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ARAŞTIRMA MAKALESİ (Research Article)

A COMPACT 2-WAY MULTISECTION POWER DIVIDER for BROADBAND OPERATIONS

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ABSTRACT

This paper represents a broadband 2-ways Wilkinson power divider for S-band (2-4 GHz), C-band (4-8 GHz) and X-bands (8-12 GHz) applications. The broadband design is proposed by dint of a multisection Wilkinson power divider topology with utilizing the microstrip technology on a single layer printed circuit board. The proposed design has a 7-sections to achieve an operating frequency bandwidth of 2-12 GHz. The surface mount resistors are utilized in the design to enhance the isolation between the output ports. In addition, a prototype of the proposed design is manufactured on a Rogers 4003C and the 0402 package surface mount resistors are soldered between the output ports of each section. The prototype has input reflection coefficient better than -15 dB, -20 dB and -10 dB, respectively in the S-, C-, X-bands. Moreover, the prototype has output reflection coefficients better -17 dB, -20 dB and -10 dB, respectively in the S-, C- and X-bands. The measured insertion loss is less than -5 dB. Furthermore, the isolation between the output ports is better than -10 dB, -17 dB and -15 dB, respectively in the S-, C- and X-bands. Furthermore, the total phase variation between the output ports are less than 1.8° in the frequency range from 2 to 12 GHz. The prototyped multisection 2-way power divider illustrates a broadband characteristic with better phase imbalance and the measurement and simulation results are close to each other. The total size of the prototype is 4x41 mm^2.

Keywords: *Wilkinson power divider, broadband, multisection, coupled line, compact*

1. INTRODUCTION

The power divider is one of the crucial passive device that is widely utilized in the modern communication systems [1]. The advantages of the microstrip power dividers are easy-manufacturing, low-cost, light-weight, low-loss and high electrical performance. In addition, the conventional Wilkinson power divider (WPD) is consisted of three ports, one of them is utilized as an input and the other two ports are utilized as the output ports [2]. In order to accomplish a low-loss characteristic, the output ports of the WPD are matched to the characteristic impedance of Z_0 [3]. Moreover, the WPD splits the incident power into the two output powers with equal phase and equal amplitude [4]. WPD has a simple structure that is formed with two quarter wavelength (λ/4) transmission line with the characteristic impedance of $\sqrt{2}Z_0$ and $2Z_0$ resistor for isolation between the outputs [5]. These advantages give power dividers opportunity to utilize in a numerous application area such as amplifiers, mixer, antenna feeding network, phase detectors etc. [6-9]. On the other hand, the conventional power dividers have a narrow frequency bandwidth and mostly designed to operate in a single frequency [10]. However, the narrow band performance is usually undesirable for many of the microwave applications.

In the literature, there are various techniques to enhance the frequency bandwidth such as tapered transmission lines, complementary conducting strip transmission lines, port expansion and multisection [11-14]. Among these techniques, the multisection WPD can be utilized to achieve broadband performance while having a reduced size with optimizing the characteristic impedances of the coupled lines in each section.

In this letter, two-way WPD with 7-sections is designed to work in the frequency range from 2 to 12 GHz. The proposed design has seven sections to achieve the broadband performance and seven isolation resistors at the output ports of each section. The prototype of the proposed design is manufactured on a Rogers 4003C substrate with the relative permittivity of 3.55 and the dielectric thickness of 0.508 mm. In addition, the prototyped WPD has input and output (I/O) reflection coefficients better than -10 dB and -12 dB, respectively in the operating frequency band from 2 to 12 GHz. In addition, the insertion loss is less than -5 dB in the 2-12 GHz, while the isolation is less than -10 dB and -15 dB in the frequency bands from 2 to 12 GHz and from 5 to 12 GHz, respectively.

2. MATERIALS AND METHODS

Wilkinson power divider (WPD) is a passive radio frequency (RF) component that capable of splitting the incident signal into two outputs with equal phase and amplitude by the dint of two symmetrically connected $\lambda/4$ transmission line with the characteristic impedance of $\sqrt{2}Z_0$ and a $2Z_0$ resistor for isolation between the output ports. Since the conventional 2-way WPD has a narrow frequency bandwidth, in the design the 2-way multisection WPD with the coupled lines is utilized to broaden the frequency bandwidth while reducing the total circuit size. Figure 1(a) depicts the schematic of the proposed 7-section WPD. In addition, Figure 1 (b) and 1 (c) depicts the even and odd mode equivalent circuits of the proposed WPD. In the schematics, i denotes the number of the section, Z_{ie} and Z_{io} denote the even/odd impedances of the transmission lines, θ_i denotes the electrical length of the coupled lines and R_i denotes the isolation resistors in each section.

