Investigation of Wideband Wilkinson Power Divider Using Multi-section Approach

N. S. A. Arshad, S. Z. Ibrahim, M. S. Razalli
School of Computer and Communication Engineering
Universiti Malaysia Perlis (UniMAP)
Kampus Pauh Putra, 02600 Arau Perlis.
andreana_oya@yahoo.co.uk, sitizuraidah@unimap.edu.my, shahrazel@unimap.edu.my

M. N. A. Karim
School of Electrical Engineering System
Universiti Malaysia Perlis (UniMAP)
Kampus Pauh Putra, 02600 Arau Perlis.
nazri1601@yahoo.com

***Abstract*—This paper investigates the performance of two Wilkinson power dividers over a wide band frequencies range from 1 to 13 GHz. The first power divider is designed and developed using single section method while the second power divider is designed using double section method. The main purpose of this study is to determine how much bandwidth improvement can be achieved using double section compared to single section approach. Both designs are investigated using CST Microwave Studio simulation tool. The designs are fabricated on microstrip printed circuit board and measured using vector network analyzer. The simulated and experimental results of both developed dividers are compared and analyzed.**

Keywords—wilkinson power divider; wideband; single section; double section; microstrip

I. INTRODUCTION

Power dividers are one of the passive microwave components that are widely used in many communication systems [1]. They are used in the RF front ends of microwave transceivers (in amplifiers and mixers) and in the beamforming networks of array antennas. The simplest type of power divider is a T-junction, a three-port network with one input port and two output ports. However, its isolation between the output ports is very low. To overcome the isolation problems, the Wilkinson power divider is considered as a good choice. It improves the matching characteristics of T-junction by minimizing the reflection at the ports. This can be done by inserting shunt resistor between the two output ports to provide large isolation. The importance of Wilkinson power divider in microwave systems comes from its properties of high return losses in its three ports and high isolation in its two output ports [2].

In its basic configuration, the typical Wilkinson power is formed by single section approach [3]. However, the single section power divider has limited operational bandwidth. A few approaches have been discussed in the open literature on how to improve the bandwidth of the Wilkinson power divider. One of the notable examples in [4] shows the bandwidth of the power divider is increased using one added stepped-impedance open-circuited radial stub. However, the bandwidth of the Wilkinson power divider can be simply increased by using multi-section approach [5-6]. A tri-band Wilkinson power divider using three-section transmission line transformer is presented in [6]. Therefore, this work is motivated by the presented work in [5-6] where the bandwidth of power divider can be improved using multi-section approach. The single and double stages Wilkinson power dividers are investigated within frequency band of 1 GHz to 13 GHz. In the design, a Rogers 4003C substrate with a dielectric constant of 3.38, tangent loss of 0.0017 and thickness of 0.508 mm is used. The design is aided with the available full wave EM analysis commercially and the design tool, the CST Microwave Studio.

II. DESIGN TECHNIQUE

A. Single Section Wilkinson Power Divider

The basic configuration for Wilkinson power divider is shown in Fig. 1.

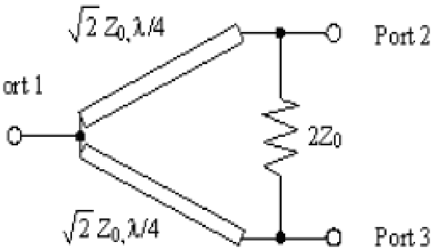


Fig. 1. A 2-way equal split Wilkinson power divider equivalent circuit.

As shown in Fig. 1, the single stage Wilkinson power divider comprises of two parallel uncoupled quadrature transmission lines with characteristic impedance, $\sqrt{2}Z_0$. A $2Z_0$ of shunt resistor is connected between the two output ports to provide the isolation between the output ports. The quarterwave transformer leads to the matched ports in the output ports. The dimensions of the single-stage power divider are calculated using expression (1) to (5)[3].

