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Design and Simulation of 2-Section Wilkinson Power Divider

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تصميم ومحاكاة مقسم قدرة ويلكنسون ثنائي المقطع

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Abstract:
This paper describes the design, simulation, and performance analysis of a two-section Wilkinson power divider with a center frequency of 4 GHz using microstrip line technology. The proposed circuit featuring five 1/4 wavelengths (λ) transmission lines and two isolation resistors provide bandwidth isolation that is superior to a typical single-section's bandwidth isolation. The entire design flow from synthesis to performance was done using Advanced Design System (ADS) software. Simulation results show that the divider performs well in all critical metrics. The insertion loss per arm is around -3.01 dB, and it provides equal power division among output ports. The input port also shows a good match with a return loss of better than -10 dB and amplified reflected power This design achieves strong output port isolation, enhancing the integrity of the engine operation by minimizing signal interference. Therefore, the obtained results indicate that the divider is an effective and suitable candidate for modern 4 GHz wireless communication systems and RF front ends.

Keywords: Microstrip line, Wilkinson power divider, Quarter-wave, Isolation resistors, Matlab.

الملخص
تصف هذه الورقة البحثية تصميم ومحاكاة وتحليل أداء مقسم طاقة ويلكنسون ثنائي المقطع بتردد مركزي يبلغ 4 جيجاهرتز بتقنية خط الشريطي الدقيق. توفر الدائرة المقترحة، التي تحتوي على خمسة خطوط نقل بأربعة أطوال موجية (λ) ومقاومتي عزل، توفر عزلًا لعرض النطاق الترددي يتفوق على عزل عرض النطاق الترددي التقليدي ذي المقطع الواحد. تم تنفيذ التصميم بالكامل، من التركيب إلى تقيم الأداء، باستخدام برنامج نظام التصميم المتقدم (ADS). تُظهر نتائج المحاكاة أن المقسم يعمل بكفاءة عالية في جميع المقاييس الأساسية؛ حيث يبلغ فقد الإدخال لكل ذراع حوالي – 3.01 ديسيبل، ويوفر توزيعًا متساويًا للطاقة بين منافذ الخارجة. كما يُظهر منفذ الإدخال تطابقًا جيدًا مع فقد الرجوع يزيد عن – 10 ديسيبل، وتضخيم في الطاقة المنعكسة. يحقق هذا التصميم عزلًا قويًا لمنفذ الخارجة، مما يعزز موثوقية عمل النظام من خلال تقليل

تداخل الإشارة. لذلك، تشير النتائج المتحصل عليها إلى أن المقسم خيار فعال ومناسب لأنظمة الاتصالات اللاسلكية الحديثة بتردد 4 جيجاهرتز وواجهات الترددات الراديوية الأمامية.

الكلمات المفتاحية: خط الشريطي الدقيق، مقسم قدرة ويلكنسون، ربع طول الموجة، مقاومات عزل، ماتلاب.

Introduction

A Wilkinson Power Divider (WPD) is an important component in RF and microwave engineering. This device can divide the input signal into two identical output signals [1]. Further, it functions with low loss and high isolation between the ports. Ever since Ernest J. Wilkinson invented the design in 1960 [2], it has been used to construct power amplifier networks, beam-forming networks for antenna arrays, and balanced mixers [3]. The basic design consists of two quarter-wave transformers and a single isolation resistor. Although usually used, the traditional single-section WPD is limited by its narrow operational bandwidth. The quarter-wave transmission lines used in its implementation cause this restriction in bandwidth to occur as a result of frequency [2]. With the new wireless standards specifying higher data rate and more sophisticated modulations, components with a wider bandwidth and better performance are becoming essential fast [4]. Multi-section WPDs were developed to avoid the bandwidth limitation of the single-section design [5]. Using several quarter-wave sections causes the impedance transformation to happen progressively from the input to output port enabling effective matching and isolation over a wider frequency band [6]. In this paper, the design and simulation performance of two-section Wilkinson Power Divider at the center frequency of 4 GHz which comes under C-band [7] .

