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Research Article

DESIGN AND IMPLEMENTATION OF COMPACT FOUR WAY WILKINSON POWER DIVIDER FOR UHF APPLICATIONS

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ABSTRACT

In this study, a compact four equal way Wilkinson Power Divider (WPD) circuit design was designed for UHF applications. The circuit whose center frequency was selected as 0.8 GHz operates between the frequencies of 0.54-1.08 GHz and has a bandwidth of approximately 67.5%. The length of each outlet way has been curved to take up less space in the circuit. In this respect, the proposed WPD has a compact structure with high applicability. A butterfly stub, the length of which was determined by parameter sweep, has been placed in the input for the purpose of matching impedance.
The simulation and measurement results of the designed circuit were well aligned with each other below 15 dB Return Loss and Isolation. In addition, 0.3 dB Insertion Loss was obtained on the output ways. It has been calculated that the proposed four-way power divider takes about 40% less space than the conventional circuit design.
Keywords: Wilkinson power divider, compact WPD, four way power divider.

1. INTRODUCTION

Microwave passive circuits are generally designed for special applications in many electronic circuits. Some microwave circuit design applications are produced in a compact manner [1-3].

In electronic circuits and systems, microwave circuit elements that divide the input power by the number of gate at the output are called ‘power dividers’. Wilkinson Power Divider (WPD) is the circuit that can make the power division lossless when the output gates are matched [4, 5].

There are many WPD circuits in the literature [6-11]. Some studies have also been specifically designed to divide the input power into more than two arms [12, 13]. In circuits requiring multiple supply inputs, such as array antennas, integrated circuits, and active circuits, the need for equal (or non-equal) division of power has increased the importance of multi-way power divider circuit design [2-4, 9, 14-16].

In recent designs, microwave power divider circuits have focused on achieving lower return loss (RL), insertion loss (IL) isolation loss (IS) and reaching higher bandwidth levels, which include more frequencies [17-20]. Besides, it is preferred for various applications due to the small size of the structure. [1].

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In this study, a WPD circuit was proposed which divides the input power into four equal ways at Ultra High Frequencies (UHF). The length of each arm was curved to minimize the space required by the circuit. Thus, the circuit occupies less space. With the shrinkage of the area, the amount of space on the structure decreased. Therefore, the proposed circuit is designed in a compact structure that can operate in UHF Band applications.

In the second part, the structure of the proposed four-way circuit was explained. The characteristics of the output arms, impedance calculation and theoretical analysis of S parameters were given. The dimensions and specifications of the circuit were also included in this section. In the third part, simulation and measurement results were given together. All electromagnetic simulation designs and parameter sweeps were performed on ADS 2009 program. The manufactured circuit was measured with Rohde Schwarz FSH6 Spectrum/Network Analyzer. The return losses, transmission coefficients, insertion losses, phases and isolation results were indicated for all ports. In this section, the comparison of the results with the previous studies in the literature was tabulated. In the fourth and final section, the results were re-emphasized and evaluated.

2. DESIGN OF 4 WAY WPD

The proposed design is a Wilkinson power divider circuit with an input and four output ports. The power dividing process consists of two stages. In the first stage, the input power is divided into two equal branches. Then, these branches are divided into two equal-arm circuits. Therefore, the proposed circuit has three two-branch and equal-division WPD circuits. In these two division operations, the length of each arm was selected as the quarter wavelength (ℓ) of the central frequency (f_0). In each divide (according to [5]), even-odd mode analysis has an R=100 Ω isolation resistance.

