2 way Wilkinson power divider for X band navigation radar

W Desvasari¹, Sulistyaningsih¹, Taufiqqurrachman¹, D P Kurniadi¹, D Mahmudin¹, E J Pristianto¹, P Daud¹, P Putranto¹, A Setiawan¹, F Darwis¹, Y N Wijayanto¹, S Hardiati¹, D Kurniawan¹

¹ Research Center for Electronics and Telecommunication, Indonesian Institute of Sciences, Bandung, Indonesia

Abstract. A compact radar system becomes a necessity in order to build a lightweight navigation radar. Researches were conducted to create an integrated radar system in the form of one board of 9.3 GHz navigation radar system. Microstrip technology was used for its simple structure and miniaturization at high frequencies. Power divider as a part of the radar system was used to divide the signal from Voltage-Controlled Oscillator (VCO) to Transmitter front end and mixer on the Receiver end. This paper proposed the design and simulation of the Wilkinson Power Divider on Duroid RT5880 substrate using Advanced Design System (ADS) software. The S parameters were analyzed to see the performance of the divider. The proposed design already met the expected requirement of the power divider with more than -30 dB return loss, -3.059 dB insertion loss, and -29.541 dB isolation between divider output ports.

1. Introduction

Researches on lightweight navigation radar were conducted to achieve a compact radar system. One board radar systems were being developed to achieve it. Microstrip technology was chosen for its simple structure, high performance and easily miniaturization at higher frequencies and can be connected to passive and active devices [1].

Power divider as a passive component is a part of navigation radar system which function is to divide signal power which in this system was from Voltage-Controlled Oscillator (VCO) to Transmitter front end and to mixer in Receiver module as seen in Figure 1. Wilkinson power divider was chosen for its high isolation between the two output port. With an addition of a resistor between it two quarter wave transformers that differ it from T-junction contribute a significant isolation between the output ports. T-junction divider, resistive divider, and Wilkinson divider were the commonly used power divider. While T-junction able to provide lossless divider, it cannot match in all it ports and cannot provide isolation between the output ports. Resistive power divider able to be matched at all ports, but it cannot provide a lossless divider and isolation between the output ports. Meanwhile Wilkinson power divider able to provide all three qualities, which a lossless divider, a matched impedance in all ports, and isolation between all output ports [2].

There were many researches on power divider that were already done to achieve a better performance of the divider, such as by comparing between the used of microstrip and coupled line [3], combining the Wilkinson power divider and Gysel power divider in order to get a higher bandwidth [4], implemented the defected structure of the microstrip to achieve a minimized dimension of the divider [5] and a tapered line transformer power divider to get an ultra-wideband divider [6]. One of the previous works was fabricate the power divider for different frequency on different substrate such as alumina [7], so in this research the Wilkinson power divider will be applied on duroid RT 5880 for 9.3 GHz center frequency.
2. Wilkinson power divider

2-way Power Divider divides the signal into two equal output powers. Wilkinson Power divider (WPD) consists of quarter-wave transformers and a resistor in between its output ports as seen in Figure 2. The resistor holds a significant role to the high isolation between the output ports while maintaining the matching impedance on all ports.

\[
Z = \sqrt{2Z_0}
\]

\[
R = 2Z_0
\]

where \(Z = 50 \, \Omega\) is system impedance so \(R = 100 \, \Omega\).

The equivalent dimension of the power divider was calculated using equation (3)-(8) [1]:

\[
\phi = \frac{2\pi f}{c} \sqrt{\varepsilon_r}
\]

\[
Z_0 = \begin{cases} 
\frac{60 \ln \left( \frac{8h}{w} + \frac{w}{4h} \right)}{\sqrt{\varepsilon_r}} & \text{for } \frac{w}{h} \leq 1 \\
\frac{120\pi}{\sqrt{\varepsilon_r}} \frac{w}{h} + 1.393 + 0.667 \ln \left( \frac{w}{h} + 1.444 \right) & \text{for } \frac{w}{h} \geq 1
\end{cases}
\]
\[ w/h = \begin{cases} \frac{8e^4}{e^{2\pi} - 2} & \text{for } \frac{w}{h} < 2 \\ \frac{2}{\pi} & B - 1 - \ln(2B - 1) + \frac{\varepsilon_r}{2\varepsilon_r} \left[ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] & \text{for } \frac{w}{h} > 2 \end{cases} \] (5)

\[ \varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12 \frac{h}{w}}} \] (6)

\[ A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( \frac{0.23 + 0.11}{\varepsilon_r} \right)} \] (7)

\[ B = \frac{377\pi}{2Z_0 \sqrt{\varepsilon_r}} \] (8)

where \( Z_0 \) is the characteristic impedance, while \( w \) is the width of the microstrip, \( h \) is substrate thickness, \( t \) is conductor thickness, \( \varepsilon_r \) is the dielectric constant and \( \varepsilon_{re} \) is the effective dielectric constant.

