Design and realization of 4 way Chebyshev Wilkinson power divider at 3 GHz frequency for 3 dimensional radar application

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Abstract. In the radar system, detection of objects with high accuracy is needed. Therefore, a low sidelobe antenna is needed to avoid interference from other detected targets. One method to suppress sidelobe antenna is by using unequal power divider with Chebyshev polynomial excitation coefficients. In this paper, we will discuss about the design and fabrication of Chebyshev Wilkinson power divider for 3 dimensional radar application. This research was conducted through 4 stages, namely design, simulation, fabrication and measurement. This power divider is realized in the form of a microstrip using Rogers R0-4003C (lossy) substrate with a thickness of 1,524 mm and a dielectric constant of 3.55. The simulation and measurement results are met the desired specifications, the operating frequency is at 3 GHz with a bandwidth of 200 MHz, the return loss is less than -10 dB, the insertion loss value is according to Chebyshev, the isolation value of the port is less than -10 dB, and the unbalance phase is smaller than 2.5°.

1. Introduction
Radar (Radio Detection and Ranging) is an object detection system that uses electromagnetic waves to determine the distance, altitude, direction and speed of objects. In radar technology, the object detected by a radar is called a target. The operating principle of radar is to measure the distance from the sensor to the target by measuring the travel time of electromagnetic waves propagating from the sensor, the target and back to the sensor [1-2]. Antenna is one of the important parts of the radar system. The antenna used in the radar system is an array antenna. To supply power to the array antenna, a power divider is needed. Power divider functions as a feeding network in array antennas that can match all antenna ports [3-6].

Wilkinson Power Divider (WPD) is basically a lossless 3 port network when all output ports are matched. Input power is divided into 2 or more outputs with the same amplitude (for equal power divider). Transformation of impedance λ / 4 is used for 1x2 WPD [7]. In general, WPD is considered a microstrip channel. The simplest WPD (1x2) consists of two transmission lines with a channel length of λ / 4, and by using resistor components which are set to increase the isolation value. In equal WPD, the characteristic impedance (Z0) is 50 Ω and the resistor impedance is 2Z0 [6-8].

WPD is classified as equal WPD and unequal WPD [9]. The difference between equal and unequal WPD is the power distribution. In equal WPD the power distribution is evenly distributed while unequal WPD is uneven [10]. One of the advantages of the unequal power divider is its ability to suppress the...
antenna sidelobe. The sidelobe emphasis is needed for applications that require high accuracy. On radar tracking, low sidelobe can prevent interference from other targets that are detected. One method to suppress sidelobe is by using Chebyshev tapered excitation on unequal power divider [11-14].

In this paper, a 4 way unequal WPD will be designed with Chebyshev tapered operating at a frequency of 3 GHz for 3 dimensional radar applications with 200 MHz bandwidth.

2. Research methods
WPD structure design is carried out through 4 stages, namely design, simulation, fabrication and measurement. The device design and simulation is done using CST Studio Suite software. The first step is designing and simulating a 1x2 WPD. After the simulation results meet the desired specifications, design and simulation is carried out for WPD 1x4. After the simulation results meet the final desired specifications, fabrication and measurement are carried out next. Stages of research can be seen in the flow chart in Figure 1.

![Figure 1. Research flow chart.](image_url)

3. Results and discussion
This section explains the 4 Way Wilkinson power divider design and simulation results and the measurements result after fabrication.
3.1. Design
The design stage is carried out to determine the power divider specifications such as design form, dimensions, work frequency, return loss, insertion loss and isolation port. For substrate specifications can be seen in Table 1 and the WPD specifications in Table 2. To do the WPD design, it is necessary to determine the characteristic impedance and resistor value first [9]. Theoretical calculations are needed to find out the width and length of the transmission line. Calculation of WPD dimensions can be seen in table 3. WPD uses excitation coefficients based on the Chebyshev polynomial where the comparison of excitation coefficients is 0.3747: 1: 1: 0.3747 or the difference in the value of insertion loss 4.2: 0: 0: 4.2 (in dB).

