

# Reconfigurable 1:4 Wilkinson Power Divider Used in ISM Band Applications



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**Abstract** Many researchers have contributed to the technical developments of a variety of multistage power dividers based on the Wilkinson topology by replacing the quarter wave transmission line section with other means. It was possible to reduce the size of the power divider to a great extent but the S-parameters were largely affected. This was due to the effect of termination, discontinuities, mismatching losses and manufacturing tolerance. Amplitude and phase imbalance also contributed to destabilised performance of power dividers. The current paper presents a reconfigurable 1:4 Wilkinson power divider (WPD) with 3 sections of 2-way WPDs operating in ISM Band applications in order to work around such limitations. The simulation of the power divider is carried out with CST software which is capable of analysis of microwave circuits, and calculation of amplitude and phases of the scattering parameters can be done very accurately. The average measured values of the S-parameters are: insertion loss  $-6.28$  dB, the bandwidth at  $-10$  dB and the return loss is 39.69%. The output ports have no reflection, and hence, they are perfectly isolated. The surface current of the power divider has no coupling of current between output ports when port 1 is excited. It indicates that the output ports are perfectly isolated. The dimensions of the power divider are  $112 \times 157$  mm.

**Keywords** Power divider · Insertion loss · Microstrip · Return loss · Reflection coefficient

## 1 Introduction

The history of a conventional WPD is summarized in [1, 2] by different authors. The main drawback of the WPD is its narrow bandwidth and larger size because of the use

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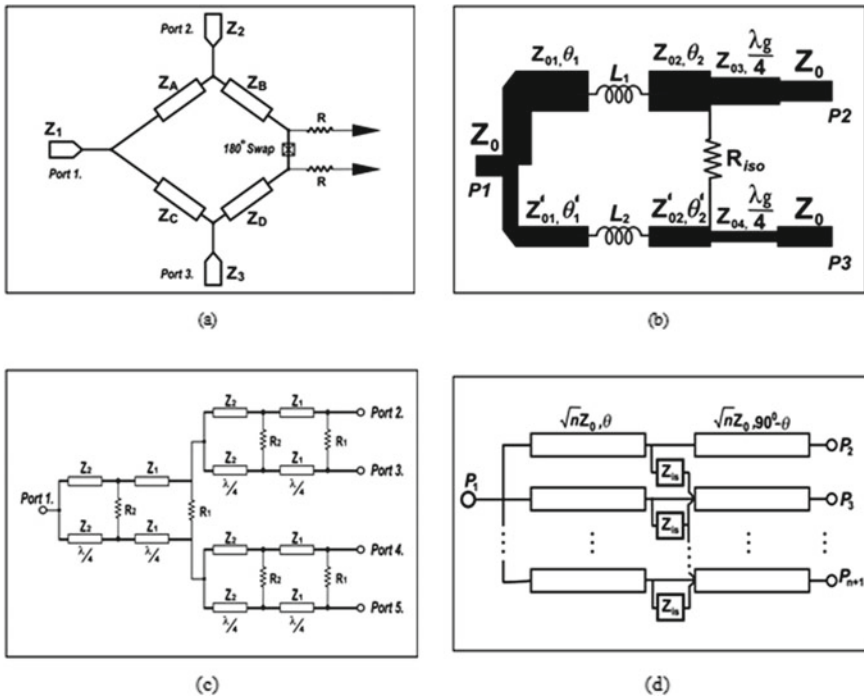
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of  $\lambda/4$  transmission line sections and its single frequency operation. In [3], the use of lumped passive components instead of a transmission line section was suggested to reduce the circuit size. However, a limited bandwidth because of inductors with a high Q factor and a higher insertion loss were the drawbacks. A novel idea was presented by Chiu et al. in [4] which included the use of parallel strip line structure as shown in Fig. 1a. However, the structure introduced a discontinuity and reduction in performance of the circuit. In 2008, Jiang et al. introduced the use of a bent microstrip line in place of a straight microstrip line to reduce the circuit size [5]. In [6], a novel compact CNS power divider was designed which used an equivalent low pass filter circuit instead of  $\lambda/4$  transmission lines. The observation here was that the reflection coefficient of the center frequency was offset slightly to the low frequency. Using structures like a two branch directional coupler was suggested by Ding et al. [7]. Even/odd modes analysis was used to design and analyze the power dividers useful in an antenna fed network. A structure based on a single layer microstrip line with capabilities to design different types of power dividers was proposed in [8]. It could reduce the occupational area and suppress the harmonic, multiband, and arbitrary dividing ratios as shown in Fig. 1b.



