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Modified Wilkinson Power Divider with Switchable Function using PIN Diode Switches

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Abstract

In this paper, a switchable circuit that functions as a power divider and a RF switch is proposed in this paper. The power divider design was based on the conventional Wilkinson power divider (WPD). Two shorted stubs were introduced at the transmission line of the output ports to compensate mismatch when the function was switched to RF switch. Rogers RO4350 (er = 3.48, h = 0.508mm) was used as a substrate material and copper (thickness = 0.035 mm) related to patch of this proposed design. The proposed design showed good performance for the simulation in physical layout as a power divider and an SPDT switch. Furthermore, the design has a compact size of 62 x 75 mm^2. The measurement results, however, show a change in resonant frequency. Although there is a correlation between results of measurement and simulation, due to the parasitic reactance of the PIN diode, the resonant frequency was shifted.

Keywords - PIN diode, SPDT Switch, Switchable, Wilkinson Power Divider.

I. INTRODUCTION

Power dividers play an important role in power combining and splitting [1] in microwave and millimeter systems applications. Power dividers can be used for distributing the input power into two different paths with the chosen dividing ratio. Nowadays, mobile terminals that can be reconfigured have become trendy. Therefore, many reconfigurable antennas have been tested and proven [2]-[4]. Advanced feeding networks are essential in order to support the systems [5], [6]. Moreover, rapid development has resulted in high demand for reconfigurable circuits in modern wireless communications.

Many techniques can be used to achieve tunable characteristics of power dividers. Most researchers focus on frequency tuning in the power divider [7]-[13]. The recent trend in power divider research is also the tuning of the power division ratio [14]-[18]. The main components used for the tunable operation of the power divider are varactors [8]-[17] and pin diodes[7], [18].

A tunable power divider does not only mean tuning the operating frequency or power division ratio, but it can also change the power divider's functions. However, few works on tunable power divider functions are available. In [19]-[21], reconfigurable power dividers were discussed that could function as a power divider or switch. In [19], the power divider was designed based on the concept of modes match and impedance match between the substrate integrated waveguide (SIW) and half-mode SIW (HMSIW). The circuit was however very bulky in size and had a complex design. In [20]-[21], two reconfigurable microstrip power dividers were discussed. The proposed designs in [20] and [21] can either perform as a power divider or a switch.

In [20], with the use of positive and negative group delays, power dividers can be tuned between paths 2 and 1 for positive group delay (PGD) or path 3 and 1 for negative group delay (NGD). However, there was a trade-off between bandwidth and group delay. Furthermore, two designs with different switch numbers were proposed in [21]. The first design allows the output power to be re-routed between ports 1 and 2 with three switches. Meanwhile, four switches and a coupled line transformer were used in the second design. However, the reflection coefficient (S11) was not ideal when power was routed from port 1 to port 2.

In this paper, a modified Wilkinson power divider (WPD) with switchable function are presented. By using PIN diode in the proposed design, the modified power divider can switch its function either as a power divider or an SPDT switch. Shorted stubs are introduced in the transmission line of the output ports to compensate mismatch when the function is switched from power divider to an SPDT switch function. In addition, the proposed design had a simpler design and showed good performances for both functions compared to [19] and [21]. In this paper, the modified WPD were designed, simulated, measured, and analyzed.

II. RESEARCH METHOD

In 1960, Ernest Wilkinson introduced the Wilkinson power divider, which provides isolation between output ports and is adept to match in all ports. It can also be lossless if the output port is matched [22]. The equivalent transmission line circuit for WPD is shown in Fig. 1 that provides equal power to the two output ports [23].

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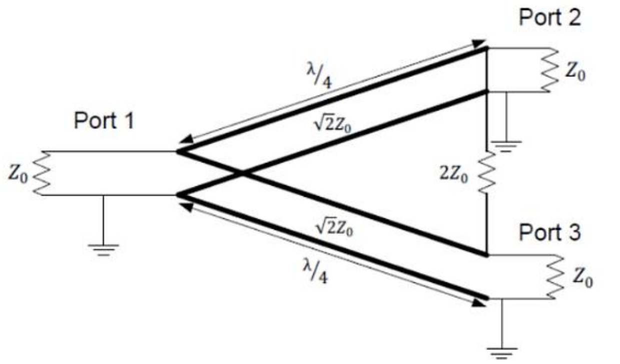


Fig. 1. The transmission line circuit model for WPD [25].

