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Design of Wilkinson power divider at 28 GHz for 5G applications

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ABSTRACT

A power divider plays a significant function in antenna’s feeding network. Many types of power divider exist yet there are only a few existing studies of Wilkinson power dividers at high frequencies (28 GHz) for 5G communications systems. This paper presents a tapered 2-way Wilkinson power divider that operates in Malaysia's 5G wireless communication band (28 GHz). CST microwave studio is used to design, simulate, and optimize the tapered 2-way Wilkinson divider. The simulation results show resonance around 23.5-37.9 GHz. The operating frequency of 28 GHz resulted in power division with a 3.2 dB insertion loss and has an isolation of 19.21 dB. The design can be made wideband with equal power division at each output port by adding an extra resistor along the tapered line to reduce output return loss and isolation, as demonstrated in this paper.

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1. INTRODUCTION

In the coming years, current cellular wireless technology will be unable to meet subscriber demand due to the rapid growth of data services. 5G cellular networks would be the solution to accommodate increasing number of cellular wireless users and traffic demand. However, the existing frequency spectrum such as at low and mid GHz is almost occupied thus demand a spectrum solution to provide more capacity as a way to mitigate the problem. In microwave applications, Wilkinson power dividers are commonly used to evenly divide the input power between output ports [1]. The Wilkinson power divider received high attention due to its simple design structure and high isolation between output ports while keeping impedance at all ports matched [2]–[20]. Although Wilkinson power divider-based feeding networks have been described in many research studies, previous communication systems are primarily developed for 4G wireless communication networks and are rarely designed for 5G systems [2]–[20]. A wideband 2-way Wilkinson power divider functioning at high frequency band 28 GHz is investigated and presented in this paper. The tapered design is proposed to address narrowband characteristic of Wilkinson divider due to the $\lambda_0/4$ matching transmission lines which is working at one frequency [1].

2. METHOD

The Wilkinson divider divides power evenly between the two output ports from the input port. The Wilkinson divider attains a lossless appearance due to the high isolation between the output ports, causing all ports to be matched and only reflected power to be dissipated from the output ports [1]. A 50-ohm input impedance, Z_0, two quarter-wavelength lines ($\lambda_0/4$) with characteristic impedance of $\sqrt{2}Z_0$ and an isolation resistor of $2Z_0$ and are used in the circuit design by Pozar at 2.45 GHz is shown in Figure 1 [1].

2.1. Tapered design

The transmission line in [1] is replaced by a tapered transmission line [6], [11]-[13], [16], [18], [20], resulting in a designed Wilkinson divider that is wideband which can operate at frequencies ranging from 28 to 29 GHz. The scattering parameters can be used to explain a 2-way Wilkinson power divider circuit behavior. The S11, S22, S33 are S-parameters for return loss, S23, S32 are S-parameters for isolation between output ports while S12, S21, S13, S31 are S- parameters of insertion loss.

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \tag{1}$$

The tapered power divider has been optimized in order to achieve as close as possible to the ideal Wilkinson divider scattering parameter as (2) [1].

$$[S] = \frac{-j}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} \tag{2}$$

The Wilkinson divider employs Rogers' RT/duroid 5880 dielectric substrate, with a dielectric constant of εr = 2.2, loss tangent of δ = 0.0009, and thickness of t = 0.254 mm, based on Rogers' RT/duroid 5870 /5880 data sheet [21]. The gap size between the two quarter-wavelength lines ($\lambda/4$) should be calculated using the size for chip SMD resistors with a 0603-case size. As a result, the chip dimension of TE Connectivity CPF0603B267RE1 and Multicomp Pro MCWF06R93R1BTL are referred to in this study [22], [23]. The layout design of tapered 2-way Wilkinson power divider is shown in Figure 2. Table 1 lists the design parameters of the power divider.

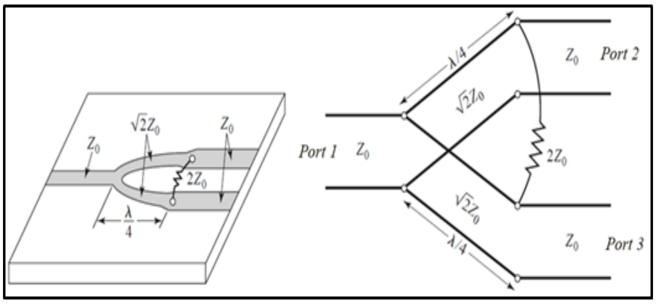

Figure 1. 2-way Wilkinson power divider's configuration and its transmission line equivalent for equal-split and phase [1]

