Dual-Band Unequal Wilkinson Power Divider with High Power-Dividing Ratio

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Abstract - **This paper presents the design of a dual-band unequal power divider with high power-dividing ratio. No reactive lump components are required. Cost and loss could be consequently reduced. For verification, a 2.45/5.8-GHz prototype with 16:1 power-dividing ratio was fabricated and measured. Simulated and measured results are consistent with each other.**

Index Terms — **Dual band, high power-dividing ratio, microstrip, unequal power divider.**

1. Introduction

Unequal Wilkinson power dividers are key components in microwave circuits, such as antenna feeding networks for pattern synthesis. A single-band 15:1 power divider has been presented [1]. Transmission lines of moderate impedances along with series inductors/shunt capacitors are used to replace the quarter-wavelength ($\lambda/4$) transformers in a traditional Wilkinson power divider. A single-band unequal power divider without reactive components has been proposed [2]. The power-dividing ratio which is not related on impedance of transmission lines can be arbitrary theoretically. Dual-band unequal Wilkinson power dividers have also been reported [3], [4]. In [3], a pair of T-shaped lines and two-section impedance transformers are utilized for dual-band operation. Power-dividing ratio is still limited. By replacing the transmission lines in [2] with composite right/left-handed transmission lines, dual-band unequal in-phase/out-of-phase power divider was presented in [4]. Reactive lump components are required.

In this paper, a dual-band unequal Wilkinson power with high power-dividing ratio (16:1) is presented. This design is a modification of previous works [2,4]. The reactive lump components are no longer needed in this modified design. As a result, the loss and distortion due to the lump components can be eliminated.

2. Design and Analysis

Fig. 1 is the proposed dual-band unequal power divider. It consists four T-shaped lines and one resistor of resistance R. Two of the T-shaped lines are formed by a transmission line of characteristic impedance Z_1, the center of which is tapped with a shorted stub of line impedance Z_{1s}. $2\theta_1$ and θ_{1s} are the electrical lengths of the series transmission line and shunt stub, respectively. The other T-shaped lines are composed of a transmission line of line impedance Z_2, the center of which is tapped with an open stub of line impedance Z_{2s}. $2\theta_2$ and θ_{2s} are, respectively, the electrical lengths of the series transmission line and shunt stub. The

proposed dual-band power divider could be derived from its single-band counterpart in [2] by replacing each transmission line section with its equivalent T-shaped line or cascaded T-shaped lines.
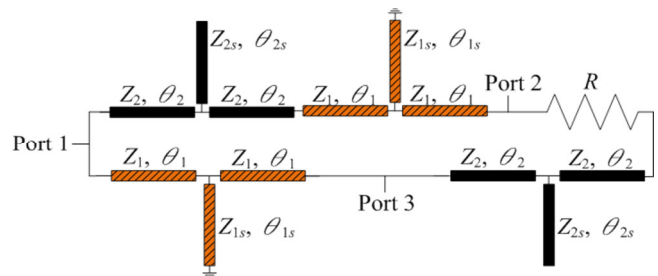

Fig. 1. Proposed dual-band unequal power divider.

(1) Theory and Equations

Port impedance of $Z_0 = 50\ \Omega$ is assumed in this design. The T-shaped line is designed to be equivalent to a transmission line of impedance $Z_c = \sqrt{2}\ Z_0$ and electrical length of $+\phi/-\phi$ at frequency f_1/f_2. For T-shaped lines with shorted and open stubs, $\phi = 90°$ and $\cos^{-1}(1/k)$ are required, respectively, where $k = |S_{21}/S_{31}| \geq 1$ is the square root of power-dividing ratio [2]. Comparing ABCD matrices of the T-shaped line and its equivalent transmission line, design equations of Z_1, Z_2, Z_{1s}, and Z_{2s} could be derived as:

$$Z_1 = \frac{\pm Z_c}{\tan \theta_1} \tag{1}$$

$$Z_{1s} = \frac{Z_1 \cdot \sin(2\theta_1)}{2 \cdot (2\sin^2 \theta_1 - 1) \cdot \tan \theta_{1s}} \tag{2}$$

$$Z_2 = Z_c \frac{\pm \tan(\phi/2)}{\tan \theta_2} \tag{3}$$

$$Z_{2s} = \frac{Z_2}{2} \frac{\sin(2\theta_2) \cdot \tan \theta_{2s}}{\cos(2\theta_2) - \cos \phi}. \tag{4}$$

The upper and lower signs in (1) and (3) are for frequencies f_1 and f_2, respectively. For dual-band operation at f_1 and f_2, θ_1, θ_{1s}, θ_2 and θ_{2s} at the frequency of $f_0 = (f_1 + f_2)/2$ should be selected as multiples of 90°. These angles should be as small as possible and carefully selected so that Z_1, Z_2, Z_{1s}, and $Z_{2s} > 0$ are guaranteed. The cascaded T-shaped lines are then equivalent to a transmission line with impedance of $\sqrt{2}\ Z_0$ and electrical length of $90°+\phi$ and $-90°-\phi$ at f_1 and f_2, respectively. According to the analysis in [4], the proposed circuit is a dual-band power divider with power-dividing ratio of k^2. For good isolation, $R = 2Z_0$ is chosen [4].