**Fig. 1** a Modified WPD with a swap and shunt resistors, b Layout of unequal power divider, c Circuit model of 4-way power divider, d Schematic of n-way power divider

A compact 1:1 and 1:9 divider at 1 GHz frequency totally based on Wilkinson topology was designed with the use of two microstrip circuits [9]. In the present topology, the first stage was a 1:2 power divider, whereas the second stage used two power dividers but converted to three output ports. A signal coming in could be separated by the resultant 1:6 power divider with equivalent amplitude of outputs into 6 output ports. Replacement of all  $\lambda/4$  lines [10] with the use of step impedance resonator (SIR), implementation of glass-based TFIPD technology and the use of Bridge T-coils [11], as shown in Fig. 1c were made to reduce the size without affecting the operational bandwidth of the proposed power divider. N-type divider with an n quarter wave transmission line was presented in [12]. Each line had a characteristic impedance that was  $\sqrt{n} Z_0$  and isolation impedance  $Z_{is}$  as shown in Fig. 1d. Because the symmetry of the structure isolation impedance acted as an open circuit, perfect input match and equal power division were possible irrespective of the electrical length  $\theta$ .

To address the demands of the standards of telecommunication, the primary focus of researchers is now the design of the dual band, the multiband and the broadband power dividers.

In 2013, a planar six-way power divider [13] was exhibited as per the Nobuo Nagai theory to reduce the size area with a good harmonic suppression. The structure shown in Fig. 2a was two dimensional, easy to design and symmetrical. A UBW power divider was designed in [14]. The structure was based on three open stubs on each branch and defected ground structure (DGS) on the back of inter digital coupled lines. Multistage, quarter wave transformers were used to increase the bandwidth and reduced the size of proposed UWB power divider in [15]. The physical model shown in Fig. 2b was simulated with HFSS software to get a desirable result and operate between the frequency band (2–18 GHz) [16]. The dielectric is enclosed between thick layer so that the width of the strip lines can be increased and the effects of the fabrication tolerances can be decreased. The performance of an unequal dual frequency power divider was analyzed based on the modeling approach line theory [17]. The structure shown in Fig. 3a minimizes the size of the dual band power divider [18] using isolation resistors and line couplers. Based on theoretical analysis it could

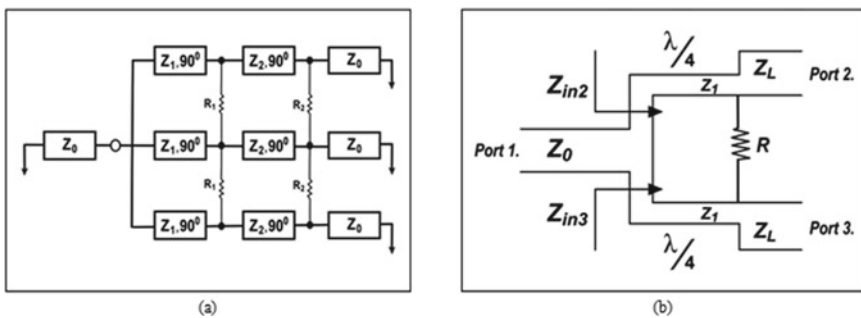
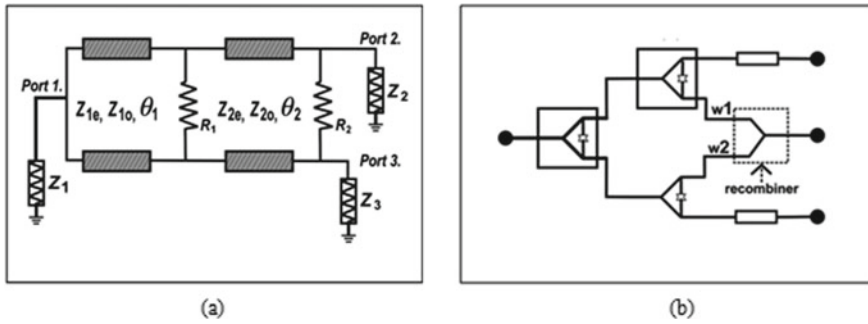