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}(0.23 + \frac{0.1}{\varepsilon_r}) \quad (1)$$

$$\frac{W}{d} = \frac{8e^A}{e^{2A} - 2} \quad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\left(\frac{d}{W1}\right)}}\right) \quad (3)$$

$$\lambda_g = \frac{c}{f_0\sqrt{\varepsilon_{eff}}} \quad (4)$$

$$l = \frac{\lambda_g}{4} \quad (5)$$

Note that ε_r in expression (1) and (3) is the dielectric constant of the substrate and d in expression (2) and (3) is the thickness of the substrate. c and f_0 in expression (4) is the velocity of light and center frequency. λ_g in expression (4) and (5) is the guided wavelength.

First, the width of transmission line, W for input and output ports are calculated using expression (1) and (2) assuming characteristic impedance, $Z_0 = 50$ Ω. Next, the width of quadrature transformer transmission line, $W1$ is obtained by substituiting $Z_0 = \sqrt{2}$ (50) Ω into expression (1). The length of quadrature transformer is calculated using expression (3) to (5). The shunt resistor, $R = 100$ Ω assuming $Z_0 = 50$ Ω.

Fig. 2 shows the CST layout of the single stage power divider.

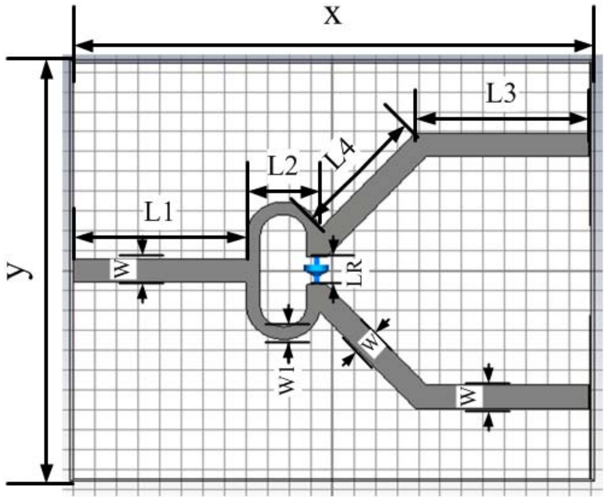


Fig. 2. CST layout of the single stage power divider.

In Fig. 1, the significant parameters to be considered are the length and the width of quarter wavelength transformer. In this design, the value of $L2$ is related to the diameter of the first stage, because the length of this circle is dependent on its diameter. The simulated results are changed accordingly to the values of LR and $L4$; therefore these values are also optimized using CST to obtain their best performances. The value of $L1$, $L3$, x and y are not optimized as they do not contribute to the performance of the simulation results. These values are also shown here as a reference dimensions in the layout. Summary of the optimized dimensions are shown in Table 1.

TABLE I. DIMENSIONS OF SINGLE-STAGE POWER DIVIDER

Parameter	Dimension (mm)
Width of 50 Ω transmission line, *W*	1.18
Width of quarterwave transformer, *W1*	0.64
Length of transmission line at input port, *L1*	8.00
Diameter of quarterwave transformer, *L2*	2.80
Length of transmission line at output port, *L3*	8.00
Length of transmission line, *L4*	7.39
The length of shunt resistor, *LR*	1.40
Length of substrate, *x*	24.00
Width of substrate, *y*	21.00

B. Double Section Wilkinson Power Divider

Fig. 3 shows the basic layout of the double-stage Wilkinson power divider.

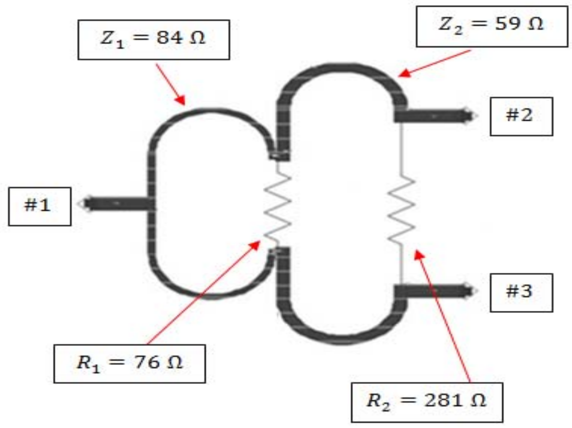


Fig. 3. Basic Layout of double-stage power divider.

