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Two-Layer Three-Way Horst Power Divider and Combiner Based-on Microstrip Line with Fixed Characteristic Impedance

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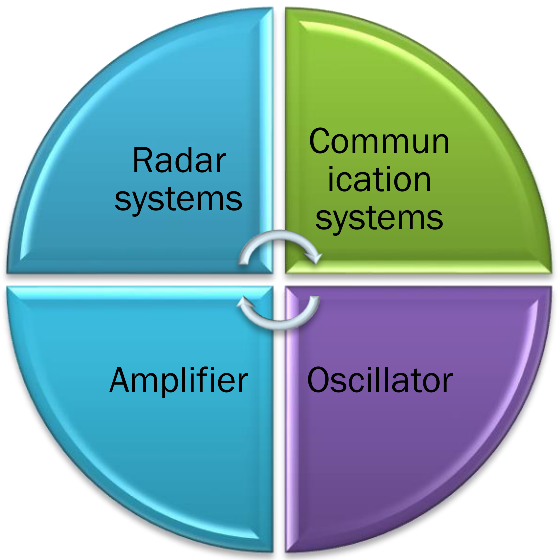
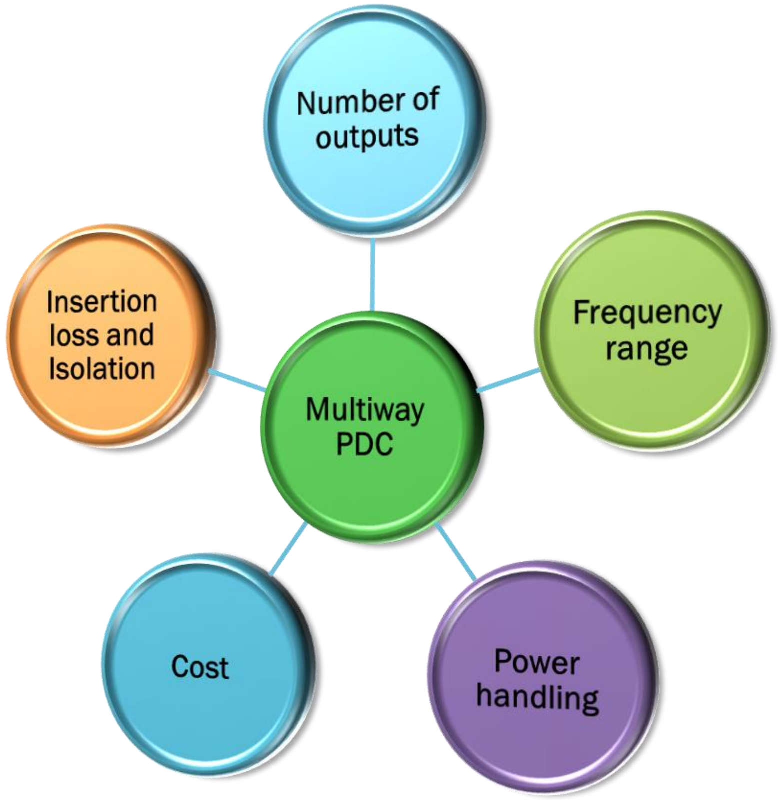
- Introduction
- Multiway PDC Problematic and Challenges
- State of art with Fixed Characteristic Impedance
- Theoretical Analysis
- Design Guidelines
- Experimental Results
- Conclusion

Introduction

The multiway power divider/ combiner typically consists of a network of transmission lines that are designed to divide or combine the input signal into equal or unequal parts