Fig. 2 a Three-way power divider based on Nabuo Nagai, b WPD in microstrip form



**Fig. 3** a Dual band coupled line WPD, c Standard model cell for dual band power divider

operate over a wide frequency range (1 to 3 GHz) without additional requirements on the microstrip fabrication and could cover all other dividers. The planar structure proposed in [19] and based on a recombined structure concept was useful to design an arbitrary planner power divider (it could be generalized to any number). The large separation between  $W_1$  and  $W_2$  shown in Fig. 3b) reduced the parasitic effect without reducing the efficiencies of the power divider. Multisection impedance transformers were proposed to increase the operation band [20]. The offset double side parallel strip provided high impedance in unequal power dividers. A presentation in [21] brought forth a generalized WPD that included lumped elements which were able to enable dual band and unequal power division. This particular divider had an edge in the characteristics of isolation and bandwidth of reflection at the output terminals as well as in the choice of inductance. Moreover, this was accomplished with no degradation in the impedance as well as in the power division characteristics. Haijun Fan et al. came up with an innovative, reconfigurable structure with a high dividing ratio power divider [22]. Merely three pin diodes were utilized without any D.C. blocking capacitors. The planar, wide band with tunable power division ratio was the focus of the design in [23]. Artificial transmission line (ATL) technology [24] and double sided parallel strip lines (DSPSL) were used to design a 4:1 unequal WPD [25] so as to reduce the size in the low frequency band and hence minimize the structure in order to suit wireless communication applications. The concept of complete termination for 3 dB power dividers was presented in a Hybrid microstrip form [26]. The accuracy of the design approach was confirmed with the measurement of S-parameters based on their characterization.

Filtering power dividers have been the focus of the multiple studies in recent times. Low pass filter [27] were used to substitute two-quarter wave length transformers in the conventional WPD. In [28], there was a report of a novel class of power dividers that filtered on the basis of quasi-band pass section. It had features like frequency controllable single/multiband operation. Innovative wide band power dividers that include filter function are proposed, searched and presented in [29].

To overcome the limitations observed in the literature survey, this paper proposes a design based on reconfigurable 1:4 WPD which is modified with three sections of

2-port symmetrical power dividers operating in ISM band applications. Z-parameters and S-parameters are analytically convenient to calculate the system performance by cascading individual components of a microwave system.

The paper is systemized as: In Sect. 2, statistical data is analyzed to find out the inter relationship between the S-parameters. Section 3 contains the research methodology where in theoretical analysis of Z-parameters, S-parameters and microstrip lines are explained. Section 4 presents Design and Simulation of the proposed power divider. Section 5 presents the performance comparison of the reported power dividers. The Conclusion based on our research is given in Sect. 6 References are cited at the end of the paper.

## 2 Statistical Data Analysis

In this, we have summarized all the reviewed literature in Table 1 which compares S-parameters.

Table 1 contains a comparison of the main variables of RF and microwave power dividers such as return loss, insertion loss, isolation and size. Various reference papers are reviewed along with the technology used. The return loss shown in Table 1 varies from 15 [11] to 30.4 dB [3] for power dividers operating at single design frequency. The dual frequency power dividers show excellent return loss from 15 [20] to 50 dB [17]. The highest insertion loss observed is 8 dB [13] and the lowest is 0.16 dB [6] due to the CMOS technology used. It is further observed that isolation loss reduces with increasing output ports. In general, the reduction in isolation marked is 30.5 to 27.2% when the output ports go up from 4 to 6.

The main scope of this paper is to present previous statistical data available on microwave power dividers. We have reviewed multiple approaches for the design of multiband power dividers. Moreover, a discussion on varying frequencies and power ratios for multiband WPDs using various methods has been conducted. The size reduction marked varies from 57.67 to 91.25%. It is further observed that the isolation loss goes down by 30.5 to 27.2% when output ports vary from 4 to 6.

The main variables of RF and microwave power dividers have a barter relationship, and hence, the selection is made by the designer depending upon the requirements of the applications. In the area of wideband and ultra-band filter design, the technique for co-design of filters and power dividers is a new topic of interest. Using computer aided design tools capable of analysis of microwave circuits, the calculation of the amplitude and phase of the scattering parameters can be done very accurately. The use of a multilayer substrate can be useful for increasing the bandwidth, reducing the size and improving the isolation of power dividers.

**Table 1** Performance comparison of S-parameter

Method	Return loss (dB)	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq. (GHz)	Remarks
Lu et al. [3]	> 30.4	< 0.16	27	0.015	4.5	Limited bandwidth because of high frequency Q factor and insertion loss
Chiu et al. [4]	2	< 0.7	> 25	25.10 cm <sup>2</sup>	2	Parallel strip lines introduced a discontinuity and reduction in performance of the circuit
HJiang et al. [5]	Good	4.77	> 30	31.32	0.9	Size is reduced drastically due to bent microstrip lines but it has introduced phase imbalance variations of the order of $\pm 0.35$
Yuenjin and Menjiang et al. [6]	Notquoted	Not quoted	Not quoted	0.36	1.616	Reflection coefficient of the center frequency was offset slightly toward the low frequency
Ding et al. [7]	< -20	Not quoted	> 17	87.40	2.5	Simple, compact and easy design and fabrication
Mirzavand et al. [8]	27.34	3.34	30	3.78 cm <sup>2</sup>	1	Due to approximation in values of the elements, extra circuit loss occurs. Moreover the response of the structure used depends on self-resonant frequency of used lumped inductors

