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Center-Slotted Wideband Hybrid 10 dB Coupler

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ABSTRACT

In this paper, a wideband microstrip hybrid coupler designed, simulated, built and tested. These couplers have advantage of easy fabrication, lightweight and incorporation with other microwave devices and validated using 3D planar electromagnetic softwares like Sonnet Suites. The final design is composition of two parallel lines with symmetric slits and a center slot. Directional coupler is designed and simulated to operate in the frequency range from 1 GHz to 5 GHz with 2.4 Ghz coupling -10 dB return loss bandwidth between 1.6 - 4 GHz. The fabricated coupler shows good agreement between measured and simulated results with very low isolation characteristics. Four symmetric orthogonal U-Shaped structures at the center of the coupling region distinguishes the proposed design with other works. It makes significant improvement in calculation duration thereby achieving lower response latency and lowers the possible manufacturing errors compared with previously published similar works.

Keywords: Sonnet software, Directional Coupler, Microstrip, Hybrid, 10 dB.

INTRODUCTION

Microstrip directional couplers with two parallel signal lines are used in RF filter and various microwave integrated routing devices for isolating, separating. (Chang et al, 2004). Directional couplers are passive devices used for sampling, in the field of radio technology, power splitters or power combiners. Directional couplers are one of the most often used devices of Microwave power for measurement purposes (Abbas et al, 2013). However, inhomogeneous air transmission lines and dielectric substrate make the directional coupler a weak device from its orientation (Kim et al, 2007). To improve the directivity, some approaches include symmetrical across the coupled arms at the center and the utilization of active devices. (Sohn et al, 2016). If two transmission lines are close to each other, these are extensively known as quad couplers because a 90° phase diffrence between its two output ports. (Muller et al, 2010). Some similar works of 10 dB couplers use conventional brancline structure with DGS (defected ground structure) which requires higher fabrication costs. Our design has an advantage because it has very simple orthogonal U shaped metals and full metal ground. (Tamasi et. al, 2012) Many projects require a wide bandwidth, the solution for this is to use coupled stripline circuits. To increase the bandwidth of a coupler, the first multi-section configuration is preferred by (Mousavi et al, 2015). A recent work of 10 dB high frequency microstrip coupler is presented for motion detection sensor (Giovanni et al. 2018). They have two conventional designs having only 1 GHz bandwidth in X-Band. Easier solution to achieve broader bandwidth is to use symmetrical coupler, which is presented here. 10 dB couplers are quite commonly used. In this project, the main purpose was to design high directivity characteristics of a microstrip coupler. Details of the work with parametric studies and the simulated-measured results are discussed, and figures-tables presented (Imeci et al, 2011). There are very high frequency 10 dB coupler designs operating from 325 GHz to 400 GHz based on the short-slot Riblet-type coupling configuration and fabricated using the deep reactive ion etching (DRIE) silicon micromachining technique in literature but those are beyond the scope of the proposed design (Hu et al. 2015).

COUPLER DESIGN

The coupler in this study is designed in Sonnet software which is made up of 4 ports located in each four sides of the structure to maintain easy measuring capabilities in the Lab and better housing specs while connecting to other devices. The coupling region of the structure is symmetric in order to maintain the reciprocity. In this work, we used some of the following properties and methods. Some geometrical values were changed in order to prove that our configuration will work properly in different applications.

The material used fort he substrate is FR4 ($\varepsilon_r = 4.4$). The thickness of dielectric layer is used as 1.55 mm. The top and 3D view of the microstrip directional coupler is shown in Fig. 1 and Fig. 2.