The line impedance seen at the input and output ports is $Z_0 = 50\ \Omega$. The width of this line is $W_0 = 2.9$ mm. The characteristic impedance of the transmission lines on all branches dividing the power is calculated from (1) as $Z_1 = 70.7\ \Omega$ [5]. The width of the line according to the characteristic impedance is $W_L = 1.6$ mm. Schematic view of the circuit is given in Fig. 1.

$$Z_1 = Z_0 x\sqrt{2} \tag{1}$$

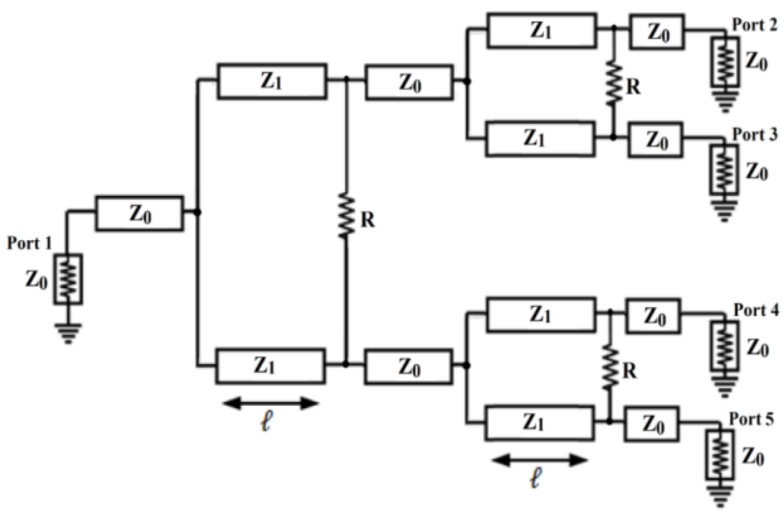

Figure 1. Schematic View of Four Way WPD.

Theoretically, in a four equal way power divider circuit, the output powers can be calculated as approximately -6 dB of the input power [21]. In non-ideal circuits, less than this value can be transmitted. This amount of loss is defined as Insertion Loss [22]. As can be seen from Eq. (2), IL can be obtained by subtracting -6 dB from the transmission parameter.

$$IL = S_{i1} - (-6) \text{ (dB)} \quad (2)$$

where $i = 2,3,4$ and 5 respectively.

The output ways of the circuit are designed with the same length. Therefore, there will be no phase difference between the ways. In addition, the return loss caused by the reflection of the incoming power in all arms will be the same. Return loss can be calculated from (3)

$$RL = 20 \log S_{ii} \text{ (dB)} \quad (3)$$

In the four way WPD circuit, the center frequency was selected as $f_0 = 0.8$ GHz The electrical permittivity of the substrate material used is $\epsilon_r = 4.3$ and the tangential loss is $\tan(\delta) = 0.025$. The reason for selecting FR4 substrate is that it is cheap, easily available and its application on PCB is simple. Also, another reason for choosing FR4 is that it has a high dielectric permittivity. Thus, the effective wavelength will be shorter and will respond better to size reduction. The thickness of the material is 1.5 mm. The length of each branch selected in the quarter wavelength at frequency f_0 was calculated as $\ell = \lambda/4 = 51$ mm. The external dimensions of the design are shown in Fig. 2. All dimension, length and numerical properties of the design were listed in Table 1.

Table 1. Parameters List.

Parameter	Value	Parameter	Value
L	49 mm	W_0	2.9 mm
W	47.5 mm	W_1	11 mm
h	1.5 mm	W_2	14.6 mm
t	35 µm	W_{line}	1.6 mm
ϵ_r	4.3	L_1	8.7 mm
$tan\delta$	0.025	L_2	37 mm
R	100 Ω	L_3	5 mm
Deg	18°	L_{rad}	3 mm
Rad	3.85 mm	gap	2 mm

The transmission line was designed in a meandered structure to take up less space in the design. Although different geometries and layouts have been tried before the proposed design, the transmission line structure consisting of 4 semicircles provided better size reduction and higher insulation properties. This curve affected the external dimensions of the circuit $L = 49$ mm and $W = 47.5$ mm. The dimensions of the circuit according to wavelength are $0.236 \times 0.229\ \lambda^2$. If there were no meandering; the width of the circuit would be $W' = 2 \times W_2 + W_{line}$ mm and the length $L' = L_1 + 2 \times \lambda/4 + W_1$ mm also. The dimensions of the non-crimped circuit could be calculated as $0.155 \times 0.588\,\lambda^2$ Thus, approximately 40% of the residential area has been saved. Thus, the power division circuit becomes more compact.

