Optimized Broad Band Riblet Short-Slot Waveguide Coupler for X-Band Applications

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Abstract — The full-wave modeling and design of Riblet short-slot waveguide coupler (RSC) is addressed in this contribution. This type of directional couplers is commonly used by its compact size in comparison with other waveguide configurations. Simulation is achieved by the commercial software Computer Simulation Technology (CST2011) in the frequency range 8-10 GHz. For this purpose the standard WR-90 waveguide is used, and then the simulated results are compared with their experimental measurements.

Index Terms— Microwave, Multiport measurement, Power Divider/Combiner, Riblet Short-Slot Coupler (RSC), Waveguide Components.

1. Introduction

Directional waveguide couplers are found in many microwave systems. They can be designed in diverse technologies and can take many configurations. This wide range of options is motivated by the diverse functions that they can carry out [1], [2]. For instance, one common application is power monitoring or power division/combination [3] in balanced amplifiers and mixers. They can also be found in beam-forming networks for multi-beam array antennas. In this context, they are used in Butler matrices [4]. Six-port Riblet couplers have been also designed in [5], with equal power division for the three output ports. From a CAD point of view, the structure is an H-plane structure (the E-plane case would be dual) and its analysis and design can be carried out very efficiently by general techniques such as the Finite Element Method (FEM) or by modal techniques such as the Boundary Integral-Resonant Mode Expansion (BI-RME) [6] or the Boundary Contour Mode-Matching method (BCMM) [7].

The most suitable configuration for a specific application is determined by the frequency of operation, bandwidth, insertion losses and power handling capabilities [1], [2]. In addition, the selected structure must be able to provide the desired coupling and its size must comply with the mass and volume restrictions of the system. From this last point of view, the short-slot Riblet coupler [8] presents very interesting properties, because of its compact size and less weight. It can be used to implement the hybrid junction used in many microwave circuits, with high isolation and low return loss. It is usually shorter than other types of couplers such as the branch-line or the multiple-slot configurations, which is a significant advantage for spatial applications. Another relevant feature is its simple manufacturing, since it can be implemented in E/H-plane configuration. This contribution is focused on H-plane type of couplers, showing optimized design using the CST2011 software for modeling and compared with the measured results.

2. Scattering Matrix of the Quadrature Hybrid

The physical structure of Riblet short-slot coupler Fig. 1 consists of two waveguides with a common sidewall. Coupling takes place in the region where part of the common wall has been removed. In this region, both the TE_{10} (even) and the TE_{20} (odd) mode are excited, and by proper design can be made to cause cancellation at the isolated port and addition at the coupled port. The width of the interaction region must generally be reduced to prevent propagation of the undesired TE_{30} mode. For a 3 dB coupler, the length of the coupling region must be greater than half wavelength at center frequency.

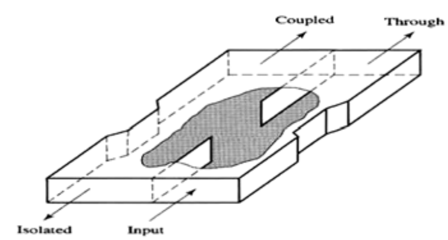

Fig. 1. Riblet short-slot coupler (RSC) [9].

The General Scattering Matrix (GSM) for a four port junction Fig. 2 is

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \qquad (1)$$

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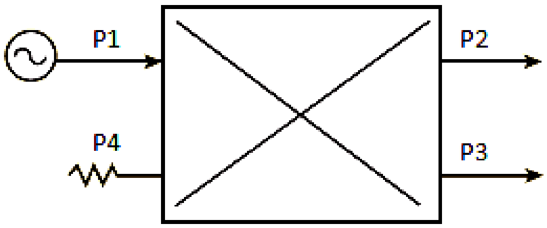

Fig. 2. Quadrature Hybrid Junction.

