Combiners in Substrate Integrated Waveguide Technology

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Outline

- Introduction
- SIW Divider and Combiner Circuits
- SIW Dividers/Combiners with Filtering Functions
- Filtering Four-port Combiner

  Theory; Waveguide and SIW Implementations
- Eight-port SIW Combiner
- Other Options

  Transmission zeros in filtering functions

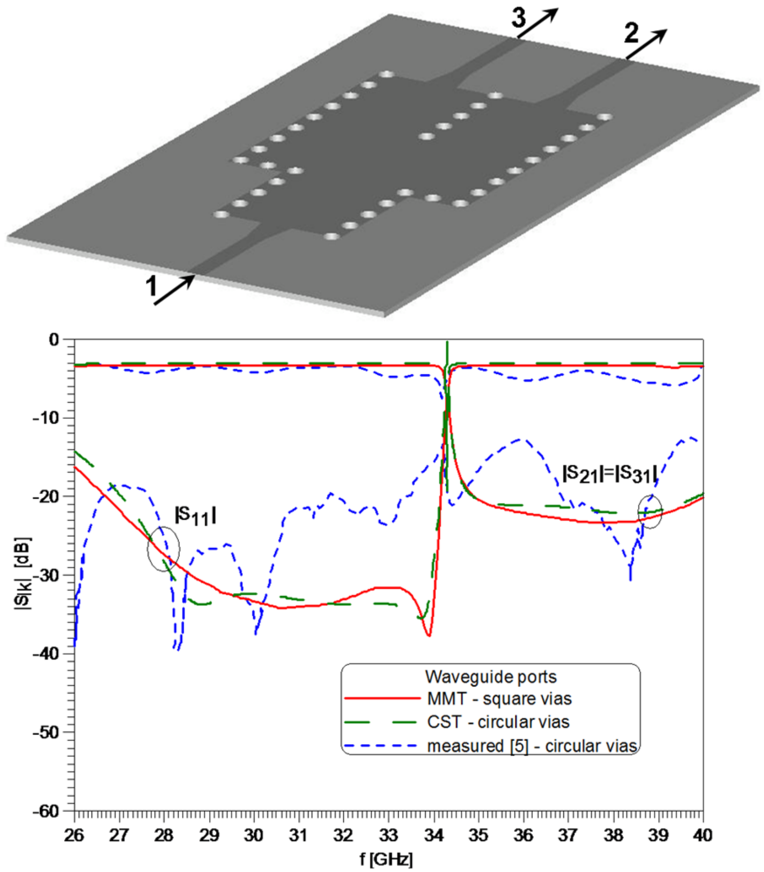
  3-D SIW technology
- Conclusions

Introduction

- Substrate integrated waveguide (SIW) technology is well established, and almost all H-plane waveguide circuits have been translated to SIW, including power dividers and combiners.
- Modern microwave equipment requires traditional, stand-alone components to be amalgamated.
- Different implementations providing the combinations of power splitting and filtering functions have been proposed. But most are not suitable for single-layer SIW production.
- Therefore, this presentation is devoted to multi-port combiners/dividers with inherent bandpass filter characteristics that can be fabricated in standard SIW technology.
- The design concept is introduced with respect to typical combiner performance expectations as well as the possibility of enhancing filtering characteristics within the combiner function.

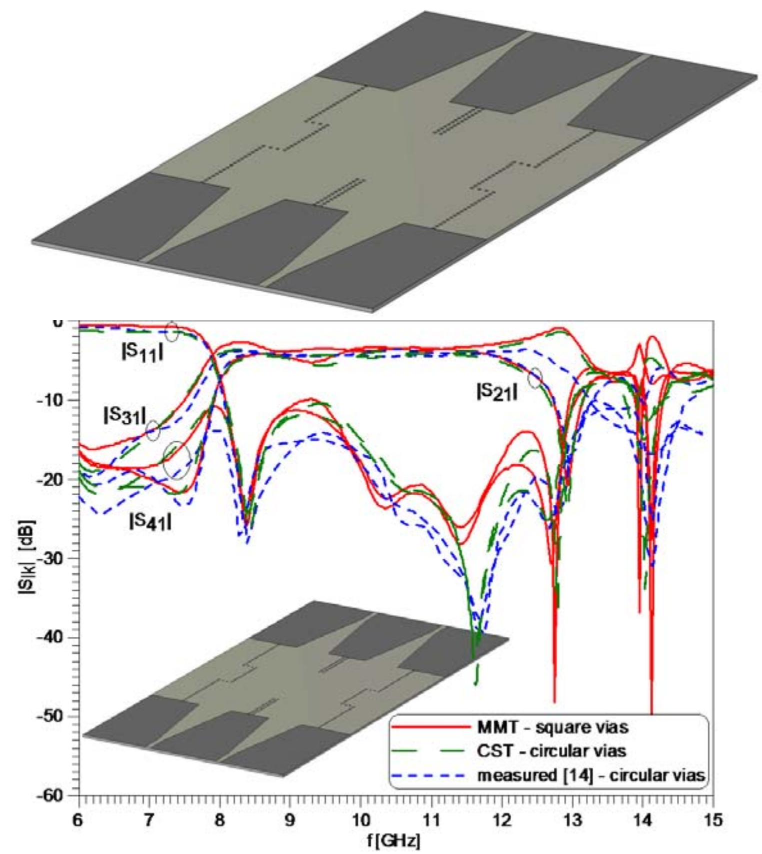
SIW Divider and Combiner Circuits

0-deg, 3-dB Power Divider (no isolation)