Fig. 1 illustrates that WPD is a three-port network comprising one input port and two output ports. Generally, the power can be divided equally or unequally depending on the application at two different working frequencies.

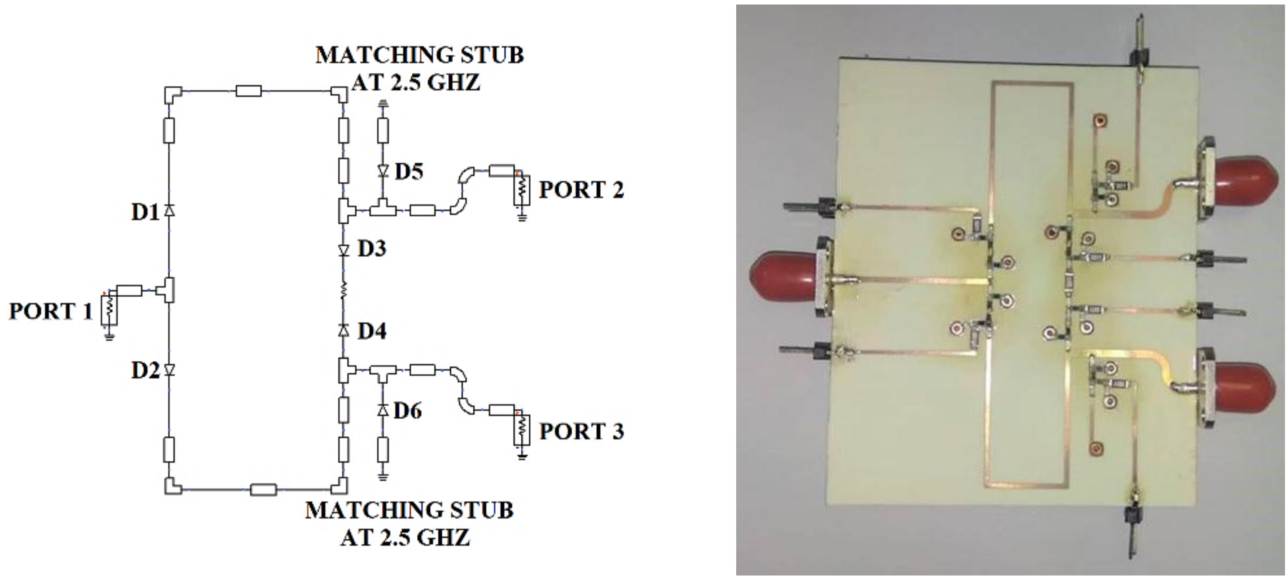
WPD has been designed based on the conventional WPD at the operating frequency of 2.5 GHz. Z_0 value of 50 Ω was used in the design. The design also included the isolation resistor with a value of $2Z_0$ = 100 Ω and a quarter-wave split transmission line impedance with a value of $\sqrt{2}Z_0$ = 70.7Ω. In (1), it shows a perfect scattering matrix (S-matrix) of WPD with a load.

$$S = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad (1)$$

The S-matrix indicates that when the signal enters port 2, it is the same as port 3 because it divided equally into port 2 and port 3. Ports that are matched sets (S11, S22, and S33) are equal to zero. When the signal enters port 1, the power divider is lossless. The magnitude, which is the total squares each component of column one of the S-matrix, is equivalent to one [23].