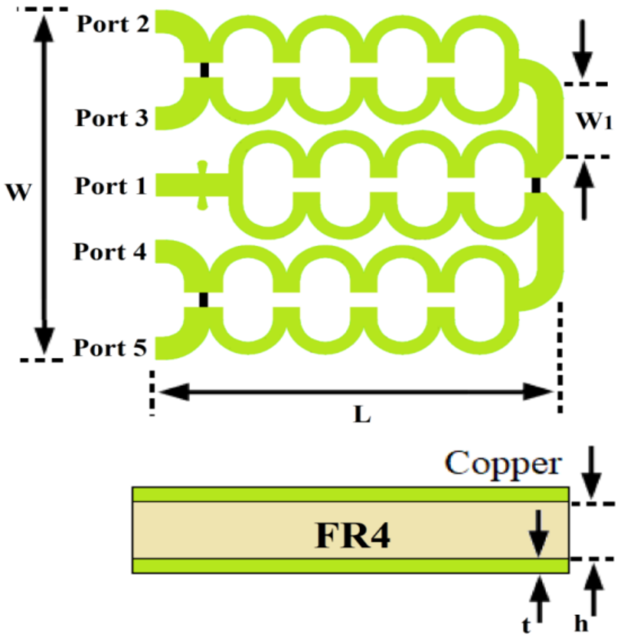

Figure 2. External Sizes of the Circuit.

Butterfly stub is one of easy ways to match the input impedance of the circuit at the operating frequencies. In order to match the input port of the impedance, the length of the butterfly stub $L_{rad} = 3$ mm was determined by parametric analysis, as shown below. As a result of similar sweep applications, $L_3 = 5$ mm and Deg $= 18°$ were selected. The internal dimensions of the design are given in Fig. 3. The figure shows the size of a single divider layer. In addition, the lengths $L_2 = 37$ mm, $W_2 = 14.6$ mm, $gap = 2$ mm, $Rad = 3.85$ mm and $W_{line} = 1.6$ mm are the same in the three divider layers. The manufactured circuit is shown in Fig.4.

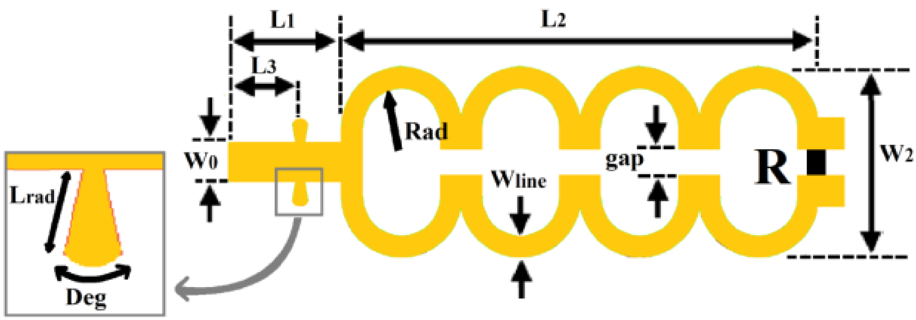

Figure 3. Internal Sizes of Proposed 4 Way WPD.

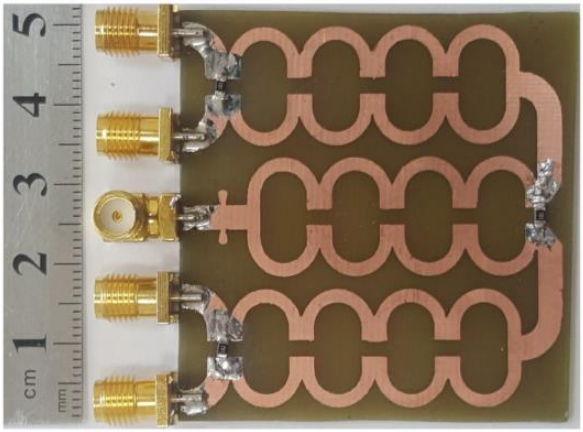

Figure 4. Manufactured View of the 4 Way WPD.