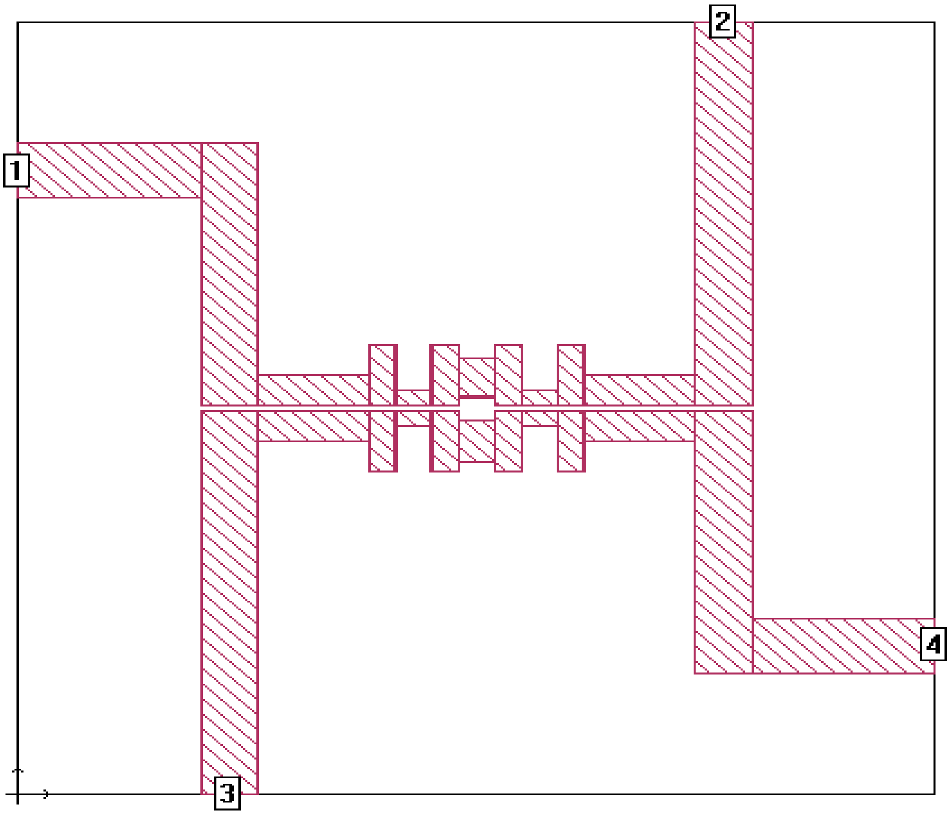

Figure 1. The top view of the coupler

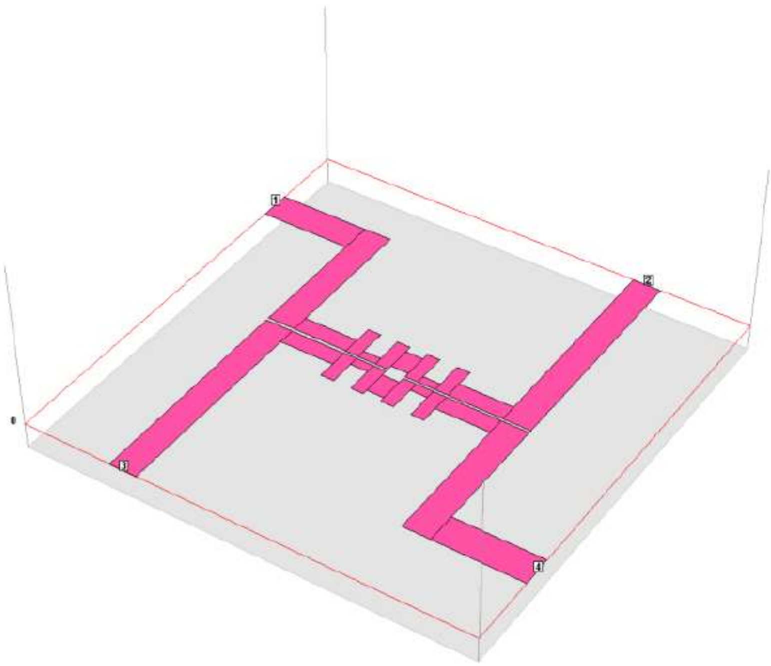

Figure 2. 3D view of the coupler

For a single section coupler the odd and even mode characteristic impedances are defined. When normalized to the charteristic impedance of the input ports and isolation of the coupler ensure,

$$Z_0 = \sqrt{Z_{0e}Z_{0o}}\Omega \text{ Normalizes } z_{0e}z_{0o} = 1 \quad (1)$$

K is the coupling coefficient of coupled line section which is given by (2). The coupling factor can then be calculated as (Salem et al, 2006).

$$k = \frac{Z_{0e}-Z_{0o}}{Z_{0e}+Z_{0o}} \quad \text{or} \quad C_{dB} = 20\log k \quad (2), (3)$$

In another saying, ideal coupler is lossless, reciprocal and matched 4-port device, and the S-parameters are shown in equation 4 below (Imeci et al, 2010). Figure 3 has the schematic of the coupler.