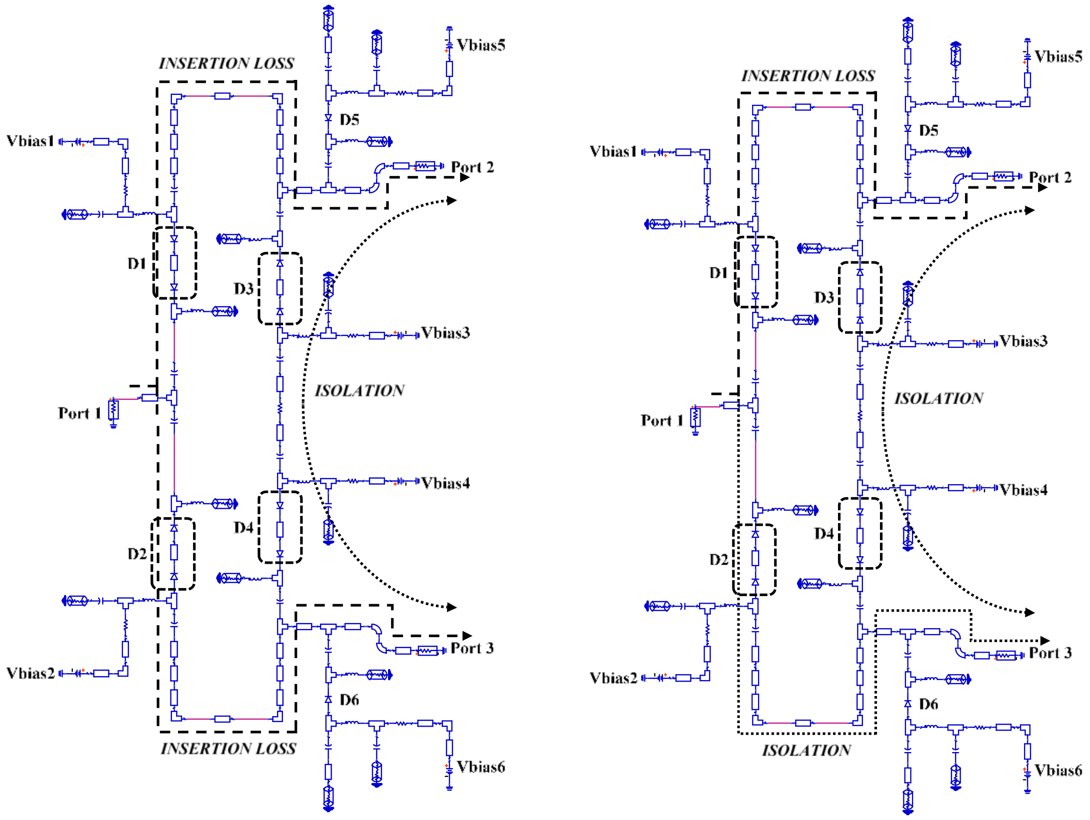
The circuit was then converted to the form of a microstrip line using Advanced Design System (ADS) software based on the transmission line circuit model. The designed WPD is then modified by integrating PIN diode into the WPD's design in order to achieve switchable function. Matching stubs were also added into the modified WPD's design to compensate mismatch when the function was switched from power divider to an SPDT switch function. After that, the proposed design was fabricated in the laboratory using substrate Rogers RO4350. Fig. 2 shows the circuit configuration of switchable modified WPD with positions of PIN diodes (D1-D6) and the circuit prototype.

Based on Fig. 2, the proposed modified power divider operates as a power divider at 2.5 GHz when D5, and D6 were switched off and operates as an SPDT switch (Port 2 is in on state) at 2.5 GHz when D2, D3, D4, and D6 were switched off. D5 and D6 controlled the matching stubs to be turned on or off. Fig. 3 (a) and (b) show the circuit configurations when the proposed design operates as a power divider at 2.5 GHz and an SPDT switch at 2.5 GHz, respectively.



(a) (b)

Fig. 2. (a) The circuit configuration of switchable modified WPD and **(b)** circuit prototype.



(a) (b)

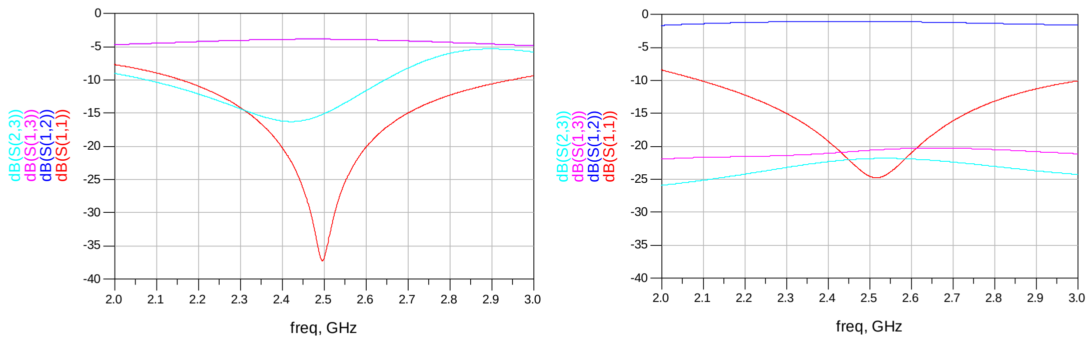
Fig. 3. The circuit configurations when the power divider operates as (a) a power divider and (b) an SPDT switch.

III. RESULTS AND DISCUSSION

Based on Fig. 2, the proposed design can achieve switchable function by varying the voltage biasing of the PIN diodes. The circuit configurations in Fig. 3 was simulated for S-parameters, S11, S12, S13, and S23. Fig. 4 (a) and (b) show the simulation results for modified WPD operates as a power divider and an SPDT switch at 2.5 GHz respectively.