The C-band is extensively used in satellite communication, Wi-Fi and radar etc [8]. The suggested divider is made up of microstrip technology the low cost, ease of fabrication and good integration with other planar circuit components have all been taken into account [4]. The two-section topology made of five quarter-wave transmission lines and two isolation resistors provides a broader bandwidth and better performance than a single-section design. The design and analysis were accomplished using Advanced Design System (ADS) from Keysight Technologies [9]. It is an industry-standard high-frequency circuit simulation software. The divider performance is assessed according to S-parameters S11 (input return loss), S21/S31 (insertion loss and power division equality), and S23 (isolation between output ports). The simulation results show that the two-section WPD, which has been designed, is capable of equal power division (-3.01 dB), an input return loss greater than 10 dB, and high inter-port isolation at the design frequency, thus confirming its potential for broadband RF applications.

Power dividers are considered as one of the most useful passive microwave components and widely used for many communication systems .It is a three ports network used in dividing power from the input to output ports. In general, power dividers have three most common types of dividers, T-junctions, resistive and Wilkinson power dividers [10].

The lossless T-junction power divider is simply three transmission lines connected at a single junction as shown in Figure 1. This junction has a reactance associated with it due to fringing fields and higher order modes. This type is capable of being reciprocal but has the drawback of three posts can't be simultaneously matched at all ports [11].

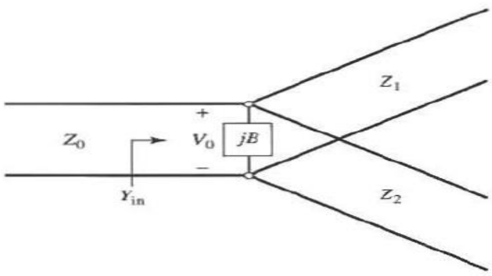

Figure 1. Lossless T-junction power divider

The problem of matching in lossless T-junction power divider is solved resistive power dividers is implemented to ensure that the same impedance is achieved at all ports. Thus, the ports can be matched. In contrast, resistive power dividers have significant power losses and the isolation between output ports is poor quality. Figure 2 shows a typical resistive power divider model [12].

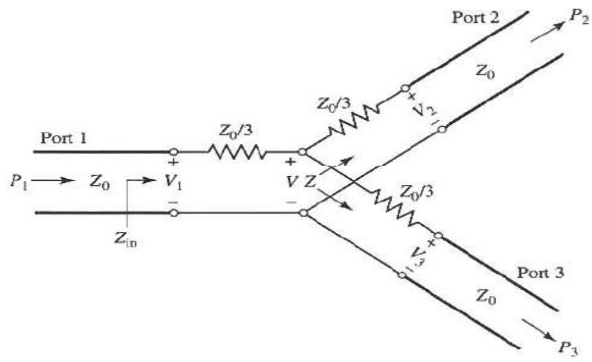

Figure 2: Resistive power divider

Wilkinson power dividers (WPD) have been used to solve the issue of impedance matching and ports isolation [13]. In this model, the output ports incorporate quarter-wave sections of transmission lines of characteristic impedance $\sqrt{2}Z_0$, which are connected together using a resister of $2Z_0$. Wilkinson power divider and equivalent transmission line circuit are shown in Figure 3 [14].

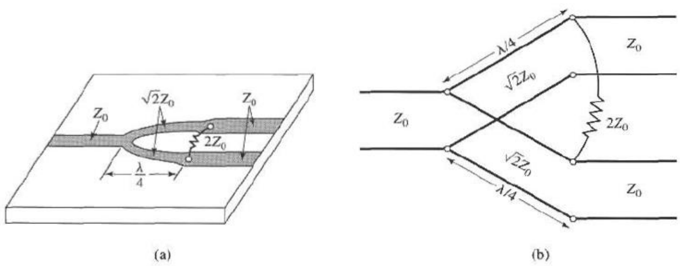

Figure 3. The Wilkinson Power Divider. (a). Wilkinson power divider and (b). Equivalent transmission line

This paper is intended to design and simulate 2-section Wilkinson power divider. The mentioned power divider is designed using quarter-wave microstrip transmission line technology and at center frequency 4GHz. The rest sections in this paper are organized as follows: section 2 is design methodology. Section 2 highlights the simulation results and discussion. Lastly, section 3 is summarizing the acquired results and providing the summary conclusion then followed by the list of up-to-date references.

Design Methodology

The schematic configuration of 2-section WPD is shown in Figure 4. It consists of two quarter-wavelength line ($\lambda_g/4$) segments at the center frequency [3]. These two sections have characteristic impedances Z_1 and Z_2 respectively. In addition, two isolation resistors R_1 and R_2 are connected between output ports. The design specifications for 2-section WPD are illustrated in table 1 below [15].