Z. Kordiboroujeni, J. Bornemann, *7th EuCAP*, Apr. 2013.

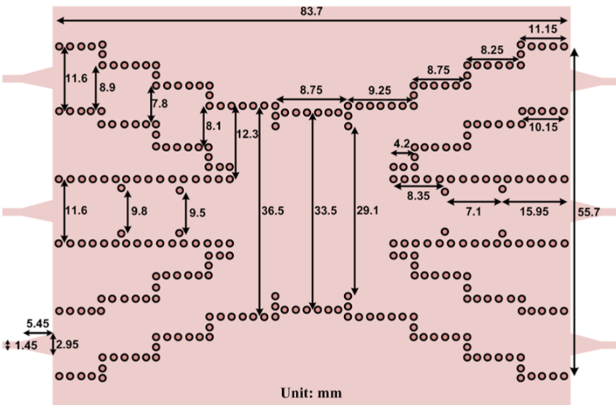
90-deg, 3-dB Coupler (isolation)

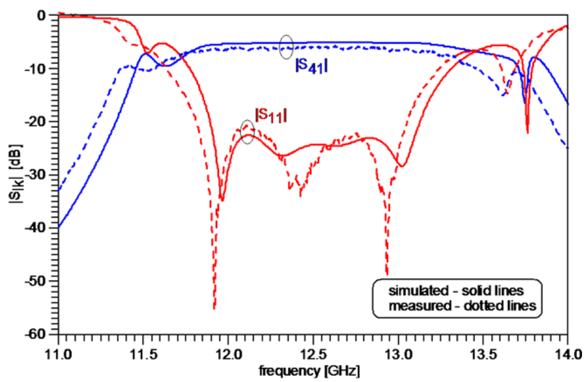


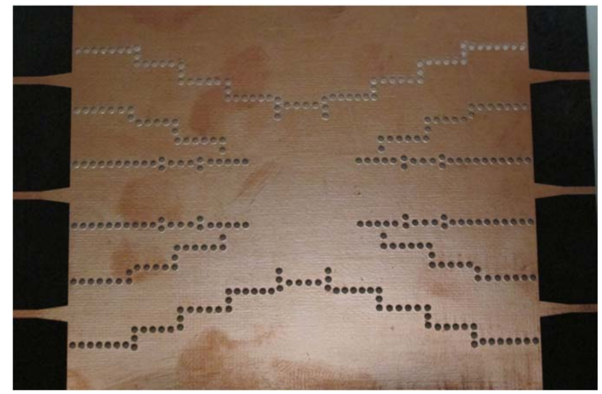
L. Locke, Z. Kordiboroujeni, J. Bornemann, S. Claude, *7th EuCAP*, Apr. 2013.

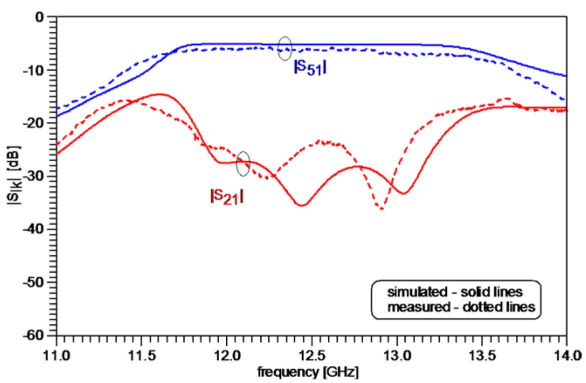
SIW Dividers/Combiners with Filtering Functions

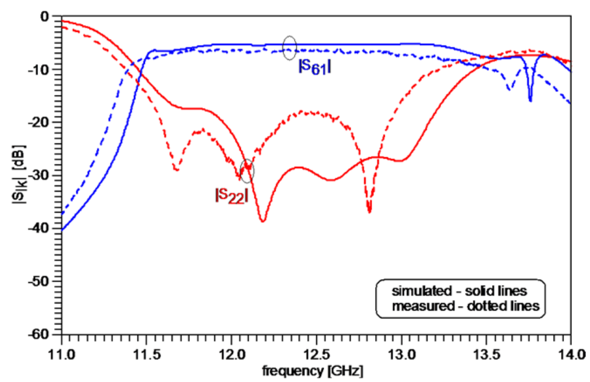
Six-port coupler as three-way divider/combiner with resonators in each port

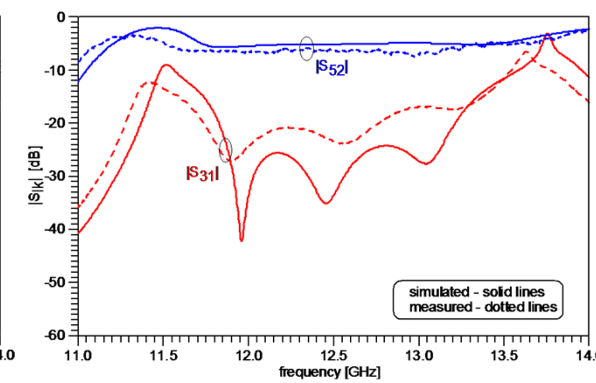








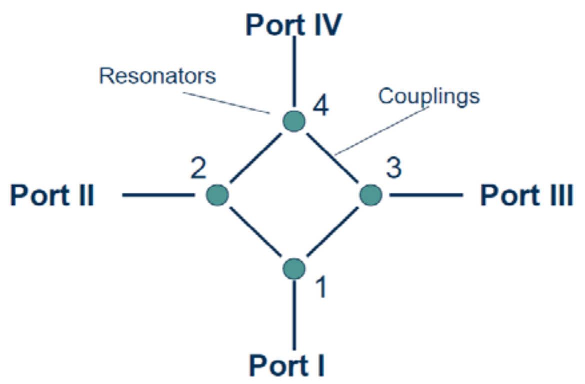




M. Salehi, J. Bornemann, E. Mehrshahi, *Microwave Opt. Technol. Lett.*, Dec. 2013

Filtering Four-port Combiner

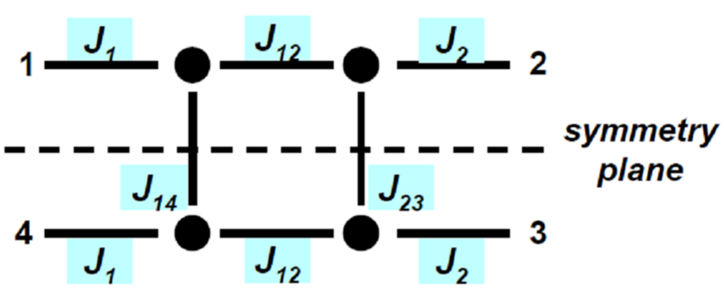
180-deg coupler with four resonators



- 3-dB power distribution (passband)
  port I (port IV) to ports II and III
  port II (port III) to ports I and IV
- Isolation
  between ports I and IV, and II and III
- 2nd-order bandpass characteristic