(continued)

**Table 1** (continued)

Method	Return loss (dB)	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq. (GHz)	Remarks
Pribawa et al. [9]	< 12.3	< 7.8	< 12.8	Not quoted	1.5	The isolation of S <sub>24</sub> and S <sub>57</sub> are lesser than other ports due to the effect of wirebonds length
Fu et al. [10]	-20	< 0.02	-20	14.4	1.6-2.1 Pass band	The SIR is used to modify the isolation and input port return loss. No serious limitations are mentioned in the published work
	< -20	0.5	> 20		1.7-3.7 Pass band	
Tseng et al. [11]	15	1.75	15	21.16	1.6	Glass-based TFIPD technology was used to compact chip size. Broad band 4 -way PD
Choe et al. [12]	16.2	4.8	24	0.06	2	n-way WPD reduced the insertion loss and circuit size but the process of analysis involved plenty of theory
Wan et al. [13]	-20	8	> 20	Not quoted	1.71-2.5	Planner six-way broad band, 1:6 PD based on Nubuo Nagal theory
Liu et al. [14]	< 10	Small	< -10	0.285	3.1-10.6	Simulated and experimental values of S <sub>21</sub> at high frequency differ due to the use of open stubs
Xu et al. [15]	< 1.25	-3.5	-22	9.30 cm <sup>2</sup>	2-8	Measured results are worse than simulation result due to fabrication technique when the divider is welded SMA adaptors

(continued)

**Table 1** (continued)

Method	Return loss (dB)	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq. (GHz)	Remarks
Afanasieve et al. [16]	1.5	0.4	-18	8.36 cm <sup>2</sup>	2-18	Coupled strip lines used to improve isolation and impedance matching at high frequencies. UWB PD. No limitations are mentioned in the published work
Wei et al. [17]	50	-	> 50	Not quoted	$f_1 = 0.9$	There exist some deviations to ideal values due to loss of characteristics of the material it self
	50	-	> 50		$f_2 = 1.8$	
Wu et al. [18]	> 25	> -3.15	> 30	2.36 cm <sup>2</sup>	$f_1 = 1.1$	Additional interconnecting transmission lines are required to obtained in phase characteristics in dual band applications
	> 25	> -3.19	> 30	2.36 cm <sup>2</sup>	$f_2 = 2.2$	
Wu et al. [19]	Not quoted	1.51	< -21	Not quoted	$f_1 = 0.6$	The discrepancies between measured and simulated result occurred due to reactive components at high frequencies
		1.57	-9.8	Not quoted	$f_2 = 2.45$	
Shie et al. [20]	> 15	-7.36	-26	Not quoted	$f_1 = 2.45$	Physical size of power divider is increased due to multisection impedance transformers
	> 15	-7.37	-25		$f_2 = 5.25$	

(continued)



**Table 1** (continued)

Method	Return loss (dB)	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq. (GHz)	Remarks
Wang et al. [21]	< -20	-4.77	< -20	Not quoted	$f_1 = 1$	There are no remarks on the size reduction on 4 types of power divider developed
	< -20	1.76	< -20		$f_2 = 1.8$	
Fan et al. [22]	> 15.4	1.6	> 18	Not quoted	5	Simulations are executed by HFSS and ADS with pin diode equivalent circuits 0.1:5 power divider
Guo et al. [23]	10	3.5–5.8	> 15	6.0cm <sup>2</sup>	0.7–1.4	Ring cavity multiple –way technique is used
Wang et al. [24]	10	1.17	15	20.90 cm <sup>2</sup>	0.9	4:1 unequal WPD with artificial transmission line (ATL) are used to get high impedance
Huang et al. [25]	> -20	Not quoted	> -20	12cm <sup>2</sup>	3.5	Even–odd mode analysis was used in generalized power divider
Piacibello et al. [26]	> 25	4.75	23	0.02 $\lambda_g^2$	0.9	Branch directional coupler is used
Tu et al. [27]	Not quoted	0.9	Not quoted	Not quoted	0.8 to 1.2	Reconfigurable, single /multiband Filtering PD
Dimitra Psychogiou et al. [28]	< -15	Not quoted	> 17	0.80 $\lambda_g \times 0.50 \lambda_g$	1.55–4.24	Wide band filtering PD operation by embedding transversal filters is realized

