EM Simulation and Layout Performance Analysis of N-Way Wilkinson Power Divider

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Abstract: *A Wilkinson Power Divider(WPD) is a RF passive device that is used to split the power fed at the input port equally or unequally between the N output ports. The WPD has the advantage of delivering better performance compared to resistor power divider. Due to this advantage, WPD is widely employed in phased array antennas to feed the multiple antenna set up. This work aims at designing an N way WPD using Microstrip line at a frequency range of 1.5- 4.5GHz. The design is simulated and analysed using Agilent's Advanced Design System(ADS). Layout for themicrostrip line power divider is generated and EM simulation is carried out to analyse the layout performance of the WPD.*

Keywords: Wilkinson Power Divider (WPD), Advanced Design System (ADS), Microstrip line, Lumped elements, EM simulation.

1. Introduction

Power dividers are RF passive devices employed in radio technology, where input signal is fed at the input port and the power is split between the output ports. The number of output ports can be two, four, eight, sixteen and so on depending on the application. The number of output ports is usually limited to eight considering the performance of the power divider. The Wilkinson Power Divider is the most popular type of power divider as it provides a better matching between input and output ports and high isolation between the output ports. The WPD is widely employed in feeding power to the receivers, it can be used in reverse configuration to act a power combiner, it can also be used to feed phased array antennas and radars. One can even feed the amplifier output to the power divider and split the amplified output into number of portions to feed various components of required power. The idea of integrating an amplifier to a power divider is in the scope of future work.

The objective of this work is to design a two-way, four-way and eight-way WPD using microstrip lines. The use of lumped elements at microwave frequencies is ruled out as the dimension of the components becomes comparable with that of the wavelength. A layout is generated for the microstrip WPD and its EM simulation is performed. The performance of the layout is analysed and compared with the simulation results of the schematic. The frequency of operation is chosen to be in the range of 1.5 to 4.5GHz. The return loss is expected to be less than -10dB and isolation less than -20dB. The simulation results for insertion loss, return loss and isolation loss are plotted for two-way, four-way and eight-way WPD.

2. Wilkinson power divider

A Wilkinson power divider splits the input power into two equal phase output signals. If there are N output ports, then the input power will be divided into N equal phase output signals. The characteristic impedance of the WPD at the input port and output ports is Z_o. To match the split ports to a common port a quarter wave transformer is connected between input and output ports. The length of the line is one fourth of the wavelength($\lambda/4$) of operation of the power divider and hence the name quarter wave line [1]. The impedance of the quarter wave section is $Z_o\sqrt{2}$. To provide very high isolation a resistor, whose value is twice that of the characteristic impedance($2Z_o$) is connected across the two output ports. The circuit diagram of a two-way WPD is shown in Figure 1 and the block diagram of an N-way WPD is shown in Figure2. The performance of the WPD is measured in terms of return loss, insertion loss and isolation represented using S-parameter S_{11}, S_{21} and S_{23} respectively.

2.1 Return loss (S_{11})

Return loss is the ratio of incident power to reflected power. It is expressed in dB as in (1).
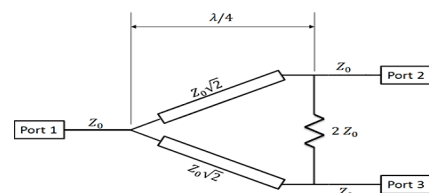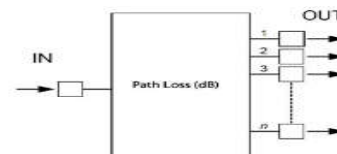

Figure 1: Two-way Wilkinson Power Divider[1]

Figure 2:N-way Wilkinson Power Divider

$$R_L(dB) = 10\log\left(\frac{P_i}{P_r}\right) \qquad (1)$$

It represents the loss associated with power due to reflections of the incident power if the output ports are mismatched or not properly terminated. The return loss is represented in terms of reflection coefficient 'Γ' as

$$R_L\,(dB) = -20\log(\Gamma) \qquad (2)$$

2.2 Insertion Loss (S_{12})

Insertion loss is the loss associated after inserting a device/ component/circuit between the input and output ports. It is

the ratio of power at the output port before inserting the device (P_{ob}) to the output power after inserting the device (P_{oa}). Insertion loss is expressed in dB as in (3)

$$I_L(dB) = 10log \frac{P_{ob}}{P_{oa}} \qquad (3)$$

It is usually measured between two ports i.e., input and output ports. The value of insertion loss for a WPD varies with the number of output ports. Table.1. summarises different values of insertion loss for different number of output ports.