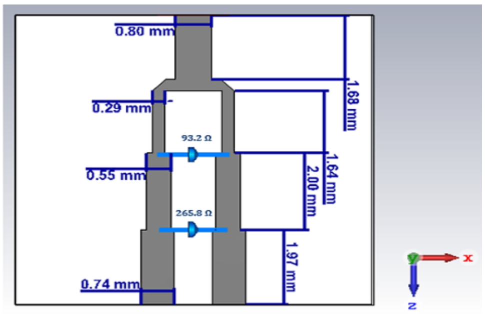

Figure 2. Layout design of tapered 2-way Wilkinson power divider at 28 GHz

Two isolation resistors, 265.8 Ω and 93.2 Ω are calculated based on Cohn's table of performance limits and normalized parameters of three- port hybrid designs to have two sections wideband Wilkinson divider [24]. The bandwidth specification of (22-34) GHz results in a factor of 1.54 with a center frequency at 28 GHz. The impedances required to have an N = 2 section divider with a bandwidth ratio of 1.5 is calculated based on (3-6).

$$Z_1 = 1.1998 \times Z_0 \tag{3}$$

$$Z_2 = 1.6670 \times Z_0 \tag{4}$$

$$R_1 = 5.3163 \times Z_0 \tag{5}$$

$$R_2 = 1.8643 \times Z_0 \tag{6}$$

Table 1. Design parameters of 2-way Wilkinson power divider

	TAPERED				OPTIMIZED			
	Z (Ω)	R (Ω)	W (mm)	L (mm)	Z (Ω)	R (Ω)	W (mm)	L (mm)
Input (Port 1)	50	-	0.74	1.97	50	-	0.74	10
Section 1	83.4	93.2	0.29	2.04	83.4	93.2	0.29	2.04
Section 2	60	265.8	0.55	2	60	265.8	0.55	2
Output (Port 2 & 3)	50	-	0.74	1.97	50	-	0.74	20

2.2. Optimized design

The optimized design is developed using two resistors, 265.8 Ω and 93.2 Ω, which are computed based on Cohn's table of performance limits and normalized parameters of three-port hybrid designs and used with a case size of 0603 [24]. The gap size between the two output ports are calculated using the size for a 2.92 mm coaxial radio-frequency (RF) connector with length of 12.7 mm. As a result, the RF connector dimension of Johnson-Cinch connectivity 145-0711-812 is referred to in this study [25]. Finally, the layout design of the optimized Wilkinson divider is designed as shown in Figure 3 and its dimensions as listed in Table 1. Figure 4 shows a photo of the fabricated design, which includes two transmission lines, two isolation resistors, and SMA connectors at each input and output port.

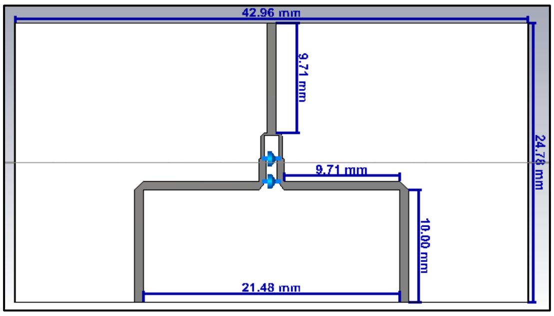

Figure 3. Optimized layout design of tapered 2-way Wilkinson power divider at 28 GHz

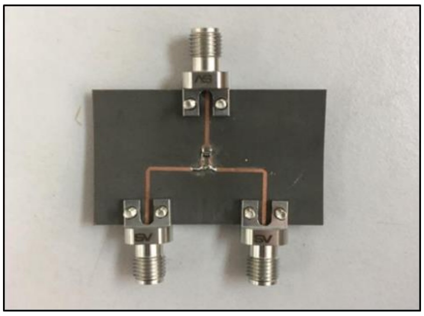

Figure 4. The fabricated 2-way Wilkinson power divider

3. RESULTS AND DISCUSSION

3.1. Tapered design

The simulated S-parameters graph for the tapered 2- way Wilkinson divider is shown in Figure 5. The insertion loss between the ports, return loss of input and output ports and the isolation between output ports at 28 GHz are tabulated in Table 2. The proposed design has a wideband characteristic, with return loss more than 10 dB from 23.5 GHz to 37.9 GHz. The S21 and S31 magnitude are -3.17 dB and -3.12 for the proposed design as shown in Figure 5 at the operational frequency of 28 GHz. This value is about 0.12–0.17 dB off from the ideal -3 dB due to the loss of signal power from the power divider transmission line. The magnitude of insertion loss is acceptable since the value is close to -3 dB. The simulation result shows that the S11 parameter is -15.45 dB at 28 GHz and -16.45 dB at 29 GHz. The return loss performance can be improved by adding more isolation resistors [24]. At 28 GHz, the value of the S32 parameter of the proposed design is -17.36 dB, as shown in Figure 5.