3. SIMULATION AND EXPERIMENTAL RESULTS

On the simulation program, a butterfly stub was applied to match the impedance at the input port of the WPD. The length of the stub was determined according to the parametric sweep. The butterfly stub was swept for 5 different values in the range of $L_{rad} = 2.5 - 3.5$ mm and the best length was chosen as 3 mm. Figure 5 shows the sweep graph against the return loss of the butterfly stub length. The most suitable solutions were found by applying the same sweeps for $Deg = 18°$ and $L_3 = 5$ mm parameters. There is no need to add sweep applications here.

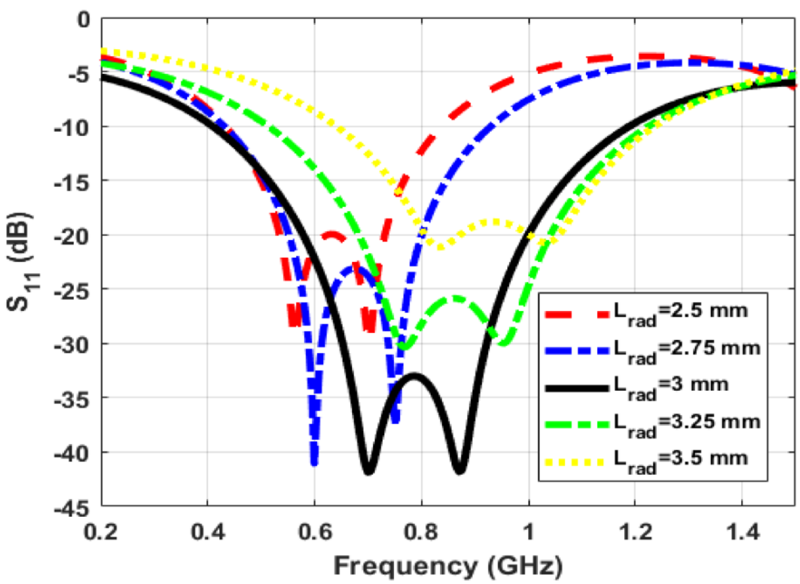

Figure 5. Parameter Sweep of L_{rad} vs. Return Loss.

The Return Loss graph (S_{11}) of the four way WPD circuit is shown in Fig. 6. Here, $RL \geq 15$ dB was accepted. The designed circuit operates in the frequency range $BW = 0.54 - 1.08$ GHz. according to the selected $f_0 = 0.8$ GHz center frequency, it has 67.5% of fractional bandwidth.

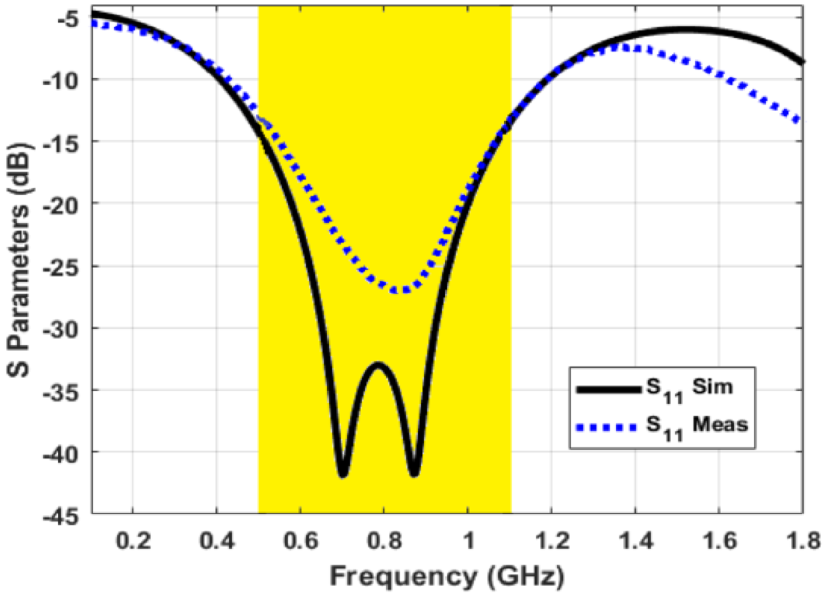

Figure 6. Return loss of the WPD.