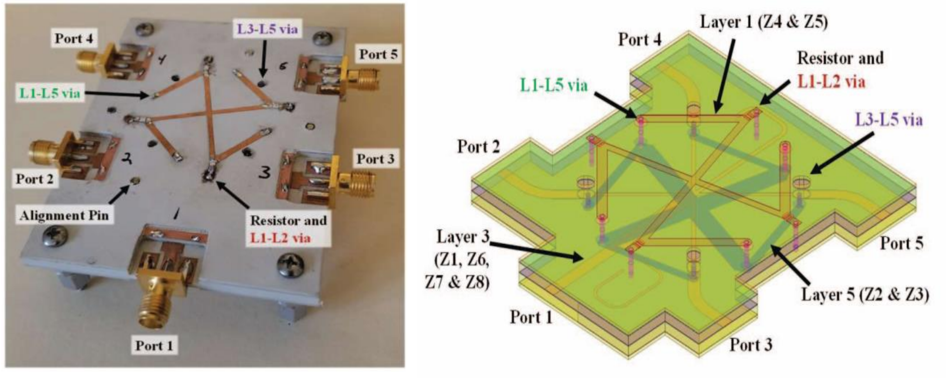


Multiway PDC Applications

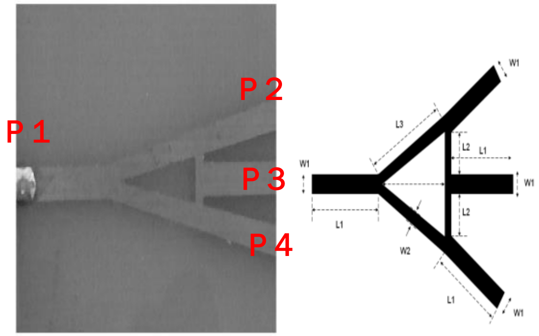


The performance of a multiway PDC

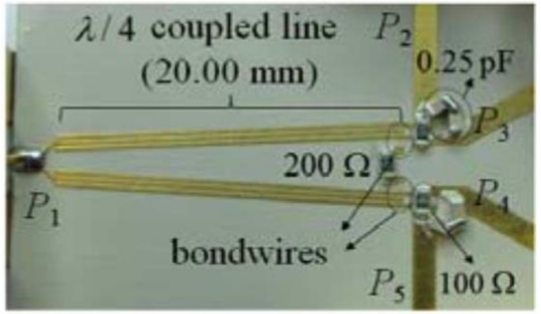
Multiway PDC
Problematic and Challenges



4-Way PDC Based on MSL and stripline at 3 Ghz [1]



3-Way PD Based on MSL at 5Ghz [2]



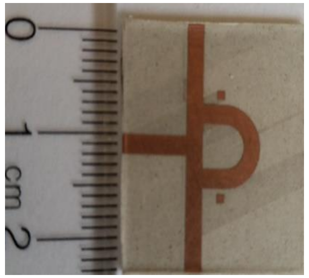
4-Way PDC Based on MSL Coupled Lines at 2Ghz [3]

- The use of different TL widths in a design can add significant constraints on substrate selection and the fabrication process

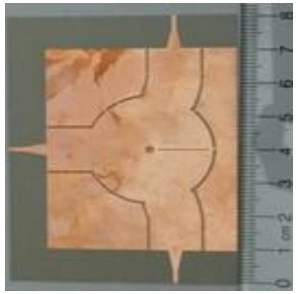
- At higher frequencies, radiation loss and lumped element lengths must be carefully analyzed and considered.

[1] J. Furgal, K. Xu, J. H. Choi and J. K. Lee, "Broadband Equal-Split Planar 4-Way Power Divider/Combiner Suitable for High Power Applications," *2020 50th EuMC*, Utrecht, Netherlands, 2021, pp. 840-843
[2] G. -Y. Chen, J. -S. Sun, S. -Y. Huang and YD_Chen, "The Novel 3-Way Power Dividers/Combiners Structure and Design," *2006 IEEE AWMTC*, Clearwater Beach, FL, USA, 2006, pp. 1-4
[3] S. Kim, S. Jeon and J. Jeong, "Compact Two-Way and Four-Way Power Dividers Using Multi-Conductor Coupled Lines," in *IEEE Microwave and Wireless Components Letters*, vol. 21, no. 3, pp. 130-132, March 2011

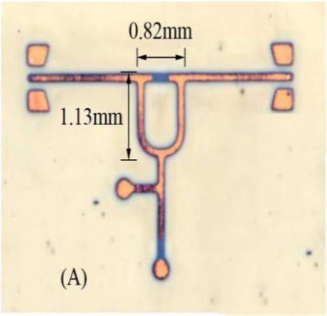
State of art with Fixed Characteristic Impedance



Gysel Power Divider based on Microstrip **at 10 GHz** [1]