(continued)

**Table 1** (continued)

Method	Return loss (dB)	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq. (GHz)	Remarks
Jiao et al. [29]	> 19.5	4.77	19.5	0.34	3.3	Asymmetric 3-way equal wide band filtering PD
Faraz shaikh et al. [32]	-10	Not quoted	-10	66.3 × 100 mm <sup>2</sup>	3-8	The modified power divider shows equal power split which is suitable for antenna feeding network
Masrakin et al. [33]	-18	Not quoted	-18	40 × 30 mm <sup>2</sup>	2	The two way power divider is used for IoT application

### 3 Research Methodology

In research methodology, the design procedure is systematically carried out to modify 1:2 WPD into a 4-port WPD. In theoretical analysis a 2 port structure of the WPD is analyzed using Z-parameters and the modified 4 port structure is presented in Sect. 3.1. In Sect. 3.2, the analysis of an S-matrix helps the designer to calculate the critical S-parameters of the proposed system.

#### 3.1 Theoretical Analysis

In the structure of the WPD shown in Fig. 4a, a resistor R is connected between the output ports to improve the matching and isolation. Let, the characteristic impedance  $Z_0$  and load impedance  $Z_L$  be  $50\Omega$  each that is  $Z_0 = Z_L = 50\Omega$ .

If all input ports are matched for no reflection then,

$$\frac{1}{Z_0} = \frac{1}{Z_{in2}} = \frac{1}{Z_{in3}} \quad (1)$$

From Fig. 2a,

$$Z_{in2} = Z_{in3} = Z_1 + Z_L \quad (2)$$

where  $Z_1$  is the characteristic impedance of the  $\lambda/4$  transmission line.

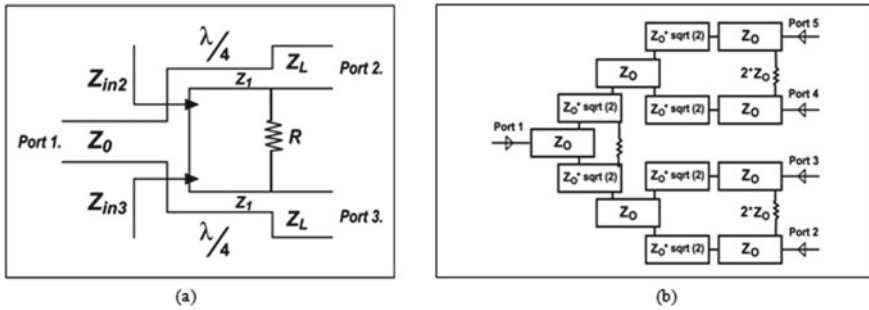


Fig. 4 a 2 port structure of WPD, b 4 Port Structure of WPD

According to the quarter wave impedance transforming theory,

$$Z_{in2} \times Z_L = Z_1^2 \tag{3}$$

$$Z_{in3} \times Z_L = Z_1^2 \tag{4}$$

By solving Eqs. 2, 3 and 4  $Z_1$  is expressed as

$$Z_1 = 2Z_0 \tag{5}$$

From the even/odd mode analysis, the resistor  $R$  is obtained as:

$$R = 2Z_0$$

The proposed WPD is modified with three sections of two-port symmetrical conventional power dividers to get 4 output ports as shown in Fig. 4b.

### 3.2 S-parameters

S-parameters are complex numbers having real and imaginary parts. Here, S-parameters are used to describe the relationship between different ports when it becomes important to describe the network in terms of amplitude and phase versus frequency rather than voltages and currents. They are measured in dB. To derive the fundamental properties of a lossless, reciprocal 3 port junction power divider the general expression of S-parameters in matrix form is derived as under.

The matrix of S-parameters for an ideal three-port WPD is

$$S = \begin{bmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{bmatrix}$$

For reciprocal networks the matrix is symmetric and ideally, to avoid any loss of power, the network would be lossless and matched at all ports. When all ports are matched and the reciprocal matrix reduces to

$$S = \begin{bmatrix} 0 & s_{12} & s_{13} \\ s_{21} & 0 & s_{23} \\ s_{31} & s_{32} & 0 \end{bmatrix}$$

If the network is lossless, [S] must be unitary, which implies the following conditions:

$$\begin{aligned} S_{31}^* S_{32} &= 0 \\ S_{21} S_{23} &= 0 \\ S_{12} S_{13} &= 0 \\ |S_{12}|^2 + |S_{13}|^2 &= 1 \\ |S_{21}|^2 + |S_{23}|^2 &= 1 \\ |S_{31}|^2 + |S_{32}|^2 &= 1 \end{aligned}$$