The symmetrical output ports ensure that S_{22}, S_{33}, S_{44} and S_{55} are equal. Fig. 7 shows the reflection coefficient graphs of the output ports.

There is an inconsistency between the simulation and measurement results in Fig. 6 and Fig. 7. Considering the measurement result is approximately -25 dB, the amplitude of the signal reflected back from each gates was calculated as the reflection coefficient $S_{ii} \cong 0.056$ (in real scale). The transmitted power (T) can be calculated from (4). Thus, at -25 dB reflection, approximately 99.7% of the incoming power is transmitted to each way [5]. Simulation results show that S_{ii} is about -40 dB. The difference is logarithmically large, but that is only 0.3% of the actual transmitted power. This loss due to manufacturing and soldering faults in the implemented circuits is very small.

$$T = 1 - |S_{ii}|^2 \quad (4)$$

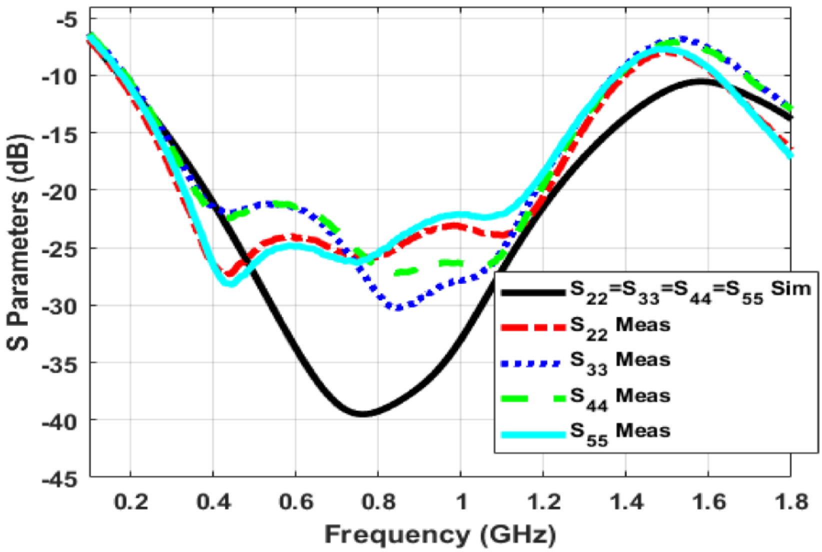

Figure 7. Output Reflection Coefficients of the WPD.

As the circuit is symmetrical, the output ports are equal for the transmission parameter ($S_{21} = S_{31} = S_{41} = S_{51}$). Since the circuit was not ideal, IL changes between minimum 0.3dB and maximum 0.6 dB throughout the BW. The graph of the transmission coefficient was given in Fig. 8.

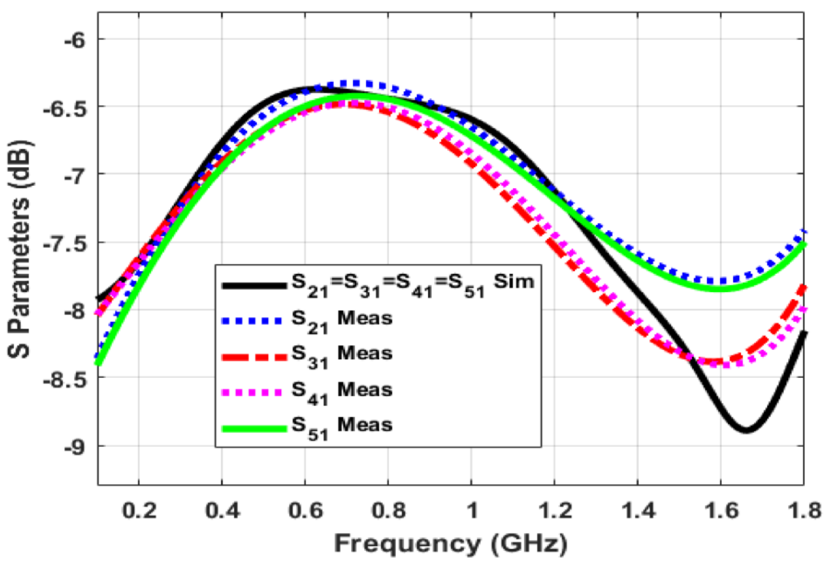

Figure 8. Transmission Coefficients of the WPD.