Table 1: Insertion loss for N-way WPD[3]

No. of Output ports	IL (dB)
2	3
3	4.8
4	6.0
5	7.0
6	7.8
8	9.0
10	10.0
12	10.8
16	12.0

2.3 Isolation (S_{23})

Isolation refers to degree of separation between output ports. A high isolation represents that when a signal is flowing from input port (1) to output port (2) for two-way WPD, with port (3) terminated, there must be zero power at port (3) and all the input power must be obtained at port (2) only. Even a small amount of power measured at terminated port indicates that there is a leakage of power from port (2) to port (3). Hence value of isolation must be very high in a N-Way WPD. Mathematically it is represented as the ratio of power obtained at the output port to power fed at input port.

$$I(dB) = 10log\left(\frac{P_{out}}{P_{in}}\right) \qquad (4)$$

Typically, the value of return loss must be less than -10dB, insertion loss must be greater than -3db and isolation must be less than -20dB.

3. Design and implementation

The 2-way, 4-way and 8-way WPD is designed using ADS. MLIN is the transmission line that is being used for the design. The Substrate used is FR4 having dielectric constant(ε_r) of 4.4. The length and width of the microstrip line is calculated using linecalc tool in ADS using the design specifications of the substrate given in Table 2.

Table 2: Design Specifications

Parameter	Value
Height of the substrate (H)	1.5 mm
Thickness of the conductor strip (T)	0.16 mm
Dielectric Constant (ε_r)	4.4
Loss tangent (TanD)	0.02
Frequency (f)	3 GHz
Characteristic Impedance (Zo)	50 Ω

Here, the centre frequency is chosen to be 3GHz for design purpose. Once the microstrip transmission line is generated for the given substrate specifications, a 2-way WPD is

constructed according to the circuit diagram shown in Figure1. The schematic diagram of a two-way WPD is as shown in Figure3. The three ports are terminated using 50Ω termination. The design is simulated and the S_{11}, S_{23} and S_{21} is plotted. The results are analysed and discussed in section 4.

To develop a multi-port power divider, each section of one to two-way power divider is replicated and connected at each of the two output ports. This leads to a power divider with one input port and four output ports, hence a four a WPD. The schematic of a one to four-way WPD is shown in Figure4. Likewise, on connecting a two-way WPD to each of the output ports of four-way WPD, an eight-way WPD can be realised. The schematic of one to eight-way WPD is shown in Figure5.
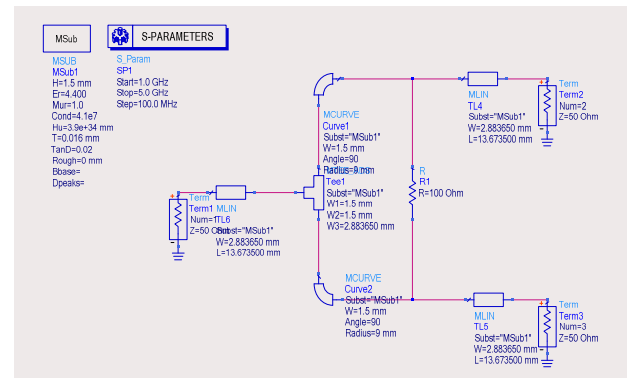

