Progress In Electromagnetics Research, Vol. 138, 283–291, 2013

A COMPACT TRI-BAND POWER DIVIDER BASED ON TRIPLE-MODE RESONATOR

Wei Qiang Liu*, **Feng Wei, and Xiao Wei Shi**

National Key Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shaanxi 710071, China

Abstract—A compact tri-band power divider based on triple-mode resonator is proposed in this paper. This tri-mode resonator comprises a conventional half-wavelength resonator, a short stub and an open stub. The interdigital coupled-lines are introduced at the input and the output to improve the performance of this power divider. The proposed tri-band power divider working at 1.57 GHz, 2.45 GHz, 3.50 GHz is simulated and fabricated, and good agreement between the simulated results and the measured results are observed.

1. INTRODUCTION

Power dividers are important components of many microwave circuits and subsystems. They are widely used in antenna arrays, power amplifiers, mixers, phase shifters, especially the Wilkinson power divider [1–7]. With the development of wireless-communication systems, such as GSM (800/900 MHz), GPS L1 (1.57 GHz), WCDMA (2.1 GHz), ISM (2.45 GHz), WiMax (3.5 GHz), multiband power dividers are increasingly used in many microwave communication circuits. Many efforts have been carried out to produce various kinds of dual-band power dividers [8–13]. In 2003, Cesar Monzon showed dual-band performance with two-section transmission lines for the first time in [10]. In [11], the structure of this dual-band power divider consists of two branches of impedance transformer, each of which consists of two sections of transmission line with different characteristic impedance, and a parallel connection of a resistor, an inductor, and a capacitor. The proposed power divider can operate at two arbitrary frequencies. A dual-frequency power divider is designed with a dumbbell defected ground structure (DGS) in [12].

Received 26 January 2013, Accepted 10 March 2013, Scheduled 24 March 2013
* Corresponding author: Wei Qiang Liu (wqliu81@126.com).

The dumbbell DGS can reduce the size of this dual-frequency power divider and realize good performance. In [13], a compact dual-band power divider is presented. An allpass coupled lines section is used to realize the necessary impedance transformation at two selected frequencies. The aforementioned power dividers are only for dual-band applications. However, multiband power dividers are required in order to improve the utilization of frequency. Only a few tri-band applications are discussed so far [14–17]. In [15], a tri-band Wilkinson power divider is presented. The quarter-wavelength transformer in a conventional Wilkinson power divider is substituted a pair of two-section transmission line and a coupled line in between, but this tri-band power divider is too large. In [16], a tri-band Wilkinson power divider is presented by using resonators. This paper used an open-circuit stub connected with a resonator for the middle frequency and cascade another one with the same idea for the lower frequency. The tri-band power divider achieved good performance of the other two frequencies, but stop-band performances are not good. A triple-band power divider is designed based on the unique amplitude and dispersion characteristics of the recent composite right-/left-handed transmission line in [17]. The measured results revealed great performances close to the simulated results of this triple-band power divider. However, three resonant frequencies cannot be adjusted freely.

A compact tri-band power divider is designed in this paper. This power divider is based on a tri-band resonator and the interdigital coupled-lines structure. The tri-band resonator comprises a half-wavelength resonator, a short stub and an open stub. This power divider can work at GPS L1 (1.57 GHz), ISM (2.45 GHz) and WiMax (3.5 GHz). The first resonant frequency and the third frequency can be controlled freely. Respectively, the measured results of the power divider are good agreement with the simulation results at three frequencies.

2. THEORY AND ANALYSIS OF THE TRI-BAND POWER DIVIDER

The structure of the proposed tri-band power divider is shown in Figure 1. The size of this power divider is reduced by folding the transmission lines. The input signal from port 1 is equal divided into two output signals. The bandwidth of each signal is broadened effectively by the Interdigital coupled-lines with a rectangle defected ground structure (DGS) which is shown in Figure 2. A triple-mode resonator is used to realize the tri-band performance, which is introduced in [18]. Figure 3 shows the structure of this triple-mode

