Compact Ultra-wideband 2-way Wilkinson Power Dividers at Ka/Ku Bands

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***Abstract*-In this paper, a miniaturized, ultra-wideband (UWB), simple and single-layer microstrip structure for a 2-way Wilkinson power divider (WPD) is realized by cascading multi-sectional WPDs. Following the proposed method, two UWB 2-way equal power dividers (PDs) with different structures are designed, and CST software is used to optimize the UWB WPD. The final overall sizes after optimization are 10×5.6×0.508 *mm*³ and 12.6×7.9×0.508 *mm*³, respectively. The proposed band range of the two PDs is 9.98-32.46 GHz and 10-36.5 GHz (|S_{11}| < -10 dB), The insertion loss within the frequency band is better than -4.5 dB, and the isolation is always kept below -11 dB. The proposed PD will be used for UWB applications and mmWave simultaneous wireless information and power transfer applications.**

***Keywords*-Wilkinson power divider (WPD), ultra-wideband (UBW), transmission lines, miniaturization.**

I. INTRODUCTION

Recently, there has been significant attention and adoption of ultra-wideband (UWB) as a burgeoning wireless communication technology. UWB systems boast notable benefits including ample bandwidth, minimal power usage, and resilience against multipath interference. Within UWB systems, the power divider (PD) serves as a crucial passive component, responsible for evenly or unevenly distributing input power among multiple output ports. This feature holds promising applications across radar [1-2], positioning [3], communication [4], and various other domains. PDs adhere to principles involving proportional power distribution within specified frequency bands, minimal insertion loss, and high isolation between output ports. Common types of PDs include T-junction power dividers, resistive power dividers, and Wilkinson power dividers (WPD) [5].

Among these, the Wilkinson power divider stands out as a prevalent choice for power distribution networks in UWB systems, owing to its straightforward design and dependable performance. Its operating principle involves employing a quarter-wavelength impedance converter to split the input port power into two equal output powers, while isolation resistors are introduced to enhance isolation between output ports [6]. The primary function of the PD is to divide a single input signal into multiple output signals, either equally or unequally, or to combine multiple input signals into a single output signal, all while maintaining isolation and favorable impedance matching between ports. The UWB WPD showcases features such as minimal insertion loss (IL), exceptional isolation, compact design, and superb impedance matching. These attributes ensure minimal signal loss during division or combination, preserve signal purity through high isolation, reduce signal reflections through good impedance matching, and facilitate easier integration into various systems [7].

In recent years, researchers have proposed many methods to design UWB PDs [8-11]. In [8], an UWB PD consisting of two impedance converters of different sizes and a miniaturized WPD structure is proposed. However, the compactness performance is poor due to the difficulty of cascading and the large insertion loss. In order to achieve UWB, a new type of UWB PD is proposed in [9] by introducing an overlapping butterfly radial stub on each branch. Although the overlapping butterfly branches increase the structure compactness, they also increase the complexity of the structure. While the overlapping butterfly branches enhance the compactness of the structure, they also elevate its complexity. Reference [11] introduces a stepped-patch WPD with a ring on the patch, expanding the operating frequency range of the PD through the addition of a ring patch, while maintaining low insertion loss and excellent isolation. Nonetheless, the proposed structure employs 5-order step patches, consequently augmenting the overall complexity of the design.

Based on the above research, this paper proposes two different structures of 2-way WPDs with equal power division for UWB based on the method of transmission line concatenation. The proposed PDs has the advantages of simple structure, miniaturization, and UBW. CST software is used to simulation of the proposed PDs, two PDs are 9.98-32.46 GHz and 10-36.5 GHz (|S_{11}| < -10 dB) band to achieve UWB. We introduce the working principle of the WPD in Section II. The proposed two PD structures and their principles are described in Section III. Section IV presents the simulation results of the UWB WPD, while Section V provides a summary of this paper.

II. PRINCIPLE OF SINGLE-STAGE WILKINSON POWER DIVIDER

Fig.1 illustrates the configuration of a single-stage 2-way Wilkinson equal power divider, consisting of an input port and two output ports. Upon receiving a signal at port 1, the divider evenly splits the signal into two, transmitting them to port 2 and port 3 with equal amplitudes and phases. Two quarter-wavelength impedance converters with the same impedance value guarantee impedance matching. Usually, an isolation resistor with a value of $2Z_0$ is placed between output ports 2 and 3 to prevent current from passing through the transmission line to better achieve isolation and impedance matching between the two ports. According to Formula (1), the isolation resistance of equal PD or unequal PD can be calculated:

$$R = Z_0(K + \frac{1}{K}) \quad (1)$$

Where R is the isolation resistance value, Z_0 is the characteristic impedance, and K is the power distribution ratio. When K=1, the power divider is equal divider.