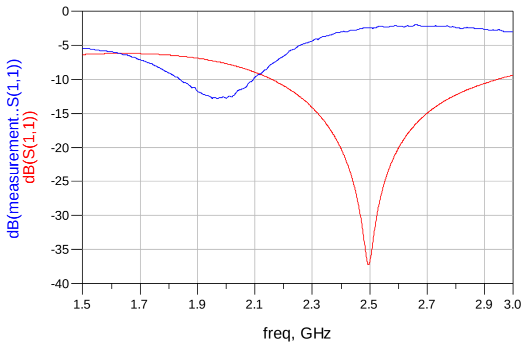
Based on Fig. 4, the simulation result S11 for modified WPD operates as a power divider at 2.5 GHz was -36.844 dB, S23 was -3.876 dB, S12, and S13 was -3.876 dB. Whereas simulation result of modified WPD's operates as an SPDT switch return loss at 2.5 GHz was -24.528 dB, insertion loss was -1.059 dB, isolation, S23 was -21.838 dB and S13 was -20.586 dB.

The proposed design was fabricated to validate the simulation results after designing with ADS software. By using a vector network analyzer, the prototype from Fig. 2 (b) was measured in terms of its S-parameters, return loss, insertion loss, and isolation. Fig. 5 and Fig. 6 show the comparison between the measurement results and simulation results, S11, S12, S13, and S23 for modified WPD operates as a power divider and an SPDT switch at 2.5 GHz respectively.

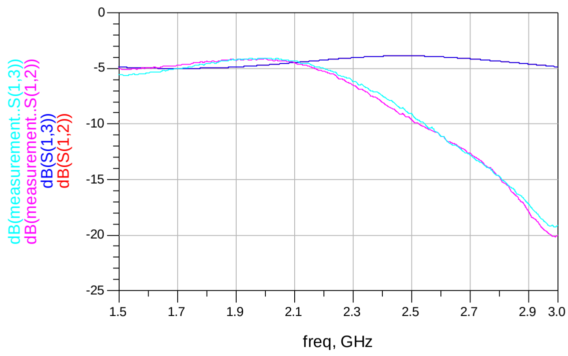


(a) (b)

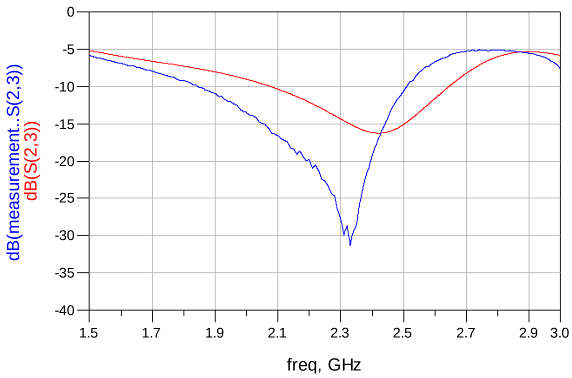
Fig. 4. Simulation results of S11, S12, S13 and S23 for modified WPD operates as (a) a power divider and **(b)** an SPDT switch at 2.5 GHz.



(a)

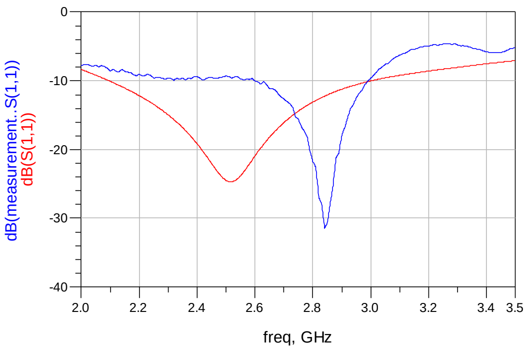


(b)

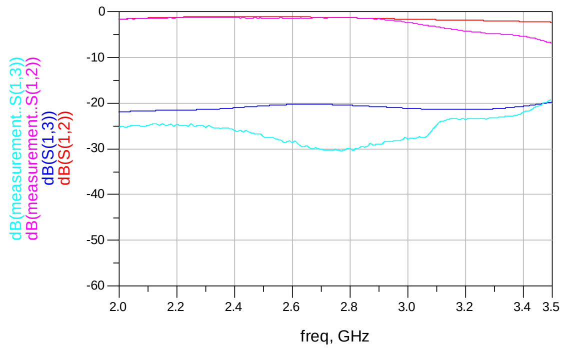


(c)