| Table 1. Substrate specifications. |
|-----------------------------|
| Material | Rogers RO-4003C (Lossy) |
| Dielectric constant (\(\varepsilon_r\)) | 3.55 |
| Electric tand | 0.0027 |
| Substrate thickness | 1.524 mm |

| Table 2. WPD specifications. |
|-----------------------------|
| Parameter | Value |
| Return loss | \(\leq 10 \text{ dB}\) |
| Isolation port | \(\leq 10 \text{ dB}\) |
| Insertion loss difference | 4.2 : 0 : 0 : 4.2 |
| Phase unbalance | 2.5° |
| Bandwidth | 200 MHz |

3.2. Simulation result
After the calculation is complete, the simulation process is then carried out using CST Studio Suite 2018. If the results of the WPD simulation obtained are not optimal, then the dimensions are changed. Optimization is carried out to get optimal results in accordance with the expected specifications. The result of the calculation of the resistor value is \(R_1 = 100 =, R_2 = 112,289 \Omega, R_3 = 112,289\). Because the resistor with the value of the calculation results is not available on the market, then the closest rounding to the resistor value is available. In this simulation a 100 ohm resistor is used instead of a 112,289 ohm resistor. In designing WPD, we first designed 1x2 WPD then 1x4 WPD. So that we get 1x4 WPD shown in figure 2, which will then be realized with the optimization dimension listed in table 4.

![Figure 2. 1x4 way WPD model.](image-url)
### Table 3. WPD dimension calculation.

| Dimension          | Formula and Result                                                                 |
|--------------------|------------------------------------------------------------------------------------|
| **Impedance**      |                                                                                   |
| Explanation:       |                                                                                   |
| Z = impedance      |                                                                                   |
| K = comparison of output power port |                                                                                   |
| $Z_1 = z_0 \sqrt{\frac{1 + K^2}{K^3}}$ |                                                                                   |
| $Z_2 = K^2 Z_4$    |                                                                                   |
| $Z_3 = Z_0 / K$    |                                                                                   |
| $Z_4 = Z_0 K$      |                                                                                   |
| $Z_{01} = \sqrt{2 Z_0}$ |                                                                                   |
| $Z_1 = 112.408 \Omega, Z_2 = 42.119 \Omega$ |                                                                                   |
| $Z_3 = 112.408 \Omega, Z_4 = 30.606 \Omega$ |                                                                                   |
| $Z_0 = 50, Z_{01} = 70.71 \Omega$ |                                                                                   |
| **Resistor**       |                                                                                   |
| Explanation:       |                                                                                   |
| R = resistor       |                                                                                   |
| $K^2 = P_1 / P_2$  |                                                                                   |
| $R = Z_0 \left( K + \frac{1}{K} \right)$ |                                                                                   |
| $R_1 = 100 \Omega$ |                                                                                   |
| $R_2 = 112.289 \Omega$ |                                                                                   |
| $R_3 = 112.289 \Omega$ |                                                                                   |
| **Transmission line width** |                                                                                   |
| Explanation:       |                                                                                   |
| W = transmission line width |                                                                                   |
| $\varepsilon_r = $ relative permittivity |                                                                                   |
| $B = \frac{377\pi}{2Z_0 \sqrt{\varepsilon_r}}$ |                                                                                   |
| $W_1 = 0.6275 \text{ mm}$ |                                                                                   |
| $W_2 = 4.441 \text{ mm}$ |                                                                                   |
| $W_3 = 1.385 \text{ mm}$ |                                                                                   |
| $W_4 = 6.961 \text{ mm}$ |                                                                                   |
| $W_{Z1} = 3.4 \text{ mm}$ |                                                                                   |
| $W_{Z0} = 1.86 \text{ mm}$ |                                                                                   |
| **Transmission line length** |                                                                                   |
| Explanation:       |                                                                                   |
| $\lambda = $ wave length |                                                                                   |
| L = transmission line length |                                                                                   |
| $\lambda_0 = \frac{c}{f} = \frac{3 \times 10^8}{\text{3} \times 10^9} = 100 \text{ mm}$, $\lambda_c = \frac{\lambda_0}{\sqrt{\varepsilon_{\text{eff}}}}$ |                                                                                   |
| $L_1 = 15.733 \text{ mm}$, $L_2 = 14.837 \text{ mm}$ |                                                                                   |
| $L_3 = 15.463 \text{ mm}$, $L_4 = 14.57 \text{ mm}$ |                                                                                   |
| $L_{Z1} = 15.322 \text{ mm}$ |                                                                                   |
| **Mitered bends**  |                                                                                   |
| Explanation:       |                                                                                   |
| X = mitered bends  |                                                                                   |
| $D = w \sqrt{2}$  |                                                                                   |
| $A = (X - D/2) \sqrt{2}$ |                                                                                   |
| $X = D(0.52 + 0.65e^{-1.35(\frac{w}{h})})$ |                                                                                   |
| $X_{Z1} = 0.792 \text{ mm}$ |                                                                                   |
| $X_{Z2} = 3.346 \text{ mm}$ |                                                                                   |
| $X_{Z3} = 1.392 \text{ mm}$ |                                                                                   |
| $X_{Z4} = 5.132 \text{ mm}$ |                                                                                   |
| $X_{Z0} = 2.654 \text{ mm}$ |                                                                                   |
| $X_{Z01} = 1.697 \text{ mm}$ |                                                                                   |
Table 4. Dimensions of WPD optimization.