These equations can be satisfied in one of two ways. Either

$$S_{12} = S_{23} = S_{31} = 0, |S_{21}| = |S_{32}| = |S_{13}| = 1$$

OR

$$S_{21} = S_{32} = S_{13} = 0, |S_{12}| = |S_{23}| = |S_{31}| = 1$$

With reference to the above, the S-matrix for 1:4 port network can be developed as

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{bmatrix} \quad (6)$$

For an ideal 1:4 WPD, the following condition must be satisfied.

$$S_{11} = S_{22} = S_{33} = S_{44} = S_{55} = 0 \quad (7)$$

$$S_{12} = S_{21}, S_{13} = S_{31}, S_{14} = S_{41}, S_{15} = S_{51} \tag{8}$$

$$S_{23} = S_{24} = S_{25} = S_{34} = S_{35} = S_{45} = 0 \tag{9}$$

Above equations show that at least two of the three parameters ( $S_{12}; S_{13}; S_{23}$ ) must be zero. However, this condition will always be inconsistent with one of equations, implying that a three-port network cannot be simultaneously lossless, reciprocal, and matched at all ports. If any one of these three conditions is relaxed, then a physically realizable device is possible. These results show that  $S_{ij} \neq S_{ji}$  for  $i \neq j$  which implies that the device must be non-reciprocal.

### 4 Design and Simulation

Figure 5 depicts the proposed WPD which plays an important role in communication systems because of its characteristics, namely simple configuration, matching of impedance, and isolation at output ports. The structure of the WPD, as displayed in Fig. 5a comprises two  $\lambda/4$  transmission lines and the branch impedances  $\sqrt{2Z_0}$  and  $2Z_0$ .

An analysis of the circuit is undertaken using the even-odd mode [10]. The prototype power divider is visible in Fig. 5b which is printed on the FR-4 substrate ( $\epsilon_r$  4.3, thickness 1.6 mm) having an overall dimension of  $157 \times 112 \text{ mm}^2$ . The WPD acts as a network of corporate feed for feeding the phase shifter with equal phase and amplitude. The output ports have no reflection, and hence, they are perfectly isolated.

The surface current for the power divider is shown in Fig. 6a-e. It can be seen that no coupling of the current is observed between ports when port 1 is excited by terminating the other ports (such as 3,4,5) and observing the current at the testing port

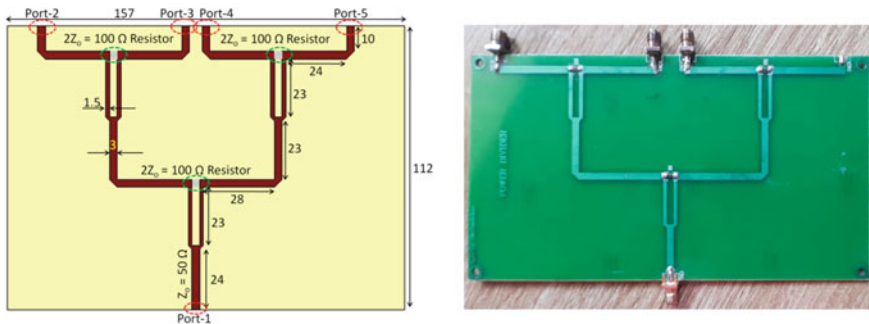
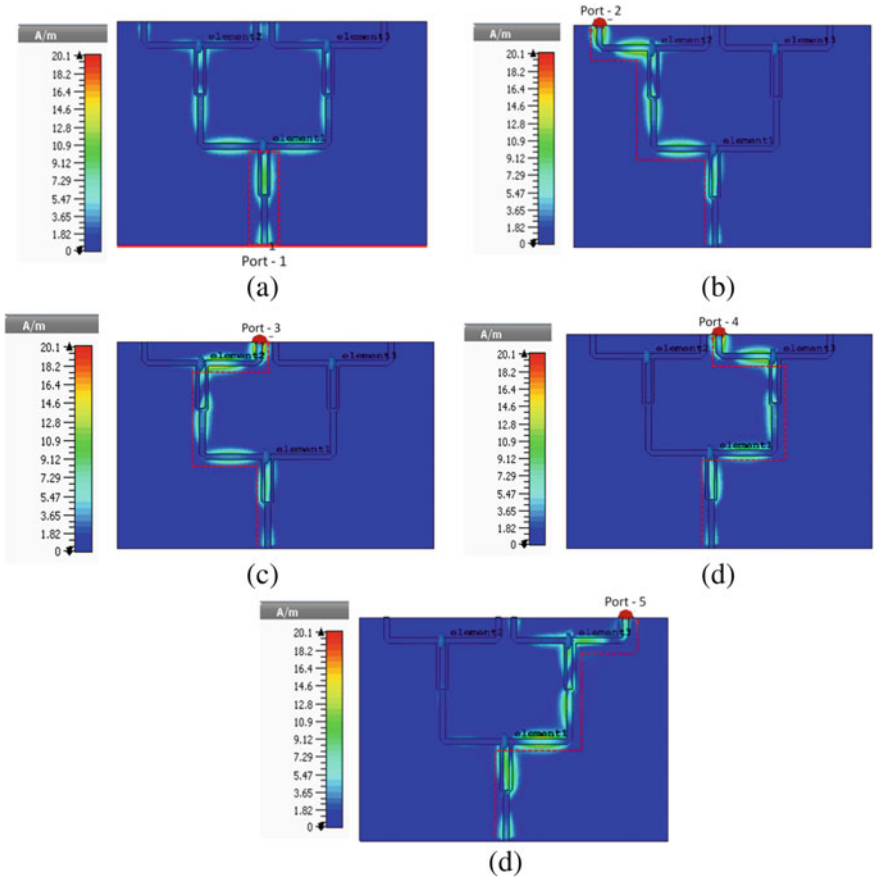


