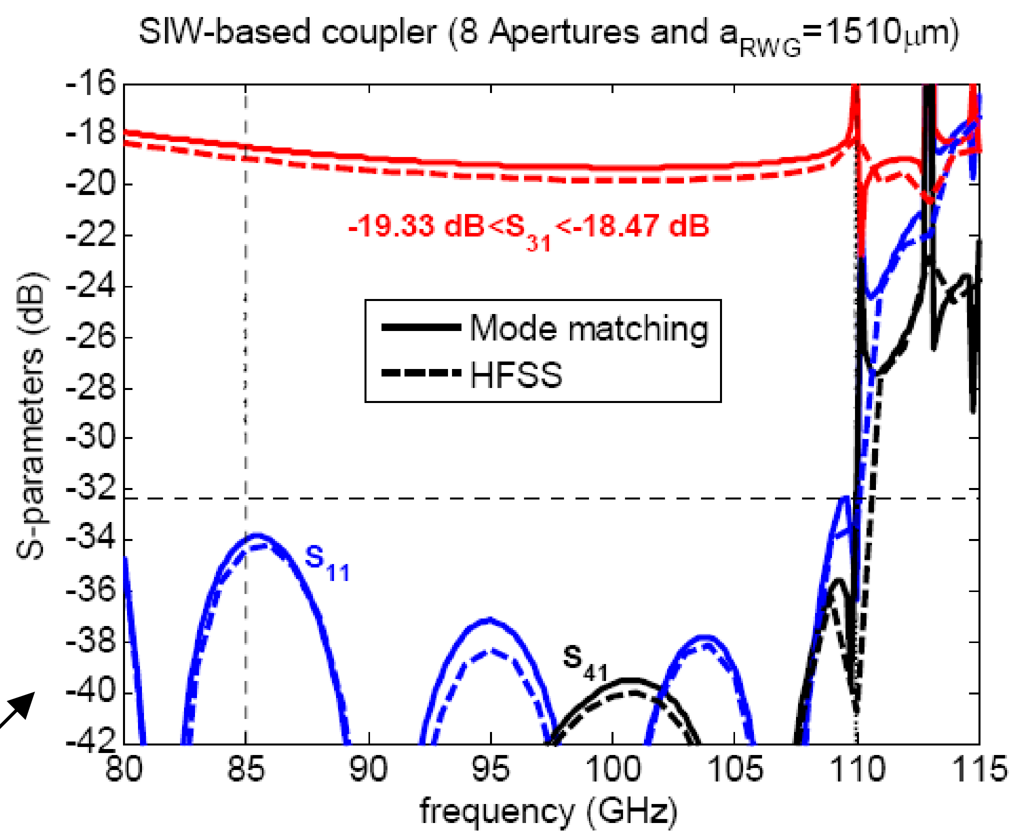
- Ansoft HFSS for the analysis of the actual SIW structure, including transitions to all-dielectric and/or microstrip ports, and fine optimization.

- CST Microwave Studio for verification of individual parts or the entire structure.

Typical Performance Comparison Between MMT and HFSS for a 100 GHz H-plane Coupler



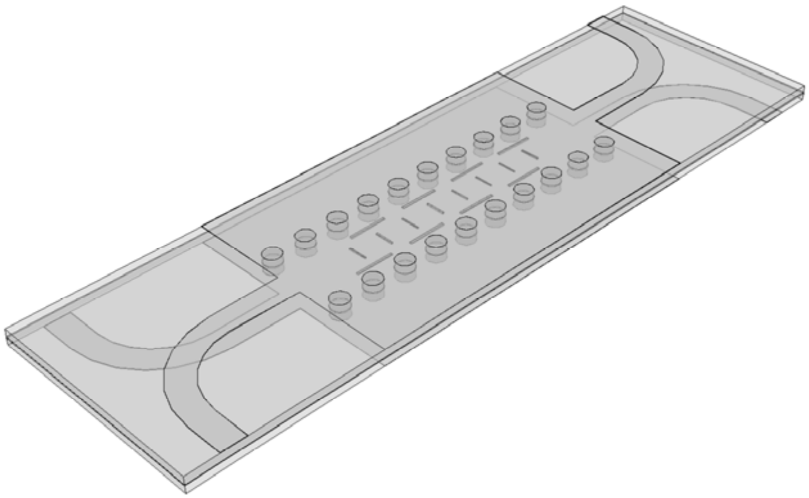
H-plane coupler designed with MMT assuming rectangular via holes.



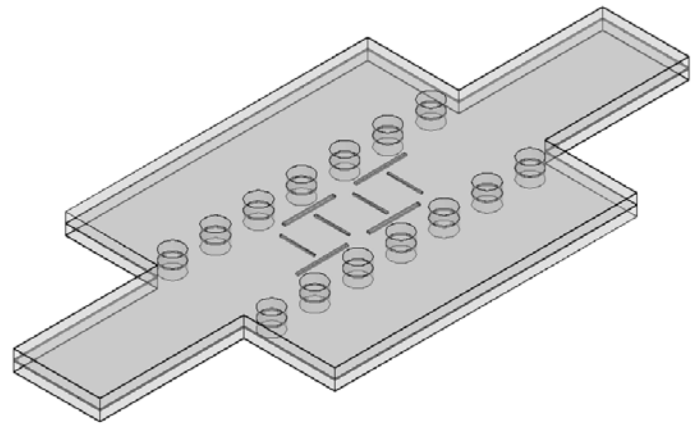
HFSS analysis of actual SIW H-plane coupler using rectangular via holes as side walls, separation walls and posts (David Dousset, 2008).

Microstrip Ports versus All-Dielectric Waveguide Ports

Examples of dual-layer Riblet-Saad couplers

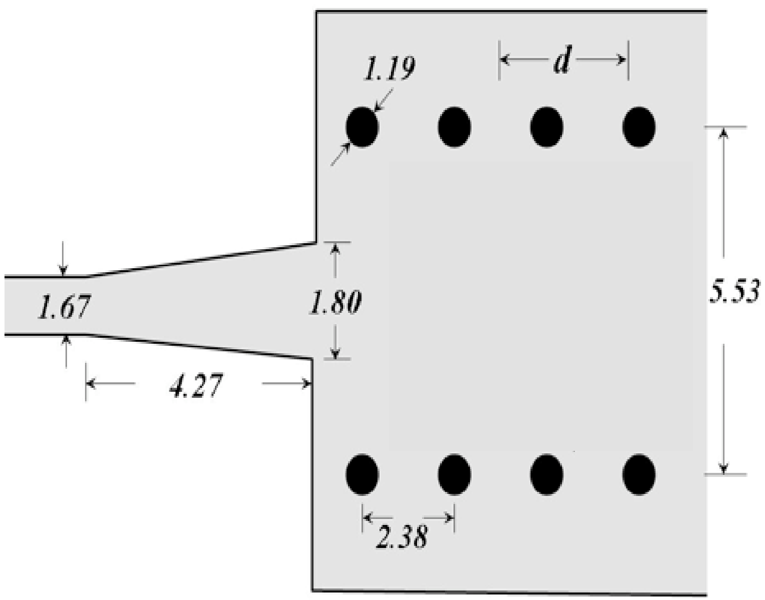


Microstrip ports used for a stand-alone coupler or measurements.

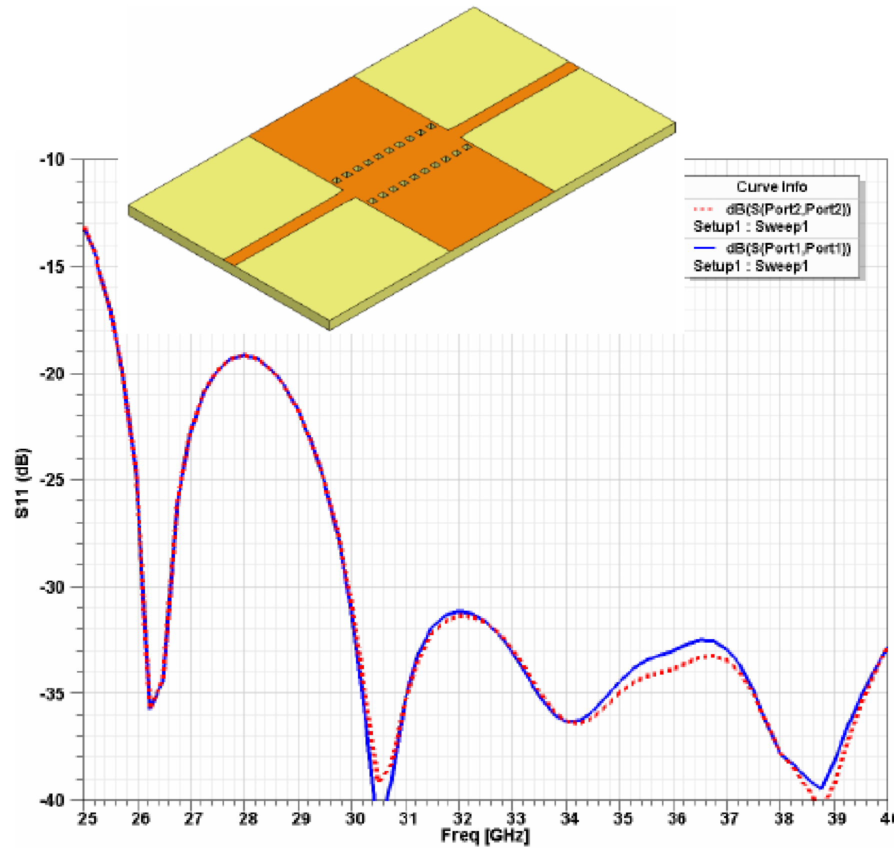


All-dielectric waveguide ports reduce the computational domain and produce more realistic results when SIW components are directly interconnected.

Microstrip-to-SIW Transitions

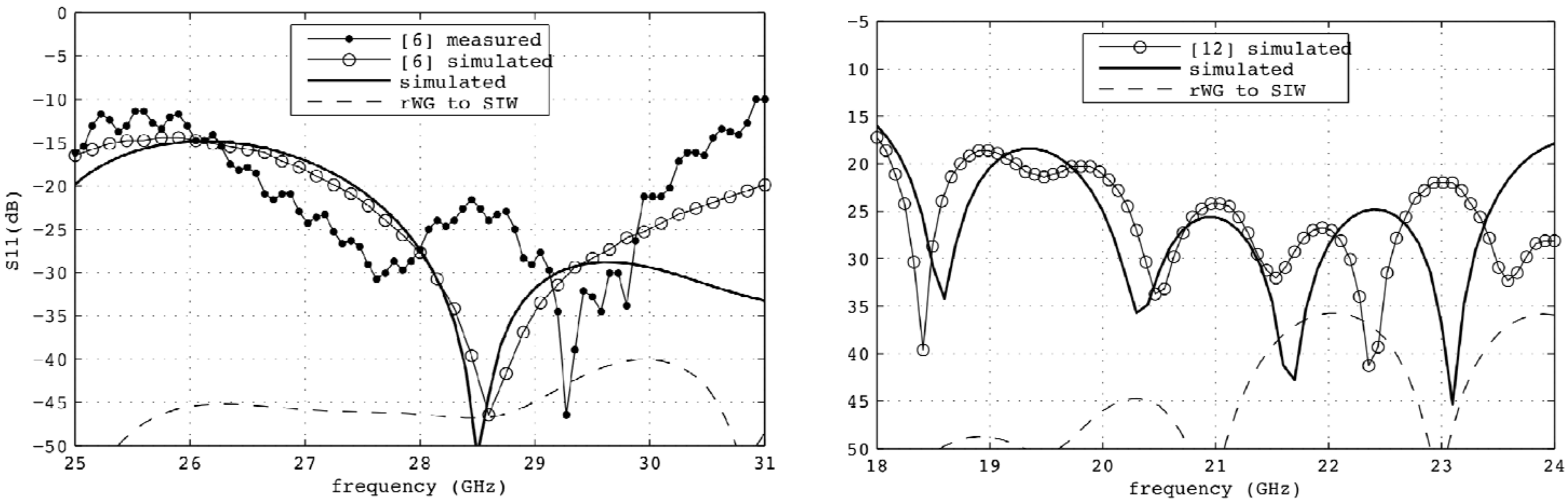


Typical dimensions of a microstrip-to-SIW transition for the 26-40 GHz range.



Typical performance (CST) of a back-to-back microstrip-to-SIW transition (David Dousset, 2009)

Back-to-back Microstrip-to-SIW Transitions



Comparisons of HFSS results (simulated) with computations and measurements in [6] and [12] of back-to-back microstrip-to SIW transitions separated by a SIW section, and when microstrip-to SIW transitions are replaced by all-dielectric rectangular waveguide ports (rWG to SIW).