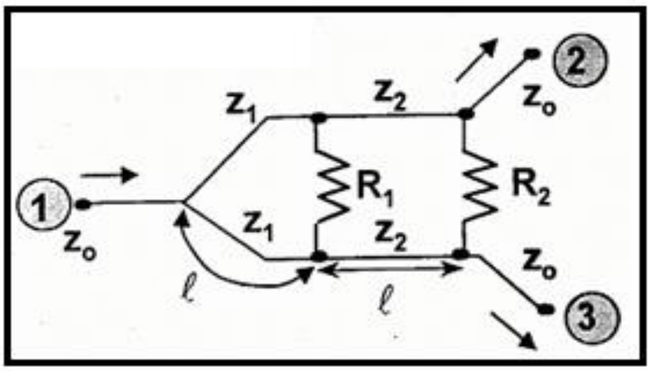

Figure 4. 2-Section of Wilkinson power divider

Table 1. Design specification.

Parameters	Design Frequency/ Center frequency	Substrate Dielectric Constant (ε_r)	Substrate thickness (h)	Loss tangent (tan δ)	Metallization	Multisession quarter wave transformer
Values	4 GHz	3.38	0.813 mm	0.0027	17μm copper	Γ = 0.20

To design 2-section WPD, the characteristics impedances Z_1 *and* Z_2 are needed to obtain firstly. In this design, Chebyshev transform design table at maximum reflection coefficient in the passband equal to 0.20 are used. Table 2 shows some parts of Chebyshev table.

Table 2. Chebyahev Transform Design

N=2		
Z_L/Z_0	$\Gamma_m = 0.20$	
	Z_1/Z_0	Z_2/Z_0
1.0	1.0000	1. 0000
1.5	1.2247	1.2247
2.0	1.3161	15197
3.0	1.4565	2.0598
4.0	1.5651	2.5558

By using Table 2, the characteristics impedances Z_1 *and* Z_2 are calculated as following [16]:

$$Z_1 = Z_0 \times 1.5197 \quad (1)$$

$$Z_2 = Z_0 \times 1.3161 \quad (2)$$

Where$Z_0 = 50\ \Omega$

To determine values of the isolation resistors, questions 1, 2, and 3 are used [17]:

$$\varphi = \frac{\pi}{2}\left[1 - \frac{1}{\sqrt{2}}\left[\frac{f_2 - f_1}{f_2 + f_1}\right]\right] \quad (3)$$

$$R_1 = \frac{2\, Z_1 Z_2}{[(Z_1 + Z_2)(Z_1 - Z_2\, cot^2\varphi)\,]^{1/2}} \quad (4)$$

$$R_2 = \frac{2R_1(\,Z_1 + Z_2)}{[R_1(\,Z_1 + Z_2) - 2Z_1\,]} \times 2\, Z_0 \quad (5)$$

As can be seen in equation 1, to obtain the value of the angle φ , bandwidth ration f_1/f_2 needs to be specified. Since this design has 2-section, the bandwidth ration equal to 2:1. Thus the frequencies f_1 *and* f_2 can be calculated as:

$$\frac{f_2}{f_1} = 2 \quad \Rightarrow \quad f_2 = 2\, f_1 \quad (6)$$

$$f_c = \frac{f_2 + f_1}{2} + f_1 \quad (7)$$

Where f_c *is* the center frequency. By solving the questions 4 and 5, f_1 *and* f_2 are obtained. However, table 3 shows all calculation values.

Table 3. Calculation parameters values

parameter		Values
Characteristic impedance Z_1 (Ohm)		75.985
Characteristic impedance Z_2 (Ohm)		65.805
Frequency f_1 (GHz)		2.67
Frequency f_2 (GHz)		5.33
The angle φ	radius	1.20148
	degree	68.8398
Isolation resistor R_1 (Ohm)		103.277
Isolation resistor R_2 (Ohm)		202.097

To obtain the length (L) and the width (W) of quarter-wave transmission lines advanced design system (ADS) software used. ADS contain tools that can calculate the dimensions of the quarter- wave transmission line called "LineCalc". The only thing that needs to be done is to select the type of transmission line (in this paper, **Microstrip technology**) applying the design specification parameters in Table1 and also the calculated once in Table 3. Table 4 below contains the length and the width of the quarter-wave transmission line.