In a theoretical ideal quadrature hybrid junction, port 1 (P1) is isolated from port 4 (P4) and so are port 2 (P2) and port 3 (P3). Therefore, these elements in the matrix are

$$S_{14} = S_{41} = S_{23} = S_{32} = 0 \qquad (2)$$

If all the ports are matched, the diagonal elements therefore equal zero

$$S_{11} = S_{22} = S_{33} = S_{44} = 0 \qquad (3)$$

The junction is reciprocal. This makes the rest of the matrix's elements symmetrical, therefore they become

$$\begin{aligned} S_{12} = S_{21} = S_{24} = S_{42} &= 1/\sqrt{2} \\ S_{13} = S_{31} = S_{24} = S_{42} &= -j/\sqrt{2} \end{aligned} \qquad (4)$$

The resulted matrix becomes

$$S = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & -j & 0 \\ 1 & 0 & 0 & -j \\ -j & 0 & 0 & 1 \\ 0 & -j & 1 & 0 \end{bmatrix} \qquad (5)$$

If port 1 (P1) is taken as input port, one can deduce that output signals from port 2 (P2) and port 3 (P3) are with equal amplitudes, but with 90° phase difference.

3. Simulation and Measurement

In practice, a capacitive dome (tuning screws) Fig. 3(a), (b) and (c) is placed in the coupling region in order to adjust the 90^0 phase difference (phase balance between modes TE_{10} and TE_{20}). Nevertheless, the structure can be also designed without these elements [10], which may simplify the manufacturing. Full wave simulation and optimization are done using the CST2011. Optimized dimensions are shown in Table. 1.

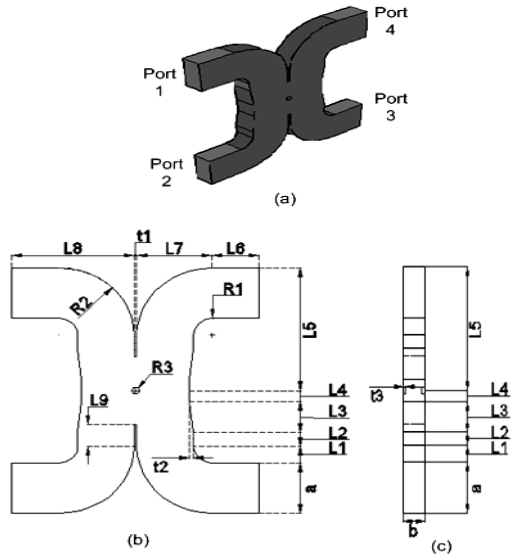

Fig. 3. (a) Simulated structure in CST, (b) Front profile, (c) Side profile.

TABLE 1
Optimized Dimensions of RSC.

Dimensions	Value (mm)	Dimensions	Value (mm)
a	22.86	L4	5
b	10.16	L5	55.36
L1	7.5	L6	19.14
L2	6	L7	30.36
L3	14	L8	49.5
L9	9.7	t1	1
t2	1.5	t3	1.5
R1	7.5	R2	30.36
R3	1.5		

The fabricated RSC Fig. 4 is measured by Network Analyzer (NA) and waveguide calibration is used. Return loss parameters are shown in Fig. 5. This figure shows a good agreement between simulated and measured S-parameters (<-23.5 dB) in the frequency range 8-10 GHz. Transmission parameters are shown in Fig. 6. It shows about $-3.2 \pm 0.3\,dB$.

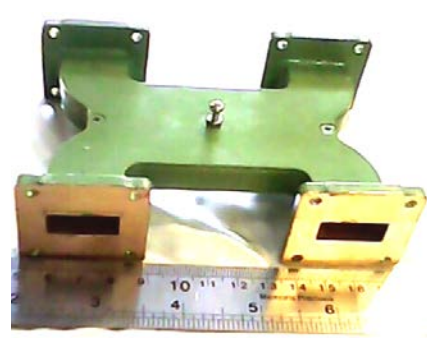

Fig. 4. Photograph of the manufactured device.

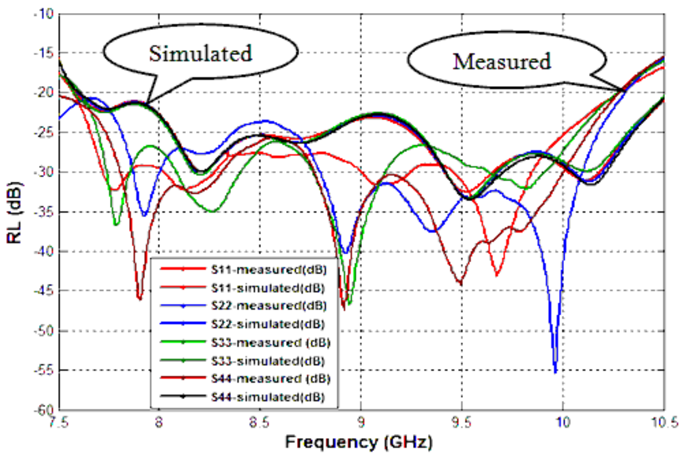

Fig. 5. Simulated and measured Return Loss (RL (dB)) parameters.