References:

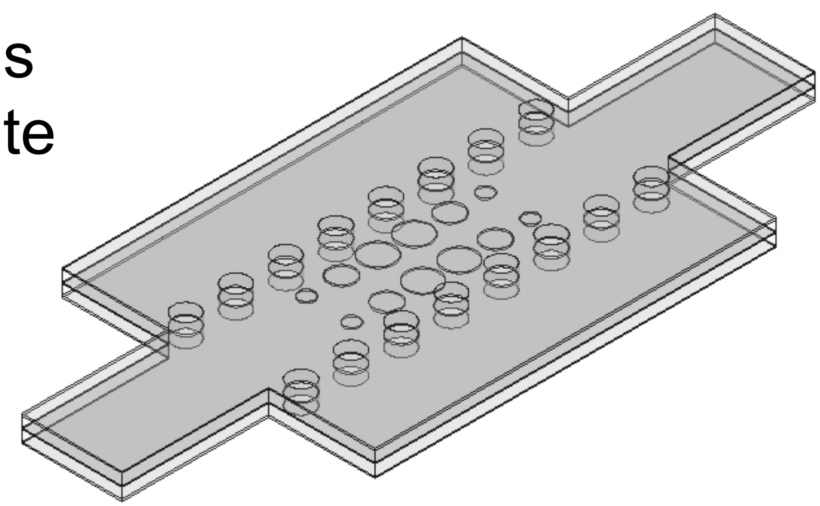
[6] D. Deslandes and K. Wu, *IEEE Microwave Wireless Comp. Lett*., Feb. 2001.

[12] I.J. Wood, “Linear Tapered Slot Antenna for Imaging Array”, *M.A.Sc. Thesis*, University of Victoria, 2007.

Multilayered SIW Directional Couplers
Dual-hole Couplers

Design

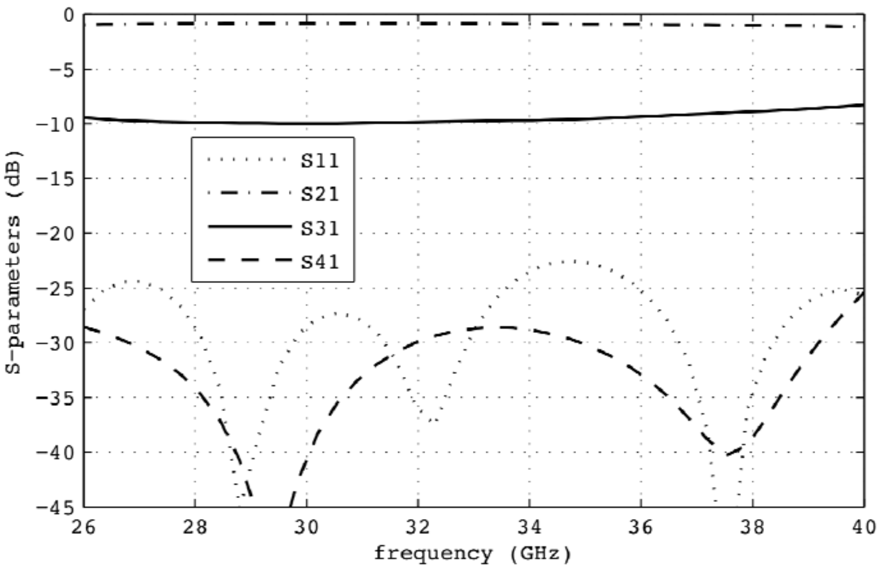
- For given specifications, design an E-plane waveguide dual-hole coupler according to MYJ and link it to an MMT algorithm.
- For given substrate and via-hole parameters, translate dimensions to SIW application and recalculate using, e.g., HFSS.
- Fine-optimize within HFSS.



Dual-Hole Couplers

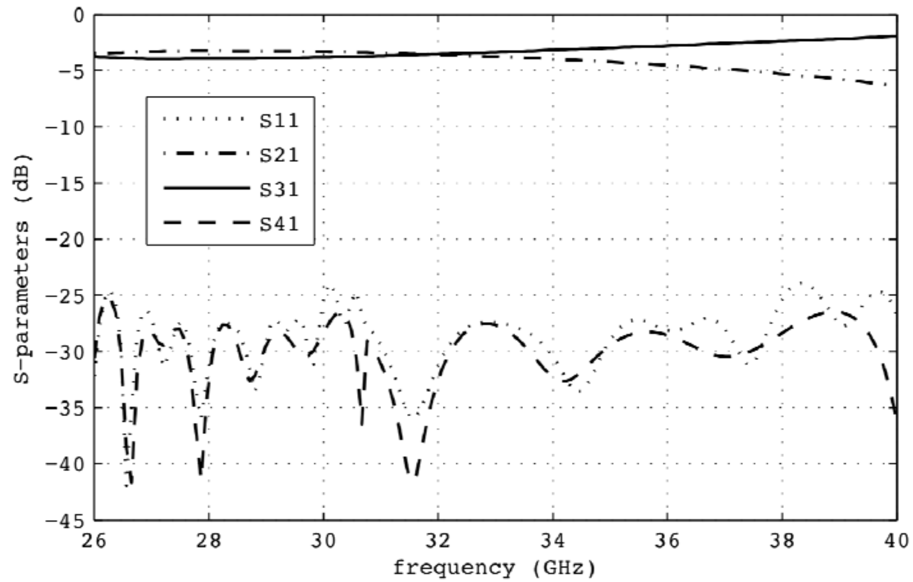
Performances of **broad-band** dual-layer SIW dual-hole couplers with SIW parameters:

a_{equ} = 5.524 mm, b = 0.508 mm, p = 2.397 mm, d = 1.198 mm, t = 35 μm, ε_r = 2.2,



10-dB coupler

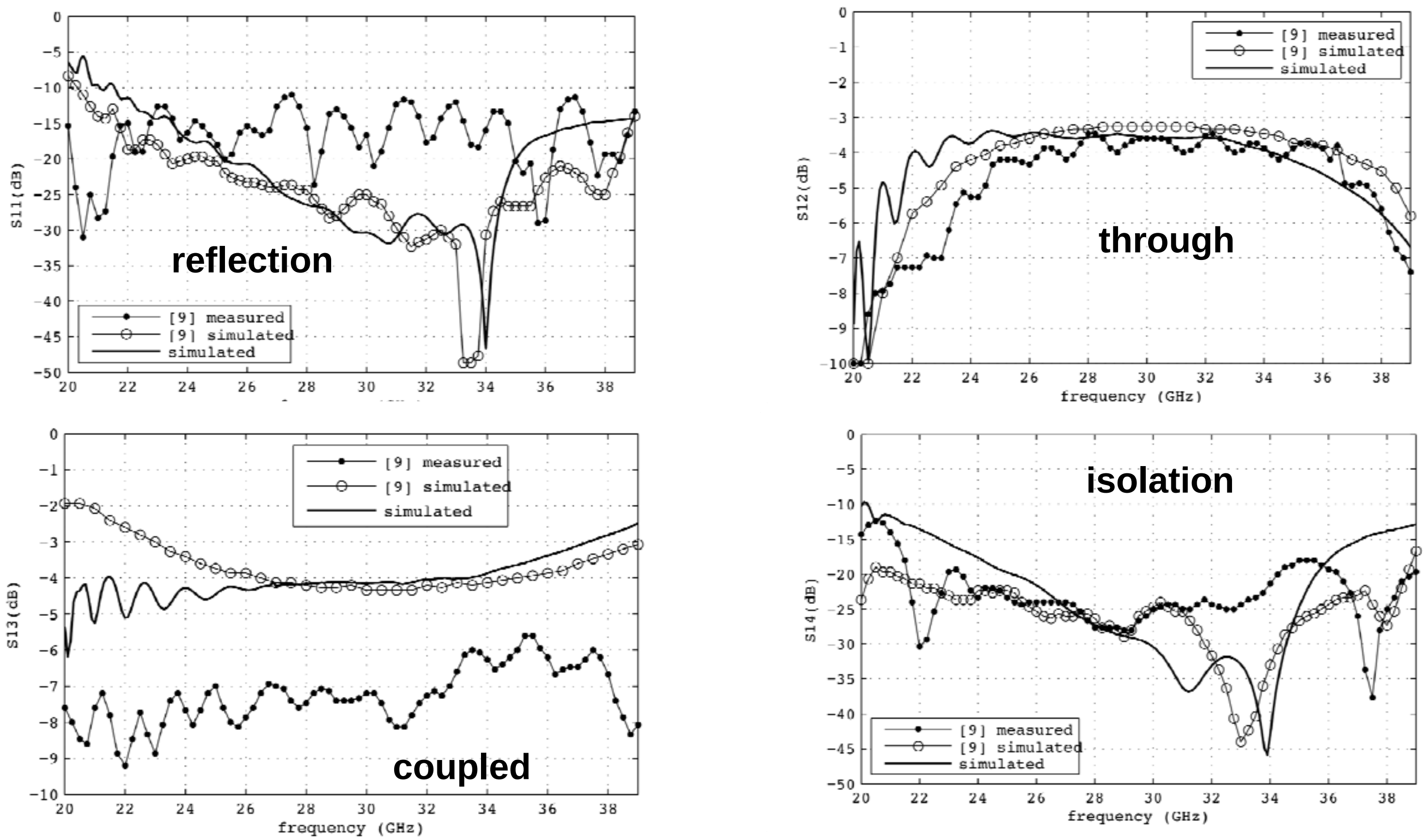
6 circular aperture pairs



3-dB coupler

23 circular aperture pairs

Dual-hole Coupler - Comparison

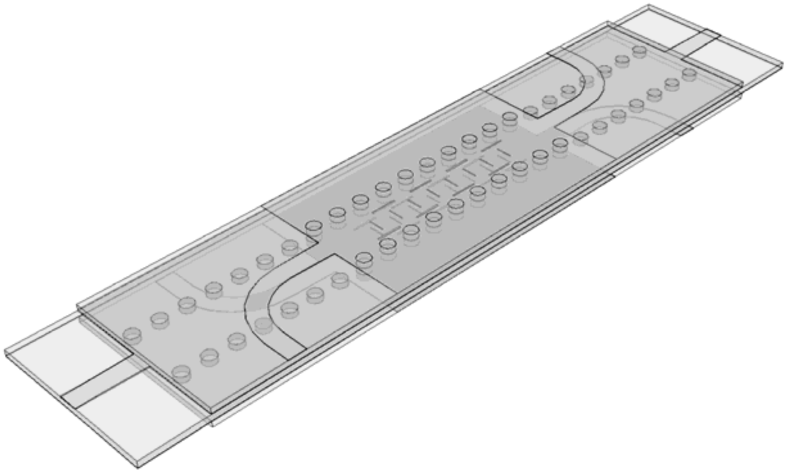


Comparison of HFSS results (simulated) with measurements and computations in [9] (Y. Cassivi, D. Deslandes and K. Wu, *Proc. Asia-Pacific Microwave Conf.*, 2002) of SIW E-plane 3-dB coupler with 14 pairs of circular apertures; microstrip-to SIW transitions included at all ports.

Riblet-Saad Couplers

Design

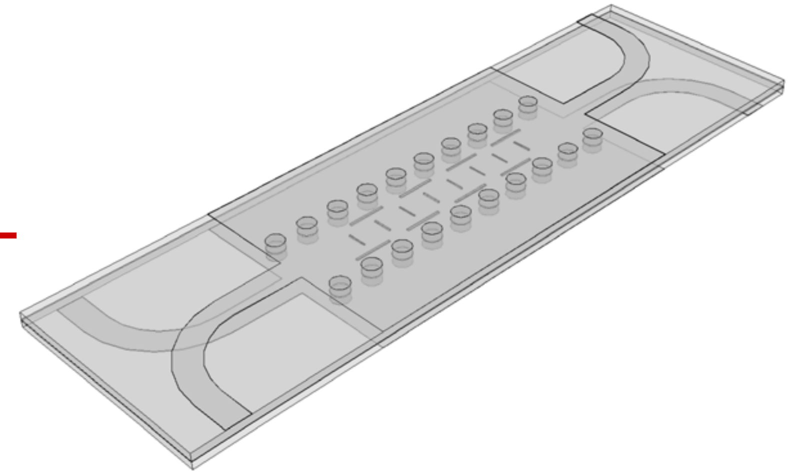
- Design an equivalent dual-hole coupler according to the previous section.
- Translate the dual-holes into Riblet-Saad slot pairs. In order to avoid overlapping slots, maintain the same slot dimensions throughout the coupler. Recalculate with HFSS.
- Repeat initial design to counteract deviation from specified coupling (due to identical apertures).
- Recalculate and fine-optimize within HFSS.