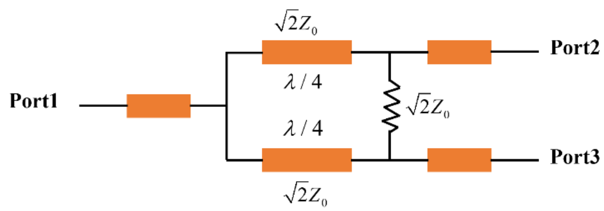


Fig. 1 The transmission line modelling of WPD

III. DESIGN OF UWB WILKINSON POWER DIVIDERS

Two different structures of the proposed 2-way equally divided UWB WPD, structure I and Structure II, are shown in Figs. 2 and 3, respectively. Both designs are implemented on a Rogers RT 5880 ($\varepsilon_r = 2.2,\ \tan\theta = 0.0009$) substrate with a thickness of 0.508mm. The 2-way PD consists of three ports: port 1 serves as the input port, while ports 2 and 3 function as output ports. All three ports are terminated with a 50 Ω impedance. By cascading the single-stage WPD, the operating frequency band's bandwidth is extended to achieve ultra-wideband performance. The proposed structures underwent optimization using CST software, and the dimensions for both designs in Tables I and II. The proposed structure was optimized using CST software, and the final dimensions optimized for the two structures are listed in Tables I and II. The final overall sizes of structure I and II after optimization are$10 \times 5.6 \times 0.508$ mm^3 and $12.6 \times 7.9 \times 0.508$ mm^3, respectively, indicating that the proposed two structures are more compact.

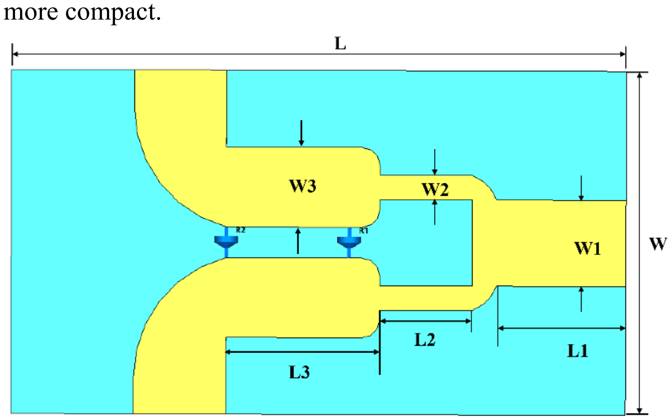


Fig. 2 The diagram of the proposed structure I.

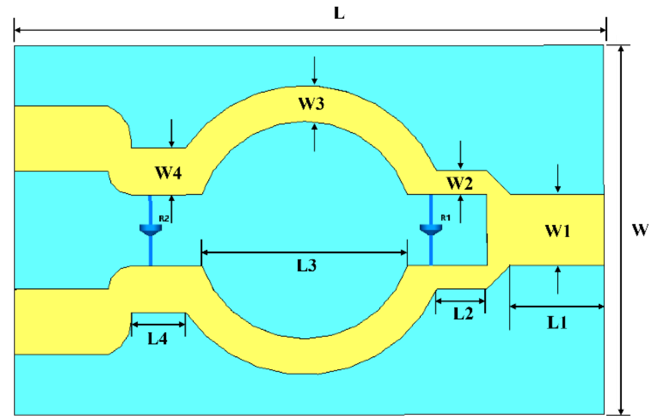


Fig. 3 The diagram of the proposed structure II.