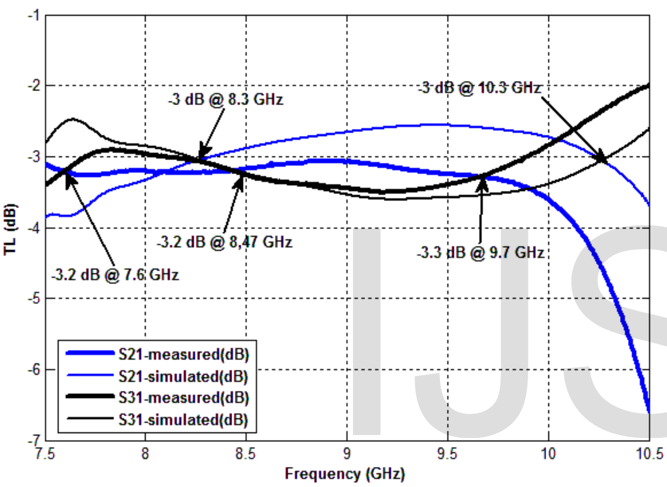

Fig. 6. Simulated and Measured Transmission Parameters (TL (dB)).

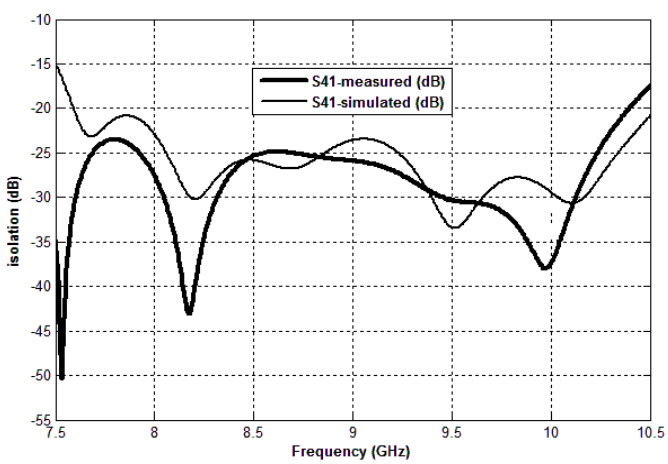

Fig. 7. Simulated and Measured Isolation (dB).

Isolation is shown in Fig. 7. It shows that isolation is better than 25 dB (<-25 dB). Phase difference is shown in Fig. 8, which shows a phase balance about $-90^{o} \pm 1.3^{o}$.

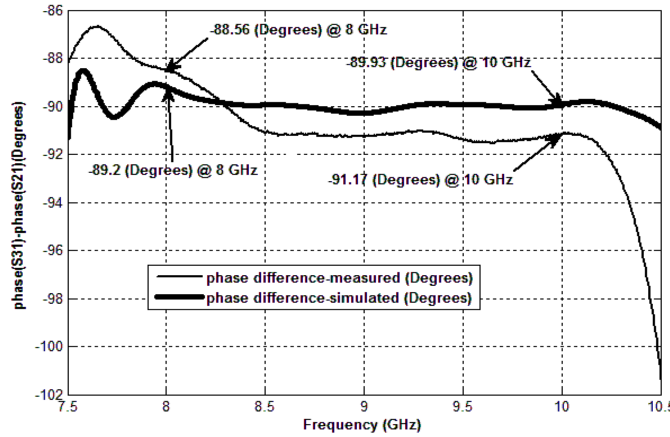

Fig. 8. Simulated and Measured phase balance (Degrees).

4. Conclusion

RSC in X-band has been presented with bandwidth about 22.2 %. Its main properties and modeling has been described, with special emphasis on their electrical properties. The experimental results have been compared with the simulations results.

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