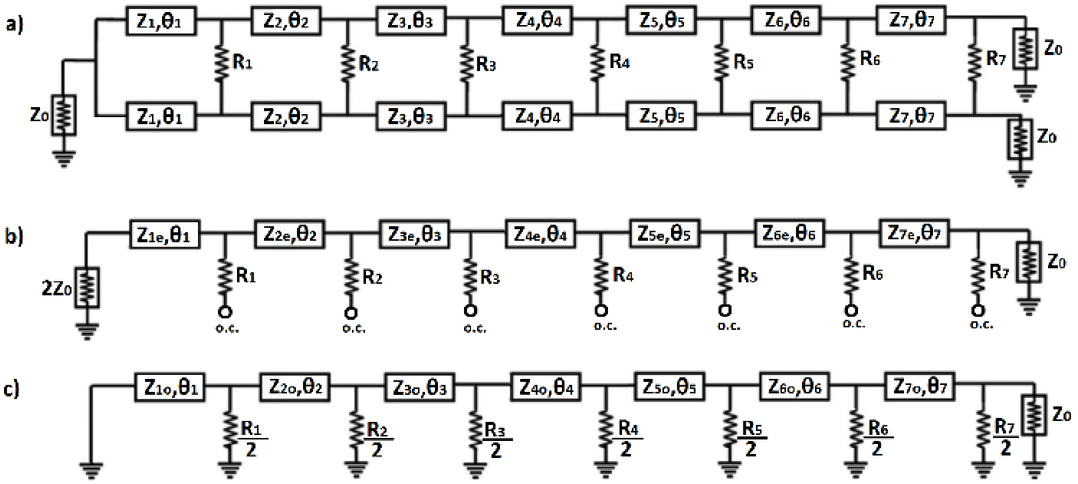

Figure 1. a) The schematic of the proposed WPD b) even- and c) odd-mode equivalent circuit.

In the even mode the input impedance of $2Z_0$ need to be matched to the output characteristic impedance of Z_0 at seven different frequencies. On the other hand, in the odd mode the characteristic output impedance of Z_0 is matched to the short circuit. In the even/odd mode analysis, the characteristic impedances of the equivalent circuit are calculated for center frequency of 7 GHz as in the Table 1. In addition, the coupled lines' impedances are calculated with utilizing the Equation 1.

$$Z_i = \sqrt{Z_{ie} Z_{io}} \tag{1}$$

Table 1. The characteristic impedance of the coupled lines.

i	**Z_i (Ω)**	**Z_{ie} (Ω)**	**Z_{io} (Ω)**	**θ_i (°)**
1	71.04	75.82	66.56	104.6
2	66.76	71.19	62.61	70.05
3	65.49	69.82	61.44	70.15
4	57.79	61.47	54.33	79.61
5	48.98	51.93	46.21	78.74
6	42.60	45.03	40.31	90.35
7	42.12	44.50	39.86	72.34

In the design, each section is designed with the coupled lines and the distance between the each coupled line is kept equal to each other. In addition, the outputs of each section are terminated with the isolation resistor to enhance the isolation performance. Moreover, the Keysight's ADS Momentum tool is utilized to design the layout and the method of moment (MoM) method is utilized in the electromagnetic (EM) simulations. In the layout design, the output ports are located at the different sides of the printed circuit board (PCB) to mount the South West SMA-female connector. Figure 2

JSR C
Journal of Scientific Reports

Arıcan, G.O., Journal of Scientific Reports-C, Sayı 2, 1-10, Aralık 2021.
Arıcan, G.O, Journal of Scientific Reports-C, Number 2, 1-10, December 2021.

depicts the layout of the proposed WPD. Table 2 illustrates the dimension of coupled lines and values of the isolation resistor. In the layout design, W_i, L_i denote, respectively, the width and length of coupled line, S_i denotes the space between coupled line in the i^{th} section and R_i denotes the value of the isolation resistor of the i^{th} section.