Table 4. Dimensions of the quarter- wave transmission lines

Quarter-wave transmission line		Value (mm)
Transmission line (TL1),with Z_0 characteristic impedance	W	1.859140
	L	11.437500
Transmission line (TL2, TL3) with Z_1 characteristic impedance	W	0.870757
	L	11.787000
Transmission line (TL4, TL5), with Z_2 characteristic impedance	W	1.156010
	L	11.663700

Figure 5 shows ADS schematic of 2-section Wilkinson power divider, and the layout is plotted as shown in Figure 6.

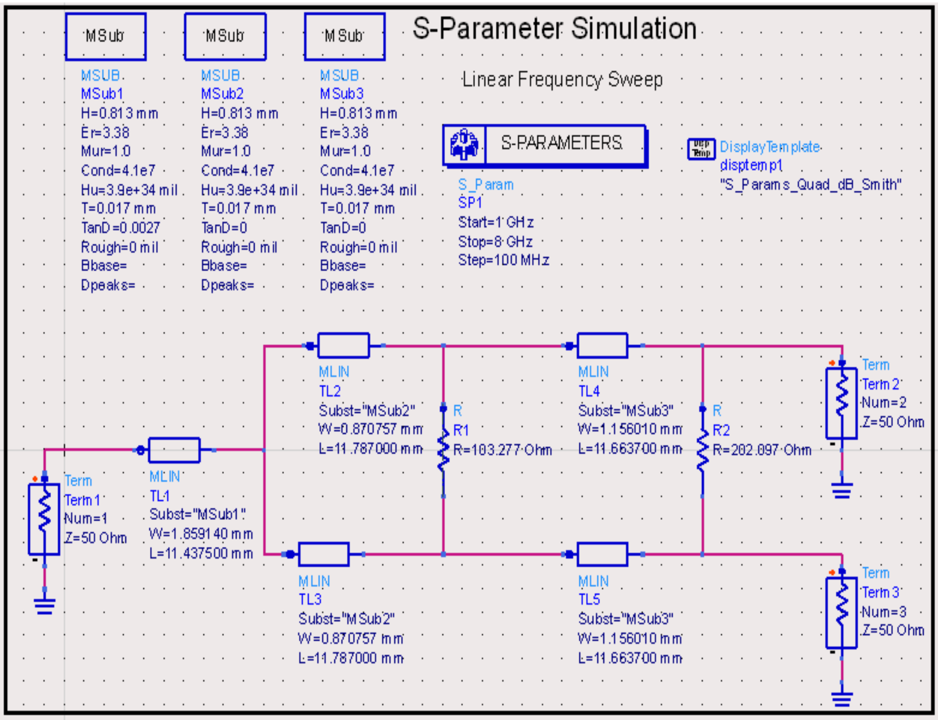

Figure 5. ADS schematic of 2-section microstrip Wilkinson power divider.

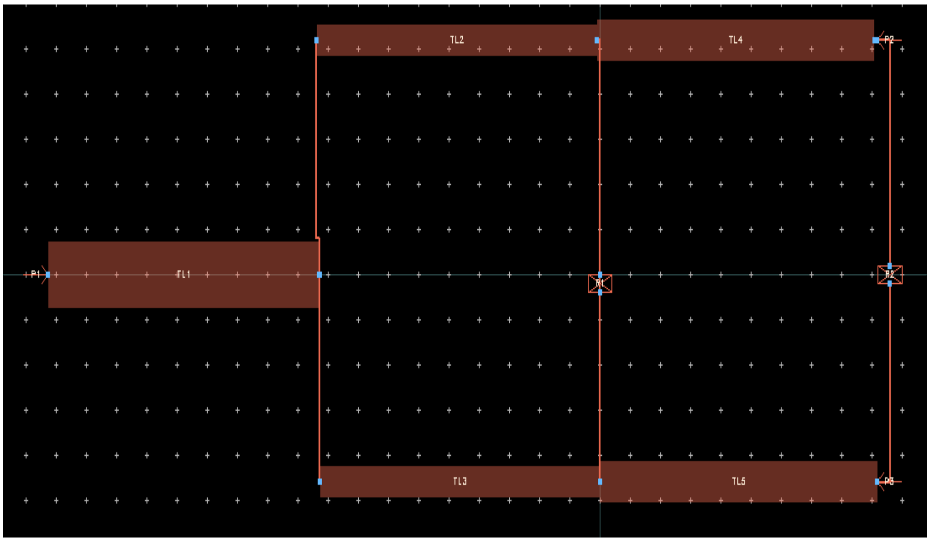

Figure 6. ADS layout of 2-section microstrip Wilkinson power divider

Simulation Results and Discussion

2-section microstrip Wilkinson power divider is designed and simulated. The performance of the designed power divider is evaluated by analysis of the simulation results in which they are the scattering parameters of the connected ports. Figures 7, 8 and 9 are shown as the s-parameter results.