An indication that all output ports are symmetrical is that the phases of the transmission parameters are equal. Thus, no phase difference between the ports will occur during any electromagnetic signal communication. Fig. 9 shows the phase change of the transmission parameter on all ports. As can be seen, the phases on all output ports are the same.

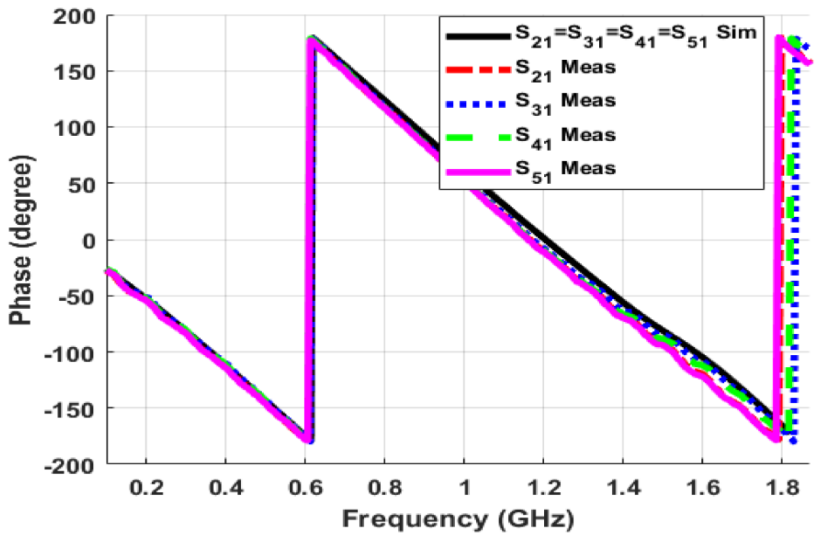

Figure 9. Phase responses of transmission ports.

The isolation shows the measure that the output arms do not affect each other. In the four way WPD circuit, the isolation parameters of the ports have the same frequency response. The isolation of neighboring ports $S_{32} = S_{54}$ is given in Fig. 10. The response of isolating between cross ports is also shown in Fig. 11 ($S_{42} = S_{43} = S_{52} = S_{53}$). The isolation responses of the ports being cross-distant to each other are also shown in Fig. 10 ($S_{42} = S_{43} = S_{52} = S_{53}$). In the BW range, approximately IS $= -15$ dB isolation can be observed.

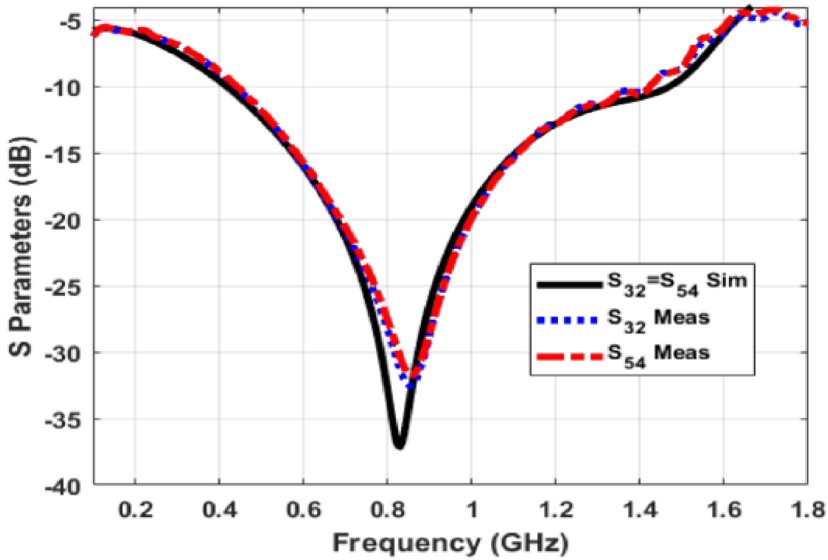

Figure 10. Isolation between neighbor ports.