Theory

Even-odd mode synthesis



$$\begin{pmatrix} A_e & B_e \\ C_e & D_e \end{pmatrix} = \begin{pmatrix} 0 & \frac{j}{J_1} \\ jJ_1 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ s + jB_1 + jJ_{14} & 1 \end{pmatrix} \begin{pmatrix} 0 & \frac{j}{J_{12}} \\ jJ_{12} & 0 \end{pmatrix} \times \begin{pmatrix} 1 & 0 \\ s + jB_3 + jJ_{23} & 1 \end{pmatrix} \begin{pmatrix} 0 & \frac{j}{J_2} \\ jJ_2 & 0 \end{pmatrix}$$

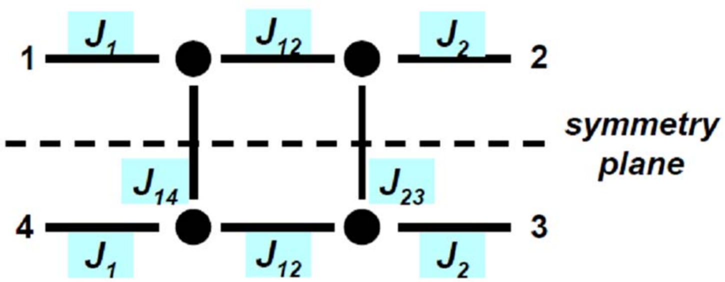
$$\begin{pmatrix} A_o & B_o \\ C_o & D_o \end{pmatrix} = \begin{pmatrix} 0 & \frac{j}{J_1} \\ jJ_1 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ s + jB_1 - jJ_{14} & 1 \end{pmatrix} \begin{pmatrix} 0 & \frac{j}{J_{12}} \\ jJ_{12} & 0 \end{pmatrix} \times \begin{pmatrix} 1 & 0 \\ s + jB_3 - jJ_{23} & 1 \end{pmatrix} \begin{pmatrix} 0 & \frac{j}{J_2} \\ jJ_2 & 0 \end{pmatrix}$$

U. Rosenberg, M. Salehi, S. Amari, J. Bornemann, *MTT Trans.*, Nov. 2014

Filtering Four-port Combiner

Theory

$$S=\begin{pmatrix} \frac{S_{11}^e+S_{11}^o}{2} & \frac{S_{12}^e+S_{12}^o}{2} & \frac{S_{12}^e-S_{12}^o}{2} & \frac{S_{11}^e-S_{11}^o}{2} \\ \frac{S_{12}^e+S_{12}^o}{2} & \frac{S_{22}^e+S_{22}^o}{2} & \frac{S_{11}^e-S_{11}^o}{2} & \frac{S_{12}^e-S_{12}^o}{2} \\ \frac{S_{12}^e-S_{12}^o}{2} & \frac{S_{11}^e-S_{11}^o}{2} & \frac{S_{22}^e-S_{22}^o}{2} & \frac{S_{12}^e+S_{12}^o}{2} \\ \frac{S_{11}^e-S_{11}^o}{2} & \frac{S_{12}^e-S_{12}^o}{2} & \frac{S_{12}^e+S_{12}^o}{2} & \frac{S_{11}^e-S_{11}^o}{2} \end{pmatrix}$$



Design for $J_{14}=-J_{23}$, , $J_1=J_2$ and $B_1=B_3$

$$S_{11}=S_{22}=S_{33}=S_{44} = \frac{s^2+2jsB_1-B_1^2+J_{14}^2+J_{12}^2-J_1^4}{s^2+2s(jB_1+J_1^2)+2jJ_{12}^2B_1-B_1^2+J_{14}^2+J_{12}^2+J_1^4}$$

$$S_{12}=S_{21}=S_{34}=S_{43} = \frac{2jJ_1^2J_{12}}{s^2+2s(jB_1+J_1^2)+2jJ_{12}^2B_1-B_1^2+J_{14}^2+J_{12}^2+J_1^4}$$

$$S_{14}=S_{41}=-S_{23}=-S_{32} = \frac{2jJ_1^2J_{14}}{s^2+2s(jB_1+J_1^2)+2jJ_{12}^2B_1-B_1^2+J_{14}^2+J_{12}^2+J_1^4}$$

$$S_{13}=S_{31}=S_{24}=S_{42}=0$$

Proceed as with coupled–resonator filters …

Filtering Four-port Combiner

Example: Second-order transmission coefficients

$$S_{21} = \frac{ja_{21}}{s^2 + d_1 s + d_2} \; , \quad S_{41} = \frac{ja_{41}}{s^2 + d_1 s + d_2}$$