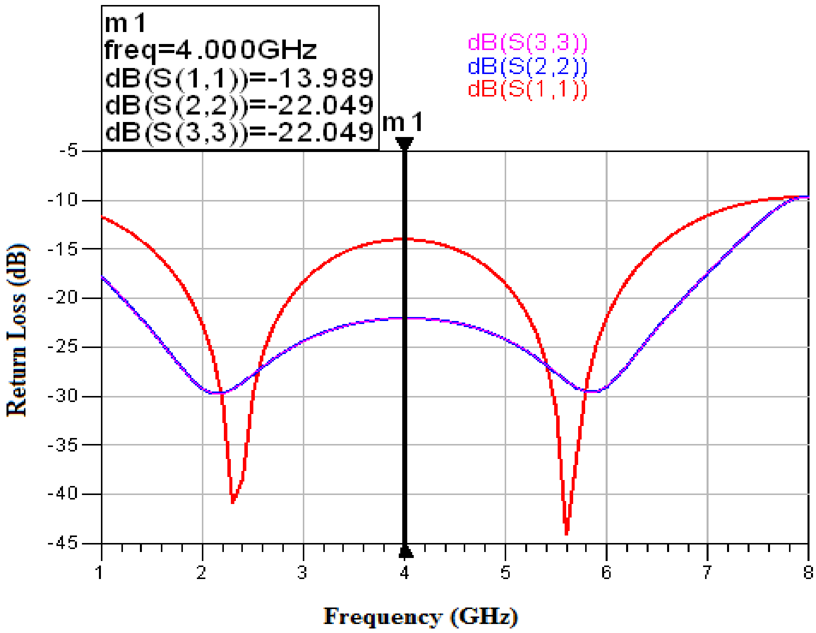

Figure 7. Return loss Vs frequency.

As can be seen in Figure 7, all ports have good return loss that is greater than 10dB at center frequency. For the input port ($S_{11} \cong -14\ dB$), therefore, return loss is:

$$RL = -20 \log|\Gamma| \tag{8}$$

where $\Gamma = S_{ii}$, thus the return loss is greater than 10dB. By the same way, for output ports ($S_{22}, S_{33} = -22\ dB$), the return loss is greater than 10dB.

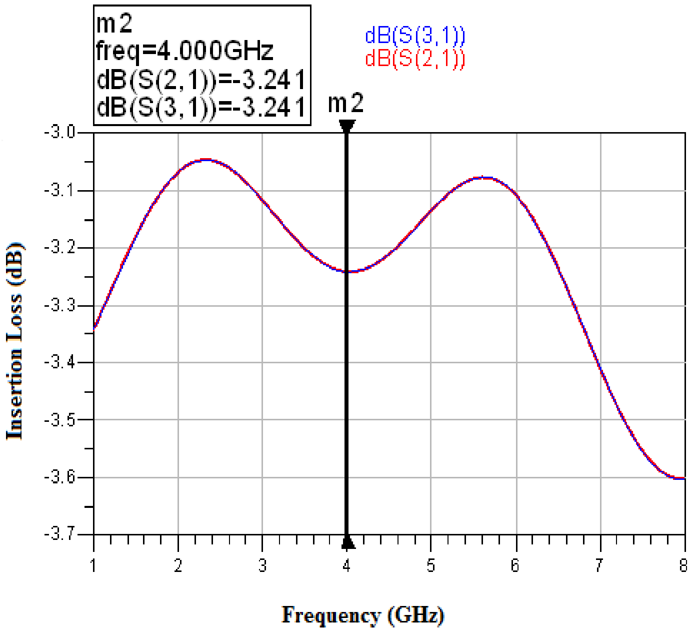

Figure 8. Insertion Vs frequency

The insertion loss shown in Figure 8 illustrates that the designed power divider divides the power equally at center frequency. The division power at output ports is ($S_{21}, S_{31} = -3.241dB$) approximately -3 dB.

