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 (λ/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.

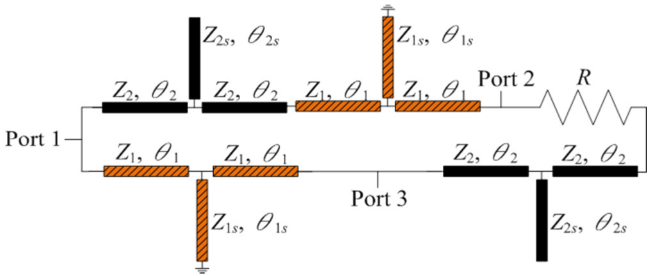

Fig. 1. Proposed dual-band unequal power divider.

(1) Theory and Equations

Port impedance of Z_0 = 50 Ω 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 θ_2 = 90° and θ_{2s} = 180° at f_0 are selected, k^2 could be in the range from 2 to 20. High power-dividing ratio is sustained.

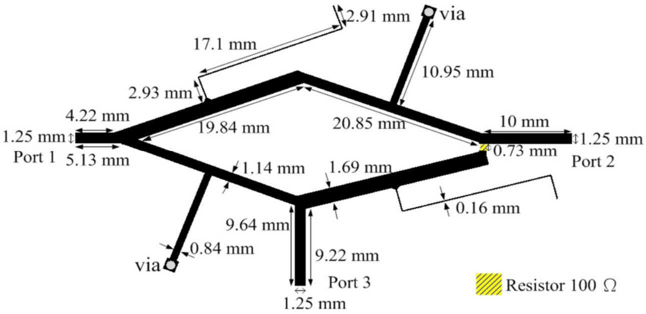

Fig. 2. Layout of the fabricated 16:1 power divider.

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 θ_{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.

Acknowledgment

This work was supported in part by Ministry of Science and Technology, Taiwan, R.O.C., under Grant MOST 104-2221-E-390-008-. The authors thank National Chip Implementation Center (CIC), National Applied Research Laboratories, Taiwan, R.O.C. for their support in simulation software.

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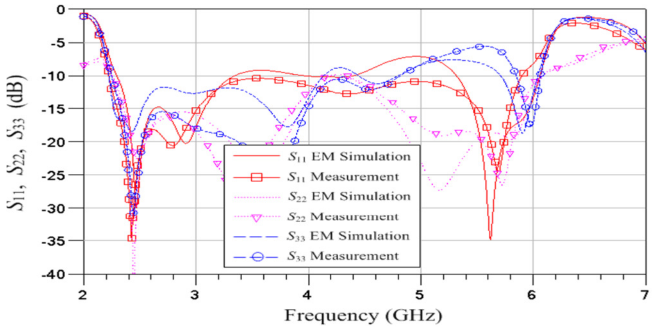

Fig. 3. Simulated and measured return loss.

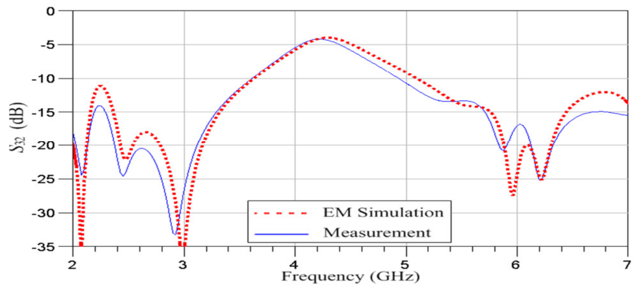

Fig. 4. Simulated and measured port isolation.

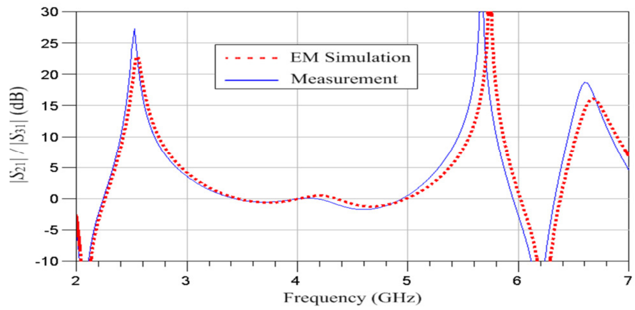

Fig. 5. Simulated and measured power-dividing ratio.

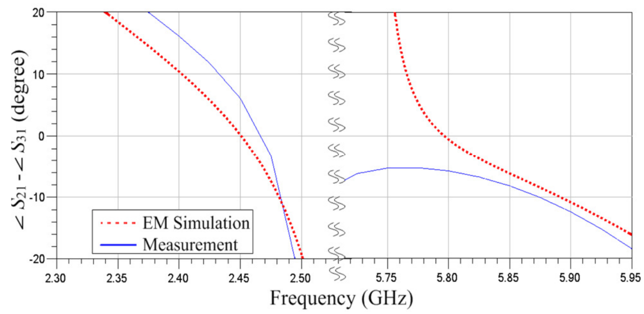

Fig. 6. Simulated and measured phase imbalance.