Comparing coefficients yields

$$2J_1^2 J_{12} = a_{21} \quad , \quad 2J_1^2 J_{14} = a_{41}$$

$$2(jB_1^2 + J_1^2) = d_1$$

$$2\,jJ_{12}^2 B_1 - B_1^2 + J_{14}^2 + J_{12}^2 + J_1^4 = d_2$$

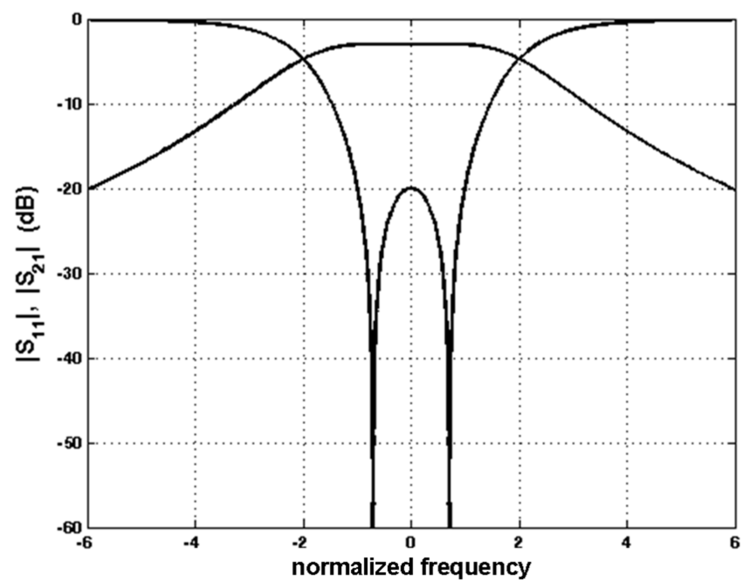
For a second-order 3-dB Chebychev response with ripple constant ε=0.1005 and return loss of 20 dB, we get

$$S_{21} = S_{41} = \frac{j3.5169}{s^2 + 2.9996s + 4.9987}$$

which leads to

$$d_1 = 2.9996\,, \quad B_1 = 0\,, \quad J_1 = 1.2247$$

$$J_{12} = 1.1725\,, \quad J_{14} = 1.1725$$

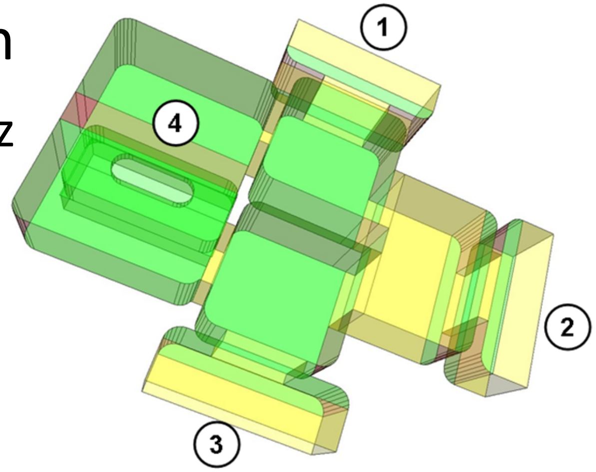


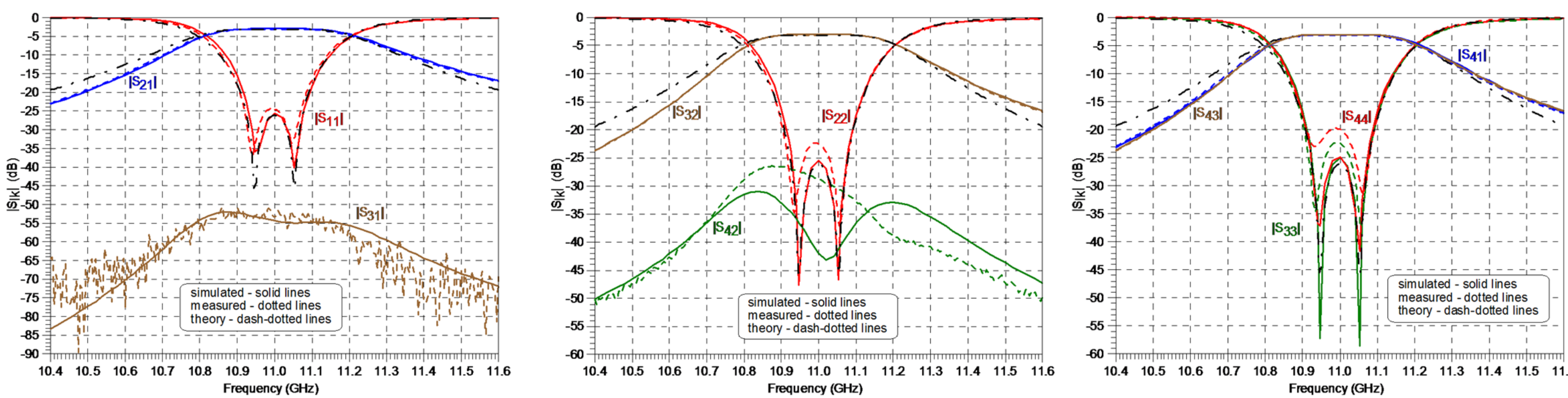
Response of second-order 3-dB Chebychev filter.

Filtering Four-port Combiner

Waveguide Implementation

- 150 MHz bandwidth at 11 GHz
- return loss 26 dB
- Normalized parameters:
  $B_1=0, J_{12}=J_{14}=-J_{23}=1.4874,$
  $J_1=1.4072.$
- Fine optimization in μWave Wizard