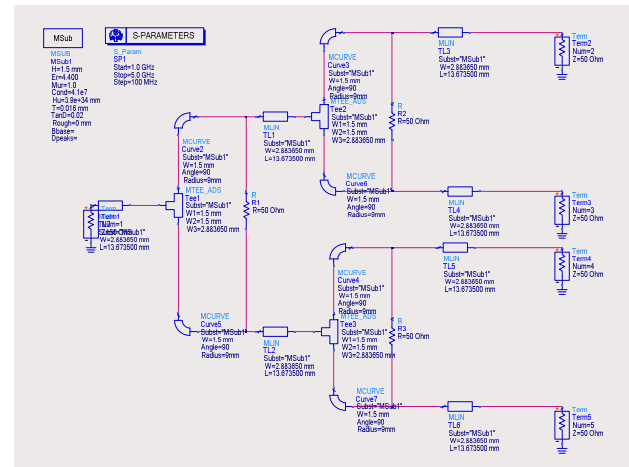**Figure3:** Two-way Wilkinson Power Divider
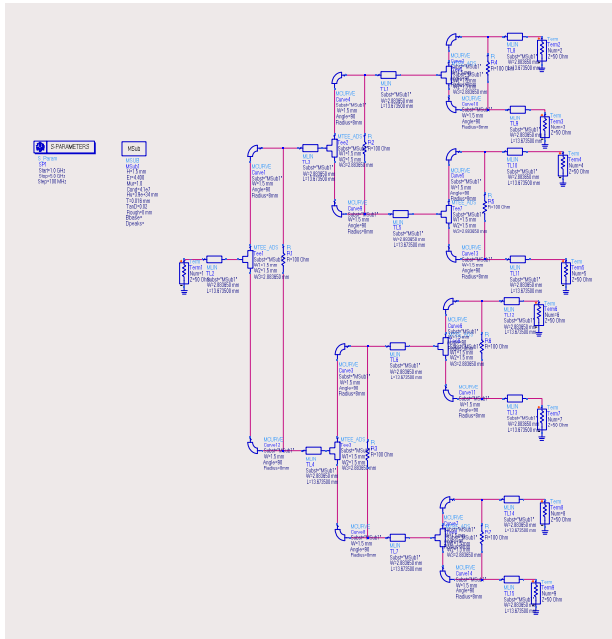

Figure 4: Four-way Wilkinson Power Divider

Figure 5: Eight-way Wilkinson Power Divider

Figure 7: S-parameters for four-way WPD

Figure 8: S-parameters for eight-way WPD

4. Simulation Results

As mentioned earlier the performance of the power divider is measured in terms of S-parameters such as return loss(S_{11}), insertion loss(S_{12}) and isolation(S_{23}). For the proposed design of WPD, the return loss must be less than -10dB. Figure6. shows the plot of frequency versus S-parameters for a two-way WPD. The value ofS_{11} for a two-way WPD is obtained as-61.934dB at a frequency of 2.7GHz. The measured value is satisfying the expected results. The next performance parameter is the isolation(S_{23}). Higher the isolation between the output ports, higher the performance. Hence a resistor is connected across the two output ports to ensure good isolation. The measured value of S_{23} is found to be -36.841dB at a frequency of 2.7GHz.The last performance parameter is the insertion loss(S_{12}). As specified in Table 1, the insertion loss varies fortwo-way, four-way and eight-way power divider. From Figure 6. the value of S_{12} is obtained as -3.372dB at 2.7GHz frequency. Thus, the simulated S-parameter results for a two-way WPD are in accordance with the expected results.
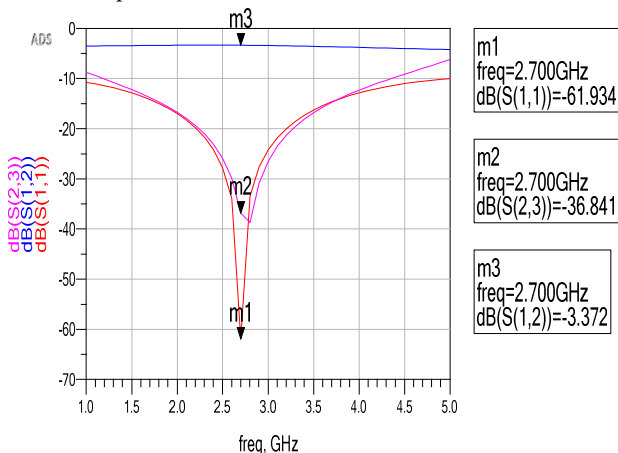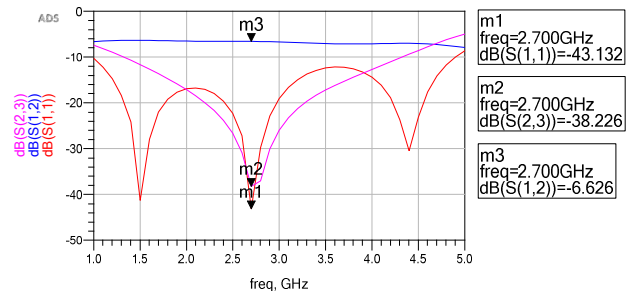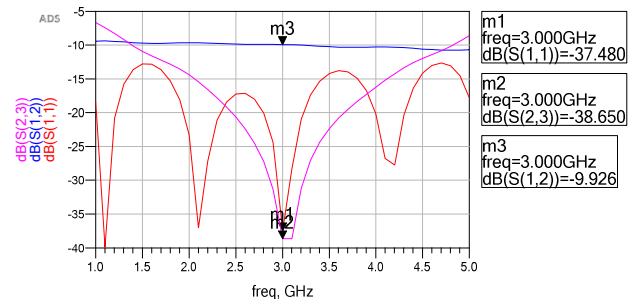
Likewise, the simulation results for a four-way WPD is shown in Figure 7. The S_{11} at 2.7GHz is about -43.132dB. The value of S_{23} is obtained as -38.226dB and S_{12} obtained as -6.626dB.