The impedance values, Z_0 and the shunt resistors, R of the first and second stage quarter wave transformer are obtained from [7]. The same expression (from (1) to (5)) are applied to find the initial dimensions of double-stage power divider. In this case, the width of quadrature transformer transmission line for the first stage, $W1$ and the second stage, $W2$ are obtained by substituiting $Z_0 = 82$ Ω and $Z_0 = 61$ Ω into expression (1).

Fig. 4 shows the CST layout of the double stage power divider. All of the optimized dimensions are shown in Table 2.

TABLE II. DIMENSIONS OF DOUBLE-STAGE POWER DIVIDER

Parameter	Dimension (mm)
Width of 50 Ω transmission line, *W*	1.18
Width of quarterwave transformer of the first stage, *W1*	0.50
Width of quarterwave transformer of the second stage, *W2*	0.88
Length of transmission line at input port, *L1*	8.00
Length of quarterwave transformer of the first stage, *L2*	5.20
Length of quarterwave transformer of the second stage, *L3*	3.00
Length of transmission line at output port, *L4*	8.00
Length of transmission line, *L5*	11.18
The length of shunt resistor1, *LR1*	1.50
The length of shunt resistor2, *LR2*	2.00
Length of substrate, *x*	34.00
Width of substrate, *y*	21.00

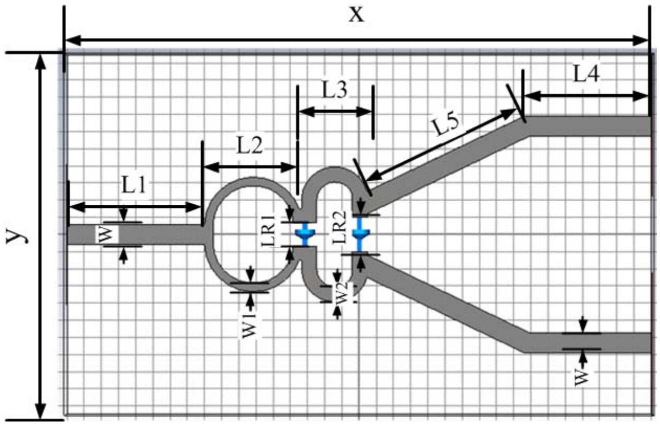


Fig. 4. CST layout of the double stage power divider.

III. Results and Discussion

The photograph of the fabricated single and double stage Wilkinson power dividers are shown in Fig. 5.

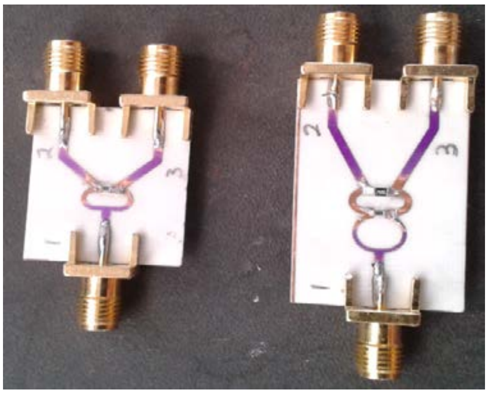
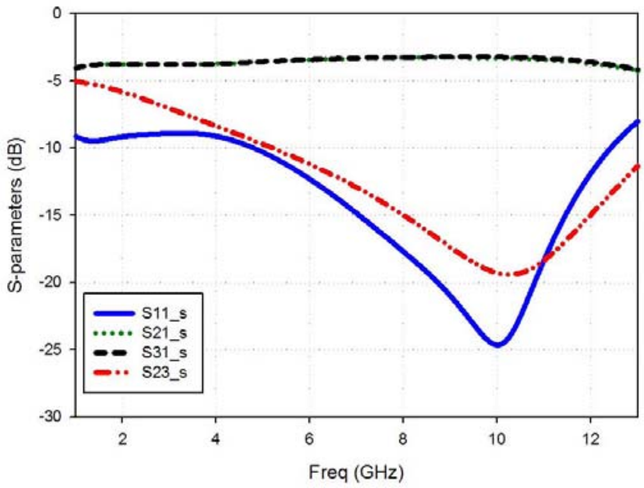