| Parameter                | Dimension Value |
|--------------------------|-----------------|
| Substrate Length         | 111.838 mm      |
| Substrate Width          | 60.462 mm       |
| Transmission line width  |                 |
| $W_{z1}$ = 0.5 mm, $W_{z2}$ = 6 mm |
| $W_{z3}$ = 2.09 mm, $W_{z4}$ = 6.5 mm |
| $W_{z0}$ = 3.23 mm, $W_{z01}$ = 1.781 mm |
| Transmission line length |                 |
| $L_{z1}$ = 14.57 mm, $L_{z2}$ = 15.459 mm |
| $L_{z3}$ = 14.44 mm, $L_{z4}$ = 16.37 mm |
| $L_{z0}$ = 16 mm         |
| Mitered Bends            |                 |
| $X_{z1}$ = 1.03 mm, $X_{z2}$ = 6 mm |
| $X_{z3}$ = 1.39 mm, $X_{z4}$ = 4.79 mm |
| $X_{z0}$ = 3.15 mm, $X_{z01}$ = 2 mm |

Figure 3 shows the overall results for return loss from ports S11 to S55 at frequencies 2.9 - 3.1 GHz, which are smaller than -10 dB. Figure 4 shows the overall insertion loss results for ports S21 to S51 where the value meets the weighting of Chebyshev. Figure 5 shows the isolation value between ports both adjacent and far apart with values below -10 dB at 2.9 - 3.1 GHz. To find out the output port is in phase or not, it can be seen in the phase value of each output port. If the value of the phase is the same, it means it’s in phase. It can be seen in figure 6 that the values of S21, S31, S41 and S51 are in phase with the phase unbalance smaller than 2.5°.
3.3. Fabrication result and measurement
The realization of the design from WPD 1x4 was printed on Rogers RO-4003 C (lossy) material, with SMA connector (SubMiniature version A) and 100 ohm resistor value. The results can be seen in Figure 7. All parameters are measured using Vector Network Analyzer (VNA).

![Figure 7. WPD fabrication result.](image)

![Figure 8. Comparison graph of return loss measurement and 1x4 WPD simulation.](image)

![Figure 9. Comparison graph of insertion loss measurement and 1x4 WPD simulation.](image)

![Figure 10. Comparison graph of isolation port measurement and 1x4 WPD simulation.](image)

![Figure 11. Phase measurement graph of 1x4 WPD.](image)
From the measurements it was found that the results of each parameter met the specifications. Figure 8-10 show the simulations and measurements comparison charts. Figure 8 shows a return loss that less than -10 dB at 2.9 - 3.1 GHz. Figure 9 is an insertion loss that have met the specifications. Figure 10 is an isolation port that less than -10 dB at 2.9 - 3.1 GHz. Figure 11 shows the output port is in phase with a phase unbalance smaller than 2.5 °.

4. Conclusion

4 Way Chebyshev Wilkinson power divider at 3 GHz frequency with 200 MHz bandwidth for 3 dimensional radar applications has been designed and realized. Simulation results and fabrication results meet the desired specifications, where the return loss value is less than -10 dB, insertion loss values are in accordance with Chebyshev weighting, isolation ports are smaller than -10 dB and phase unbalance is smaller than 2.5 °.

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