Lastly, the simulation results for eight-way WPD is shown in Figure 8. which is also analysed in a manner like the other two power dividers. The S_{11} at 3GHz is about -37.480dB. The value of S_{23} is obtained as -38.650dB and S_{12} obtained as -9.926dB.

5. Layout Performance of N-way WPD

The layout of N-way WPD can be generated from the schematic in ADS tool. The transmission lines and the ports are arranged as per the schematic. Pins, input and output terminals are connected. The substrate and frequency is defined for the EM simulation. S-parameters are obtained after simulation. A new symbol is generated from the layout and is simulated by connecting terminations and a resistor. The results obtained are compared with the schematic results

5.1 Layout structure with FR4 substrate

After developing the schematic of the WPD for the given specification, to take up the design to the fabrication level, a layout is generated. The steps involved in generating the layout and analysing its performance are as follows:
1) Choose, generate and update layout, from the tools menu once the schematic is structured.
2) Layout for the schematic will be generated. Now arrange the transmission lines and the ports in proper order as per the schematic.
3) Go to, EM simulation tool and assign the required substrate and its dimension.
4) Simulate the layout for S-parameters.
5) Now cerate the symbol of the design and place the component in a new schematic.

Figure 6: S-parameters for two-way WPD

6) Now simulate the symbol and observe the results. Compare the results obtained for the schematic with that of the results obtained for the layout.

Figure 9. shows the layout structure of the two-way WPD. The resistor across the output port is removed since the lumped component cannot be used without being specified by the vendor for the specific application.To indicate the presence of the resistor, pins are connected at each end after the quarter wave transformer.