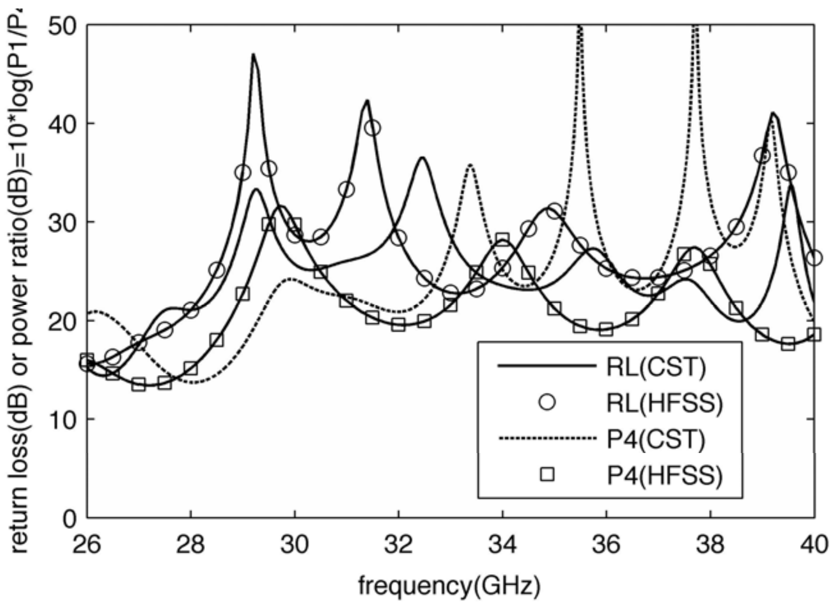


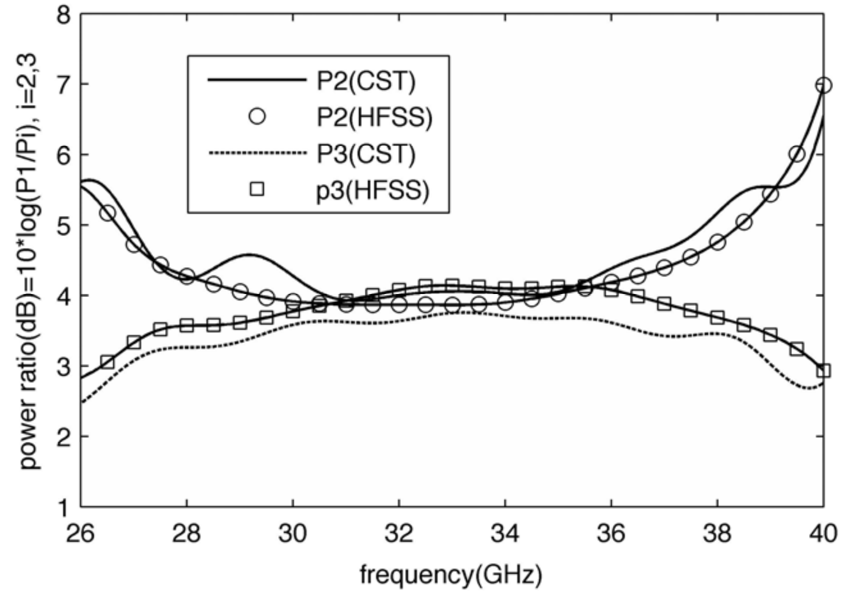
For all dimensions including MS-SIW transitions:

V.A. Labay and J. Bornemann, "Simplified design of multi-layered substrate-integrated waveguide Riblet-Saad couplers", *Microwave Opt. Technol. Lett.*, Vol. 52, pp. 1142-1144, May 2010.

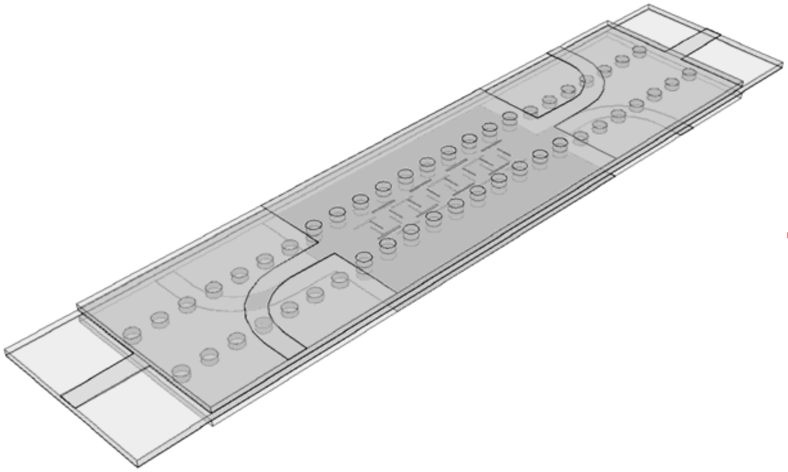
Dual-layer 3-dB Riblet-Saad Coupler

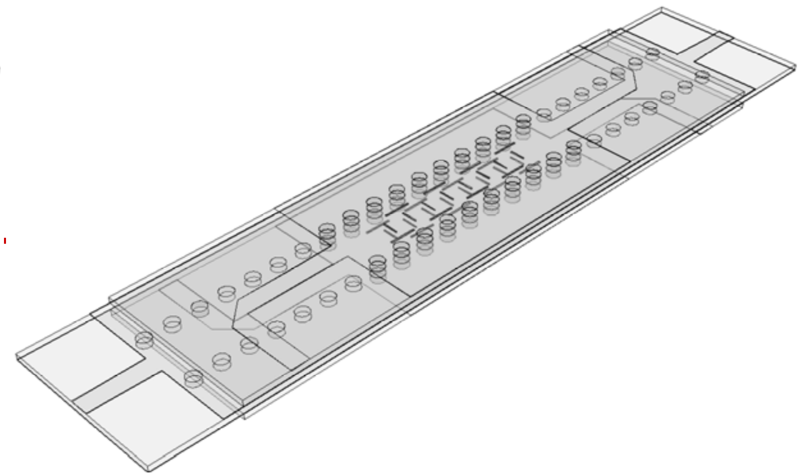


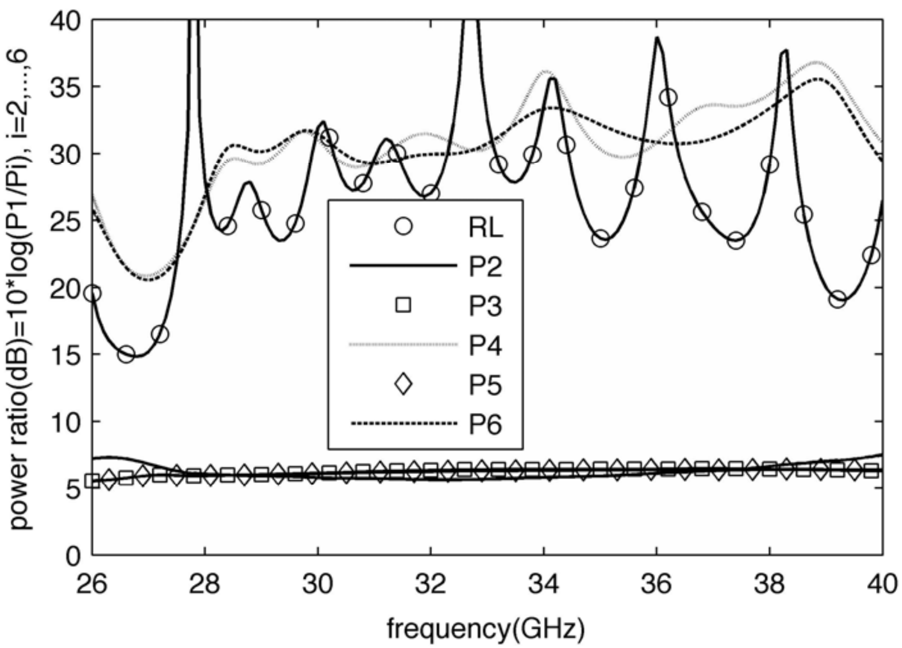


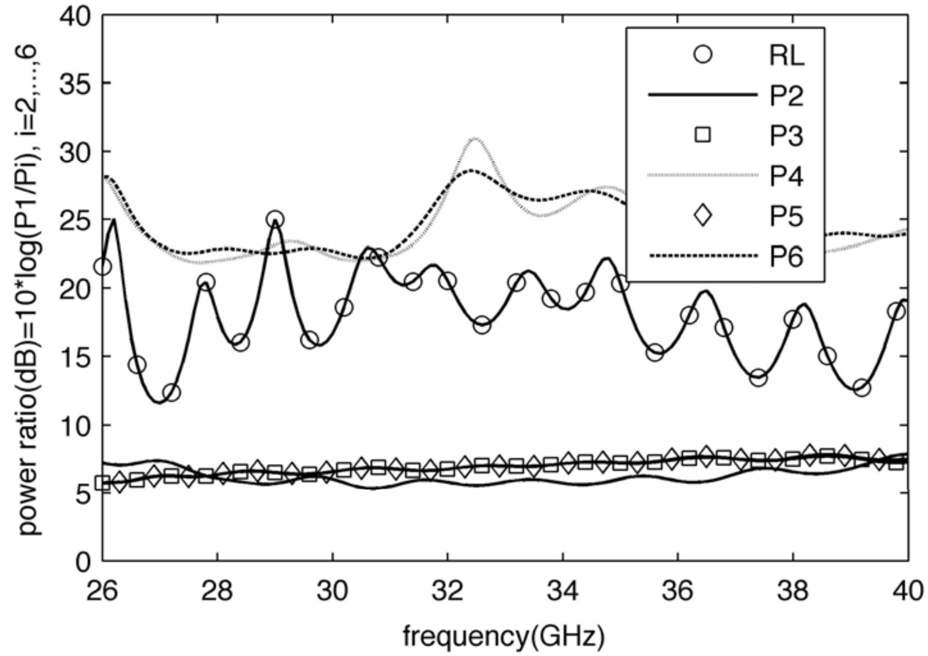


Dual-layer eight-section 3-dB Riblet-Saad coupler with microstrip-to-SIW transitions; performance comparison between HFSS and CST for return loss and isolation (left), and through port and coupled port (right).







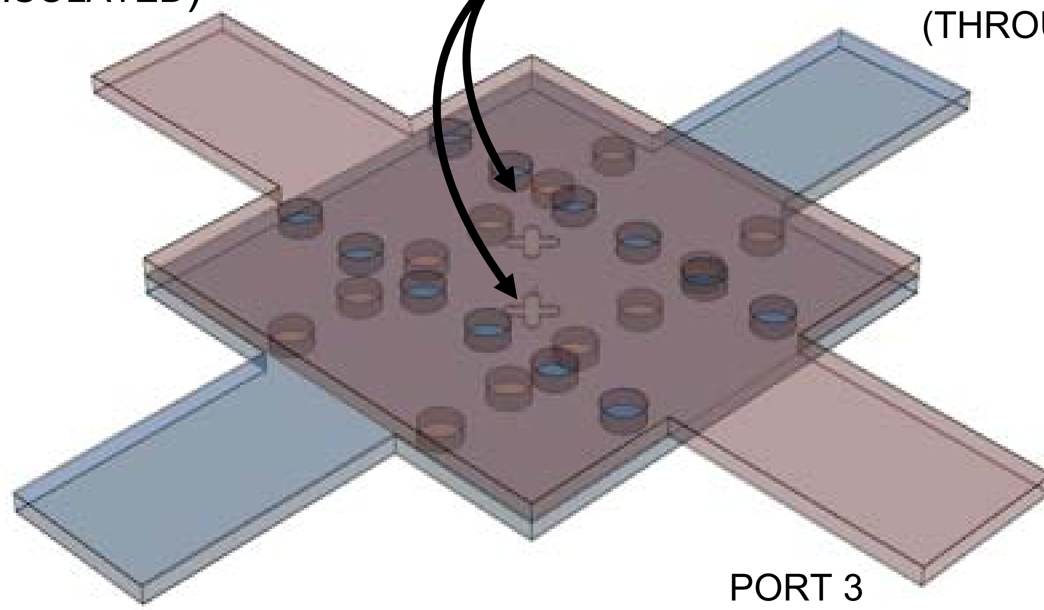


Triple-layer eight-section Riblet-Saad 4.78-dB couplers with straight/bent microstrip ports (left) and straight/mitered microstrip ports (right).

Moreno Cross-Slot Couplers (with T. Rama Rao)

Design

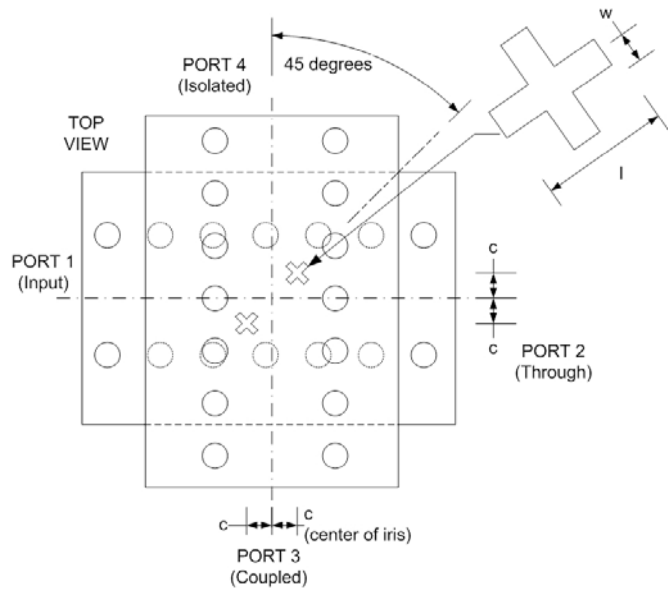
- Initial cross-slot parameters can be obtained from closed-form polarizability expressions in [3].
- For a given coupling value, the dimensions of the coupling crosses (*w*, *l*) are modified and fine optimized in HFSS.