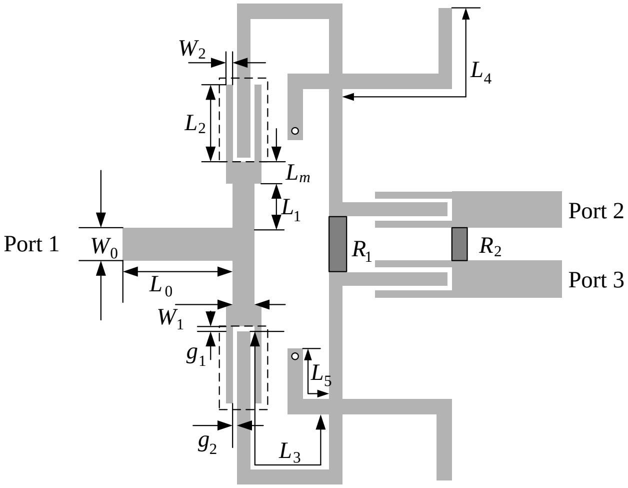


Figure 1. The structure of the proposed tri-band power divider.

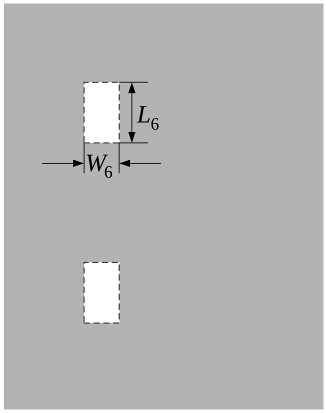


Figure 2. The rectangle defected ground structure (DGS).

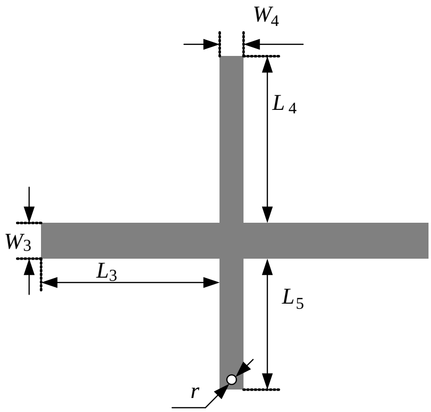


Figure 3. The triple-mode resonator.

resonator which comprises a half-wavelength resonator, a short stub and an open stub.

The triple-mode resonator is symmetrical to the center line of the open stub and the short stub. So the odd and even-mode method can be used to analyze it. In Figure 3, L_3 denotes the half length of the half-wavelength resonator, and L_4, L_5 denote the lengths of the open stub and the short stub.

For odd-mode excitation, the equivalent circuit is shown in

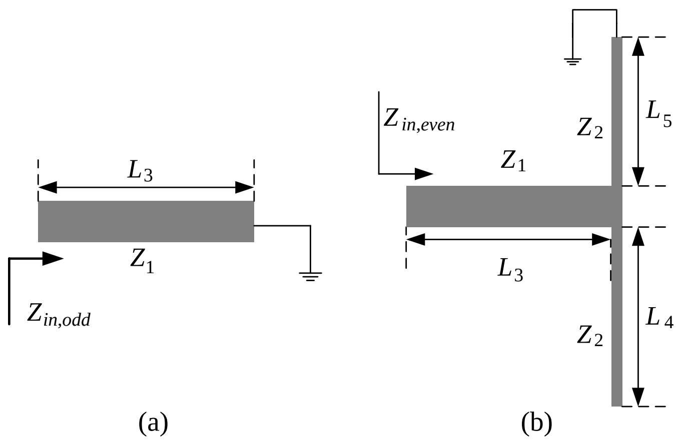


Figure 4. The equivalent circuit of the odd-mode and the even-mode. (a) Odd-mode equivalent circuit. (b) Even-mode equivalent circuit.

Figure 4(a). Z_1 is the characteristic impedance of the half-wavelength resonator. Because of the resonance condition of $Y_{in,odd} = 0$, the first odd-mode resonant frequency can be obtained from (1) and (2).

$$Z_{in,odd} = jZ_1 \tan \beta L_3 \tag{1}$$

$$f_{odd1} = \frac{c}{4L_3\sqrt{\varepsilon_e}} \tag{2}$$

where c is the speed of the light in free space, and ε_e denotes the effective dielectric constant of the substrate.

For even-mode excitation, the equivalent circuit is shown in Figure 4(b). Z_2 is the characteristic impedance of the open stub and the short stub. The even-mode equivalent circuit can be divided into two parts to analyze.