Likewise, when the symbol for the layout is created a resistor is connected across the new pins and the design is simulated. The results are observed and compared with the results of the schematic. Figure 10. shows the symbol for a two-way WPD.
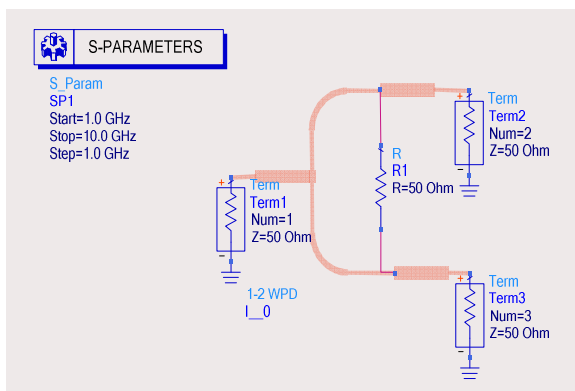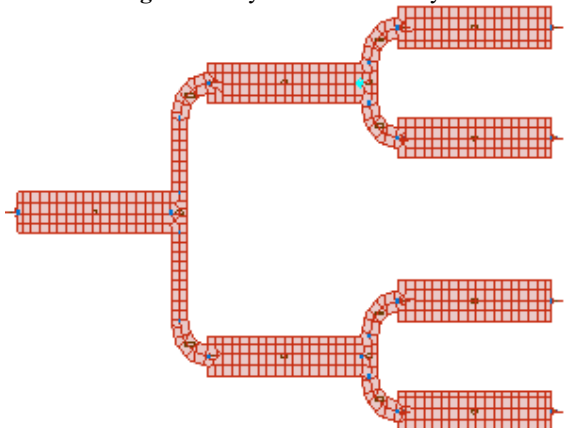
In the same way, the layout and its symbol is created for four-way and eight-way WPDs. Figure 11. and Figure. 12. shows the layout for a four-way and eight-way WPD respectively. The corresponding symbols for four-way and eight-way WPD are as in Figure 13. and Figure 14. respectively.
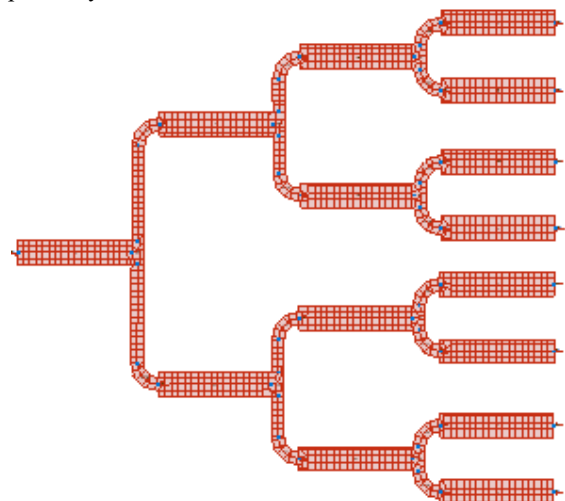

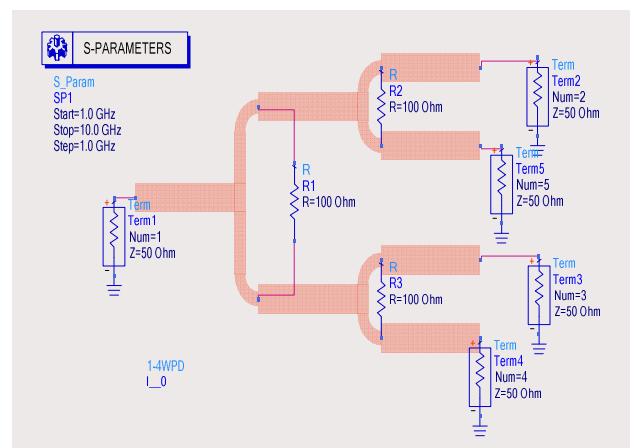**Figure 12:** Layout for eight-way WPD
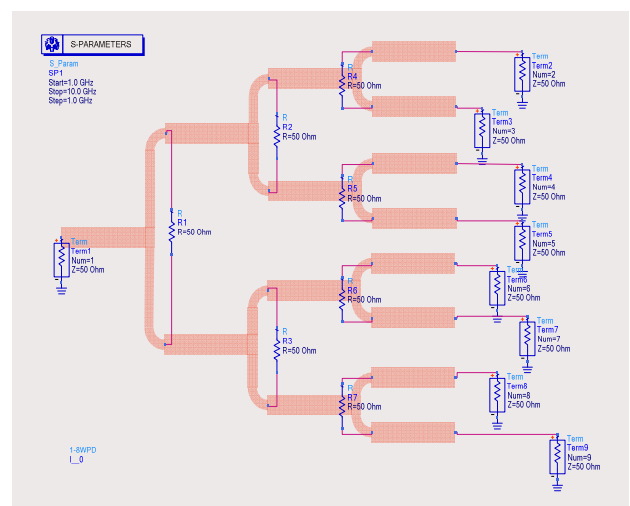

Figure 9: Layout for two-way WPD

Figure 13: Symbol for four-way WPD

Figure 10: Symbol for two-way WPD

Figure 14: Symbol for eight-way WPD

Figure 11: Layout for four-way WPD

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The EM simulation for the above generated layout structures is discussed in the next section