Fig. 5 Wilkinson power divider (WPD) a Geometry b Fabricated prototype

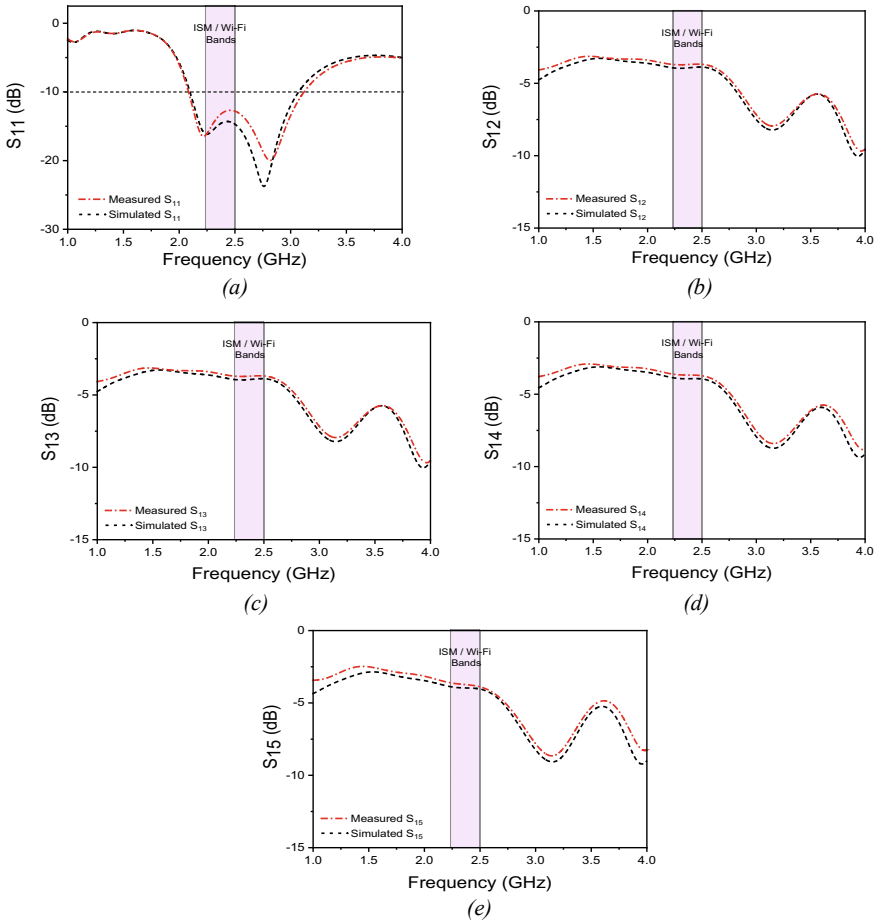


**Fig. 6** Surface current at a Port 1 b Port 2 c Port 3 d Port 4 e Port 5

2. Similarly the same procedure is true for testing port 3, 4 and 5 keeping excitation port as 1.

Figure 7 illustrates that the power divider has a measured fractional bandwidth of 39.69%. It can also be visualized that the measured  $S_{21}$ ,  $S_{31}$ ,  $S_{41}$ , and  $S_{51}$  are  $-6.25$ ,  $-6.31$ ,  $-6.28$ , and  $-6.31$ , respectively, which are very low and shows good agreement with the simulated values. It can also be seen that,  $S_{21}$ , resembles  $S_{31}$ ,  $S_{41}$ , and  $S_{51}$  which indicates equal power distributed to all the output ports.