Reference:

[3] K. Rambabu, H.A. Thiart and J. Bornemann, "Simplified analysis for the initial design of rectangular waveguide cross-slot couplers", *IEE Proc.-Microw. Antennas Propag.*, Vol. 152, pp. 226-230, Aug. 2005.

Dual-layer 20-dB Moreno Cross-Slot Coupler

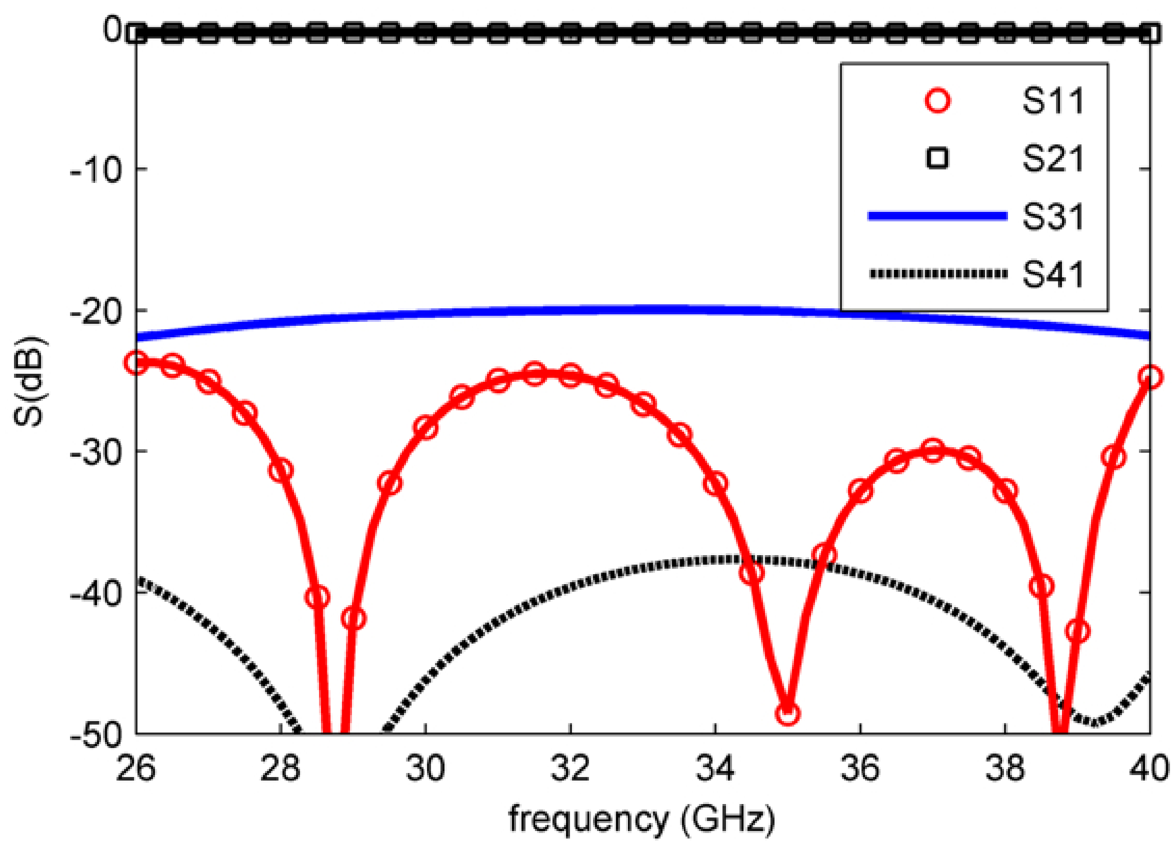


Dimensions (mm) [2]

w = 0.40

l = 1.45

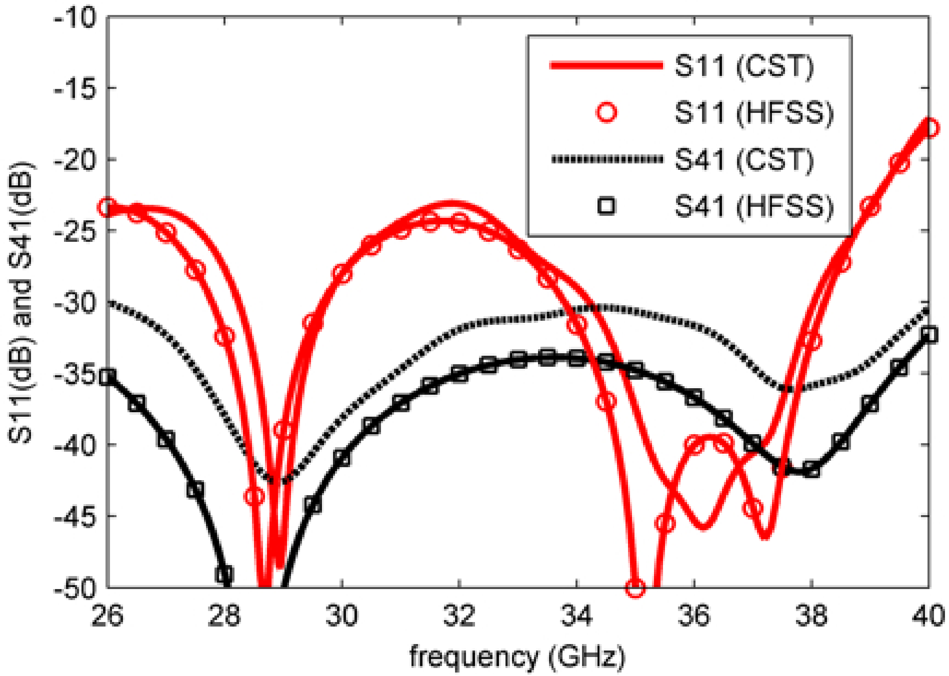
c = 1.10

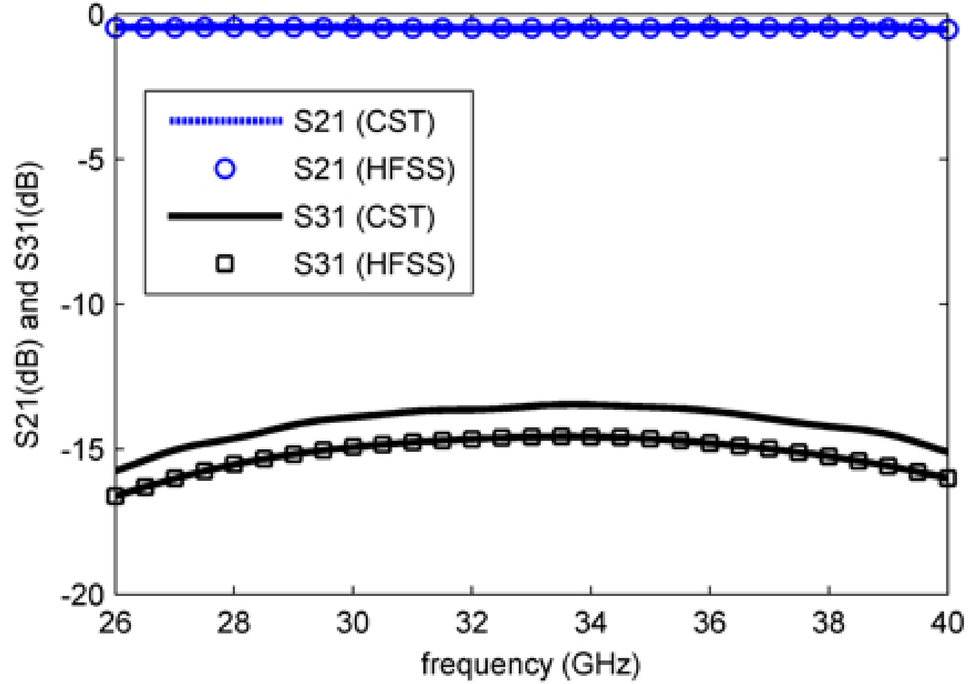


Reference:

[2] V.A. Labay, J. Bornemann and T. Rama Rao, "Design of multilayered substrate-integrated waveguide cross-slot couplers", *Proc. 39th European Microwave Conf.*, pp. 409-412, Rome, Italy, Sep./Oct. 2009.

Dual-layer 15-dB Moreno Cross-Slot Coupler
Comparison HFSS - CST



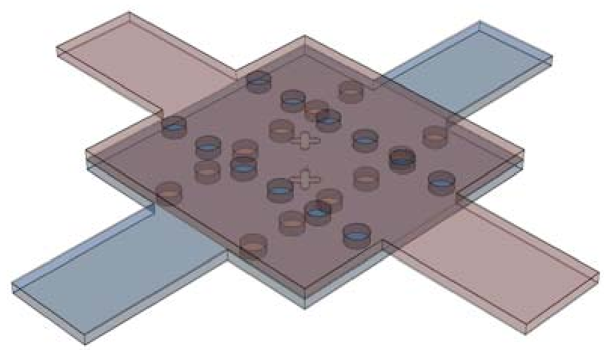


Dimensions (mm)

w = 0.40

l = 1.70

c = 1.1 0



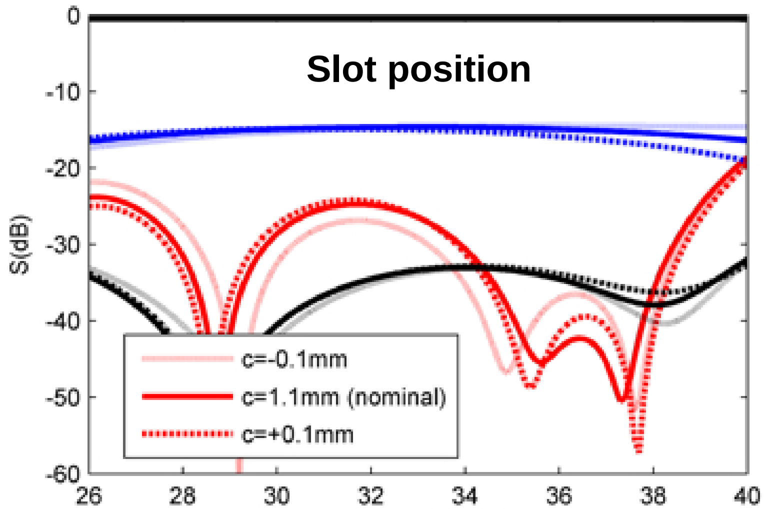
GONZAGA UNIVERSITY

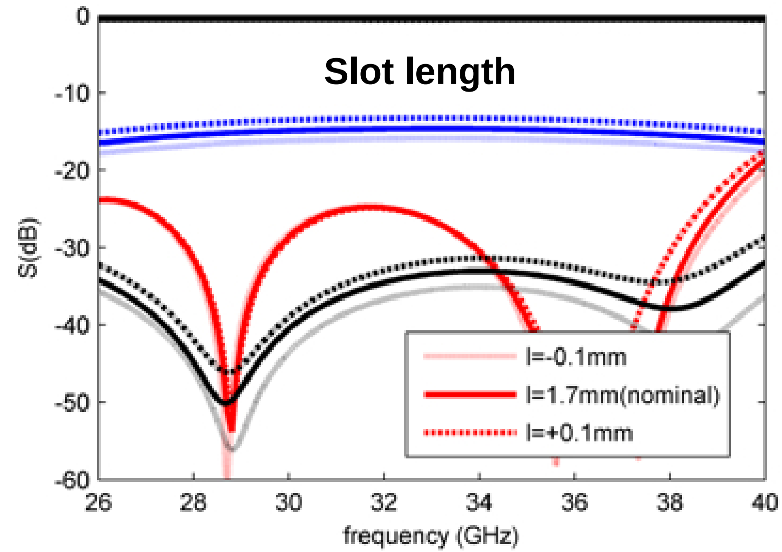
University of Victoria

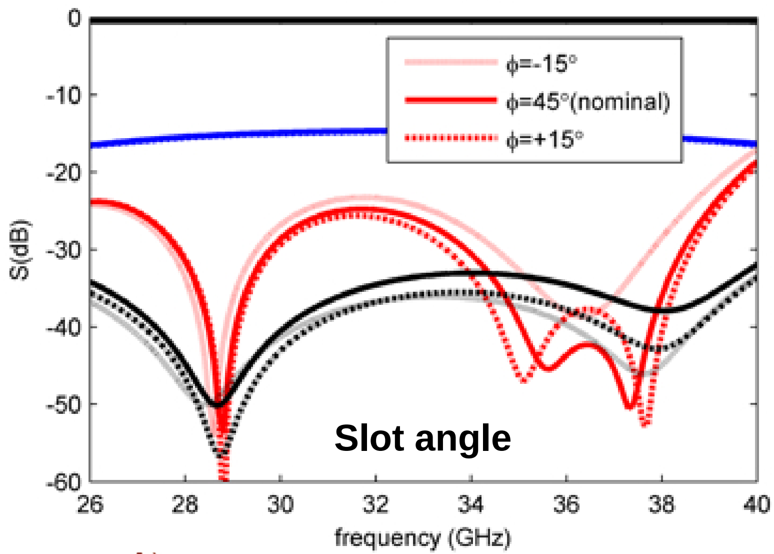
WSI: Substrate Integrated Circuits (SICs)