Fig. 5. Photograph of the fabricated single and double stage Wilkinson power divider.

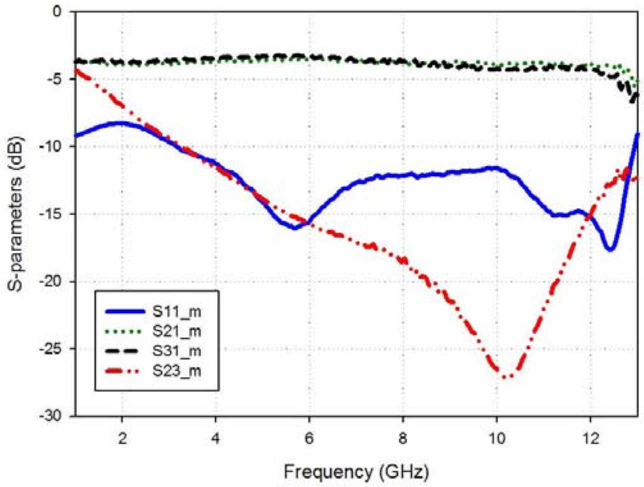
The shunt resistor of single stage divider, R = 100 Ω is realized using a chip resistor 0603 with dimension of 1.6 x 0.8 mm. The shunt resistors of double stage power divider are realized using 0603 with dimension of 1.6 x 0.8 mm (at first stage) and 0805 with dimension of 2.0 x 0.8 mm (at the second stage). The S-parameters of the fabricated Wilkinson dividers are measured using Agilent PNA Network Analyzer E8362B.

A. Single Stage Wilkinson Power Divider

The simulated and measured results of the single stage Wilkinson power divider are shown in Fig. 6. The simulated and experimental testing is investigated over the frequency band range from 1 GHz to 13 GHz. As shown in Fig. 6(a), the simulated power division of 3±0.5 dB can be noticed across the whole band. The simulated reflection coefficient, S11 is better than 10 dB across the band from 4.8 GHz - 12.3 GHz. The simulated isolation, S23 is greater than 10 dB across the same band. By considering all s-parameters, the simulated bandwidth in the single stage power divider is obtained from 4.8 GHz to 12.3 GHz. In terms of percentage, the simulated bandwidth of the single stage power divider is 87.7%.



(a)



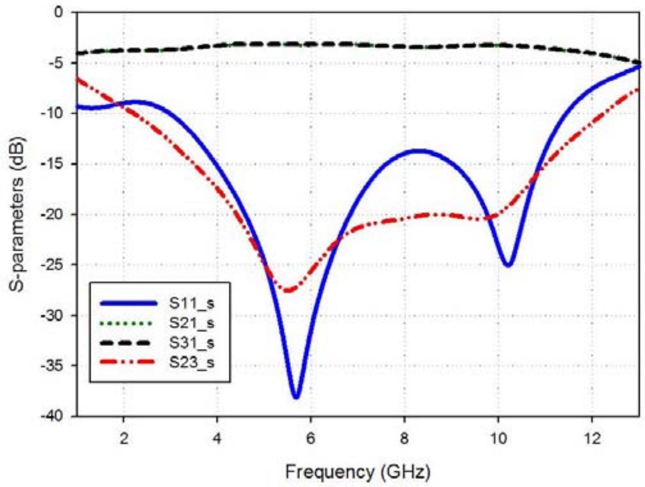
(b)