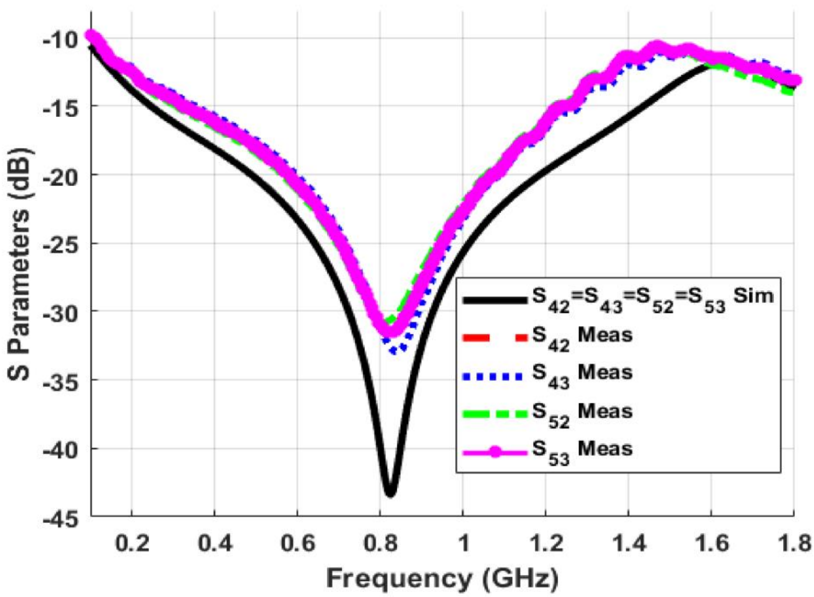

Figure 11. Isolation between Cross Ports.

Considering all the plots of results, the RL and IL are low, the IS is high, and the phase on the output ways are equal, indicate that the quite low coupling effect between the output branches. The proposed four-way WPD circuit is compared with previous studies in Table 2 for the parameters mentioned above. The area covered by WPD using meandered lines is lower than given in recent literature studies. In this respect, the four Way WPD circuit has a compact structure and the success of crimping and size reduction.

The improvement and novelty made in the proposed study is to be able to design a WPD at frequencies with relatively high wavelengths such as UHF in these dimensions and bandwidth. This design will provide advantage in saving space in micro-strip UHF circuits as it is more compact.

Table 2. Comparison with previous publications.

Ref.	WPD Type	f_0 (GHz)	RL (dB)	IL (dB)	IS (dB)	# of ways	BW and % BW	Size (λ^2)
[9]	Serial Power Divider	0.915 2.44	10	0.8	12 10.5	4	0.902-0.928 2.40-2.48 *	0.22×0.28 0.58×0.73
[2]	Bagley Polygon Divider	1.0	20	*	*	4	* 20%	40% reduction**
[19]	Inter-Stage Transmission Lines	3.0	10	0.5	15	4	2.45-3.80 *	**
[20]	Singly One Pair of Resonators	2.4	20.4	0.8	18.1	4	* 18%	0.35×0.21
This Work	**Meandered Line WPD**	**0.8**	**15**	**0.3 min**	**15**	**4**	**0.54-1.08** **67.5%**	$\mathbf{0.236 \times 0.229}$ **40% reduction**

*: Parameter or BW has not been given on those articles.
**: WPD dimensions have not been found in the article.

4. CONCLUSION

In this study, a four way WPD circuit was designed. The length of each output branch was meandered to minimize taking less space. Thus, the area covered by the circuit is reduced. The meandered line WPD circuit was chosen as the center frequency $f_0 = 0.8$ GHz to operate in the UHF band. The circuit provided 67.5% of fractional bandwidth in the $BW = 0.54 - 1.08$ GHz frequency range. The simulation and measurement results were in good agreement.

Measured RL, IL and IS values show better performance than literature studies. The proposed design is compact in the space occupying 40% smaller than the conventional circuit design. The four way WPD circuit can be used in antenna arrays and active microwave circuits, power division or combining applications at the UHF power and communication frequencies.

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