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A NOVEL DESIGN OF DUAL-BAND UNEQUAL WILKINSON POWER DIVIDER

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Abstract—This paper presents the design of a novel dual-band unequal Wilkinson power divider. The proposed power divider can operate at arbitrary two frequencies without reactive components. The design and analysis of power divider are presented. The structure of the power divider and the formulas used to determine the design parameters have been given. Closed-form design equations are derived based on network theory. For verification, a microwave power divider operating at 1 and 2 GHz is fabricated, the experimental results show that the designed unequal power divider fulfills all the features of a conventional Wilkinson power divider.

1. INTRODUCTION

Power dividers and combiners [1–22] are key components in microwave and millimeter-wave system. A conventional Wilkinson power divider is implemented with quarter-wave transmission line and has narrow bandwidth around a single frequency. In recent years, many dual-band power dividers [6–12, 17–19] have been reported due to the development of multiband technologies. However, they don't involve the issue of unequal power dividing ratio, which has been proposed in [13–15] for single band operation.

In this paper, a novel unequal power divider circuit for dual-band operation is introduced. Its main advantages include: (1) no extra lumped elements are needed for the dual-band operation other than a single resistor, which means that the power divider can be fabricated

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easily and the parasitic effect can be greatly reduced. (2) An open stub and a short stub can be chosen flexibly.

In Section 2, the design equations of the proposed unequal dual-band Wilkinson power divider are derived using network theory. For verification, both simulated and experimental results of a dual-band power divider are given in Section 3.

2. THEORY AND DESIGN EQUATIONS

The schematic diagram of the designed unequal dual-band Wilkinson power divider with an output power-dividing ratio of k ($P_3/\ P_2 = k$) is presented in Figure 1. All the impedance values are normalized with respect to the port impedance. It basically consists of two transmission line section of different characteristic impedance (Z_A and Z_B) and two stubs (jY_1 and jY_2), as well as an isolation resistor (R). Since power-dividing ratio is unequal in this structure, the traditional even- and odd-mode analysis is not available in this case. The network theory is involved to provide the analytical solutions. To achieve impedance matching at port 1, the following resistance relationships must be satisfied:

$$Z_0 = \frac{Z_{in2} Z_{in3}}{Z_{in2} + Z_{in3}} \tag{1}$$

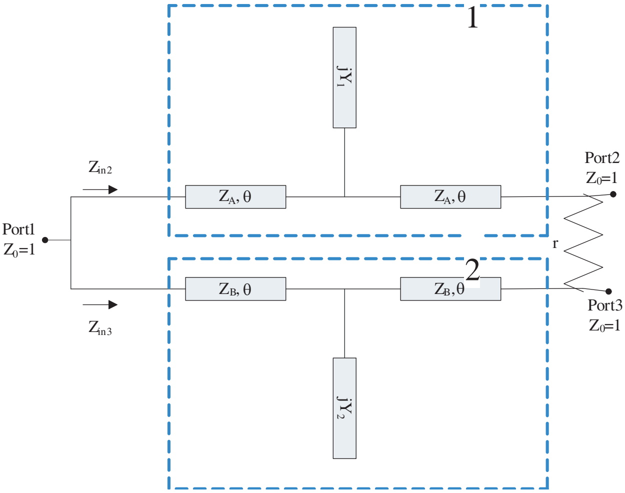


Figure 1. Circuit of the proposed dual-band unequal Wilkinson power divider.

Substituting $Z_{in2} = k^2 Z_{in3}$ into above equation, we can obtain

$$Z_0 = \frac{k^2}{1+k^2} Z_{in3} \tag{2}$$

The Equation (2) can be rewritten as:

$$Z_{in3} = \frac{1+k^2}{k^2} Z_0 \tag{3}$$

So, Z_{in2} can be calculated as:

$$Z_{in2} = \left(1+k^2\right) Z_0 \tag{4}$$

Mathematically, the $ABCD$-parameters of the network 1 and 2 can simply derived as

$$\begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix} = \begin{pmatrix} \cos\theta & jZ_A \sin\theta \\ j\sin\theta/Z_A & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 \\ jY_1 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & jZ_A \sin\theta \\ j\sin\theta/Z_A & \cos\theta \end{pmatrix} \tag{5}$$

$$\begin{pmatrix} A_2 & B_2 \\ C_2 & D_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & jZ_B \sin\theta \\ j\sin\theta/Z_B & \cos\theta \end{pmatrix} \begin{pmatrix} 1 & 0 \\ jY_2 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & jZ_B \sin\theta \\ j\sin\theta/Z_B & \cos\theta \end{pmatrix} \tag{6}$$