The short stub part is shown in Figure 5(a). Let $Z_1 = Z_2$, the first even-mode resonant frequency can be obtained from (3) and (4).

$$Z_{in,even1} = jZ_1 \tan \beta \left(L_3 + L_5\right) \tag{3}$$

$$f_{even1} = \frac{c}{4\left(L_3 + L_5\right)\sqrt{\varepsilon_e}} \tag{4}$$

The open stub part is shown in Figure 5 (b). Let $Z_1 = Z_2$, the second even-mode resonant frequency can be obtained from (5) and (6).

$$Z_{in,even2} = -jZ_1 \cot \beta \left(L_3 + L_4\right) \tag{5}$$

$$f_{even2} = \frac{c}{2\left(L_3 + L_4\right)\sqrt{\varepsilon_e}} \tag{6}$$

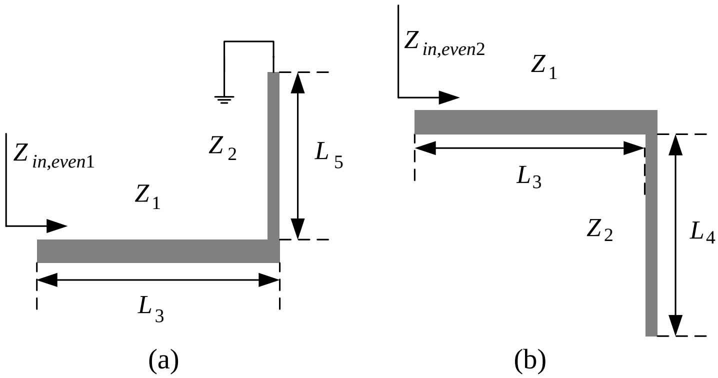


Figure 5. Two parts of even-mode equivalent circuit. (a) The short stub part. (b) The open stub part.

From (2), (4) and (6), $f_{even1} < f_{odd1} < f_{even2}$ can be obtained when $L_5 > 0$, and $L_4 < L_3$. So the first resonant frequency can be controlled by L_3 andL_5. The second resonant frequency can be controlled by tuning L_3. The third resonant frequency can be controlled by tuning L_3 and L_4.

3. IMPLEMENTATION AND RESULTS

The proposed tri-band power divider is designed and fabricated on a common substrate with a thickness of 1 mm and relative dielectric constant of 2.65. For the three resonant frequencies which is 1.57 GHz, 2.45 GHz and 3.50 GHz, the parameters of the triple-mode resonator can be deduced from (2) (4) and (6). $W_3 = 1.20$ mm, $L_3 = 19.25$ mm, $W_4 = 0.80$ mm, $L_4 = 12.80$ mm, $L_5 = 5.80$ mm, $r = 0.35$ mm. In order to get good isolation, two isolation resistors are added on the power divider. $R_1 = 100\,\Omega$, $R_2 = 120\,\Omega$. Finally, the tri-band power divider is designed and simulated in Ansoft HFSS, and the parameters of this power divider are obtained. $W_0 = 2.70$ mm, $L_0 = 8.90$ mm, $W_1 = 1.50$ mm, $L_1 = 5.15$ mm, $W_2 = 0.55$ mm, $L_2 = 7.40$ mm, $L_m = 2.80$ mm, $g_1 = 0.20$ mm, $g_2 = 0.20$ mm, $W_6 = 3.30$ mm, $L_6 = 7.70$ mm.

Figure 6 shows the simulated frequency responses of the tri-band power divider under different values of L_5 when L_3 and L_4 are fixed. The return loss of the first resonant frequency varies with different values of L_5. When the value of L_5 increases, the first resonant frequency decreases. The return loss of the second and the third resonant frequency is unchanged. Figure 7 shows the simulated

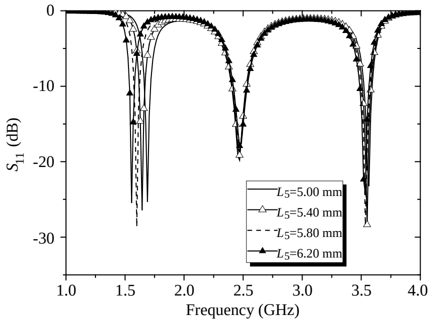


Figure 6. The simulated return loss under different values of L_5 ($L_3 = 19.25\,\text{mm}$, $L_4 = 12.80\,\text{mm}$).