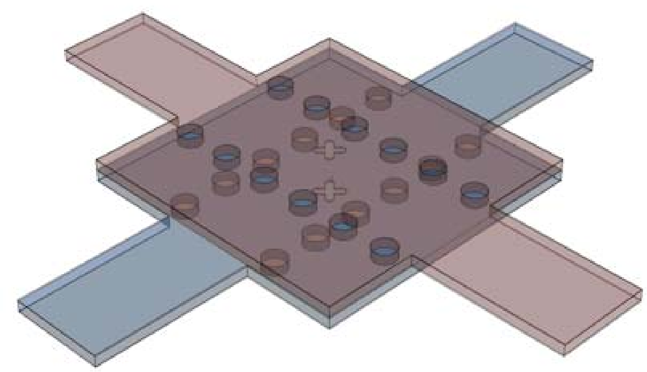
MTT-S

Dual-layer 15-dB Moreno Cross-Slot Coupler Sensitivity Analysis

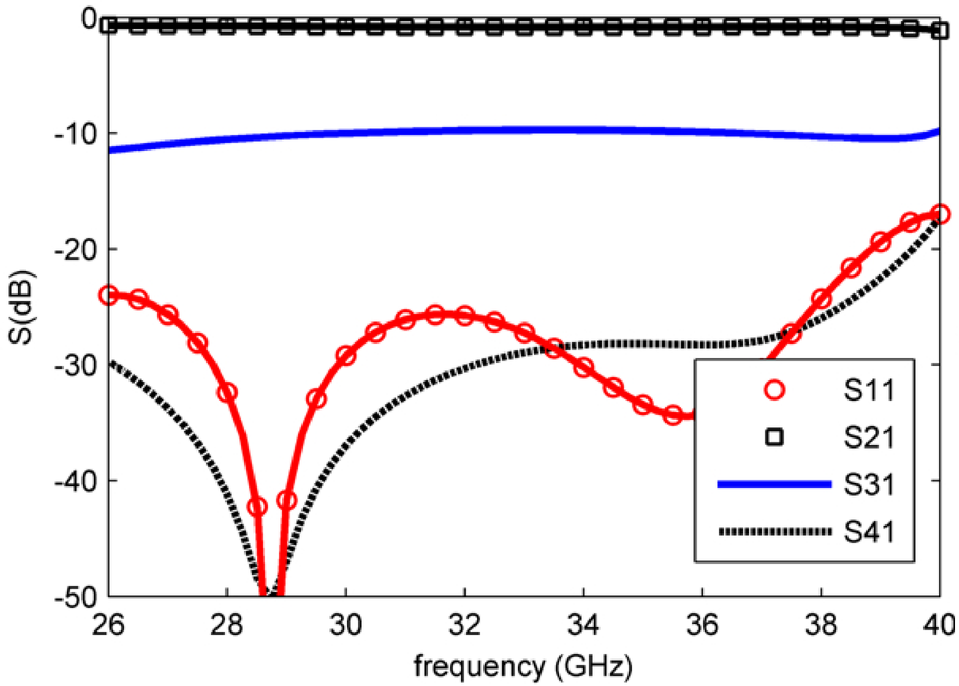


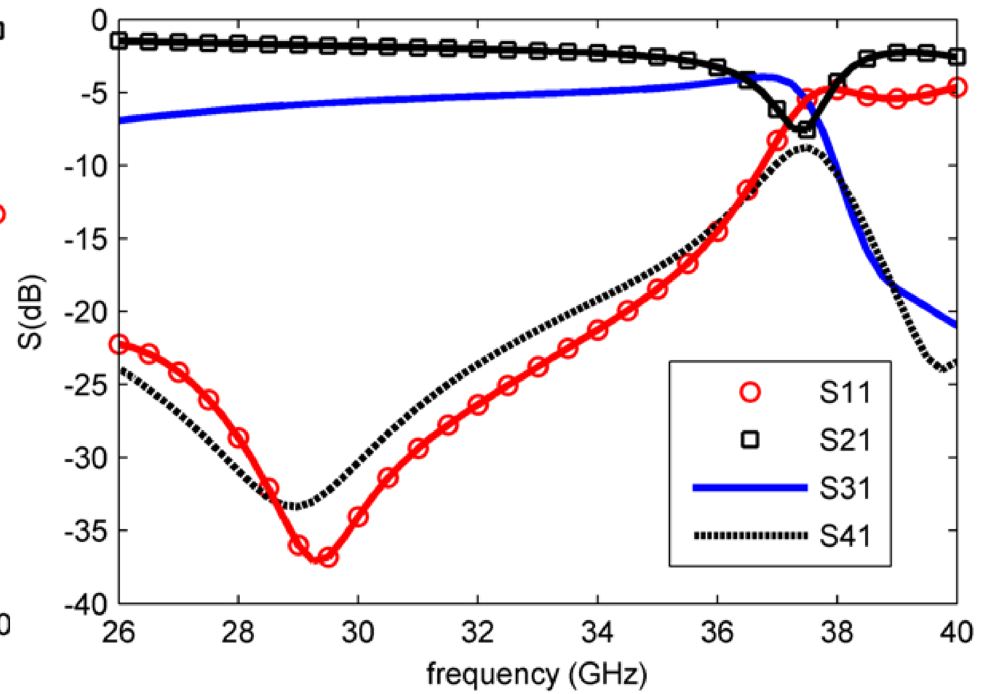






Dual-layer 10- and 6-dB Moreno Cross-Slot Couplers





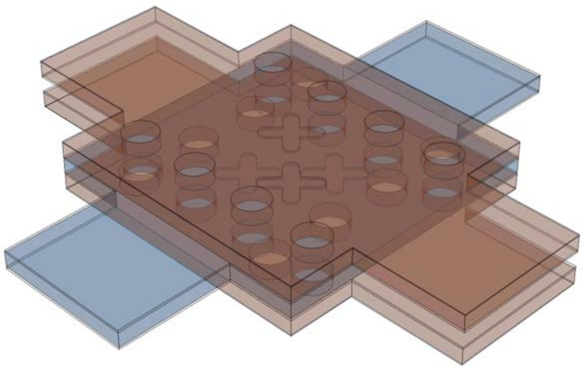
Dimensions (mm)

w = 0.40
l = 2.20
c = 1.10

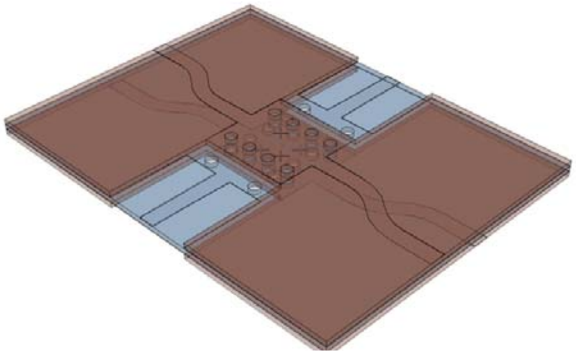
Dimensions (mm)

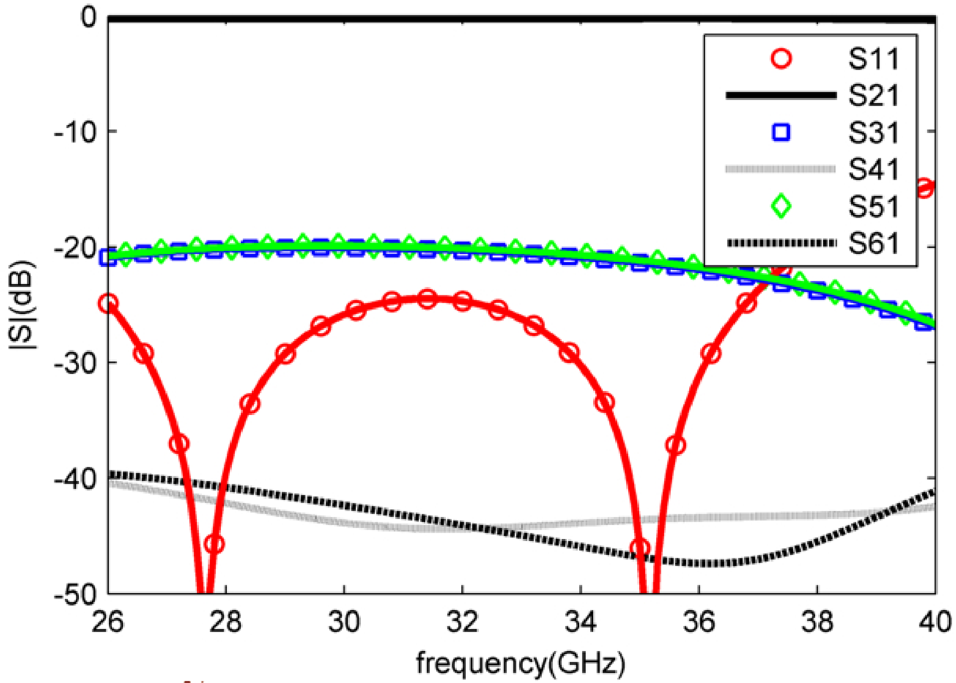
w = 0.40
l = 2.70
c = 1.10

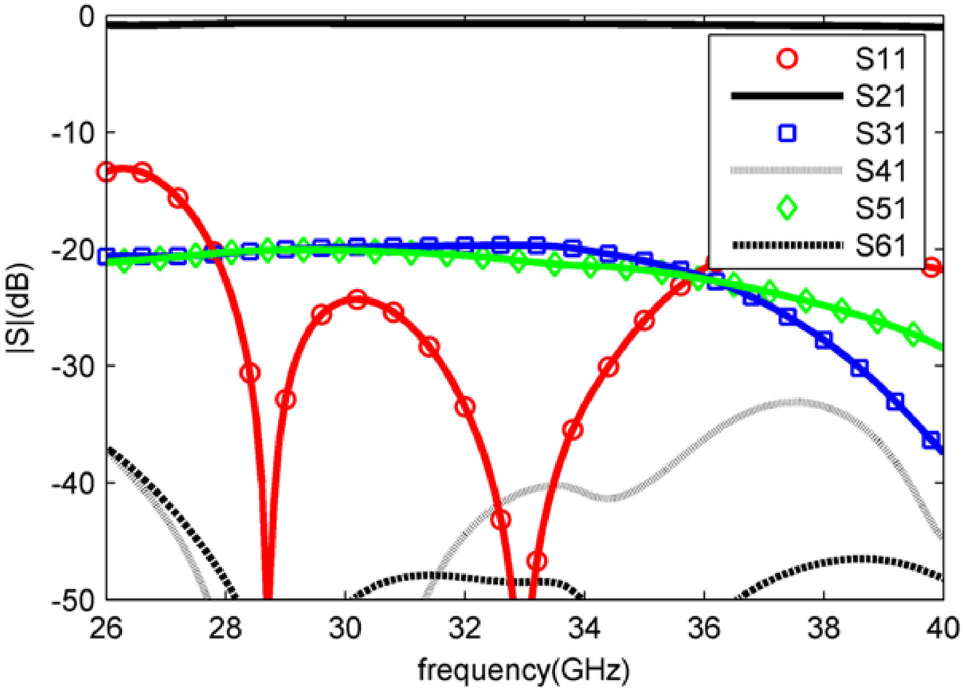
Triple-layer 20-dB Moreno Cross-Slot Coupler waveguide versus microstrip ports



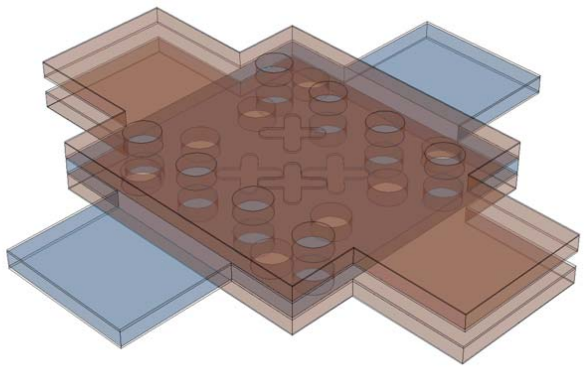
Dimensions (mm)
w = 0.13
l = 1.73
c = 1.27