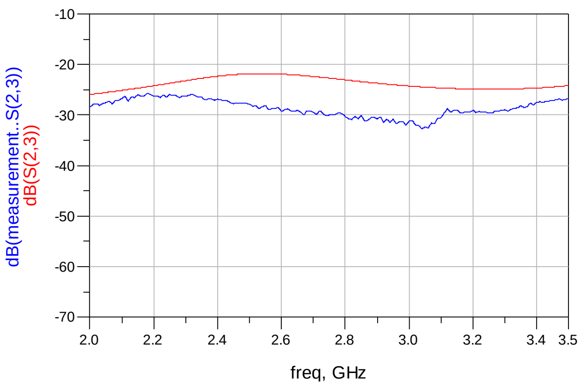
Fig. 5. The comparison of simulation and measurement results (a) S11, (b) S12 and (c) S23 for modified WPD operate as a power divider at 2.5 GHz.



(a)



(b)



(c)

Fig. 6. The comparison of simulation and measurement results
(a) S11, (b) S12 and (c) S23 for modified WPD operate as an SPDT switch at 2.5 GHz.

Based on Fig. 5, the frequency for modified WPD operates as a power divider at 2.5 GHz was shifted around 500 MHz compared to simulation results. The measurement result S11 for modified WPD at a resonant frequency of 2.02 GHz was -12.795 dB, S23 was -13.475 dB, S12, and S13 was -4.089 ± 0.02 dB. Meanwhile, based on Fig. 6, the frequency was shifted about 350 MHz for modified WPD operates as an SPDT switch at 2.5 GHz. The measurement result of modified WPD's return loss at a resonant frequency of 2.84 GHz was 31.430 dB, S23 was -30.712 dB, S12 was -1.392 dB, and S13 was -29.446 dB. The shifting frequency is due to the parasitic reactance of the PIN diode (inductance or capacitance). Diodes can be replaced by Microelectromechanical Systems (MEMS) devices in future work. Furthermore, the measurement results for power divider function between S12 and S13 showed slightly different for its insertion loss, which indicates the prototype was almost symmetrically fabricated and soldered component.

Table 1 lists the performances of previous works on switchable power dividers based on SIW/HMSIW and microstrip line. From the table, this proposed design has competitive return loss, insertion loss, and even isolation when working as SPDT or power divider. Design in [19] was based on the SIW or HMSIW technology. Nevertheless, the design was complicated, bulky and hard to fabricate. Meanwhile, in [21], the designs were based on microstrip lines and simple. However, the result of the SPDT switch function for S11 was not ideal and the result of the isolation between the output ports was not included. This work was simpler in design compared to previous works [19] and [21]. This design used matching stubs and PIN diodes to achieve switchable function. Furthermore, this design also had a good performance compared to the others.

Table 1. Comparison of tunable function circuit with different technologies.

THIS WORK			[19]	[21]	
METHOD	BASED ON MICROSTRIP LINES		BASED ON SIW/HMSIW TECHNOLOGY	BASED ON MICROSTRIP LINES	
COMPLEXITY	SIMPLE DESIGN		COMPLEX DESIGN	SIMPLE DESIGN	
CENTER FREQUENCY	2.5 GHz (SIMULATION)	2.02 GHz POWER DIVIDER / 2.84 GHz SPDT SWITCH (MEASUREMENT)	4.95 GHz	2.14 GHz	
S11	-36.844	-12.795	14.5	< -20	POWER DIVIDER (dB)
S21/S31	-3.876	-4.089 ± 0.02	4.35	> -4	
S23	-15.083	-13.475	> -7	< -20	
S11	-24.528	-31.430	-15	-17	SPDT (PORT 2 IS IN 'ON' STATE) (dB)
S21	-1.059	-1.392	-1.35	-0.8	
S31	-20.586	-29.446	-23	< -20	
S23	-21.838	-30.712	-27	-	

IV. CONCLUSION

The design of modified WPD with switchable function using PIN diode switches has been successfully designed, simulated, measured, and investigated. The modified WPD was designed with the aid of matching stubs and PIN diodes to achieve switchable function. The simulation results showed good performances for both functions with return loss more than 20 dB, isolation less than -10 dB, insertion loss less than 4 dB for power divider function and insertion loss less than 1.5 dB for SPDT switch function. Although the measured resonant frequency was shifted, the measurement results were still correlated to the results of the simulation.

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