TABLE I
DIMENSION OF STRUCTURE I

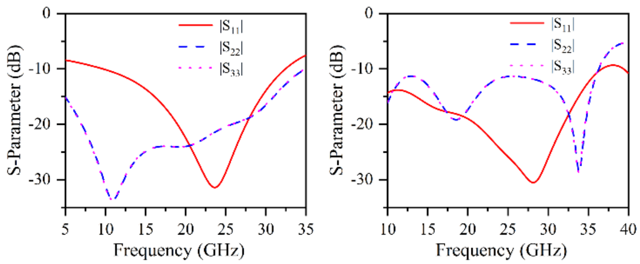
Para	Value (mm)	Para	Value (mm)
W	5.6	L2	1.5
W1	1.4	L3	2.2
W2	0.4	R1	100 Ω
L	10	R2	150 Ω
L1	2.1		

TABLE II
DIMENSION OF STRUCTURE II

Para	Value (mm)	Para	Value (mm)
W	7.9	L1	2
W1	1.52	L2	1.07
W2	0.5	L3	4.4
W3	0.8	L4	1.15
W4	1	R1	250 Ω
L	12.6	R2	230 Ω

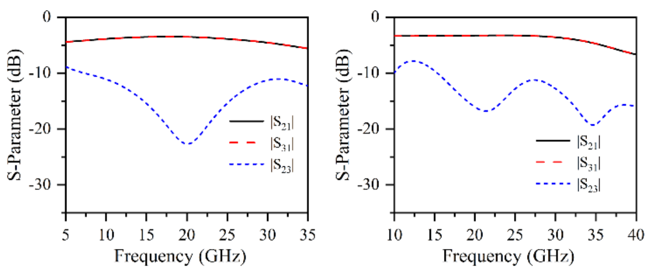
IV. SIMULATED RESULTS

Based on the analysis in Sections II and III, we verify the performance of the proposed 2-way UWB WPD. The proposed structure I and structure II of reflection coefficient ($|S_{11}|$, $|S_{22}|$ and $|S_{33}|$) results as shown in Fig. 4(a) and Fig. 4(b). Fig. 4(a) shows that structure I operates within the frequency range of 9.98 to 32.46 GHz, with a resonant frequency of 23.7 GHz. The reflection coefficients of all three ports remain below -10 dB within the operating band. Specifically, in the 19-27.6 GHz band, the reflection coefficients of the three ports are lower than -10 dB and even surpass -20 dB. Fig. 4(b) indicates that the frequency band of structure II, with reflection coefficients below -10 dB, extends from 10 to 36.5 GHz, with a resonant frequency at 29.5 GHz. The ports demonstrate good matching within the operational bandwidth, with an in-band reflection coefficient surpassing -20 dB between 20.9 and 32 GHz. The above results show that the proposed two structures can achieve UWB well.



(a) (b)

Fig. 4 The reflection coefficient results of proposed structure I and structure II (a) structure I; (b) structure II.



(a) (b)

Fig. 5 The insertion loss and isolation results of proposed structure I and structure II (a) structure I; (b) structure II.

Fig. 5(a) and Fig. 5(b) show the insertion loss and isolation results for structures I and II, respectively. Fig. 5(a) shows that the insertion loss stays under 4.5 dB throughout the operating band, with a particular insertion loss of 3.5 dB at 20 GHz. Furthermore, the isolation exceeds -11 dB and surpasses 15 dB within the 14.6-25.4 GHz band. In Fig. 5(b), the isolation is shown to be greater than 11.2 dB, while the insertion loss remains below 4.3 dB within the frequency band of interest. Specifically, at 25 GHz, the insertion loss measures -3.2 dB. Therefore, the proposed UWB WPD satisfies the requirements.

V. Conclusion

Based on the single-stage WPD, this paper designs two compact 2-way UWB WPDs with equal power. The CST software was employed to optimize both structures, and simulation results confirm that the suggested UWB PD satisfies the specifications throughout the entire operating frequency range. The operating bands of the two PDs are 9.98-32.46 GHz and 10-36.5 GHz, respectively, with reflection coefficients better than -10 dB. The insertion loss is greater than -4.5 dB and the in-band isolation exceeds -11 dB. The final overall dimensions are 10×5.6×0.508 mm³ and 12.6×7.9×0.508 mm³, respectively. The PD, designed with a quarter-wavelength multi-section matched converter, exhibits excellent characteristics such as a simple structure, miniaturization, and ultra-wideband capability. The PD incorporating a quarter-wavelength multi-band matched converter offers the benefits of a straightforward structure, compact size, and ultra-wideband capabilities. The two compact UWB structures are well suited for mmWave UWB communications.

Acknowledgment

This work is supported in part by the National Key Research and Development Program of China under Grant 2023YFE0107900, National Natural Science Foundation of China (NSFC) under Grant 62071306, 62171289, 62101341 and 61801299, and Shenzhen Science and Technology Program under Grants JSGG20210802154203011, JCYJ20200109113601723 and JSGG20210420091805014.

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