Furthermore, the input impedances can be expressed as

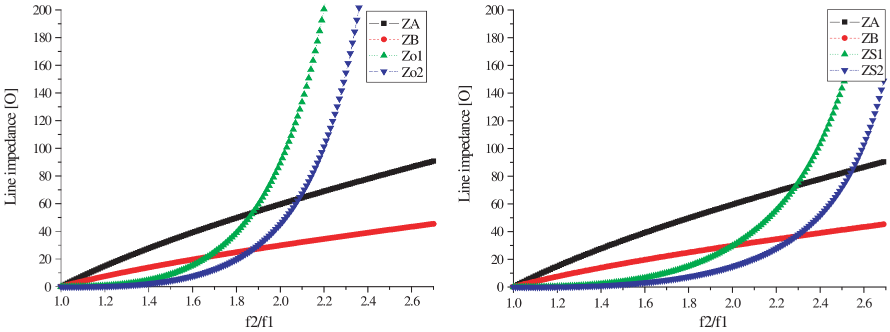
$$\begin{aligned} Z_{in2} &= \frac{A_1 Z_0 + B_1}{C_1 Z_0 + D_1} \\ Z_{in3} &= \frac{A_2 Z_0 + B_2}{C_2 Z_0 + D_2} \end{aligned} \tag{7}$$

After some algebraic manipulation, the following equations can be obtained to design the characteristic impedances of two transmission line sections:

$$\begin{aligned} Z_A &= \frac{\sqrt{(1+k)\sqrt{k}}}{\tan\theta} Z_0 \\ Z_B &= \frac{\sqrt{(1+k)}}{k^{\frac{3}{4}} \tan\theta} Z_0 \end{aligned} \tag{8}$$

For open stubs, $\theta_o = 2\theta$

$$\begin{aligned} Z_{O1} &= \frac{\tan^2 2\theta \sqrt{(1+k)\sqrt{k}}}{2\tan\theta} Z_0 \\ Z_{O2} &= \frac{\tan^2 2\theta \sqrt{(1+k)}}{2k^{\frac{3}{4}} \tan\theta} Z_0 \end{aligned} \tag{9}$$



(a) Open stubs (b) Short stubs

Figure 2. Circuit parameters versus frequency ratio when $k = 2$. (a) Open stubs. (b) Short stubs.

For short stubs, $\theta_s = \theta$

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\begin{aligned}
Z_{S1} &= \frac{\sqrt{(1+k)\sqrt{k}}}{\tan\theta(\tan^2\theta - 1)} Z_0 \\
Z_{S2} &= \frac{\sqrt{(1+k)}}{k^{\frac{3}{4}}\tan\theta(\tan^2\theta - 1)} Z_0
\end{aligned}
\tag{10}
$$

The solutions are assigned to the two frequencies f_1 and f_2 ($f_1 < f_2$), and it can be put in the following form at the lower frequency:

$$\theta = \frac{\pi}{1 + \frac{f_2}{f_1}} \tag{11}$$

The value of resistor R can be obtained as

$$R = \frac{1+k}{\sqrt{k}} \tag{12}$$

Figure 2 shows the impedance lines and stubs calculated as a function of frequency ratio (f_2/f_1) when $k = 2$. These results suggest that, the power divider can operate at frequency ratio ranging from 1.09 to 2.13 with available impedance value lies between 7 and 150 Ω for open stubs, and from 1.08 to 2.51 for short stubs. These results suggest that, the power divider can operate at a wider frequency ratio compared with [16, 20].

3. EXPERIMENT

The dual-band Wilkinson power divider has been fabricated on a substrate with thickness is 1 mm and relative dielectric constant of 2.65.