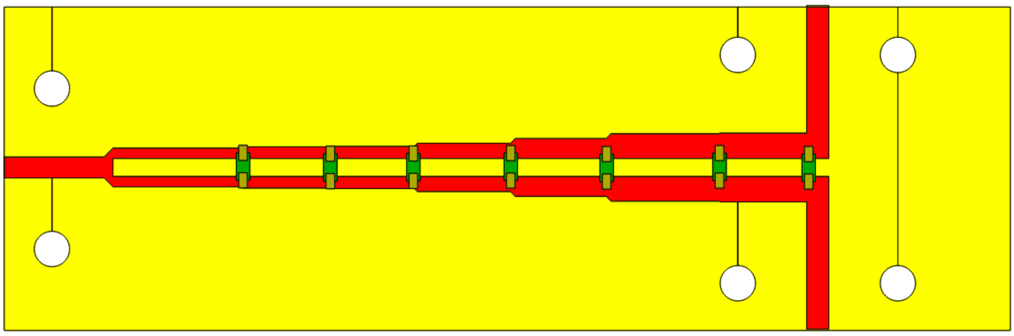

Figure 2. The layout of the proposed WPD.

Table 2. The dimension of the proposed WPD.

i	**W_i (µm)**	**S_i (µm)**	**L_i (µm)**	**R_i (Ω)**
1	609	1041	7620	10
2	686	1041	5080	10
3	711	1041	5080	10
4	889	1041	5715	10
5	1168	1041	5588	24
6	1448	1041	6350	51
7	1473	1041	5080	150

3. FABRICATION and MEASUREMENTS

To validate the design, the proposed WPD is manufactured on Rogers 4003C with the relative permittivity of 3.55, the thicknesses of the dielectric and copper are 0.508 mm and 35 µm, respectively. In addition, the S-parameter measurement is performed with using Keysight N5224B PNA in ASELSAN Inc. Figure 3 illustrates the photography of the prototyped WPD. The total occupied area of the design without connectors and 50Ω transmission lines at the I/O ports is 164 mm^2.

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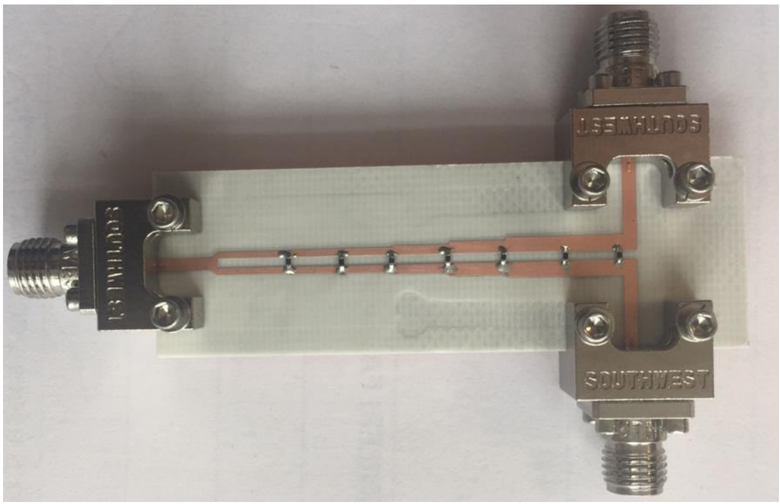

Figure 3. The photography of the prototyped WPD (4x41 mm).

Figure 4 illustrates the simulated and measured input reflection coefficient $|S_{11}|$ of the proposed design. According to the measurement results, it is observed that the measured $|S_{11}|$ of the prototype is better than -15 dB, -20 dB and -10 dB in the S-, C- and X-bands, respectively.

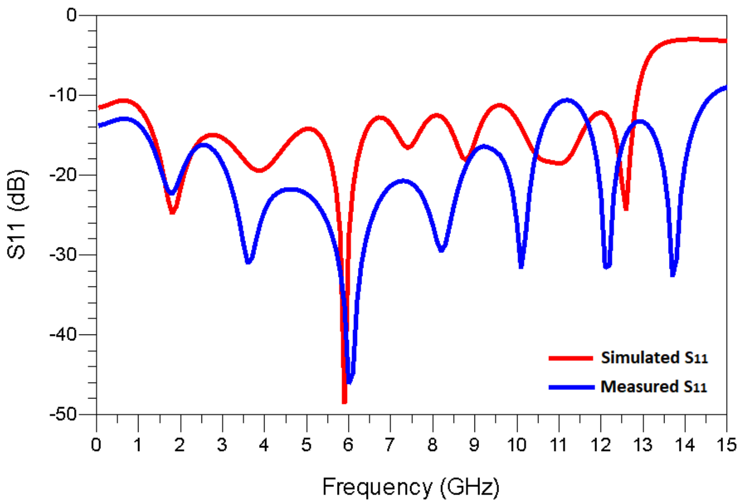

Figure 4. The S-parameter measurement and EM simulation results of the proposed WPD.