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix} \quad (4)$$

The purpose of designing couplers is to achieve low input match and high directionality at the desired frequency. The ABCD matrix is intoduced to analyze the overall transmission and reflection characteristics of the network

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_e = \begin{bmatrix} \beta_e & jZ_{oe}a_e \\ jY_{oe}a_e & \beta_e \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_o \quad (5)$$

$$= \begin{bmatrix} \beta_o - w2CZ_{oo}a_o & jZ_{oo}a_o \\ l(4wC_c\beta_o + Y_{oo} - 4w^2C^2 & \beta - w2C_cZ_{oo}a_o \end{bmatrix} \quad (6)$$

Where $a_c = \sin(\theta_e)$, $a_o = \sin(\theta_o)$, $\beta_e = \cos(\theta_e)$ and $\beta_o = \cos(\theta_o)$.Assuming $\theta_e = \frac{\pi}{2}$,C_c for zeroing the value of A_o and D_o can be found in 7, and the compensanting odd-mode chatacteritic impedance yield (Baek et al, 2008);

$$C = \frac{c_{in}(\theta_o)}{2wZ_{oo}}, Z_{ooc} = Z_{oo}\sin(\theta_o) \tag{7}$$

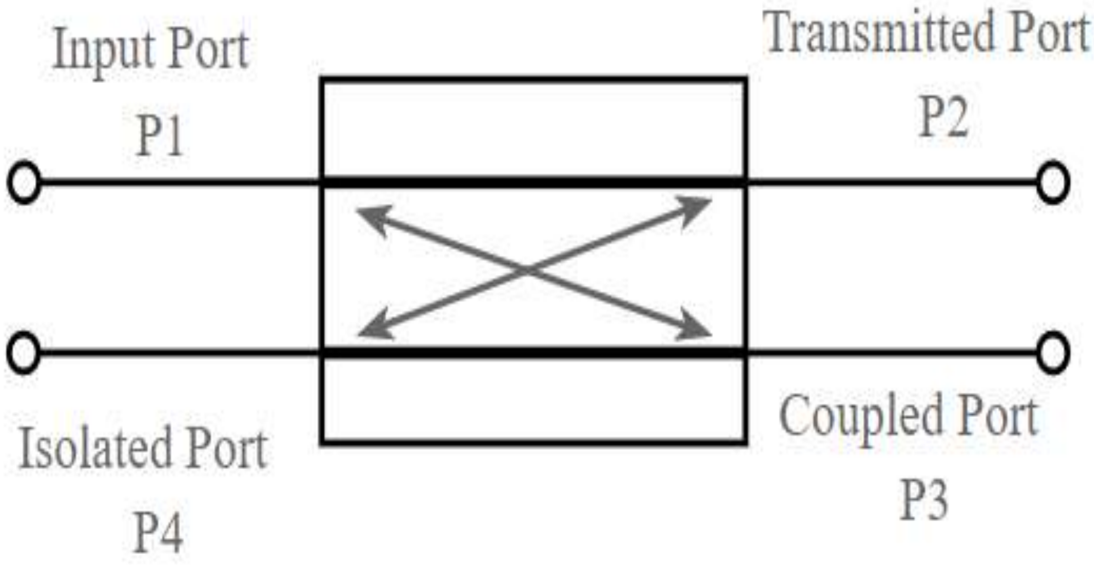

Figure 3. Four Port Microstrip Directional Coupler

Coupling shows how much of incident power is being sampled at the coupled port and directivity is a measure of how well the coupler distinguishes between forward and reverse traveling waves

$$\text{Coupling Factor (dB)} = 10log\frac{P_1}{P_3} \tag{8}$$

$$\text{Insertion loss (dB)} = 10\log[1 - \frac{P_3}{P_1}] \tag{9}$$

P_1 is the ratio of input and P_3 is power to the output power from the coupled port.

Isolation is sometimes used to describe the ''directive'' property. It is the ratio of input P_1 to the isolated P_4 , measured in dB (Asdhar et al, 2018)

$$\text{Isolation (dB)} = -10log\frac{P_4}{P_1}. \tag{10}$$

Even and odd-mode effective permittivities of microstrip couplers are calculated as follows

$$\varepsilon_{effe} = \frac{C_e}{C_{e1}} \tag{11}$$

$$\varepsilon_{effo} = \frac{C_o}{C_{o1}} \tag{12}$$

In order to find the stored energy of microstrip couple using FE calculation,

$$W = \frac{1}{2}\int \varepsilon_0\, \varepsilon_r \nabla u \nabla u\, dS \tag{13}$$

ε_0 is the permittivity of free space, ε_r is relative permittivity, u means the electric potential.