From the above analysis, it is verified that the designed 1:4 WPD exhibits a good performance, the insertion loss is low and good VSWR.



**Fig. 7** S-Parameters result of the Wilkinson power divider **a**  $S_{11}$  **b**  $S_{21}$  **c**  $S_{31}$  **d**  $S_{41}$  **e**  $S_{51}$  simulated (Solid)/measured (Dashed)

## 5 Performance Comparison

For proof of the enhanced performance a comparison of the 1:4 WPD under study, conducted including the size, S-parameters and center frequency is exhibited in Table 2. The experimental and theoretical results are tabulated so as to compare each of the modified WPDs with the proposed work. As per the theoretical calculations the maximum insertion loss expected at 2-port 3-port, 4-port, 6-port of the power dividers are  $-3$ ,  $-4.8$ ,  $-6$  and  $-7.78$  dB, respectively. Similarly, the ideal isolation loss is infinity ( $\infty$ ) for 2-port and 3-port power dividers. For 4-port and 6-port power dividers, it is 21.6 and 17.6 dB, respectively.

**Table 2** Performance comparison of with recently reported Wilkinson power dividers

Method	VSWR	Insertion loss (dB)	Isolation (dB)	Size in area mm <sup>2</sup>	Center Freq (GHz)	Comments
HJiang et al. [5]	1.92	4.2	> 25	25.10 cm <sup>2</sup>	2	A parallel-strip swap was used to enhance isolation. 1:2 PD
Yuenjin and Xing et al. [6]	–	4.77	> 30	31.32	0.9	Bent micro strip line reduced the size of the divider. 1:3 unequal PD
Agma Pribawa et al. [9]	1.75	< 7.8	< 12.8	Not quoted	1.5	Microstrip technology, 1:6 Wilkinson topology
Tseng et al. [11]	1.433	7.75	15	21.16	1.6	Glass-based TFIPD technology was used to compact chip size. Broad band 1:4 PD
Christain Mahardika et al. [30]	1.715	6.1	30	Not quoted	2	Modified 1:4 WPD operating at S band
Choe et al. [31]	1.67	6.3	33	Not quoted	2	Compact modified 1:4 WPD with physical output port isolation
Proposed work	1.614	6.28	> 20	157 × 112 mm <sup>2</sup>	2.45	Modified 1:4 WPD

The most critical parameter in the design of the power divider is the insertion loss which decides the mode of power flow in the output ports of multiport power dividers. The maximum insertion loss for the 1:4 power divider is -6 dB. But due to critical design analysis, we have obtained it as -6.28 dB in the proposed work. The same is the case with all the reported 1:4 power dividers. The VSWR of the proposed work is 1.614 which is less than 2 making it suitable for antenna applications. No coupling current is observed between output ports when the input port is excited which indicates that the isolation is perfect between output ports. The only drawback in the proposed power divider is the larger size, which is 174.84 cm<sup>2</sup> size because six  $\lambda/4$  transmission lines have been utilized and additional lines are used to make a connection between the SMA connectors and the two way power dividers. The proposed power divider is the cheapest and the simplest in design and meets all the



requirements of the so called modified versions of the WPD topology. It is most suitable as a part of feed network used in phase array.

## 6 Conclusion

Wilkinson topology has been used to design the proposed 1:4 WPD. It is distinguished to exhibit its execution in ISM band frequency range. The power divider that has been proposed in this paper uses the 1:2 power divider in the first stage and makes use of two 1:2 power dividers in the second stage. A FR4 substrate is used for deploying it. The insertion loss of the proposed power divider is  $-6.28$  dB, the VSWR is 1.614 and the isolation is greater than 20 dB at 2.45 GHz. These characteristics accommodate all the requirements at the desired frequency. The isolation at the output port is perfectly matched due to the fact that no reflection is shown at the output ports. The designed WPD meets all the requirements of an advanced modified WPD except the large size.

The technique for co-design of filters and power dividers is a new topic of future interest. Using computer aided design tools capable of analysis of microwave circuits, the calculation of the amplitude and phase of the scattering parameters can be achieved very accurately. The use of a multilayer substrate can be useful for increasing the bandwidth, improving the isolation and reducing the size of power dividers in future design of such power dividers.

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