Figure 5 illustrates the simulated and measured output reflection coefficients ($|S_{22}|$ & $|S_{33}|$) of the proposed design. According to the measurement results, it is observed that the measured $|S_{22}|$ and $|S_{33}|$ of the prototype is better than -17 dB, -20 dB and -10 dB, respectively in the S-, C- and X-bands.

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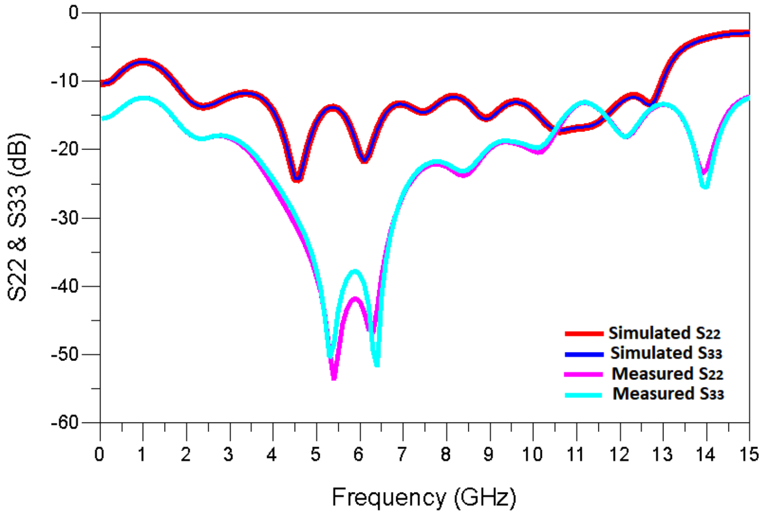

Figure 5. The S-parameter measurement and EM simulation results of the proposed WPD.

Figure 6 illustrates the simulated and measured insertion losses ($|S_{21}|$ & $|S_{31}|$) of the proposed design. According to the measurement results, it is observed that the measured $|S_{21}|$ and $|S_{31}|$ of the prototype is less than -4 dB in the S-, C-bands, and less than -5 dB in the X-band.

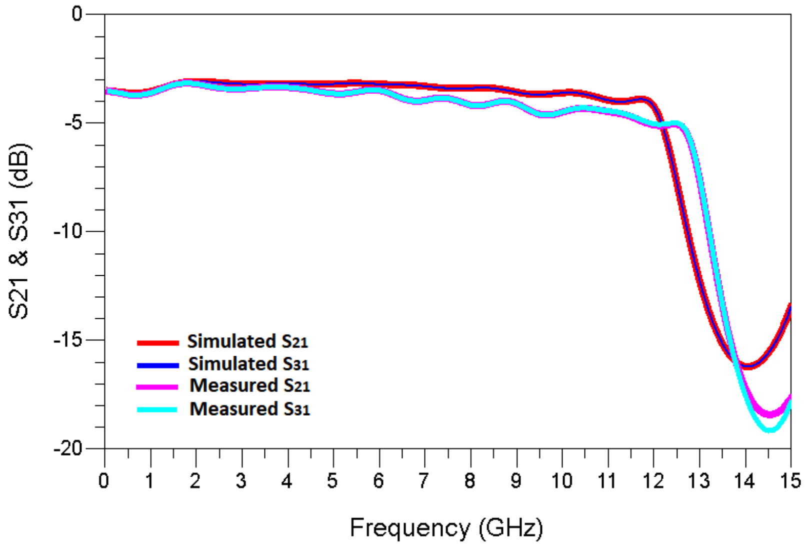

Figure 6. The S-parameter measurement and EM simulation results of the proposed WPD.

Figure 7 illustrates the simulated and measured isolation $|S_{23}|$ of the proposed design. According to the measurement results, it is observed that the measured $|S_{23}|$ of the prototype is better than -10 dB, -17 dB and -15 dB, respectively in the S-, C- and X-bands.

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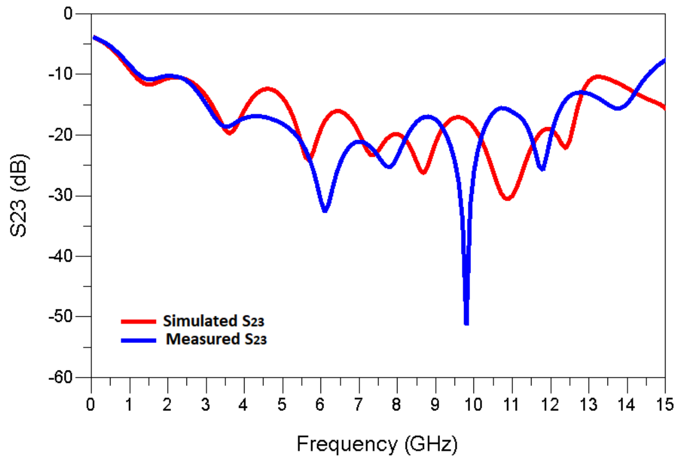

Figure 7. The S-parameter measurement and EM simulation results of the proposed WPD.