From equation 13, the capacitance is then found as

$$C = \frac{2W}{(\nabla u)^2} \tag{14}$$

ANALYSIS AND SIMULATION RESULTS

Figure 4 shows the results obtained by simulation of the center-slotted wideband hybrid coupler in Sonnet Software with coupling of -10 dB (S13) (Sonnet Suites, 2013). Simulations were performed with planar 3D electromagnetic tool. Cell size is reduced in order to get optimum simulation result. The sidewalls are far enough from the coupling section to avoid reflection of the shielded box. The air layer above the coupler, which makes the design as microstrip, is at least 3 times higher than the substrate thickness to clear the potential box resonances. The characteristic impedance of the conventional couplers is 50 Ω (Tian et al, 2001). Figure 4 has the S parameters of the coupler. In this graph its shown the values of the parameters of S11 (the input match), S12 (thru port), S13 (coupling), and S14 (isolation). As we can see from this figure, insertion loss is -1 dB, input match is less than -18 dB and isolation is less than -21 dB throughout the working band of 1.6 - 4 GHz. Figure 5 shows the angle is 90 degrees between the coupled and thru ports, which proves this is a 90 degree hybrid coupler.

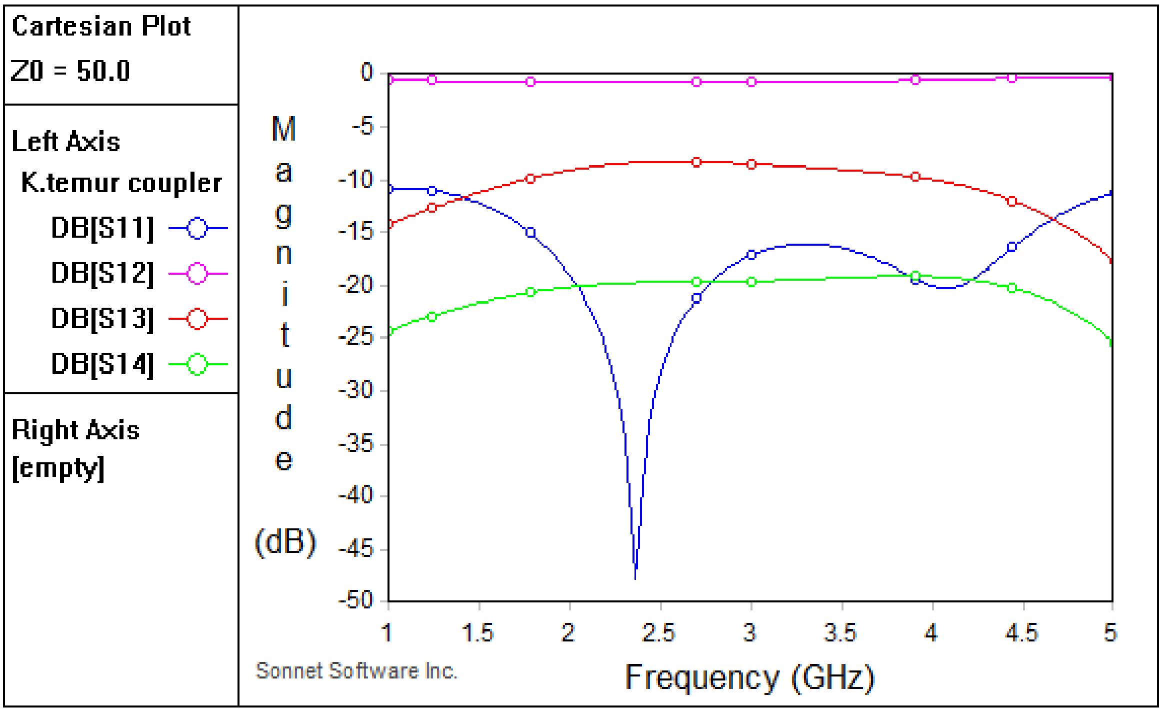

Figure 4. S-parameter of the Coupler

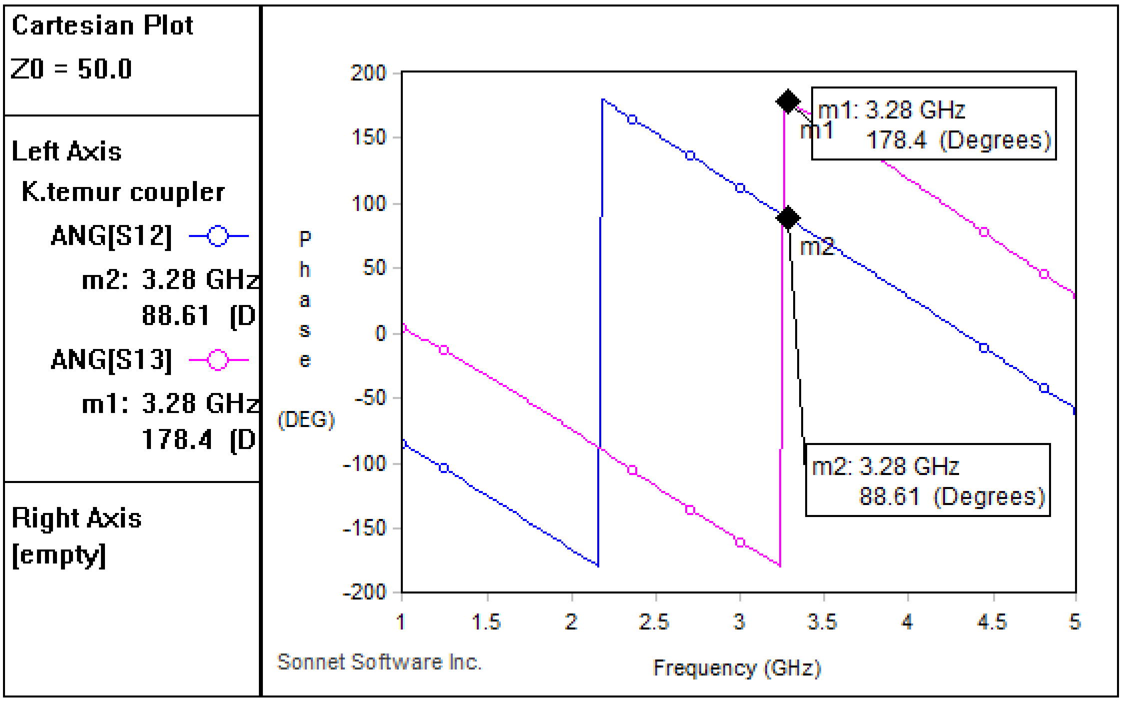

Figure 5. Angle between the Coupled and Through ports.