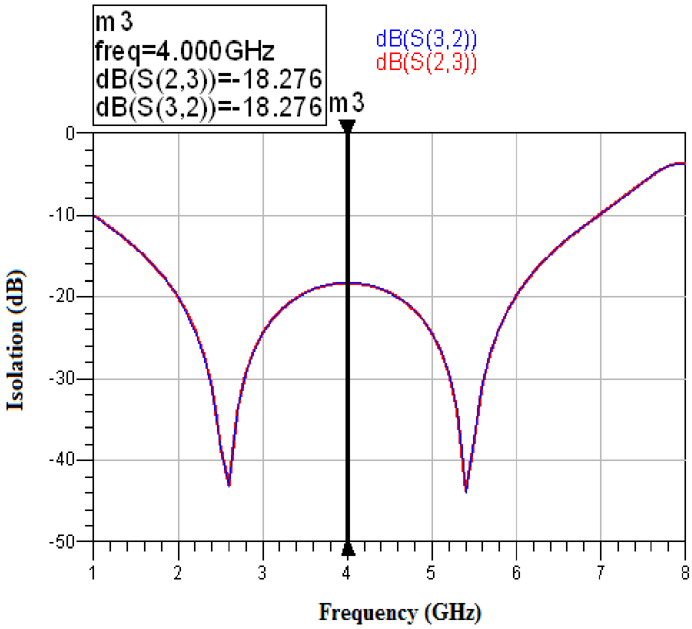

Figure 9. Isolation Vs frequency

From Figure 9, the isolation between both output ports has good isolations where ($S_{23}, S_{32} \cong -18dB$). Therefore:

$$IL = -20 \log|\Gamma| \qquad (9)$$

where $\Gamma = S_{ij}$, thus the return loss is greater than 10dB.

The plot in Figure 10 shows how the insertion loss (S2 1 & S3 1) in dB varies with frequency for the Wilkinson Power Divider. The light blue and red dashed lines are nearly equal in value, which indicates good balance between the two output ports. Marker points at 3 GHz and 7 GHz indicate almost perfect -3.01 dB power division, which is the theoretical ideal for an equal power split. The consistent response over the 3-7 GHz frequency indicates good wideband consistency and power division characteristics.

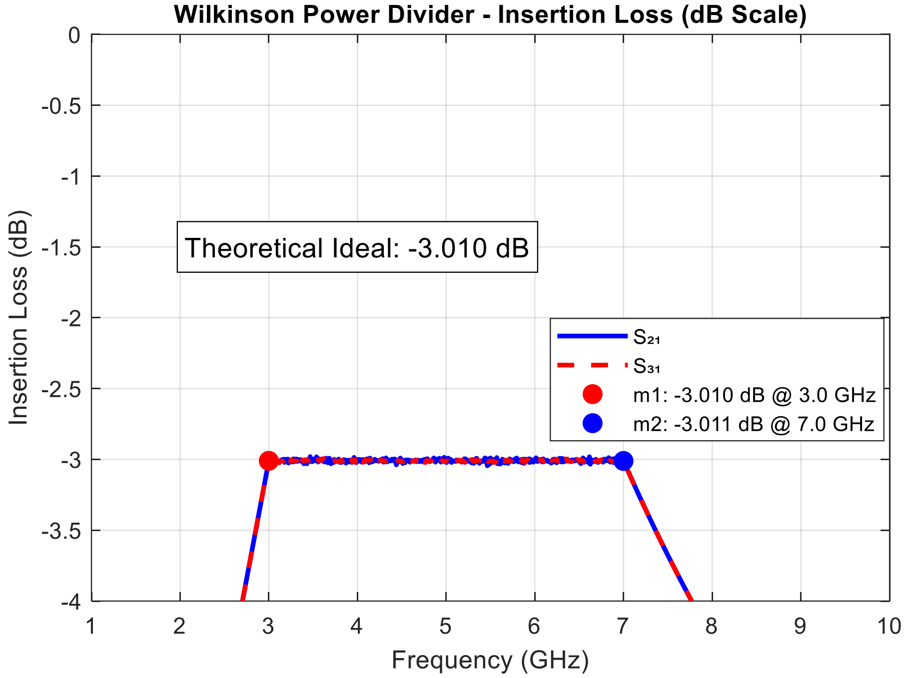

Figure 10: Wilkinson Power Divider - insertion Loss (dB Scale)

As can be seen in Figure 11, a measure of the overall power conservation of the divider. It indicates what percentage of input power gets across to the output ports. The results close to 100% show that the divider structure has very little power loss. The tracking is close to the 100% line, with the conclusion indicating that the power is effectively being transferred with little dissipation in the components or radiation losses.