Wilkinson Power based Substrate-Integrated Waveguide (SIW) **at 10 GHz**



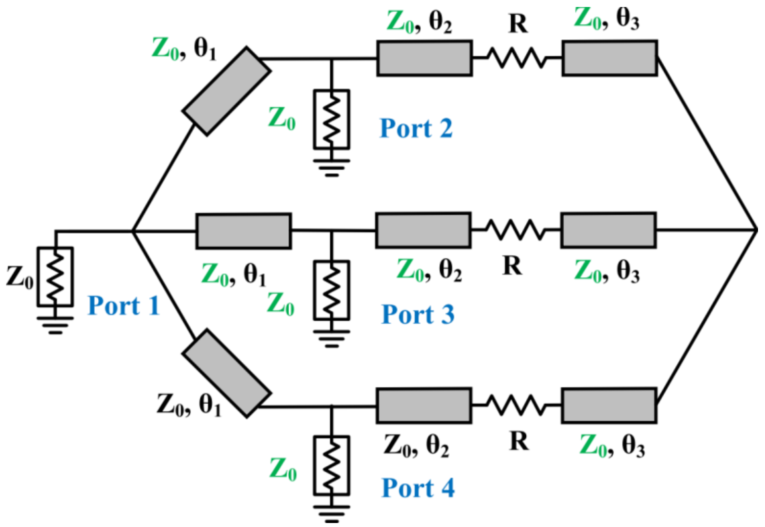
Horst Power Divider based on Microstrip **at 60 GHz**

Benefits of using a fixed-width TL :

1. Help to minimize signal losses due to impedance mismatches
2. Allow great design flexibility in millimeter-wave circuits.
3. Help mitigate the effects of discontinuities, which can contribute to a reduction in radiation.

[1] A. Moulay and T. Djerafi, "Gysel Power Divider with Fixed Characteristic Impedance," *2020 IEEE/MTT-S IMS*, Los Angeles, CA, USA, 2020, pp. 896-899
[2] A. Moulay and T. Djerafi, "Wilkinson Power Divider With Fixed Width Substrate-Integrated Waveguide Line and a Distributed Isolation Resistance," in *IEEE MWCL*, vol. 28, no. 2, pp. 114-116, Feb. 2018
[3] S. Horst, R. Bairavasubramanian, M. M. Tentzeris and J. Papapolymerou, "Modified Wilkinson Power Dividers for Millimeter-Wave Integrated Circuits," in *IEEE TMTT*, vol. 55, no. 11, pp. 2439-2446, Nov. 2007,

The proposed Two-Layer Three-Way PDC



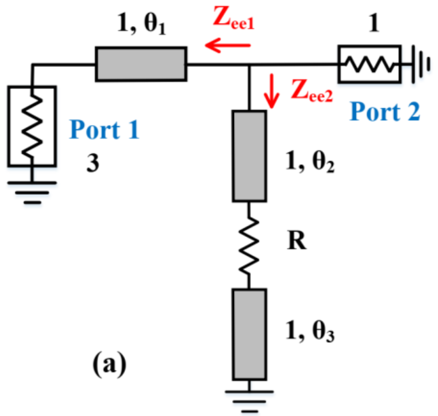
Proposed topology of the three-way PDC

- All sections have the same characteristic impedance Z
- A two-layer configuration enhances the isolation between opposite ports while maintaining compactness.

Even-even and odd-odd mode analysis

- Even-odd cases are similar to odd-odd cases, so only even-even and odd-odd cases were examined

Even-even

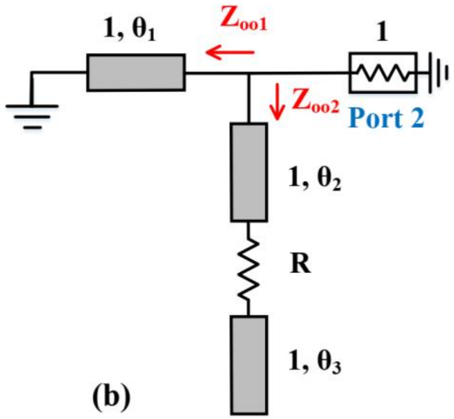


$$Y_{1ee} = (Z_{1ee})^{-1} = \left(\frac{3 + j\tan\theta_1}{1 + j3\tan\theta_1}\right)^{-1}$$