Table 1, Table 2, and Table 3 are presenting the parametric study of coupling bandwidth and coupling amplitude balance by changing the width of the separation, thickness of dielectric and constrant of the dielectric (Yildiz et al, 2020). The fequency bandwith is 2.4 GHz between 1.6-4 GHz. Table 1 shows the amplitude balance of the coupling (Yuksel et al, 2012) is increasing when separation is increased by 0.1 mm (Imeci, 2017). Table 2 and 3 show that the fabrication tolerances of the lossy dielectric FR4 is fair enough. Table 4 gives comparison of proposed design with those found in literature and listed in references.

Table 1. Comparison of the separation between the Lines

Spacing Between the Lines (mm)	Frequency Bandwidth (2.4GHz)	Coupling Port (dB)	Amplitude Balance (dB)
0.2	1.6	-10.73	0.72
	4	-10.01	
0.3	1.6	-11.91	0.98
	4	-10.93	
0.4	1.6	-12.94	1.19

	4	-11.75	
0.5	1.6	-13.87	1.35
	4	-12.52	

Table 2. Comparison of the Dielectric Thickness

Dielectric Thickness (mm)	Frequency Bandwidth (GHz)	Coupling Port (dB)	Amplitude Balance (dB)
1.45	1.6	-10.73	0.72
	4	-10.01	
1.50	1.6	-10.6	0.75
	4	-9.85	
1.60	1.6	-10.49	0.79
	4	-9.70	
1.65	1.6	-10.37	0.81
	4	-9.56	

Table 3. Comparison of the Dielectric Constant

Dielectric Constrant (ε_r)	Frequency Bandwidth (GHz)	Coupling Port (dB)	Amplitude Balance (dB)
4.3	1.6	-10.72	0.72
	4	-10.01	
4.35	1.6	-10.68	0.6
	4	-10.08	
4.45	1.6	-10.65	0.5
	4	-10.15	
4.50	1.6	-10.6	0.38
	4	-10.22	