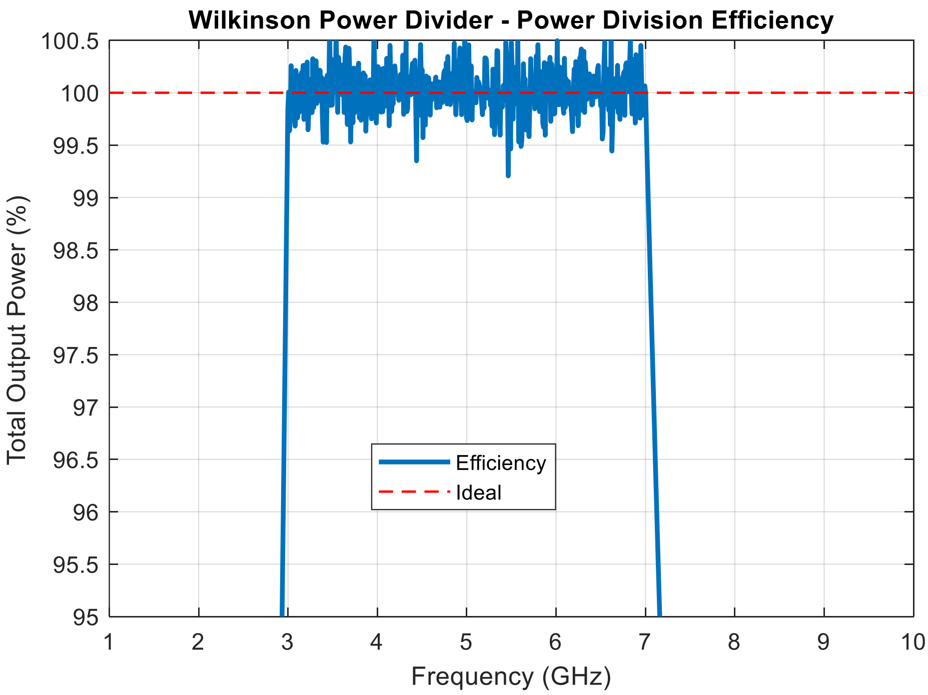

Figure 11: Wilkinson Power Divider - power division Efficiency

The power level difference between the two outputs by focusing on the symmetry between output ports illustrated in Figure 12. The output channels match extraordinarily well as indicated by imbalance values that are very low (less than 0.05 dB Specification limit). This nearly perfect balance guarantees that the two output signals will have the same power level which is important for some applications.