Triple-layer 15-dB Moreno Cross-Slot Coupler waveguide versus microstrip ports

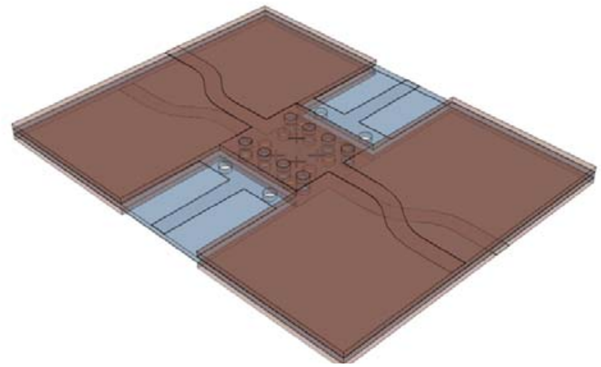


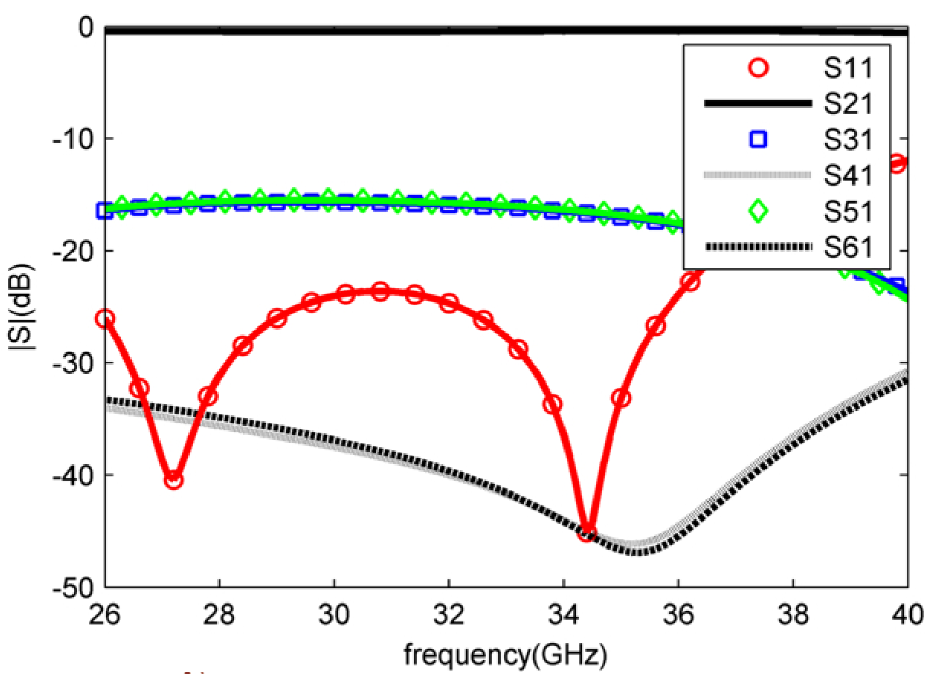
Dimensions (mm)

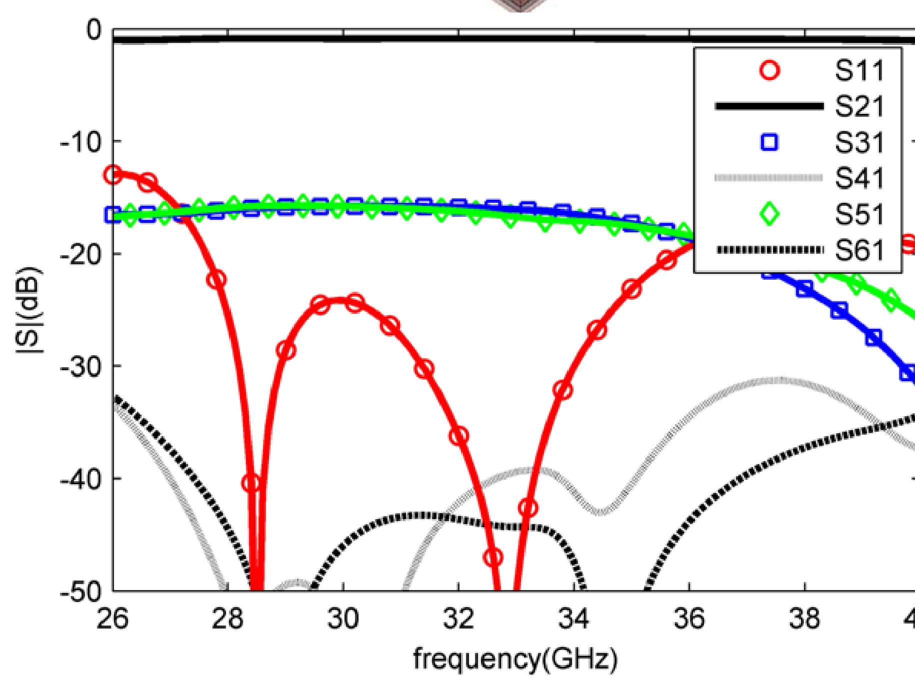
w = 0.13

l = 2.03

c = 1.27



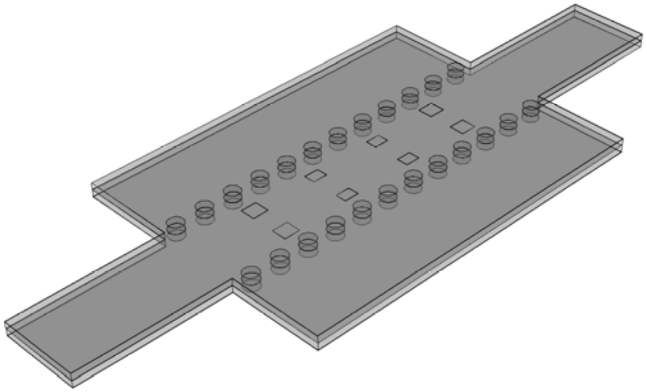


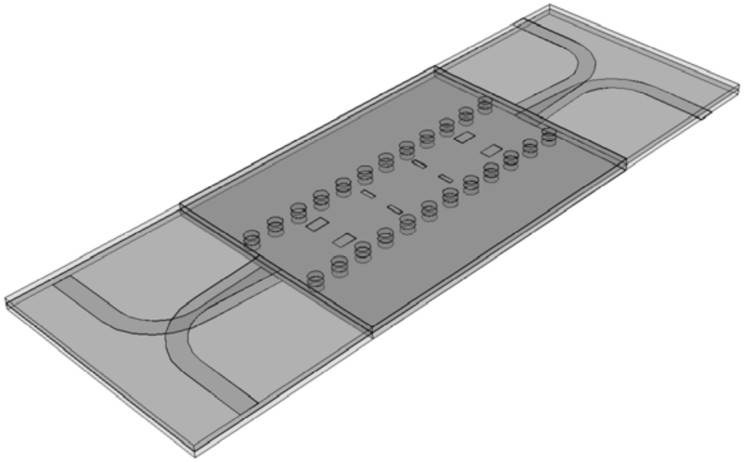


Dual-Band Couplers

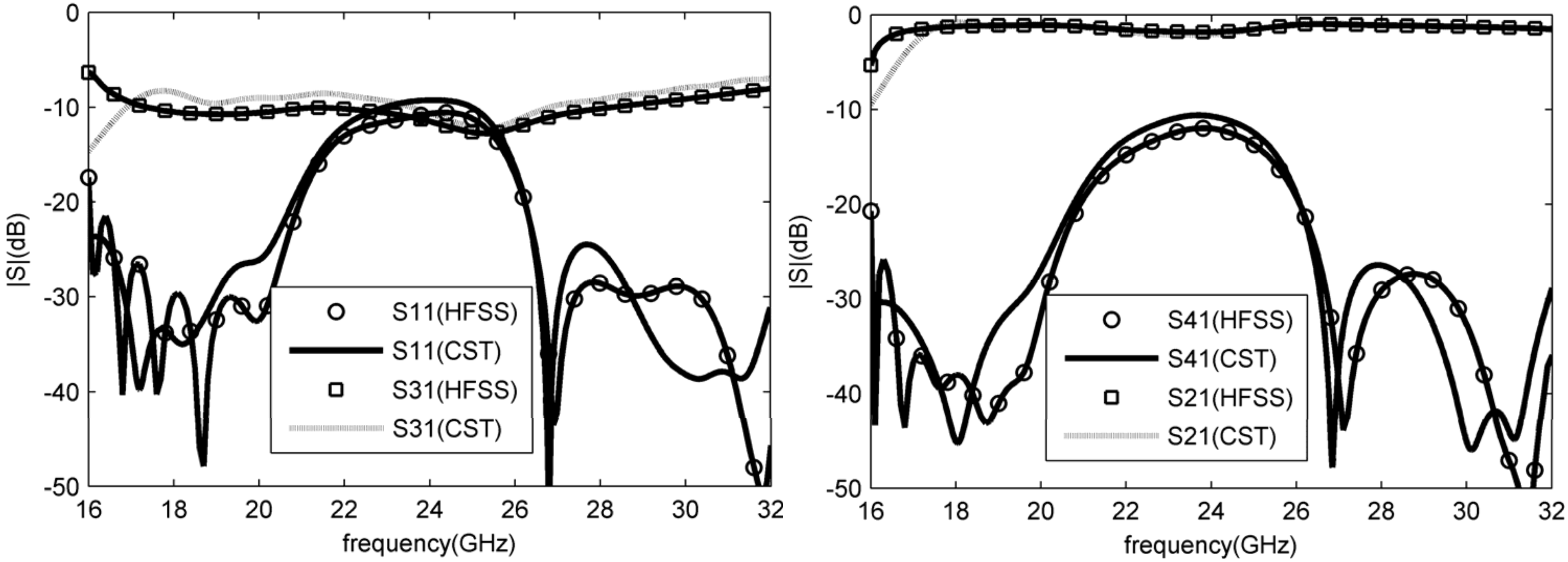
Design

- Design an equivalent dual-hole coupler for the lower band.
- Recalculate the SIW circuit with HFSS.
- Fine-optimize slot lengths and slot spacing within HFSS for satisfactory performance in both bands.