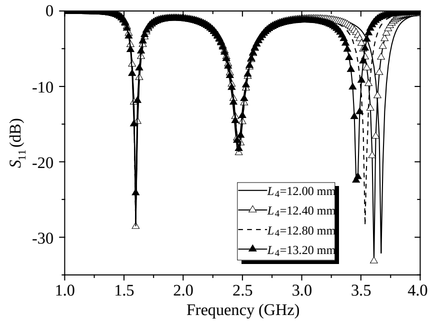
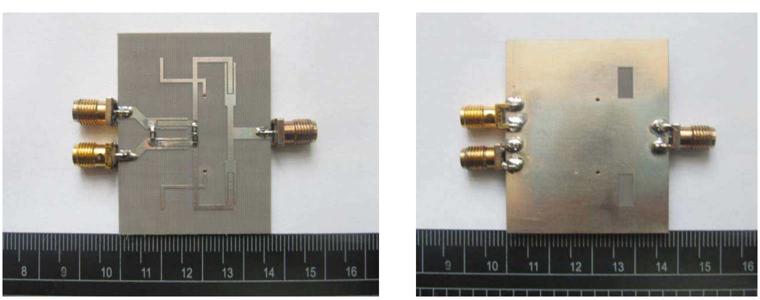


Figure 7. The simulated return loss under different values of L_4 ($L_3 = 19.25\,\text{mm}$, $L_5 = 5.80\,\text{mm}$).

frequency responses of the tri-band power divider under different values of L_4 when L_3 and L_5 are fixed. The return loss of the third resonant frequency varies with different values of L_4. When the value of L_4 increases, the third resonant frequency decreases. The return loss of the first and the second resonant frequency is unchanged. In addition, the second resonant frequency of the tri-band power divider varies with different values of L_3 from (2). When the value of L_3 increases, the second resonant frequency decreases.

The photograph of the proposed tri-band power divider is shown in Figure 8. The over all dimension of the fabricated tri-band power divider circuit is $48.00\,\text{mm} \times 36.75\,\text{mm}$. Compared with the majority of tri-band power dividers, the size of the presented power divider is reduced distinctly.



(a) (b)

Figure 8. Photograph of the proposed power divider. (a) Top view (b) Bottom view.

The power divider was measured by Agilent N5230A network analyzer. Figure 9 shows the S-parameter simulation and measurement results for the proposed tri-band power divider. The measured return loss and insertion loss in Figure 9 revealed great performances close to the simulated results of this triple-band power divider. As shown in Figure 9, good matching for outputs at designed frequencies is obtained. The return loss of the power divider at 2.45 GHz and 3.5 GHz are below −20 dB, and the return loss at 1.75 GHz is close to −20 dB. This achievement is good and shows that almost half the input power at port 1 is received at output ports 2 and 3. The measured 3-dB frequency ranges (fractional bandwidths) for the three passbands centered at 1.57, 2.45, and 3.5 GHz are 1.56–1.66 GHz (6.2%), 2.37–2.62 GHz (10%) and 3.49–3.64 GHz (4.2%).

The isolation of the tri-band power divider and the transmission coefficient from port 1 to port 3 are shown in Figure 10. The measured results of the power divider are in good agreement with the simulation results at every frequency. The measured transmission coefficient from port 1 to port 3 at three passbands are about −3 dB, so it is in good agreement with transmission coefficient from port 1 to port 2. The measured and simulated isolation at three passbands are below −20 dB. The measure isolation are −38.5 dB, −24.0 dB, −29.5 dB at 1.57 GHz, 2.45 GHz, 3.5 GHz. Respectively, based on the above results, the proposed design method of tri-band power divider is demonstrated.

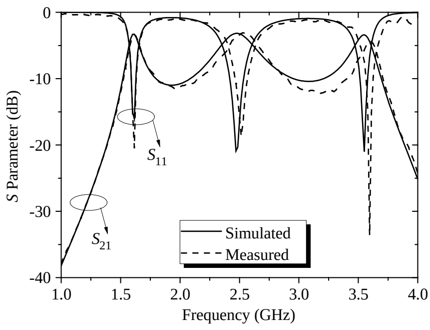


Figure 9. The simulation and measurement results of S_{11} and S_{21}.

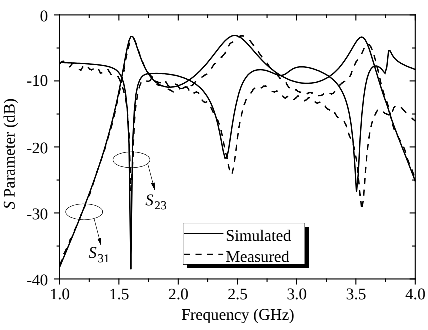


Figure 10. The simulation and measurement results of S_{23} and S_{31}.