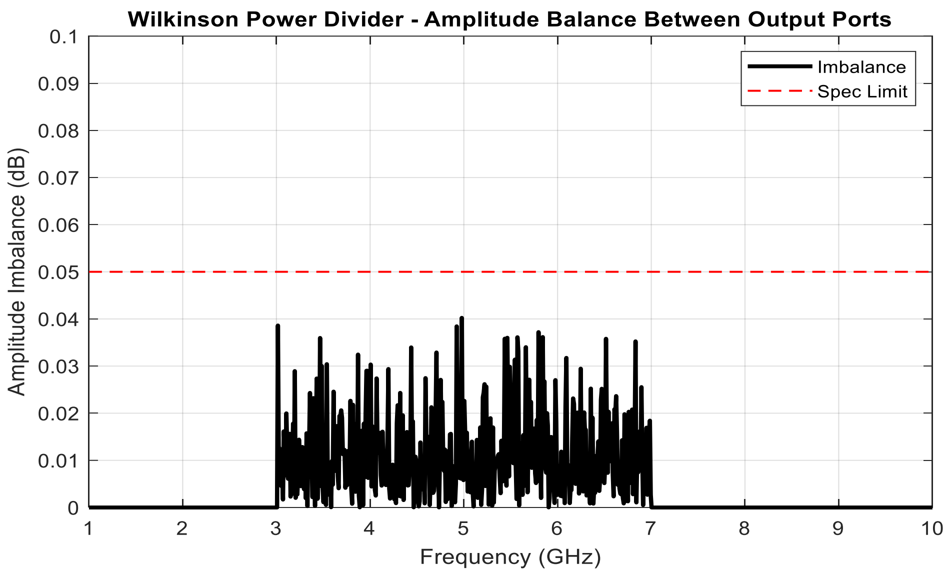

Figure 12: Wilkinson Power Divider - amplitude Balance Between Output Ports

This combined plot in Figure 13 serves as a summary of the power divider's performance at a glance. The top part confirms that power is evenly distributed throughout the whole band while the bottom part confirms an excellent impedance match, as well as good isolation between the ports. By combining these panels, we can instantaneously check that every important specification is being satisfied all through the operating frequency range.

Figure 13: Wilkinson Power Divider performance overview

The Figure 14 shows a plot of voltage division ratio in linear scale. The ideal value, 0.707, is clearly indicated. The measurement point at both 3 GHz and 7 GHz matches this theoretical value perfectly, showing a good power splitting performance. The ratio of power at each port is the same as the square of the voltage ratio. Power is proportional to squared voltage (P ∝ V2). Therefore, a ratio of 0.707 verifies that exactly 50% of the input power is delivered to each output port. (0.7072 = 0.5).

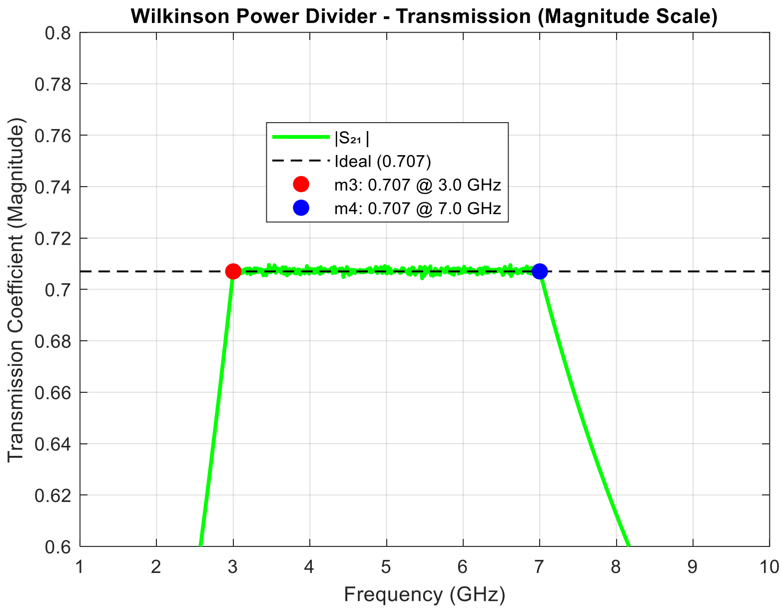

Figure 14: Wilkinson Power Divider - Transmission (Magnitude Scale).

Conclusion

Microstrip technology is used for implementing the design of a 2-section Wilkinson Power Divider (WPD). The effective execution of the simulation has been presented in this paper. Simulations run on ADS confirm that the power divider meets performance specifications according to the design. The simulation shows that there is an equal division of power of –3.01 dB at each output port which proves – the divider works as per its basic function. In addition, the input return loss (S11) and isolation between output ports (S23) are both better than 10 dB across the target frequency band, signifying a good impedance matching and effective port-to-port isolation. The designed two-section wind energy converter (WPD) was successfully simulated, supporting the design methodology of the present work. While the future Recommendations of the study are listed below: The work can be further improved despite promising results from the simulation carried out.

The most important next step is to fabricate the power divider designed on PCB and measure it using VNA. This will ensure that simulated and measured results can be compared both directly and on the same substrate to identify discrepancies.

1. The design can be optimized for better performance. Future efforts might be directed at improving return loss and isolation beyond 15 dB or 20 dB, as this is often a desirable level in practice. This may include changing instruction geometry or optimization algorithms in simulation software.
2. One benefit of the multi-section Wilkinson configuration entails the ability to obtain a wider bandwidth. Future studies might look at adding a third section or using a tapered line to achieve a broader operational bandwidth than was achieved in this two-section design.
3. Miniaturization and Advanced Materials: The power divider can be miniaturized using defected ground structures (DGS) techniques or implemented on a substrate with a high dielectric constant to meet the demands of modern-day compact systems. Choosing newer, low-loss substrate materials may make devices more effective.

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