Table 4. Advantages and disadvantages of our designs with compared to the different couplers

Our and Prior designs	**Advantages**	**Disadvantages**
Our proposed design	- wideband with relatively cheap cost, compact size - good isolation and directivity with amplitude balance less than 1 dB	- Tangent losses caused by the FR4 substrate.
Sohn, S.M. et all, A Compact high power canable and tunable high directivity microstrip coupler	- simple and cheap to manufacture - high directivity (over 40 dB)	- very low frequency
G. A, Asdhar et al, T-Junction branch line coupler with	- simple branchline design - good for radar applications	- Lossy dielectric FR4

notch band filter for radar S-band 3 GHz.		-works only in one narrow band, 3 GHz
Sorocki, J., et al. 2020. Low-Cost microwave components fabrication in hybrid technology of laminates and additive manufacturing on an example of miniaturized suspended directional coupler	- good housing options with four ports located each sidewalls - compatible with state of the art 3-D printing technology	- hard to manufacture because of stripline structure - lower bandwidth
Mousavi, S.M., et al. 2015. Design fabrication and test of a broadband high directivity directional coupler.	- ultra broadband - very high frequency (millimeters wave region)	- hard to manufacture due to stripline technology and short pins

FABRICATION AND MEASURED RESULTS

Computer numerical control machine processed a design of microstrip directional coupler by control milling technique and following a coded programme. (Nasri et al, 2020). The coupler were fabricated on FR 4 substrate with ε_r = 4.4 and 1.55 mm thickness. SMA connectors directly soldered in the edges of the coupler's four ports and the metal ground layer (Sorocki et al, 2020). Fabricated coupler is seen in Figure 6. The S parameters of the Center-Slotted Wideband Hybrid 10 dB coupler is measured by the Network Analyser in the Microwave Laboratory as seen in figure 7. Figure 7 shows that the two ports were terminated with 50 ohms while the other two ports were connected to the probes of the Network Analyzer. This process were applied to all ports and required S4p files were obtained by the Network Analyzer.