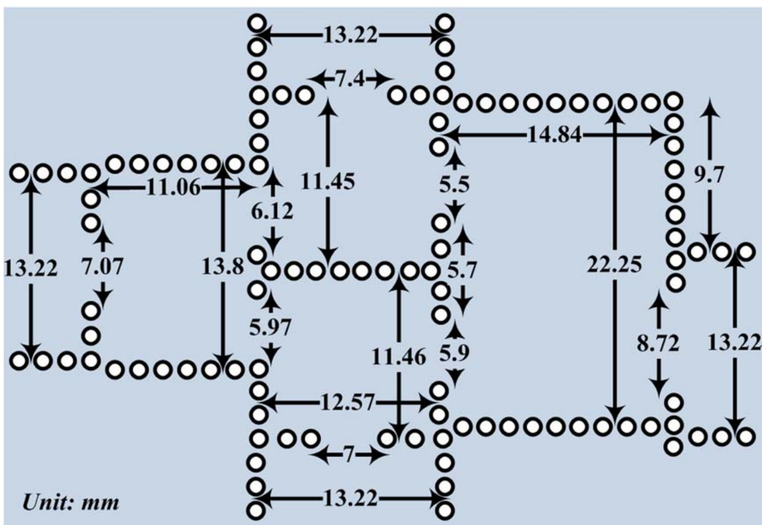


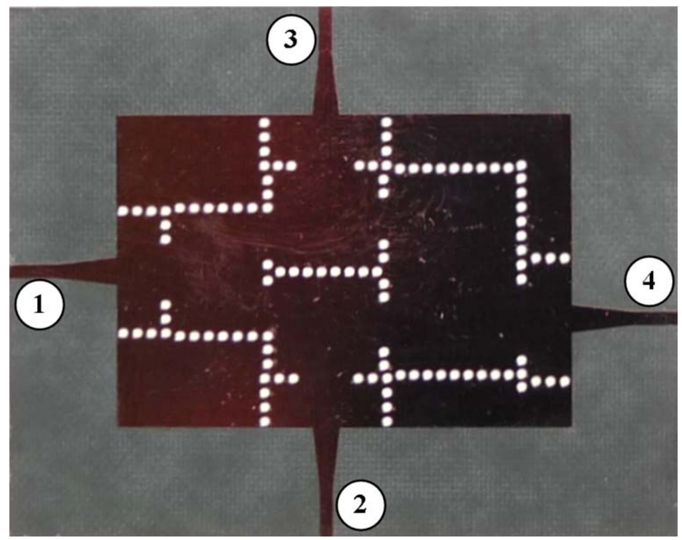


Filtering Four-port Combiner

SIW Implementation

- Note: The SIW combiner is asymmetric due to planar technology
- Waveguide widths and apertures can be calculated from equivalent waveguide width
- Extensive re-optimization is required to account for asymmetries.

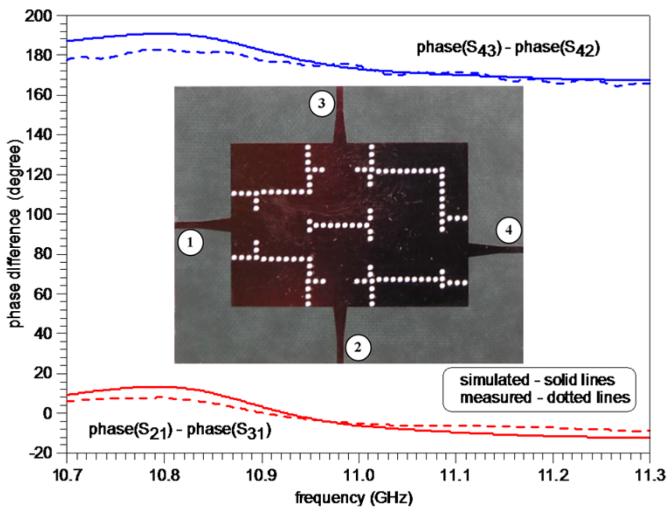


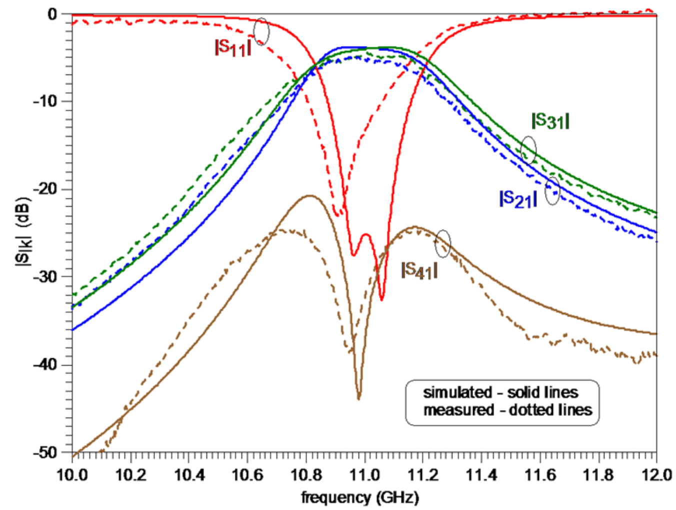


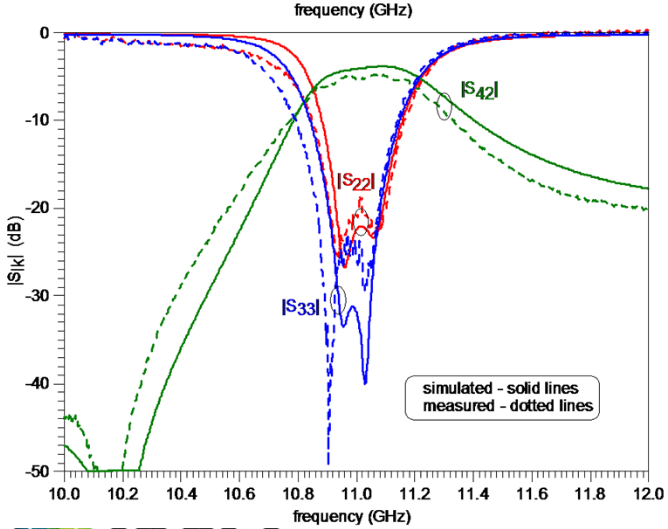
U. Rosenberg, M. Salehi, J. Bornemann, E. Mehrshahi, *MWCL,* Aug. 2013