10-dB Dual-Band Coupler Comparison HFSS - CST

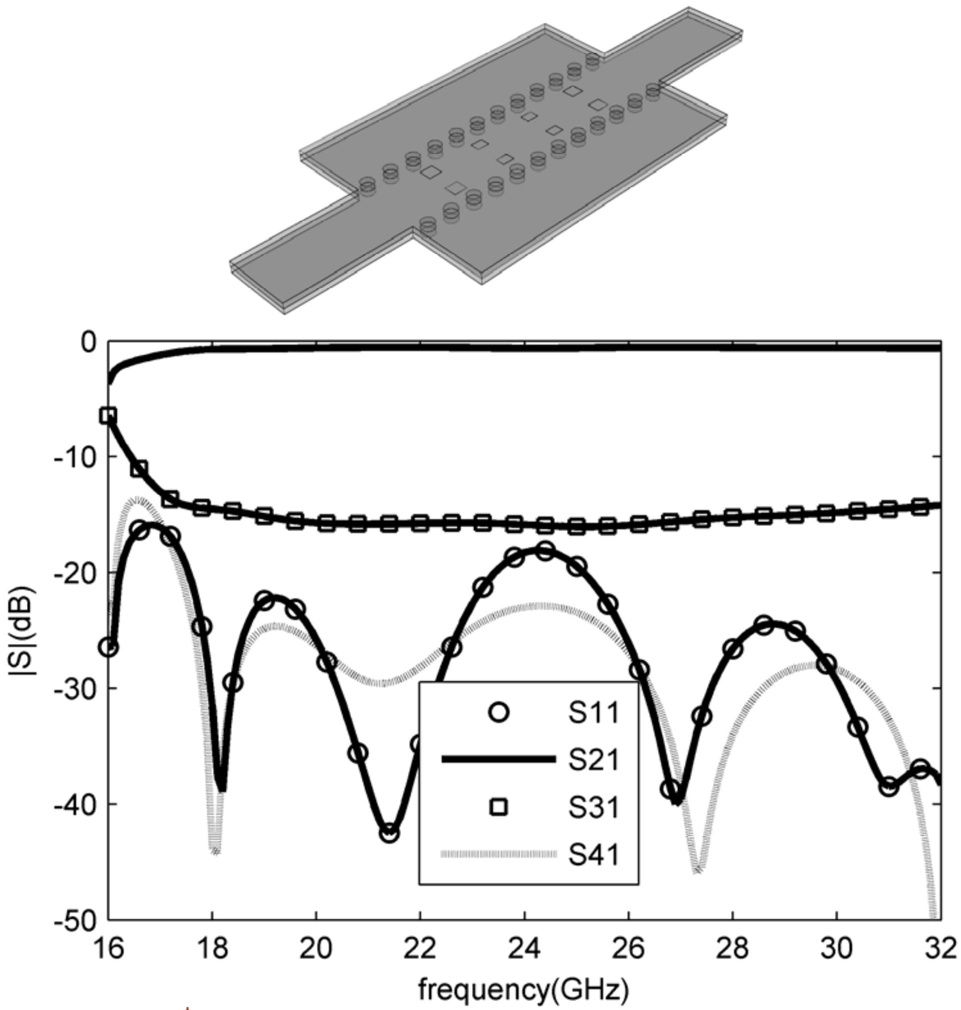


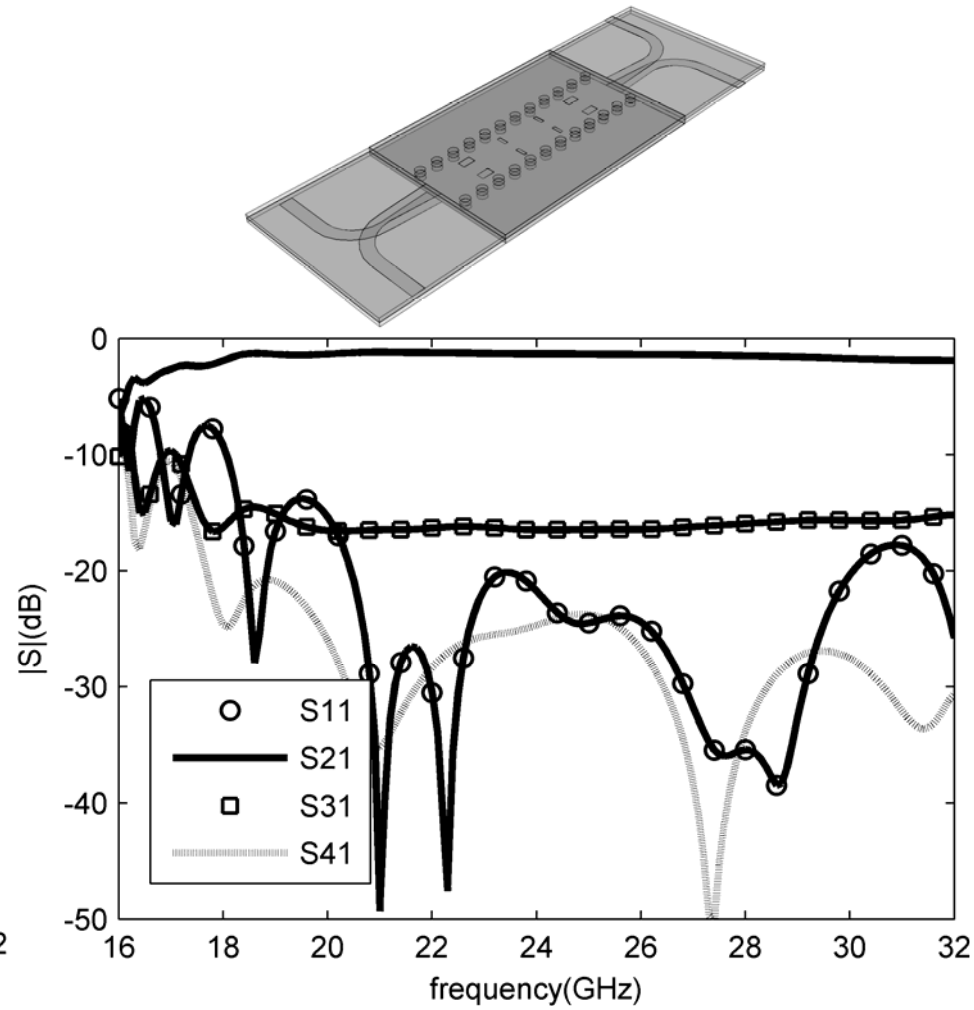
Comparison between HFSS and CST at the example of a 10 dB dual-band coupler with *N*=8 dual holes and all-dielectric waveguide ports; (left) input return loss and coupling; (right) isolation and through port (dimensions, c,f. [5]).

Reference:

[5] V.A. Labay and J. Bornemann, “Design of dual-band substrate-integrated waveguide E-plane directional couplers”, in *Proc. 2009 Asia-Pacific Microwave Conf.*, TH2D-3, 4 p., Singapore, Dec. 2009.

15-dB Dual-Band Coupler (N=4) waveguide versus microstrip ports



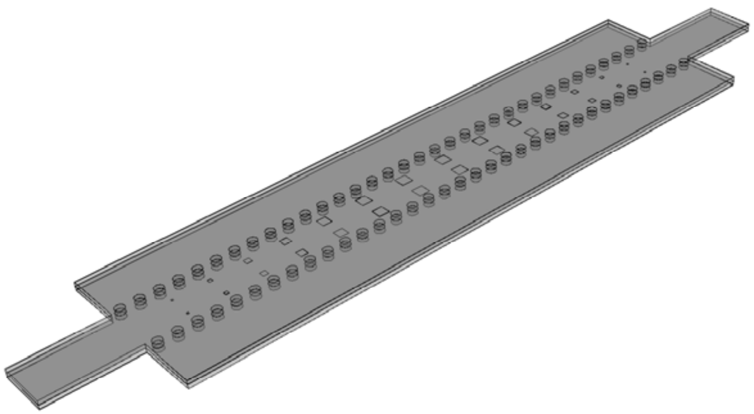


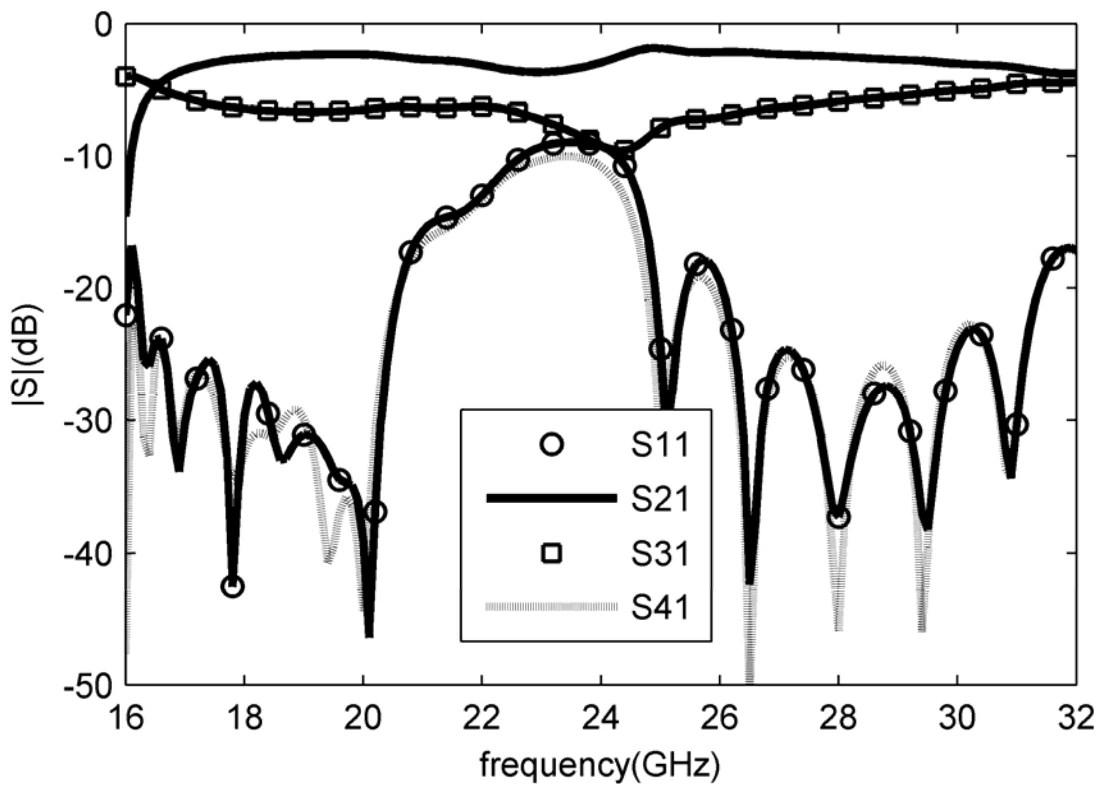
GONZAGA UNIVERSITY

University of Victoria

MTT-S

6-dB Dual-Band Coupler



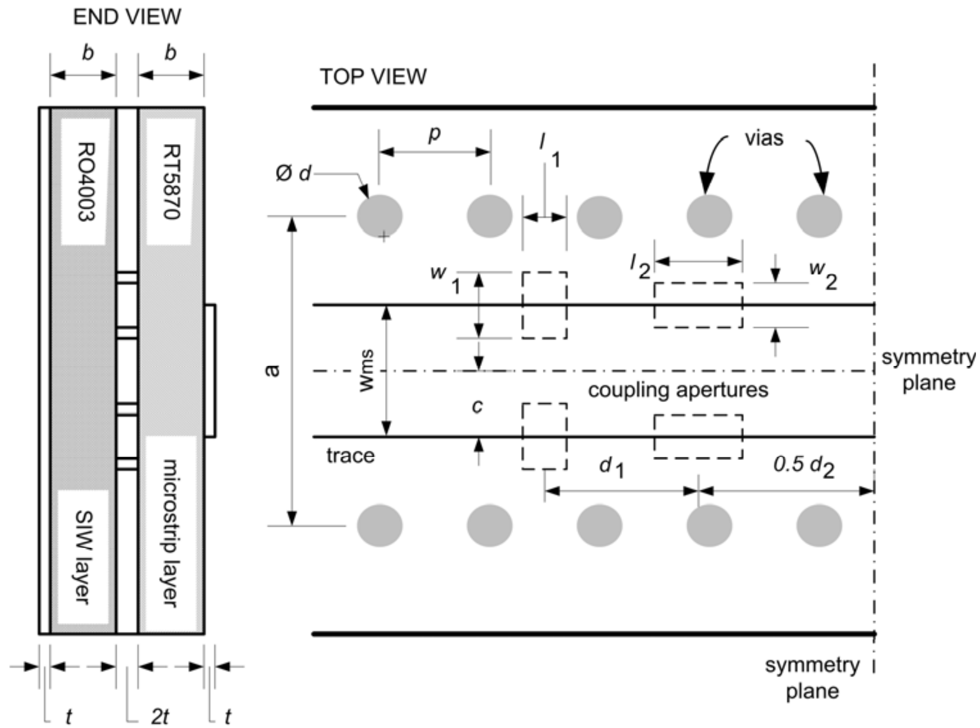


Performance of a 6-dB dual-band coupler with *N*=14 dual holes and all-dielectric waveguide ports.

Microstrip-to-SIW Couplers

Design

- Design guidelines according to [7], [8].
- Recalculate the MS-SIW circuit with HFSS.
- Fine-optimize slot dimensions and slot spacing within HFSS.