3. Design and simulation

The 2-way Wilkinson power divider was designed to be applied on RT 5880 substrate with parameter as in Table 1 and simulated by using Advanced Design System (ADS) software to see the performance of the proposed design. Momentum simulation in microwave mode using ADS was executed to see the performance of the design divider. The S parameters were the analyzed performance of the divider and a maximum 1.2 dB insertion loss and 13.5 dB isolation between the output ports was the expected performance of the divider.

Using equation (3)-(8), the dimensions of the divider were calculated as seen in Table 2. The ADS software itself has a LineCalc tools to calculate the dimension of the stripline by providing the substrate parameters and the required impedance value, the result can also be seen in Table 2. These dimensions were used as a starting point to design the divider. Through the optimizing process, the proposed design was made to achieve the performance needed. Wilkinson power divider will be operating at 9.3 GHz as the center frequency of the navigation radar and the simulation will be analyzed from 9.2 GHz to 9.4 GHz. The proposed design of the power divider can be seen in Figure 3. The resistor used would be in the form of a lumped component. There was a slight change in the length of the microstrip to get a design that is more fitting with the structure of the divider. The change in the divider length will affect the phase difference between each port.

| Parameter                  | Symbol | Value       |
|----------------------------|--------|-------------|
| Substrate                  | RT 5880|             |
| Frequency                  | \( f_0 \) | 9.3 GHz    |
| Dielectric constant        | \( \varepsilon_r \) | 2.2         |
| Relative Permeability      | \( \mu_r \) | 1           |
| Substrate Thickness        | \( H \)  | 1.575 mm    |
| Conductor thickness        | \( T \)  | 35 um       |
| Dielectric loss tangent    | \( \tan \delta \) | 0.0009      |
Table 2. Dimensions of power divider

| $Z$ [ohm] | Variable | Calculation [mm] | ADS LineCalc [mm] | Optimized [mm] |
|-----------|----------|-------------------|-------------------|---------------|
| 50        | w1       | 5.32148           | 5.01122           | 5.01122       |
|           | l1       | 5.87972           | 5.777650          | 5.777650      |
| 70.71     | w2       | 2.78372           | 2.843870          | 2.843870      |
|           | l2       | 5.98607           | 5.893480          | 15.86         |
| 50        | w3       | 5.32148           | 5.01122           | 5.01122       |
|           | l3       | 5.87972           | 5.845900          | 7.8716        |
| 50        | w4       | 5.32148           | 5.01122           | 5.01122       |
| 100       | R        | 5.87972           | 5.845900          | 9.9458        |

Figure 3. The proposed design of the 2-way Wilkinson power divider.

4. Result and analysis

The scattering parameters were the analyzed performance of the 2-way Wilkinson power divider. The return loss, insertion loss, coupling and isolation between output ports at 9.3 GHz center frequency were analyzed. Insertion loss was the degradation of signal power while traveling through a component or transmission lines. Figure 4 shows the insertion loss $S_{21}$ and $S_{31}$ of the divider. The divider equally divides the power by -3.059 dB at each output ports with approximately 0.0487 dB transmission loss.

The next parameter was the return loss. Return loss was a part of the reflected signal that goes back to the source port. Figure 5 shows the return loss $S_{11}$, $S_{22}$ and $S_{33}$ of the divider. The values were lower than -30 dB at all ports. It means that the 0.1 % signal was reflected to the source port. One of the causes of the reflected signal was the discontinuity in the designed layout.

Figure 6 shows the isolation $S_{23}$ between two output ports of the divider. -29.541 dB of isolation already met the required performance. It means that the divider was able to prevent the signal from each output port from entering the other output ports. The overall simulated design of the power divider gives a good performance than the expected requirements.
Figure 4. The insertion loss of the proposed 2-way Wilkinson power divider.

Figure 5. The return loss of the proposed 2-way Wilkinson power divider.
In microstrip technology, the accuracy of the dimension of the divider holds a significant role in the performance of the divider. A slight change in the dimension of the microstrip will shift the performance of the divider as the impedance value of the design change. Therefore, the fabrication later on will hold an important part in maintaining the designed performances.

5. Conclusion
The 2-way Wilkinson power divider has been designed, simulated and optimized for 9.3 GHz navigation radar system. The result of the simulated Wilkinson power divider already met the required performances. Return loss that was more than -30 dB for each port, insertion loss of -3.059 dB and isolation of 29.541 dB was achieved. The fabrication will be done after all the parts of the radar system were designed and integrated into the form of single-board system. For future improvement, the Duroid thickness should be smaller to get a smaller design dimension.

6. References
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