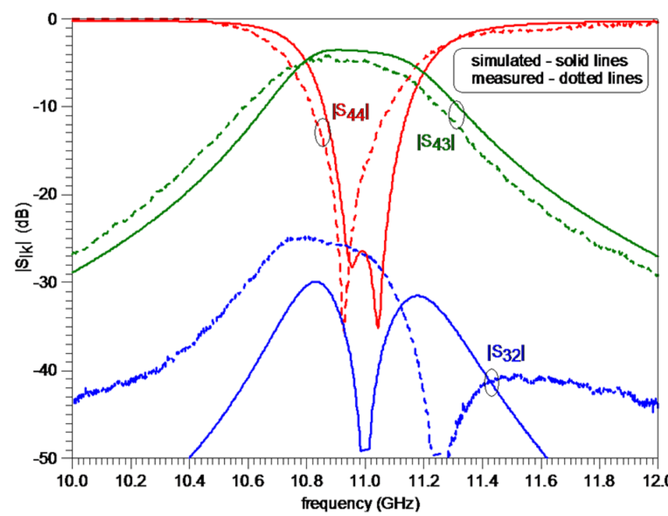
Filtering Four-port Combiner

SIW Implementation - Measurements



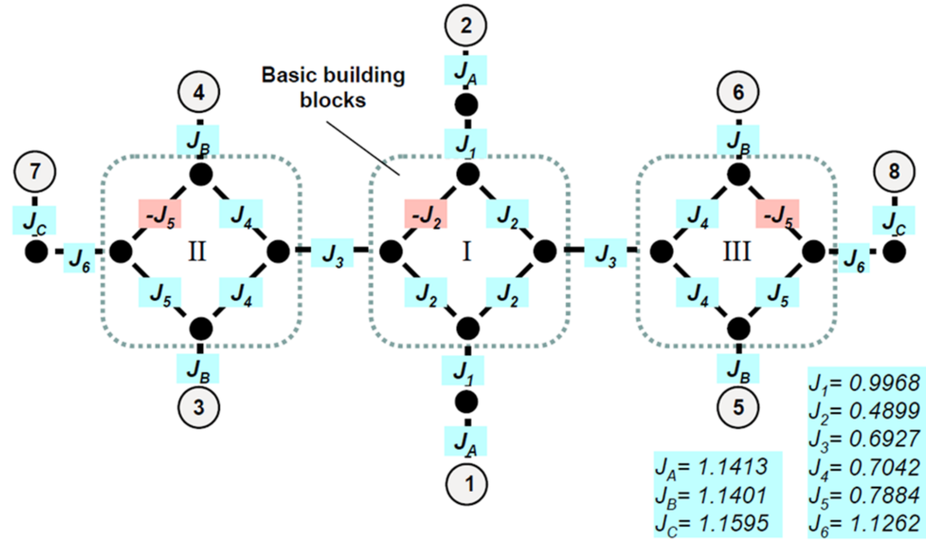


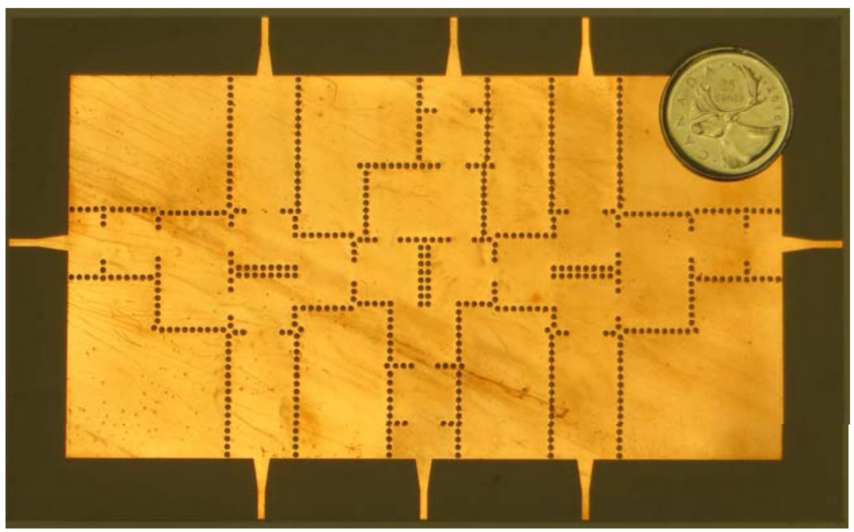




Eight-port SIW Combiner

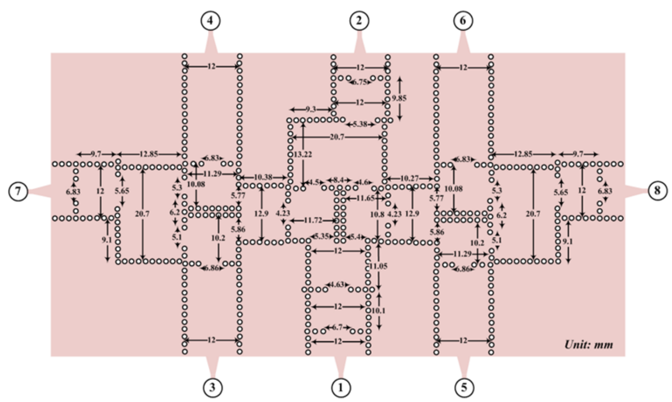
- 6-dB power distribution (passband)
  port 1 (port 2) to ports 3, 4, 5, 6
  port II (port III) to ports I and IV
- Additional resonators at ports 1, 2 ,7, 8
  5th-order bandpass filter function
- 3-dB power distribution (passband)
  port 7 to ports 3, 4 and port 8 to 5, 6
- Isolation
  between ports 1, 2, 7, 8 and 3, 4, 5, 6