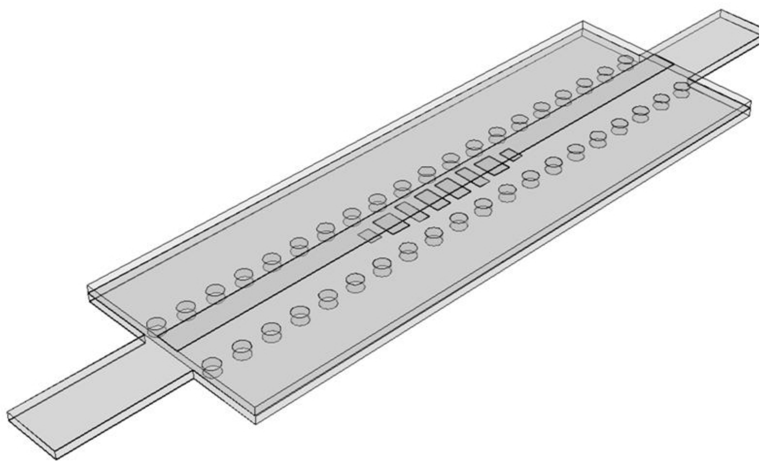


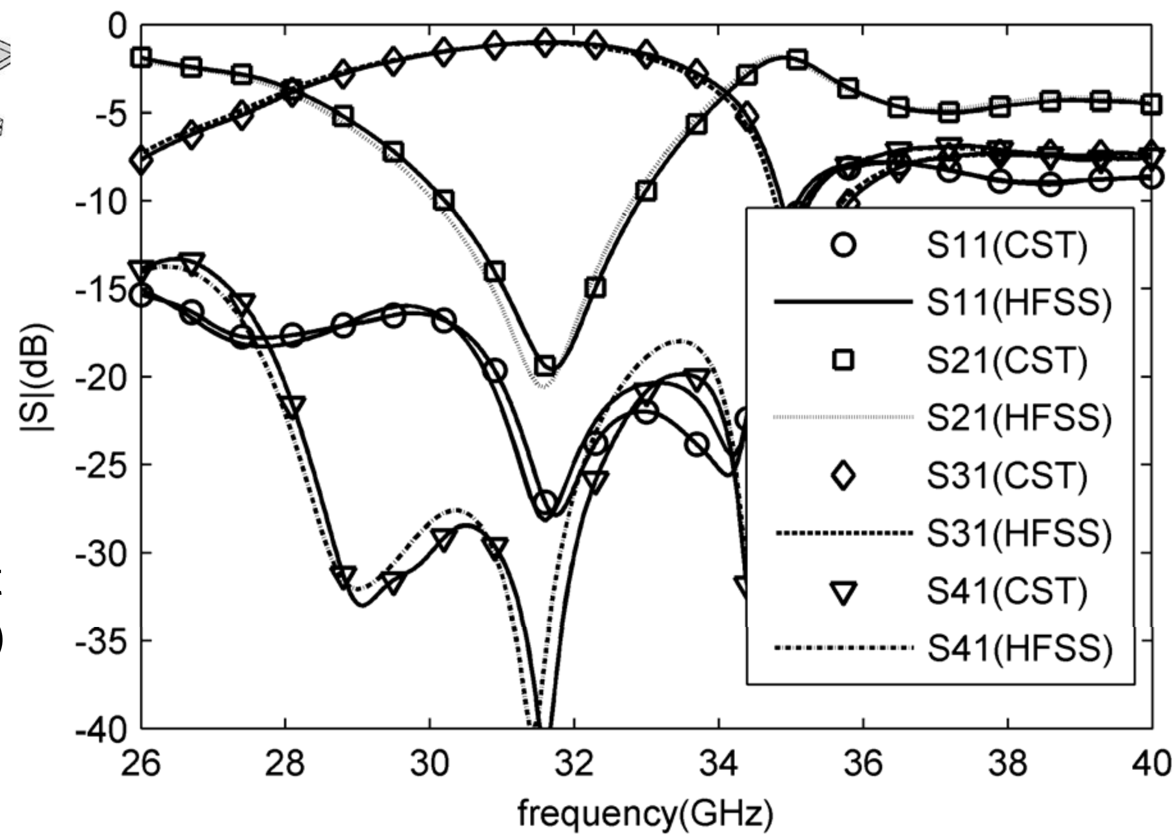
References:

[7] K. Rambabu and J. Bornemann, "Analysis and design of profiled multi-aperture stripline-to-microstrip couplers," *IEE Proc.-Microw. Antennas Propag.*, vol. 150, pp. 484-488, Dec. 2003.

[8] J.S. Rao, K.K. Joshi, and B.N. Das, "Analysis of small aperture coupling between rectangular waveguide and microstrip line," *IEEE Trans. Microwave Theory Tech.*, vol. 29, pp. 150-154, Feb. 1981.

1-dB MS-to-SIW Coupler
Comparison HFSS - CST

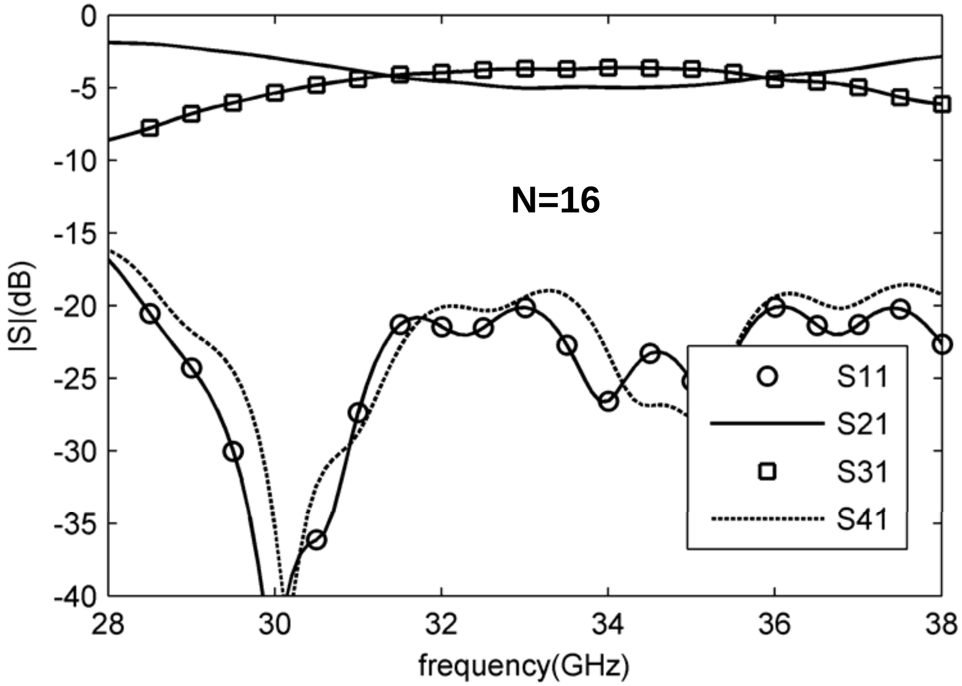


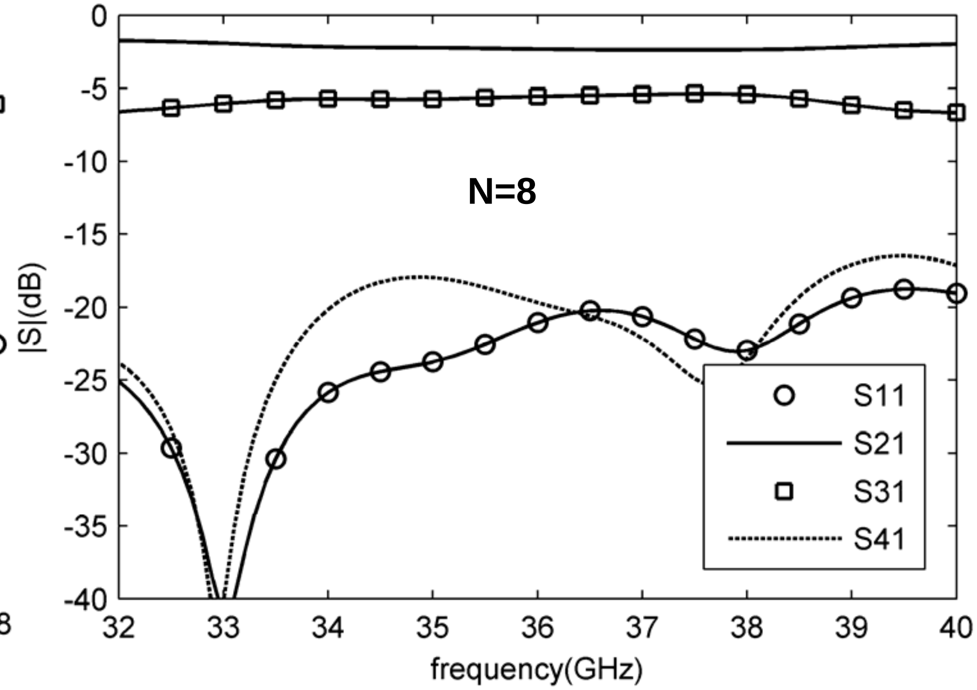


Note that the power balance at midband frequency (31.5 GHz) indicates radiation losses of approximately 1 dB.

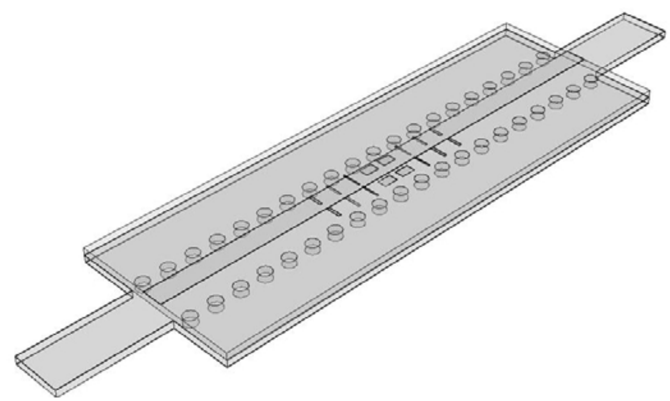
Performance comparison between HFSS and CST at the example of a 1-dB microstrip-to-SIW coupler with 8 single apertures

3-dB and 6-dB MS-to-SIW Coupler

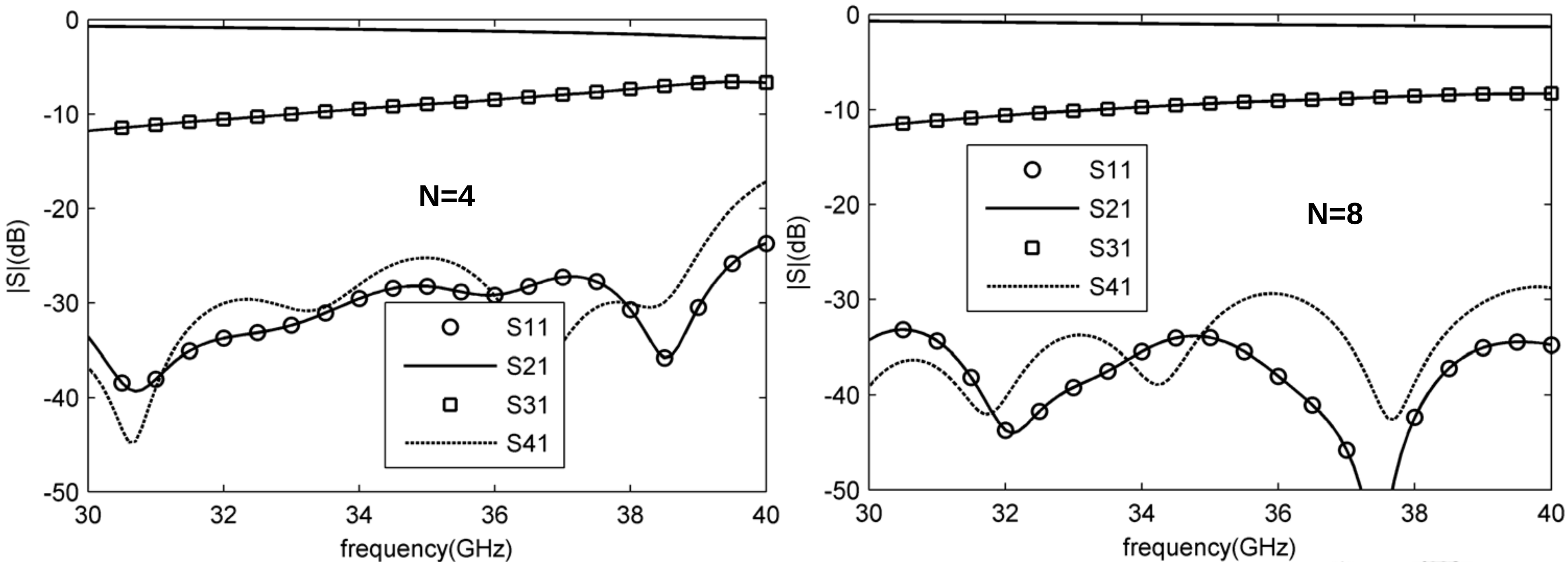




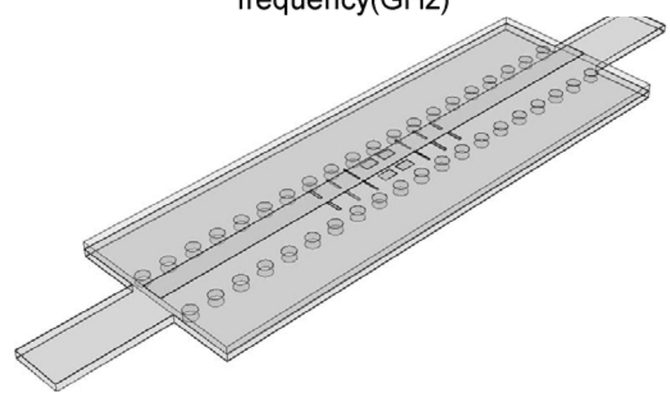
Performances 3-dB (left) and 6-dB (right) microstrip-to-SIW couplers with dual apertures.



10-dB MS-to-SIW Couplers



Performances of 10-dB microstrip-to-SIW couplers with 4 (left) and 8 (right) double apertures.



Conclusions

- Multilayered substrate-integrated waveguide (SIW) directional couplers present a viable option for implementation in SIW feed systems and/or monitoring systems.
- Simple guidelines based on the assumption of weak coupling allow for the design of wide-band and dual-band couplers with tight (3 dB dual-layer, 4.78 dB triple-layer) and weak coupling (10 – 20 dB).
- Microstrip-to-SIW couplers are prone to appr 1 dB power loss due to radiation.
- The design process is simplified by considering all-dielectric waveguide ports.
- Standard microstrip-to-SIW transitions influence the coupler performance, especially in the lower frequency range of a waveguide band.
- Practical issues due to interfacing and alignment need to be worked out (in progress).