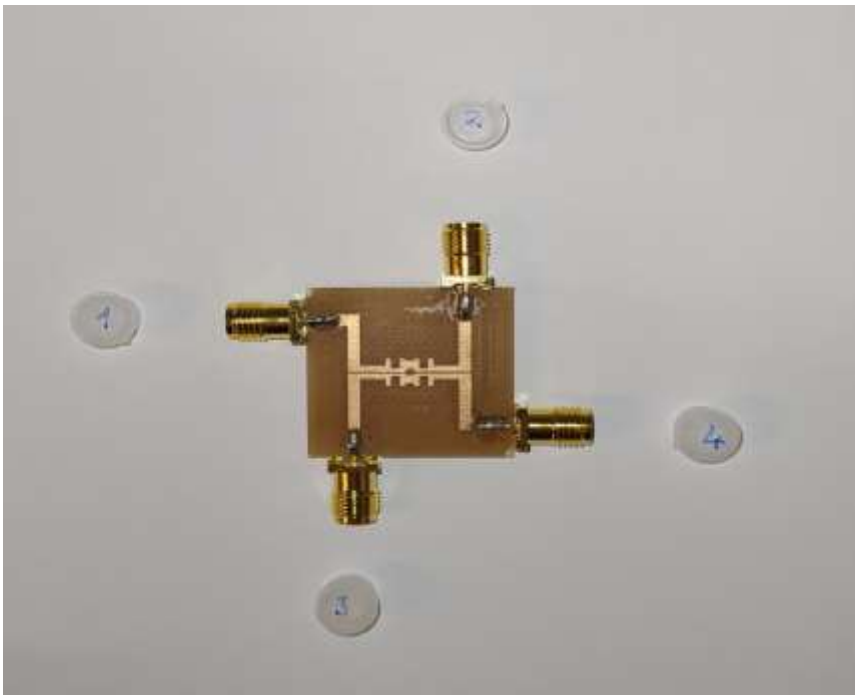

Figure 6. Top view of the Fabricated Design

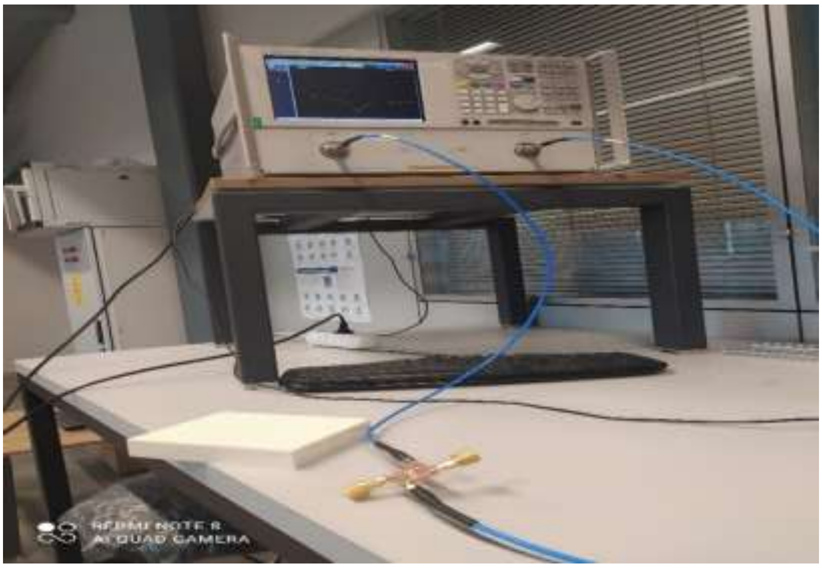

Figure 7. Coupler connected to Network Analyser

Figure 8 shows S11, S12, S13, S14 curves of the simulated and measured parameters of Center-slotted wideband hybrid 10 dB coupler. Simulation and measurement have almost the same results (Tutuncu et al, 2019). Especially having less than 1 dB of amplitude balance between the 1.6 – 4 GHz (2.4 GHz wide bandwidth) proves the novelty mentioned in the abstract. This is due to the simple orthogonal and symmetric U-shaped geometry of the couplers main center section.

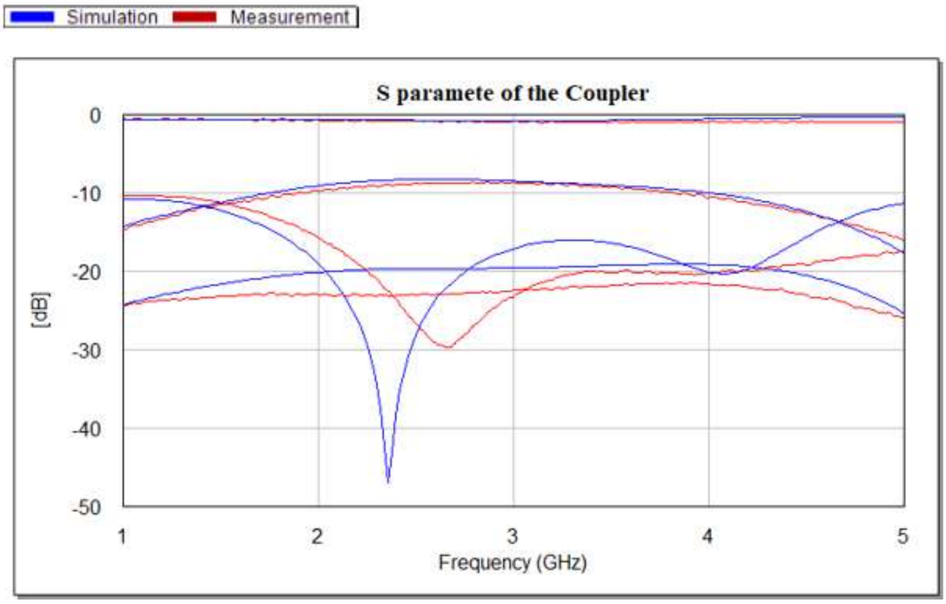

Figure 8. Simulated and Measured S-parameters of the coupler

CONCLUSION

Microstrip hybrid couplers are implemented for realizing the high directivity and isolation characteristics with desired coupling values. The proposed 10 dB coupler meets the requirements for a coupler which has great performances and economical with its low cost material used and simple geometrrical design. The results were compared with tolerance analysis of the dielectric thickness, dielectric constant and separation distance between lines and show decent results within the working band between 1.6 - 4 GHz. According to the simulation results of Sonnet Suites, all results are satisfactory (Dalar et al, 2012). The fabricated couplers S-parameters is measured by the Network Analyser at Microwave Laboratory. The measurement results show vey good agreement with the simulation results.

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