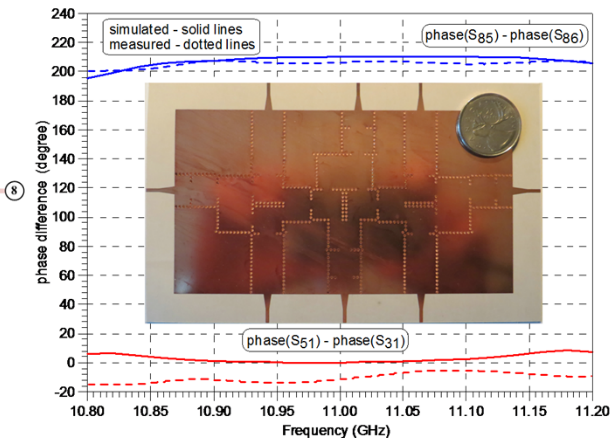


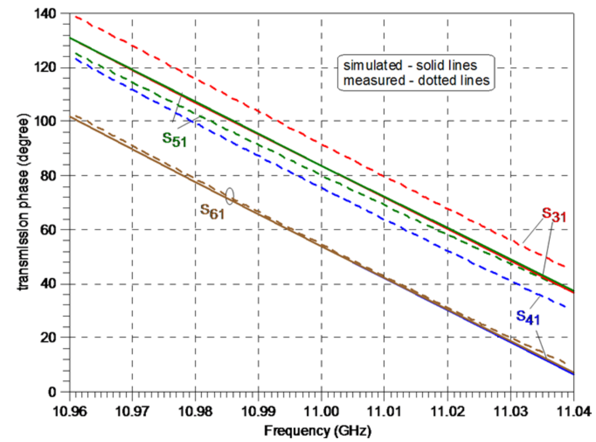


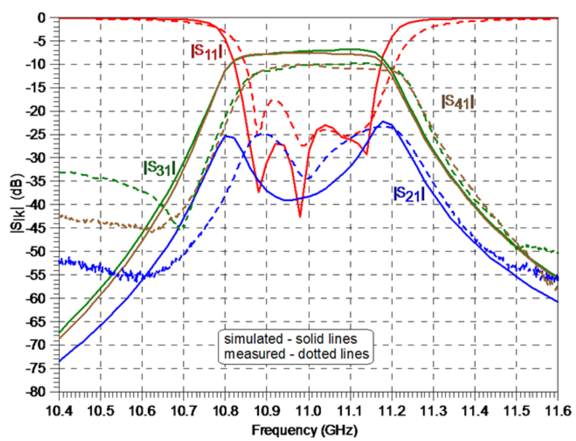
Eight-port SIW Combiner

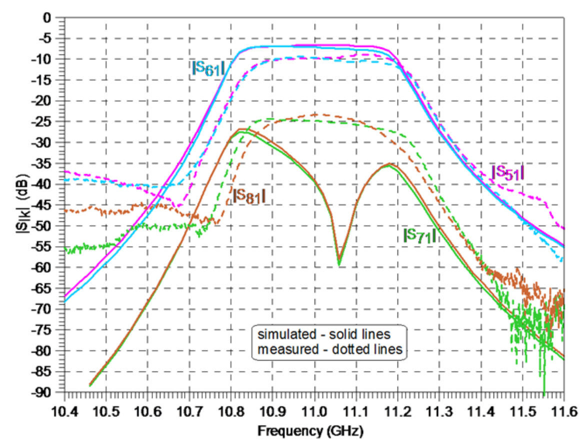
SIW Implementation - Measurements

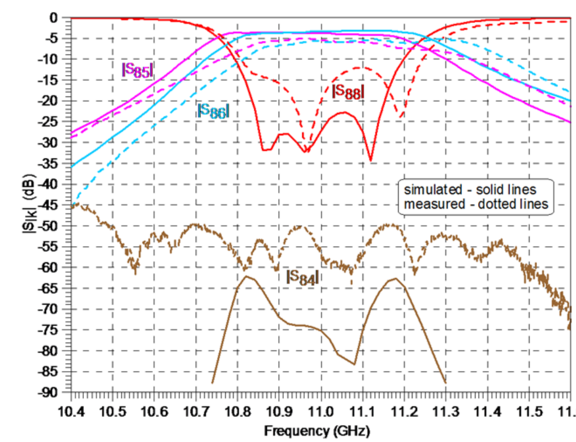












Eight-port SIW Combiner

Discrepancies between measurements and simulations

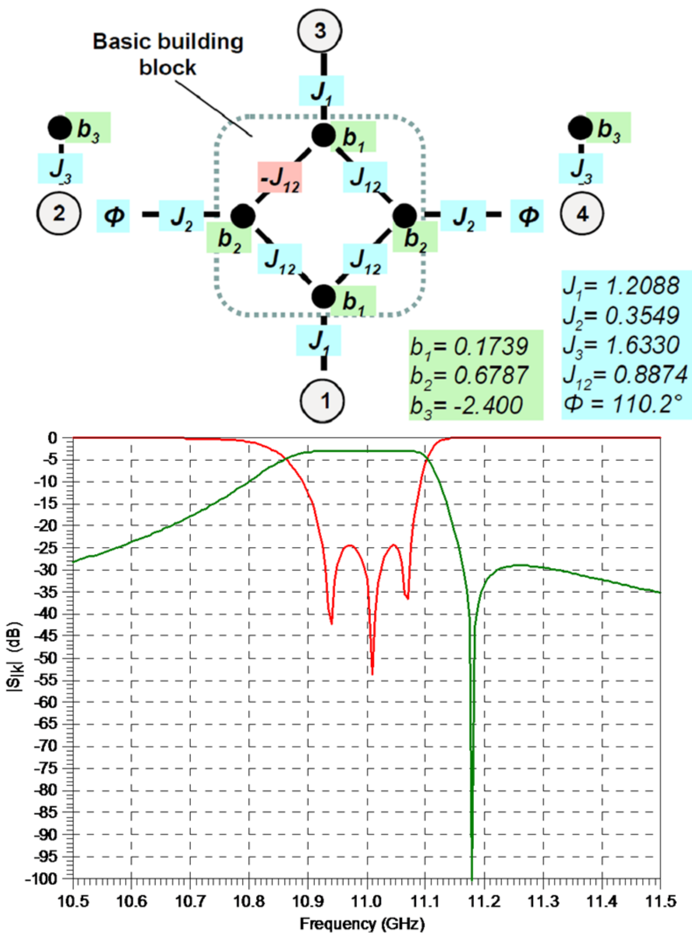
- Agreement between measurements and simulations are generally good.

- However:
- There is an added insertion loss of up to 3 dB compared to the simulations. This is comparable with many published SIW filters whose insertion losses are in the order of 2 dB.
- Only two measurements were conducted in a test fixture. All others require soldered SMA connectors which influence the calibration technique (TRL).
- The phase measurements of S_{31} and S_{41} (to the left of the input port) are off by about 10 degrees and 20 degrees, respectively, whereas those of S_{51} and S_{61} are in good agreement.
- This points to tolerances in the fabrication of the prototype on top of the soldering of connectors to the calibration standards.