$$Y_{2ee} = (Z_{2ee})^{-1} = \left(\frac{\left(\frac{r}{z_0} - j\cot\theta_3\right) + j\tan\theta_2}{1 + j\left(\frac{r}{z_0} - j\cot\theta_3\right)\tan\theta_2}\right)^{-1}$$

$$= \left(\frac{\frac{r}{z_0} + j(\tan\theta_2 - \cot\theta_3)}{1 + \tan\theta_2\cot\theta_3 + j\frac{r}{z_0}\tan\theta_2}\right)^{-1}$$

odd-odd



$$Y_{1oo} = (Z_{1oo})^{-1} = (j\tan\theta_1)^{-1}$$

$$Y_{2oo} = (Z_{2oo})^{-1} = \left(\frac{\left(\frac{r}{z_0} + j\tan\theta_3\right) + j\tan\theta_2}{1 + j\left(\frac{r}{z_0} + j\tan\theta_3\right)\tan\theta_2}\right)^{-1}$$

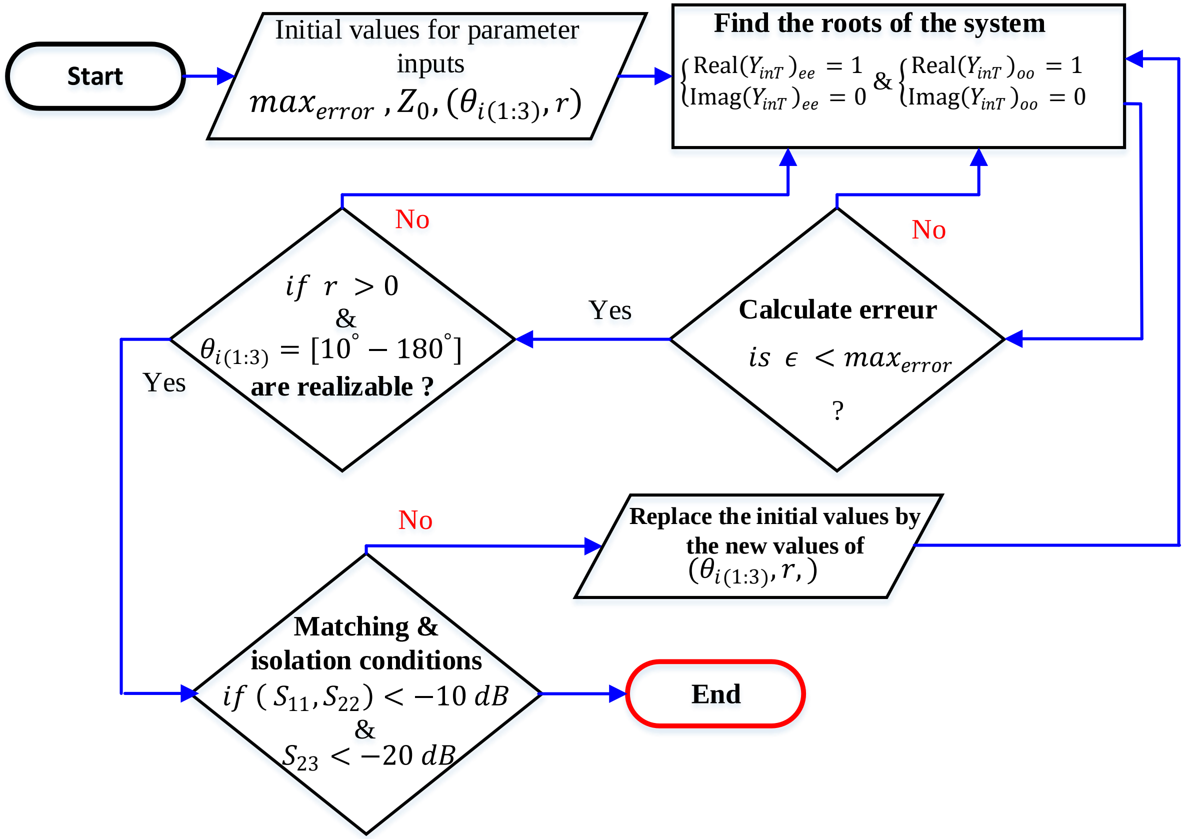
$$= \left(\frac{\frac{r}{z_0} + j(\tan\theta_2 + \tan\theta_3)}{1 - \tan\theta_2\tan\theta_3 + j\frac{r}{z_0}\tan\theta_2}\right)^{-1}$$