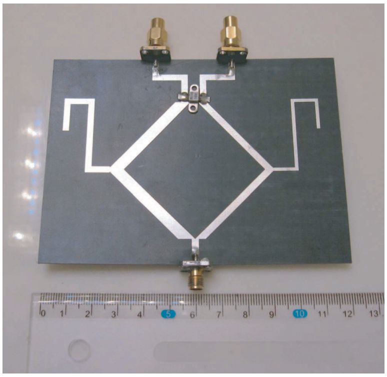
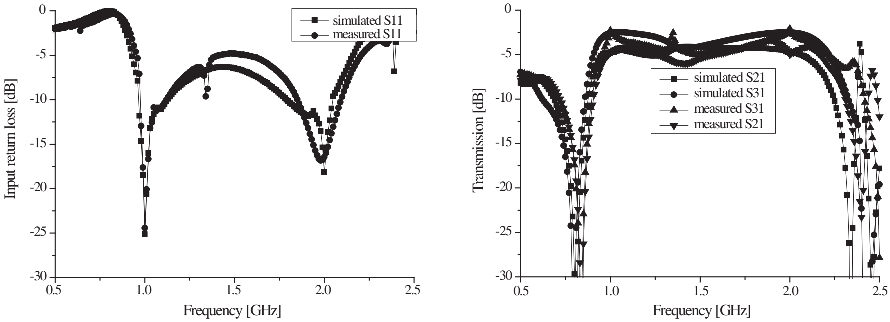
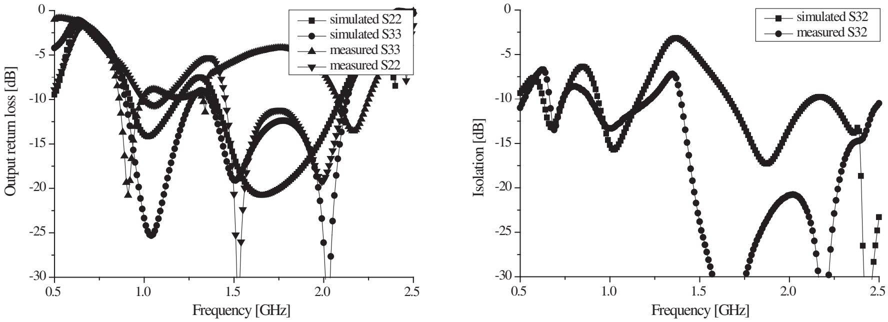


Figure 3. The photo of the fabricated power divider.



(a) Simulated and measured input return loss (b) Transmission



(c) Simulated and measured output return loss (d) Isolation

Figure 4. Frequency response of the designed dual-band power divider. (a) Simulated and measured input return loss. (b) Transmission. (c) Simulated and measured output return loss. (d) Isolation.

The power divider has been designed for $f_1 = 1\,\mathrm{GHz}$ and $f_2 = 2\,\mathrm{GHz}$ when $k = 2$. The design parameters have been calculated at first. According to (11), $\theta = 60^\circ$ at the lower frequency (f_1). Using (8), (9), the line impedance values are $Z_A = 59\,\Omega$, $Z_B = 30\,\Omega$, $Z_{o1} = 89\,\Omega$ and $Z_{o2} = 45\,\Omega$ respectively. Figure 3 shows the photo of the fabricated power divider, which occupies an area of $120 \times 88\,\mathrm{mm}^2$. The measured S-parameters data collected from WILTRON37269A network analyzer along with simulated results using HFSS are presented in Figure 4. The input return loss is $-20\,\mathrm{dB}$ at 1 GHz and $-17.35\,\mathrm{dB}$ at 2 GHz. The measured S_{21} are $-4.77\,\mathrm{dB}$ at 1 GHz and $-4.67\,\mathrm{dB}$ at 2 GHz, S_{31} are $-2.27\,\mathrm{dB}$ at 1 GHz and $-2.15\,\mathrm{dB}$ at 2 GHz. The isolation between port 2 and 3 is nearly 15 dB at 1 GHz and more than 20 dB at 2 GHz. It is found out that the transmission values are not ideal 3 dB. This little disagreement is mainly due to the negligence of substrate losses and the approximate values of components [16].

4. CONCLUSION

This paper presents a novel dual-band unequal Wilkinson power divider which can operate at arbitrary dual band without reactive components. The proposed power divider can be fabricated easily and the parasitic effect can be greatly reduced. The formulas used to determine the design parameters have been given. The analytical results are then verified through experiments.

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