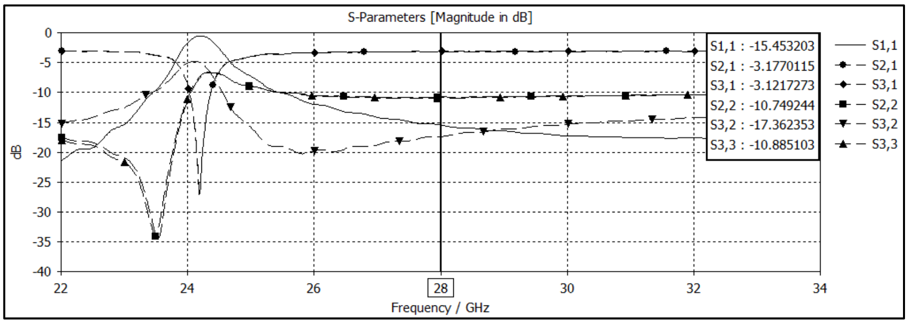

Figure 5. S-parameters graph for tapered 2-way Wilkinson power divider

3.2. Optimized design

The simulated S-parameters for the optimized design of tapered 2-way Wilkinson divider at 28 GHz to 29 GHz are shown in Figure 6. The tapered design is optimized by lengthening the input and output transmission lines to avoid overlapping of connectors with the transmission line, causing a short circuit. The gap between the output ports is 21.48 mm and length of input and output transmission lines are extended to 10 mm to fit the connectors and then simulated. The S-parameters of the output ports are shown in Table 2. On top of that, a comparison has been made between the proposed Wilkinson power divider with other works [3], [4] and [8]. From 28 to 29 GHz, the optimized power divider had higher isolation, higher return losses and equal power split between output ports compared to the tapered design. As compared to the tapered design, the input port return loss (S11) of the optimized design increases from -15.45 dB to -16.31 dB. At 28 GHz, the output port return loss (S22 and S33) is improved by 3.17 dB from -10.75 to -13.92 dB. In comparison to the proposed design, which has a magnitude of S21= -3.17 dB, the optimized Wilkinson divider achieves an insertion loss (S21) of -3.3 dB. As the magnitude increases from -17.36 dB to -23.13 dB, an improvement in output port isolation (S32) is attained. The lines passing through the PCB is optimized to be as short as possible to reduce signal ripples because of high frequency.

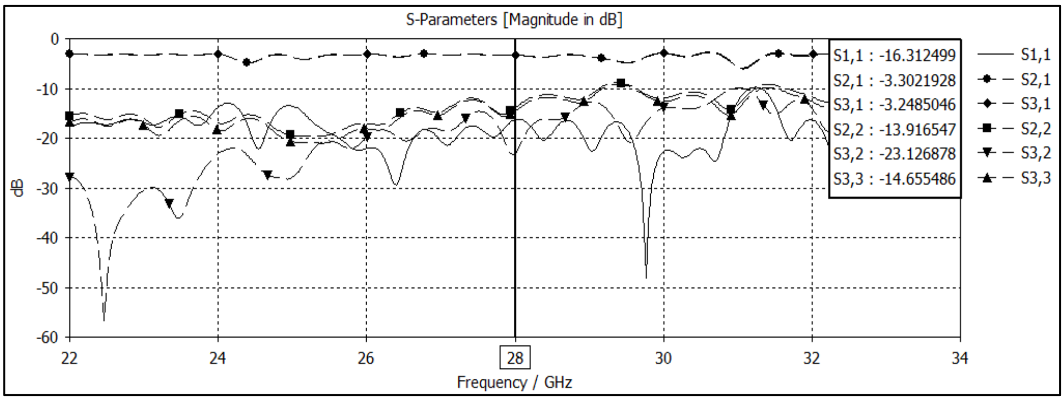

Figure 6. S-parameters graph for tapered 2-way Wilkinson power divider

Table 2 demonstrates the S-parameters performance of the optimized Wilkinson divider, operating frequency, return loss, insertion loss, and isolation between output ports at 28 GHz. In summary, the optimized design is compatible with antenna arrays operating between 28 GHz to 29 GHz.