(2) Discussion on achievable power-dividing ratio

It is noticed that the values of Z_2 and Z_{2s} depends on k. In general, the realizable characteristic impedance of a

microstrip line lies in the range from 20 Ω to 120 Ω. If $\theta_2 = 90°$ and $\theta_{2s} = 180°$ at f_0 are selected, k^2 could be in the range from 2 to 20. High power-dividing ratio is sustained.
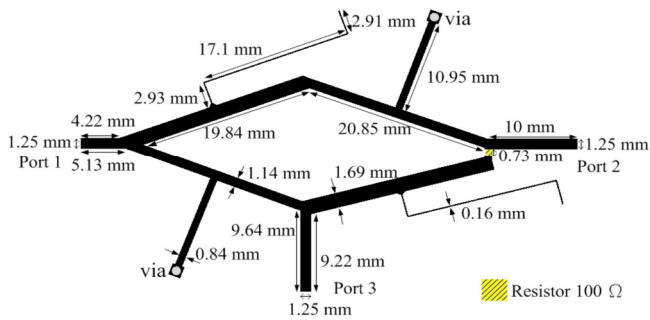

Fig. 2. Layout of the fabricated 16:1 power divider.

3. Experimental Results

A dual-band 16:1 ($k = 4$) power divider is designed to operate at $f_1/f_2 = 2.45/5.8$ GHz. It was implemented on a RO4003C substrate with a dielectric constant of 3.55 and thickness of 20 mils. $\theta_1 = \theta_{1s} = \theta_2 = 90°$ and $\theta_{2s} = 180°$ at 4.125 GHz are selected. $Z_1 = 52.4$ Ω, $Z_{1s} = 63.85$ Ω, $Z_2 = 40.6$ Ω, and $Z_{2s} = 118.12$ Ω are calculated from (1) – (4). Fig. 2 shows the layout of the power divider. Full-wave simulation was also performed with Keysight Momentum. Fig. 3 – 5 are return loss, port isolation, and power division ratio of the designed circuit. The measured return loss of Ports 1, 2, and 3 at f_1/f_2 are 29.0/14.8 dB, 22.0/21.3 dB, and 31.3/8.2 dB, respectively. The 13-dB bandwidth of S_{11} is 34.6% and 7.5% at the first and second frequency bands, respectively. The measured isolation ($1/|S_{32}|$) at f_1/f_2 are 24.6/18.3 dB. The simulated power dividing ratio at f_1/f_2 is $|S_{21}/S_{31}| = 12.3/17$ dB, while the measured data is 15.3/10.1 dB. The discrepancy is caused by frequency shift, and is enlarged due to the poor flatness of power-dividing ratio. Fig. 6 shows the phase difference. The simulated phase imbalance at f_1/f_2 is –0.17°/0.57°, while the measured imbalance is 6°/–5.77°.

4. Conclusion

A dual-band unequal Wilkinson power divider with high power-dividing ratio has been presented and validated by measurement. No reactive lump elements are required. Agreement between the simulated and measured results was observed.

References

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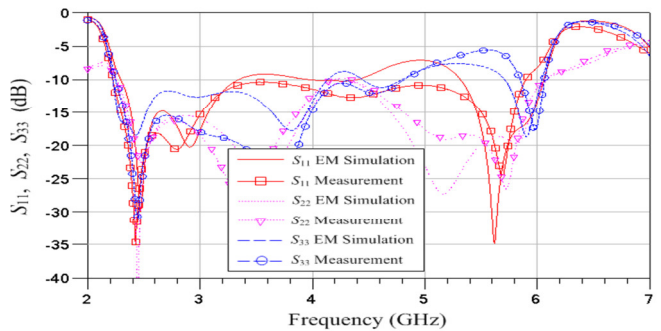
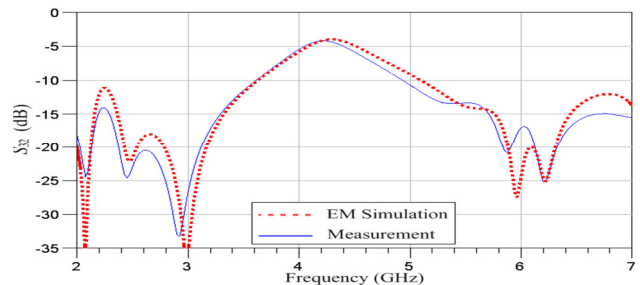Fig. 3. Simulated and measured return loss.

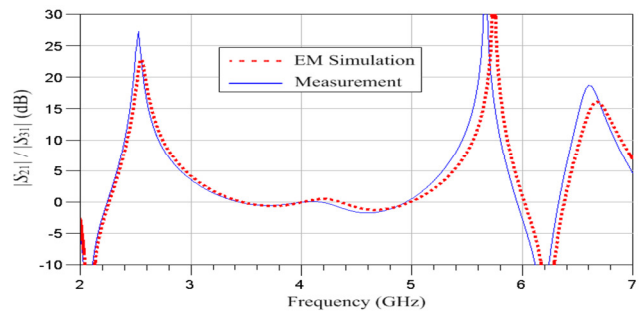Fig. 4. Simulated and measured port isolation.
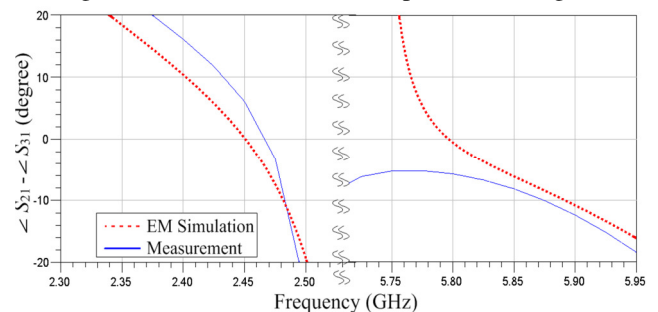

Fig. 5. Simulated and measured power-dividing ratio.

Fig. 6. Simulated and measured phase imbalance.