Calculating PDC Parameters

The equality of the real and imaginary parts :

$$(Y_{1i}+Y_{2i})_{(i=ee,oo)} = 1$$

- Constant impedance Z reduces the unknown parameters of the circuit from 7 to 4 $(\theta_1, \theta_2, \theta_3, r)$
- The roots of the system of equations is found iteratively by using root-finding methods.
- Verify that the resistor values are real and positive and TL lengths are between [10° - 180°]
- Verify that both the matching and isolation conditions are simultaneously satisfied



Flowchart for calculating PDC parameters

Theoretical Bandwidth Calculation

- Input reflection coefficient

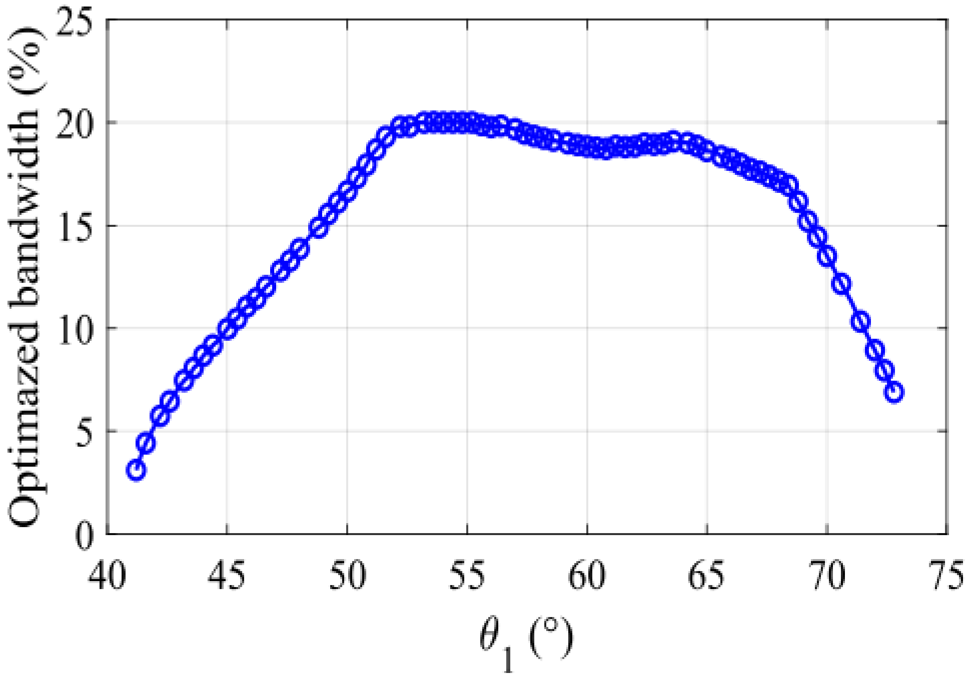
$$S_{11} = 20\log\left|\Gamma_{e,e}\right| \leq -10\ dB$$

- Output Reflection coefficient

$$S_{\mathrm{ii}(i=2,3,4)} = 20\log\left|\frac{\Gamma_{e,e}+2\Gamma_{o,o}}{3}\right| \leq -10\ dB$$