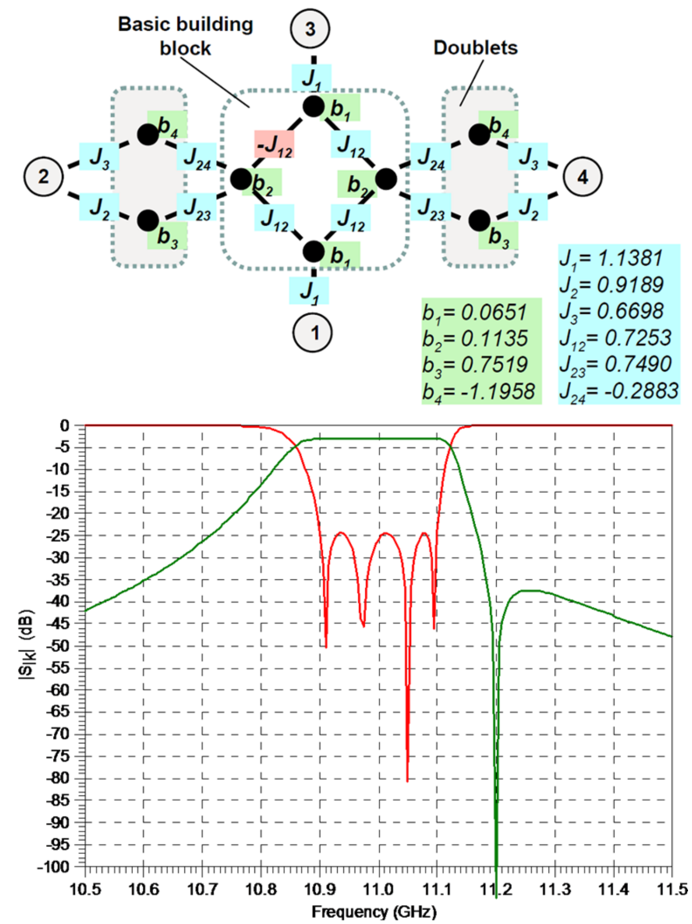
Other Options

Transmission zeros in filtering functions

Extracted poles



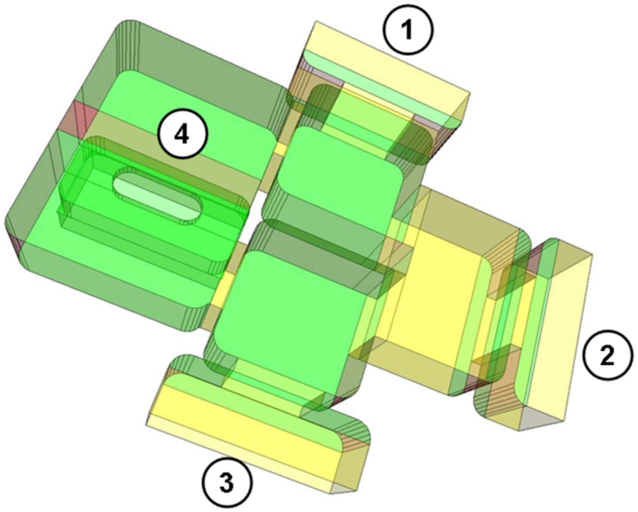
Doublets



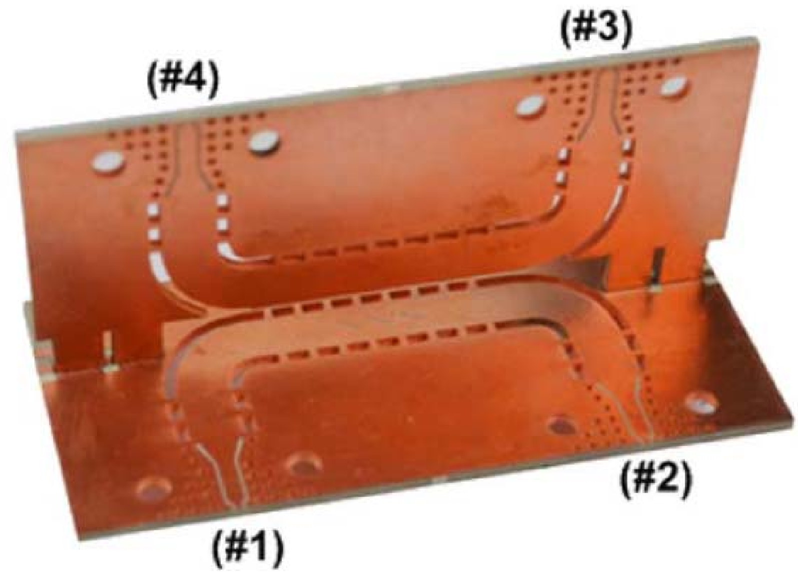
Other Options

3-D SIW technology

3-D Waveguide



3-D SIW



Doghri, Djerafi, Ghiotto, Wu, *MTT Trans.*, Jan. 2015.

3-D SIW technology will allow the SIW combiners to be built with the same symmetry as in waveguide technology.

Conclusions

- The compact and frequency-selective multi-port SIW power combiner/divider networks present attractive solutions for modern communication systems.
- The approach is based on a basic four-port building block consisting of four directly coupled resonators. Multiport networks are realized by direct coupling of several such building blocks.
- Additional cavities or complete filter sections (e.g. doublets, triplets, etc.) can be directly coupled between the building blocks or at their interfaces to accommodate special filter characteristics/requirements between individual ports.
- Consequently, this general concept offers a high degree of freedom in the design of multiport power divider/combiner networks with isolated/decoupled ports.
- The design approach is entirely based on filter theory since all cavities of the structure are directly coupled.
- Measurements of the symmetric waveguide show excellent agreement with predictions. Those of the SIW combiners show agreement in principle with the asymmetry of the planar design and measurement techniques being the main obstacles.

Acknowledgments

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