Figure 8 illustrates the measured phase variation between the output ports of the proposed design. According to the measurement results, it is observed that the phase variation of the prototype is less than 0.3°, 0.5° and 1° in the S-, C- and X-bands, respectively. Moreover, the total phase variation is less than 1.8° in the bandwidth of 2-12 GHz.

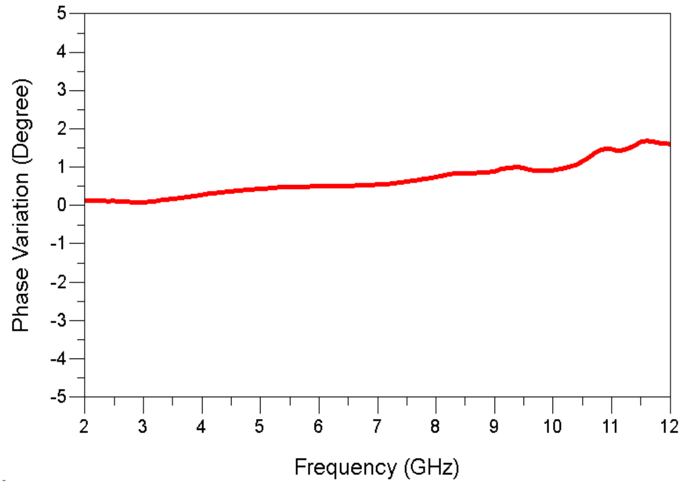

Figure 8. The S-parameter measurement and EM simulation results of the proposed WPD.

Table 3 illustrates the comparison of the simulation and measurement results of WPD. According to the comparison table, it is observed that S-parameter measurement and simulation results are close to each other. On the other hand, the measured bandwidth is approximately 500 MHz broader than the simulated bandwidth. However, the insertion loss is 1 dB higher in the measurements. Nonetheless, the total peak to peak phase variation between the output ports are less than 1.8° in the bandwidth of 2-12 GHz.

Table 3. The comparison of the simulation and measurement results.

	Frequency Bandwidth	Simulation	Measurement
$\|S_{11}\|$ (dB)	2-4 GHz	-14	-15
	4-8 GHz	-12	-20
	8-12 GHz	-10	-10
$\|S_{22}\|$&$\|S_{33}\|$ (dB)	2-4 GHz	-11	-17
	4-8 GHz	-12	-20
	8-12 GHz	-12	-10
$\|S_{21}\|$&$\|S_{31}\|$ (dB)	2-4 GHz	-3.2	-4
	4-8 GHz	-3.5	-4
	8-12 GHz	-4.2	-5
$\|S_{23}\|$ (dB)	2-4 GHz	-10	-10
	4-8 GHz	-12	-17
	8-12 GHz	-16	-15
ΔΦ (°)	2-4 GHz	0	0.3
	4-8 GHz	0	0.5
	8-12 GHz	0	1

4. RESULTS

A broadband 2-way multisection Wilkinson power divider is designed with microstrip on printed circuit board technology for S-, C- and X-band applications. The prototyped WPD has I/O reflection coefficients better than -10 dB in the frequency band from 2 to 12 GHz. In addition, the insertion loss is less than -5 dB while the isolation between the output ports is better than -10 dB in the 2-12 GHz. Furthermore, the measured phase variation between the output ports of the prototype is less than 1.8° in the operating frequency bandwidth. The proposed 2-way Wilkinson power divider could be utilized in the broadband RF/microwave applications with its low-cost, compactness and broadband features.

5. DISCUSSION

The measurement results are close to the simulation results. On the other hand, the bandwidth of the prototype is approximately 500 MHz wider than the simulation results. In addition, I/O reflection coefficients of the prototype is better than the measurement results in the S- and C-bands while the measured insertion loss is approximately 1 dB higher than simulation results at the upper frequency bandwidth. It is thought that the slight variation between the simulation and measurement results could be caused by the difference between the resistor model that is utilized in the design and the surface mount resistors that are soldered between the output ports of each section. In addition, the prototyping machine manufacturing tolerances could be caused small variations in the dimension of the coupled lines that can cause small variation in the S-parameter measurements. Moreover, the proposed WPD could be utilized in broadband microwave operations because of having broadband and low-loss characteristics, as well as having an easy and low-cost manufacturing process.

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