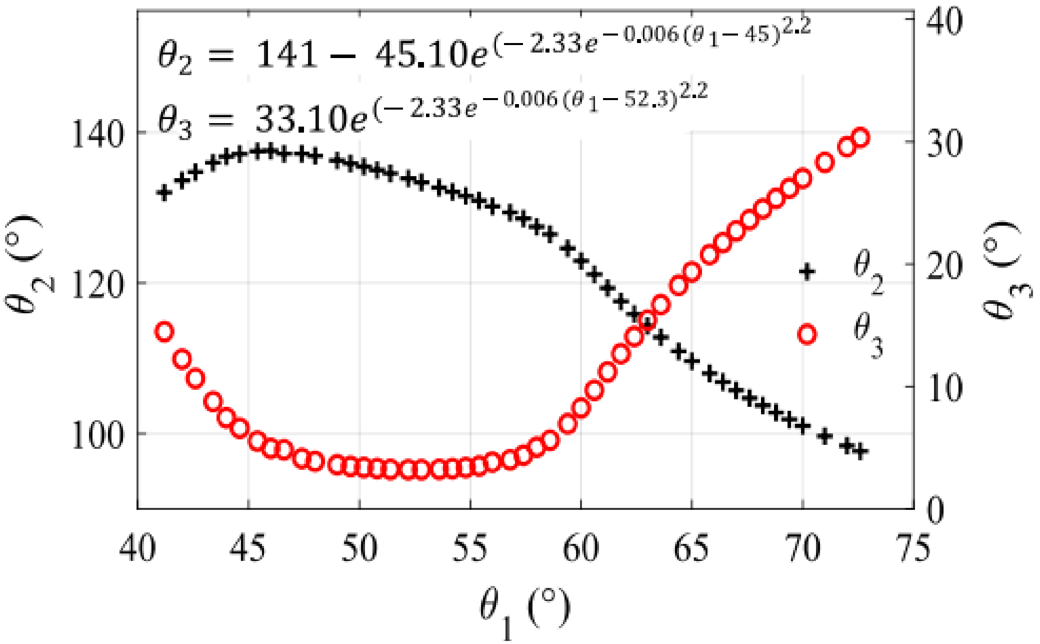
- Isolation coefficient

$$S_{\mathrm{i}j(i=2,3,4\,;\,i\neq j)} = 20\log\left|\frac{\Gamma_{e,e}-2\Gamma_{o,o}}{3}\right| \leq -20\ dB$$