3.3. Measurement result of optimized Wilkinson power divider

An etching process has been made (as mentioned in Figure 4) in order to fabricate the optimize Wilkinson power divider using Rogers' RT/duroid 5880 with its thickness of 0.254 mm. The S11 and S23 graph comparison between simulated (labeled as S1,1 and S2,3) and measured (labeled ad S1,1_1 and S2,3_1) of the optimized Wilkinson power divider is shown in Figure 7. The measured result for fabricated Wilkinson power divider at 28 GHz is tabulated and compared with the simulated result in Table 3. At 28 GHz, the fabricated Wilkinson divider has higher input return loss and lower isolation between output ports compared to the simulated Wilkinson divider. As compared to the simulated result, the S1,1_1 of the measured result of fabricated WPD increases from -16.31 dB to -15.7 dB. The difference is probably due to the inaccuracies of the dimension of the power divider produced after the etching process. On top of that, it is also due to the improper soldering and placement of the isolation resistor which is small and makes it difficult to see and solder. However, the magnitude is lower than -10 dB which is acceptable. On the other hand, an improvement in output port isolation (S32) is attained as the magnitude decreases from -23.13 dB to -25.21 dB after fabrication. The measured value consists of systematic measurement errors that occur repeatedly due to inaccuracy in the Wilkinson divider, resistors, and other components. The measurement of insertion loss (S12 and S13) was unsuccessful due to unavailability of terminator of required size and frequency in the lab to operate as a load at the output port connector. Furthermore, because the pin within the connector is so small (1.78 mm), it is prone to break during measurement.

Table 2. S-Parameters comparison of the proposed design and other works At 28 GHz

	Tapered design	Optimized design	[3]	[4]	[8]
Operation band (GHz)	28-29	28-29	27-29	27-29	9.09-10.28
dimension	8 mm×7.58 mm	42.96 mm×24.78 mm	10 mm×10 mm	10 mm×10 mm	83.14 mm×43.07 mm
Return loss (dB)	S_{11} = -15.45	S_{11} = -16.31	S_{11} = > -13.4	S_{11} = < -11	S_{11} =
	S_{22}, S_{33} = -10.75	S_{22}, S_{33} = -13.92	S_{22}, S_{33} = > -13.4	S_{22}, S_{33} = < -11	-23.1
Insertion loss (dB)	S_{21} = -3.17	S_{21} = -3.3	S_{21} = −3.5	S_{21} = −3.5	S_{21} = -3.54
	S_{31} = -3.12	S_{31} = -3.25	S_{31} = −3.5	S_{31} = −3.5	S_{31} = -3.68
Isolation (dB)	S_{32} = -17.36	S_{32} = -23.13	S_{32} = > -16.7	S_{32} = < -11	S_{32} = -16.23

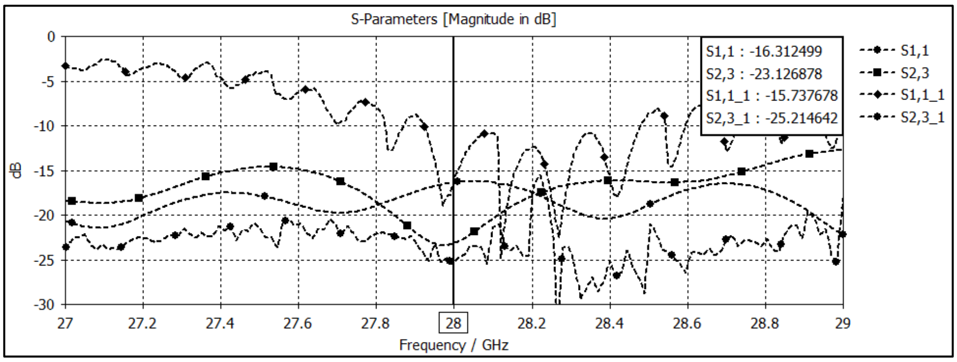

Figure 7. Comparison between simulated and measured results for S11 (S1,1: simulation and S1,1_1: measurement result) and S23 (S2,3: simulation and S2,3_1: measurement result) parameters for the optimized Wilkinson power divider

Table 3. S-parameters comparison between simulated and measured results

	Simulated result	Measured result
Frequency (GHz)	28 - 29	27 - 29
Return loss (dB)	S1,1 = -16.31	S1,1_1 = -15.74
Isolation (dB)	S2,3 = -23.13	S2,3_1 = -25.21

4. CONCLUSION

By changing the conventional Wilkinson power divider quarter wave transmission line to be multi-sections, a wideband Wilkinson power divider was created. A tapered 2-way Wilkinson power divider is proposed to feed high-frequency antenna for the 5G applications. Each output port may operate in the 28 GHz–29 GHz frequency range with good s-parameters performance. After that, the tapered Wilkinson power divider is further optimized to fit the connectors at each port. The Wilkinson divider's overall size is 42.96 mm×24.78 mm. The optimized Wilkinson divider is wideband, has better isolation between output ports and return loss, and has lower insertion loss compared to the proposed power divider. With a return loss of -16.31 dB, insertion loss of (3.25 to 3.3) dB, and isolation factor of -23.13 dB, the Wilkinson divider performs well. As a result of these qualities,the optimized design is used for fabrication. The magnitude of return loss and isolation of fabricated Wilkinson divider is close to the magnitude of return loss and isolation of simulation result with -15.74 dB return loss and high isolation factor of -25.21 dB at 28 GHz for of fabricated Wilkinson power divider.

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