Fig. 6. S-parameters results of single stage power, (a) Simulated (b) Measured

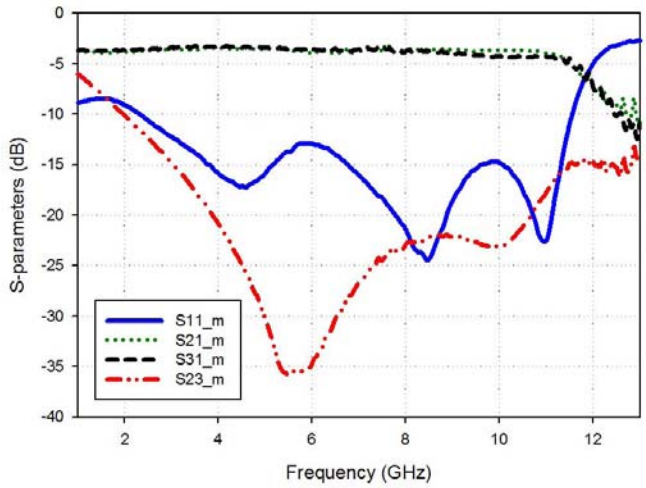
As shown in Fig. 6 (b), the measured power division of 3±0.5 dB can be noticed across frequency range from 1 GHz to 12.3 GHz. The measured reflection coefficient, S11 is better than 10 dB across the band of 3.2 GHz – 13 GHz. A good agreement can be noticed between the simulated and measured isolation. The measured isolation, S23 is greater than 10 dB from 3.4 GHz to 13 GHz which is almost similar to the simulated result, that ranging from 4.8 GHz to 12.3 GHz.

B. Double Stage Wilkinson Power Divider

The simulated and measured results of the double stage Wilkinson power divider are shown in Fig. 7. The simulated and experimental testing is investigated over the wide frequency band range from 1 GHz to 13 GHz. As shown in Fig. 7(a), the simulated power division of 3±0.5 dB can be noticed from 1 GHz to 12 GHz. The simulated reflection coefficient, S11 is better than 10 dB across the band of 3 – 11.2 GHz. The simulated isolation, S23 is greater than 10 dB across the band from 2.1 GHz to 12.1 GHz. By considering overall s-parameters, the bandwidth of the simulated double stage power divider is obtained from 3 GHz to 11.2 GHz. In terms of percentage, the simulated bandwidth of the double stage power divider is 115.5%. This has shown that, the bandwidth is increased from 87.7% to 115.5% when double stage approach is used in the Wilkinson Power Divider.



(a)



(b)

Fig. 7. S-parameters results of double stage power, (a) Simulated (b) Measured

As shown in Fig. 7 (b), the measured power division of 3±0.5 dB can be noticed across frequency band from 1 GHz to 11.2 GHz. The frequency range of the measured reflection coefficient and isolation are almost similar to the simulated by considering both parameters are greater than 10 dB. The measured reflection coefficient, S11 is better than 10 dB across the frequency band from 2.2 GHz – 11.2 GHz. The measured isolation, S23 is greater than 10 dB from 2 GHz to 11.2 GHz. By considering overall s-parameters, the bandwidth of the measured double stage power divider is obtained from 2.2 GHz to 11.2 GHz. This performance is considered excellent for Ultra Wide-Band (UWB) application which is covered from 3.1 GHz to 10.6 GHz.

IV. CONCLUSION

In this paper, two Wilkinson power dividers are designed and developed for wideband frequency range from 1 GHz to 13 GHz. The first power divider has been designed using single section method while the second power divider has been designed using double section method. Both designs have been investigated using CST Microwave Studio simulation tool. These designs have been fabricated using microstrip technology and measured using vector network analyzer. The simulated and experimental results of both developed dividers have been compared and analyzed. The bandwidth of Wilkinson power divider has been increased from 87.7% to 115.5% when double stage approach is used.

ACKNOWLEDGMENT

The author would like to thank the Ministry of Higher Education of Malaysia (MOHE) for the financial support for this research work.

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