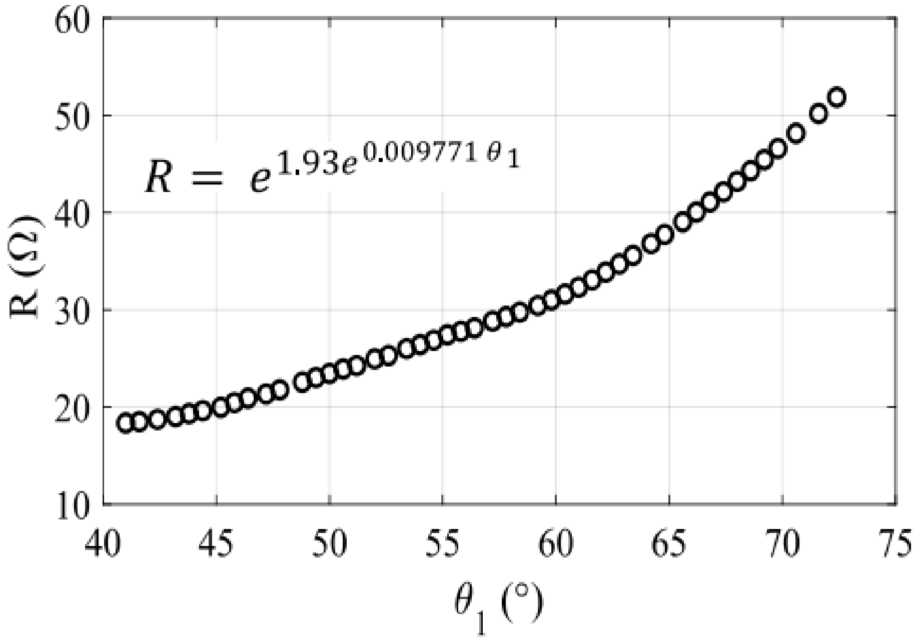


Bandwidth versus θ_1

Graphical representations with closed-form equations



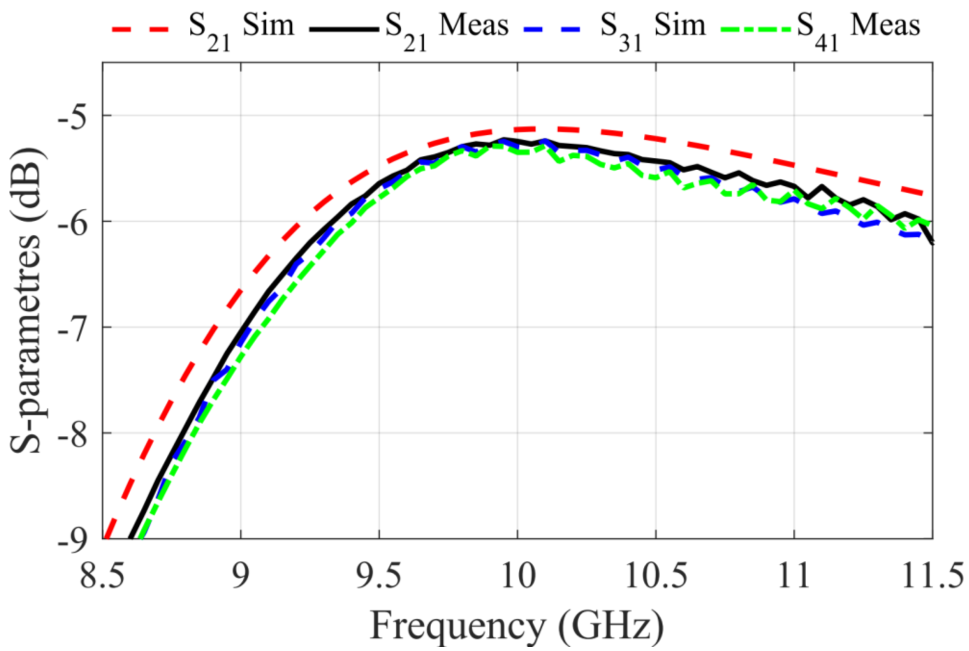
θ_2 and $\theta_3$versus θ_1



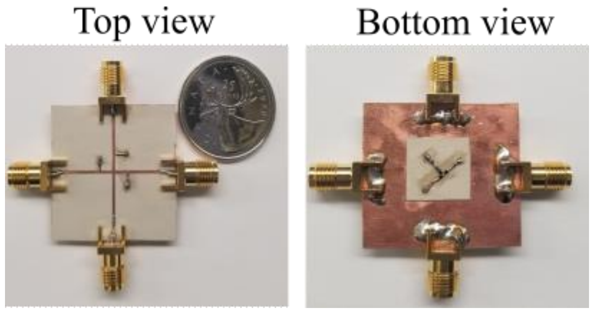
Resistance R versus θ_1

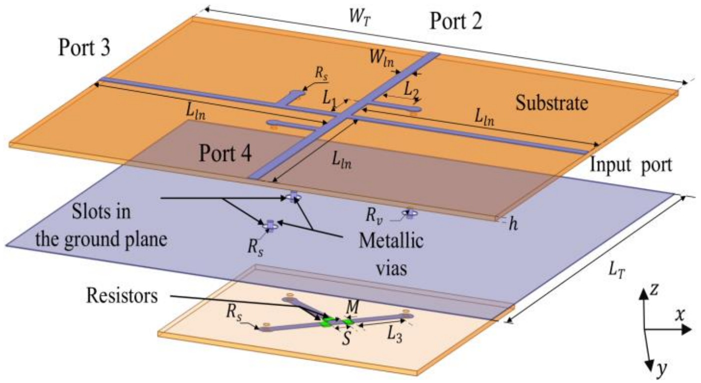
- The Graphical representations showed a slight discrepancy of 2% from the close-form equations.