5.2 EM simulated Results

The S-parameter EM simulation for the two-way, four-way and eight-way WPD layouts is discussed here. Figure 15. shows the plot of return loss(S_{11}), insertion loss(S_{12}) and isolation(S_{23}) for a two-way WPD. Figure 16. shows the plot of four-way WPD and Figure 17. shows the plot for eight-way WPD. When compared to the results of schematic, the EM simulated results show a moderate variation in the practical value.
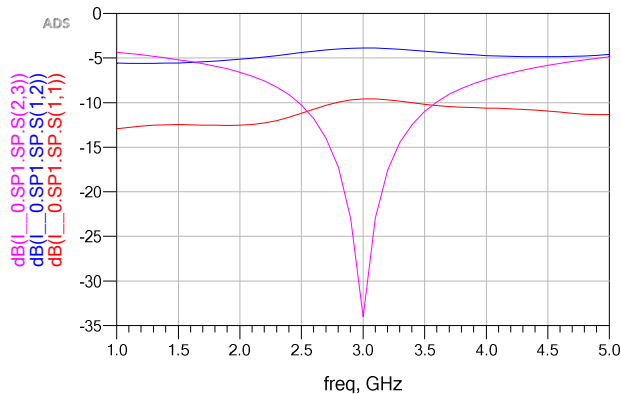

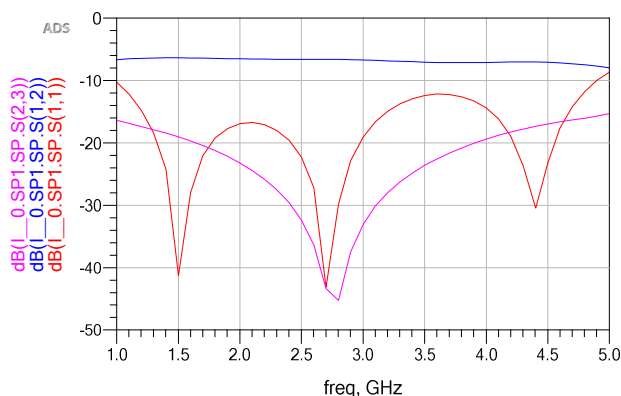**Figure 15:** EM simulated results for two-way WPD

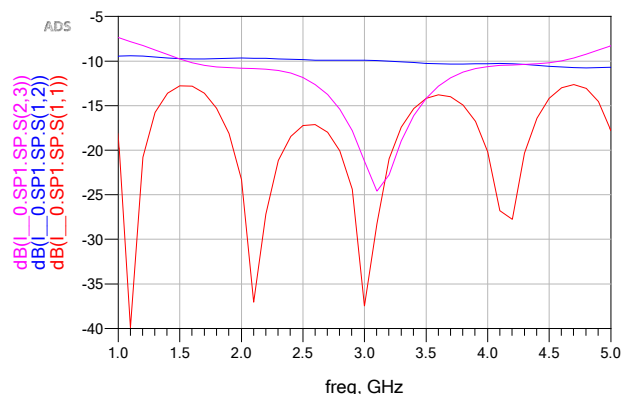**Figure 16:** EM simulated results for four-way WPD

Figure 17: EM simulated results for eight-way WPD

6. Conclusion

The objective of this work was to design an N-way Wilkinson Power Divider for a frequency band of 1.5GHz to 4.5GHz. A two-way, four-way and eight-way WPD were designed and simulated. Its layout performance was also analysed with the help of EM simulation which uses Maxwell's equations. The performance parameters such as return loss, isolation and insertion loss were obtained better than -10dB, less than -20dB and -3dB for two-way, -6dB for four-way and -9dB for eight-way WPD respectively for a frequency band of 1.5GHz to 4.5GHz. It was observed that better results were obtained at a frequency of 2.7GHz to 3GHz.

AWPD with even higher number of output ports can be designed based on the different applications. To feed an array of antennas, to divide the output power between multiple amplifiers to boost the signal to be fed to the antennas and other RF transmitting or receiving devices a power divider can be designed.

References

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