Experimental Results



Fabricated Prototype

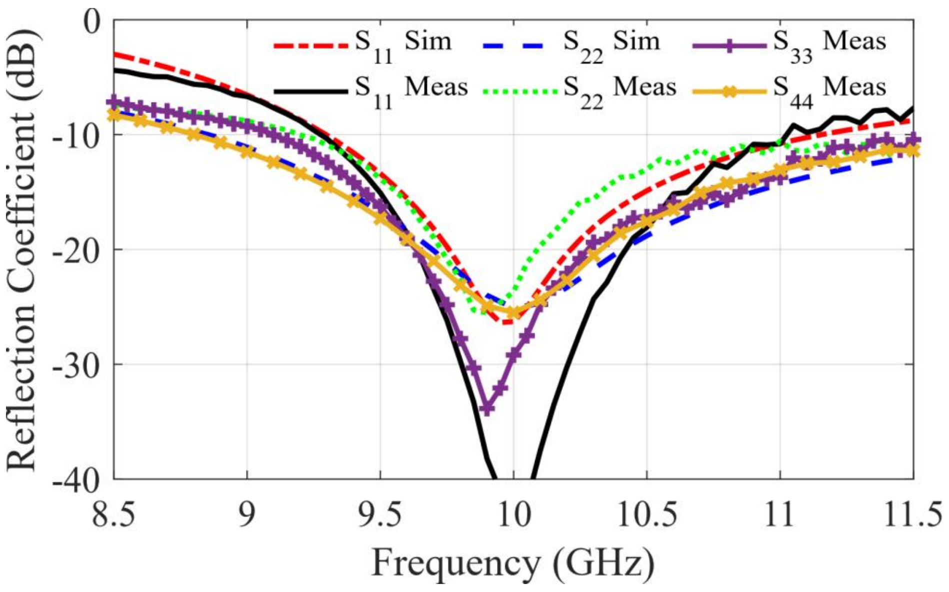


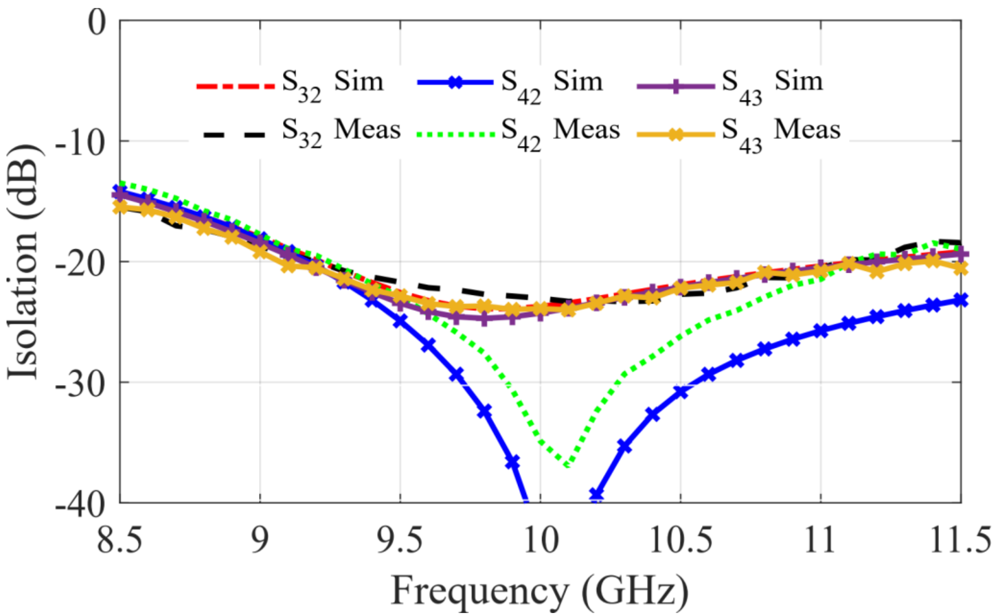


The 3-D view

- The transmission coefficient is between -5.2 and -6 dB over 2.3 GHz of bandwidth.
- The total length of the three arms is 190 deg which is smaller than 270 deg of the standard HPD and equivalent to the WPD.

Experimental Results





- Good matching better than 10 dB from 8.7 to 11 GHz
- The measured isolation between all the ports is higher than 20 dB over the 9.2-11.1 GHz

Conclusion

- Two-layer three-way power divider and combiner based on microstrip lines with fixed characteristic impedance was presented
- The design guidelines provide high flexibility, making the design process more accessible.
- Experimental prototypes demonstrate good matching and isolation performance over a broad fractional bandwidth, making it suitable for millimeter-wave applications
- This research opens up PDC design possibilities in any impedance characteristic with flexible bandwidth tailored to the specific needs of the application
- The proposed PDC design offers a simple, compact structure suitable for millimeter-wave applications that require a broader bandwidth.