4. CONCLUSION

In this paper we have proposed a tri-band power divider with a triple-mode resonator which comprises a half-wavelength resonator, a short stub and an open stub. The size of this power divider is reduced by folding the transmission lines. This power divider can work at GPS L1 (1.57 GHz), ISM (2.45 GHz) and WiMax (3.5 GHz). The first resonant frequency and the third frequency can be controlled freely. The measured results verified the tri-band operation and showed good agreement with simulation results. The proposed power divider can be useful for many tri-band applications, which are more demanding in near future.

ACKNOWLEDGMENT

This work was supported by the Fundamental Research Funds for the Central Universities (K50511020013).

REFERENCES

1. El-Tager, A. M. E., A. M. El-Akhdar, and H. M. El-Henawy, “Analysis of coupled microstrip lines for quad-band equal power dividers/combiners,” *Progress In Electromagnetics Research B*, Vol. 41, 187–211, 2012.
2. Chang, L., C. Liao, L.-L. Chen, W. Lin, X. Zheng, and Y.-L. Wu, “Design of an ultra-wideband power divider via the coarse-grained parallel micro-genetic algorithm,” *Progress In Electromagnetics Research*, Vol. 124, 425–440, 2012.
3. Deng, P.-H., J.-H. Guo, and W.-C. Kuo, “New Wilkinson power dividers based on compact stepped-impedance transmission lines and shunt open stubs,” *Progress In Electromagnetics Research*, Vol. 123, 407–426, 2012.
4. Zhang, H., X.-W. Shi, F. Wei, and L. Xu, “Compact wideband gysel power divider with arbitrary power division based on patch type structure,” *Progress In Electromagnetics Research*, Vol. 119, 395–406, 2011.
5. Wang, D., H. Zhang, T. Xu, H. Wang, and G. Zhang, “Design and optimization of equal split broadband microstrip Wilkinson power divider using enhanced particle swarm optimization algorithm,” *Progress In Electromagnetics Research*, Vol. 118, 321–334, 2011.
6. Wu, Y. and Y. Liu, “An unequal coupled-line wilkinson

power divider for arbitrary terminated impedances," *Progress In Electromagnetics Research*, Vol. 117, 181–194, 2011.

7. Huang, S., X. Xie, and B. Yan, "K band Wilkinson power divider based on a taper equation," *Progress In Electromagnetics Research Letters*, Vol. 27, 75–83, 2011.
8. Li, B., X. Wu, N. Yang, and W. Wu, "Dual-band equal/unequal Wilkinson power dividers based on coupled-line section with short-circuited stub," *Progress In Electromagnetics Research*, Vol. 111, 163–178, 2011.
9. Li, J., Y. Wu, Y. Liu, J. Shen, S. Li, and C. Yu, "A generalized coupled-line dual-band Wilkinson power divider with extended ports," *Progress In Electromagnetics Research*, Vol. 129, 197–214, 2012.
10. Monzon, C., "A small dual-frequency transformer in two sections," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, 1157–1161, 2003.
11. Lei, W., et al., "A dual-frequency Wilkinson power divider," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, 278–284, 2006.
12. Hedayati, M. K., et al., "A miniaturized dual-frequency Wilkinson power divider using defected ground structure," *2010 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, 1–5, 2010.
13. Tang, X. and K. Mouthaan, "Compact dual-band power divider with single allpass coupled lines sections," *Electronics Letters*, Vol. 46, 688–689, 2010.
14. Miao, C., B. Li, G. Yang, N. Yang, C. Hua, and W. Wu, "Design of unequal Wilkinson power divider for tri-band operation," *Progress In Electromagnetics Research Letters*, Vol. 28, 159–172, 2012.
15. Chen, H.-H. and Y.-H. Pang, "A tri-band Wilkinson power divider utilizing coupled lines," *2011 IEEE International Symposium on Antennas and Propagation (APSURSI)*, 25–28, 2011.
16. Wang, Z., et al., "Tri-band Wilkinson power divider using resonators," *2011 IEEE Radio and Wireless Symposium (RWS)*, 287–290, 2011.
17. Ochetan, A. B., G. Lojewski, H. Belyamoun, and S. Zouhdi, "Triple-band power divider based on the composite right-/left-handed metamaterial transmission line for telecommunication applications," *ELMAR*, 145–148, 2011.
18. Chen, F. C., et al., "Tri-band bandpass filter using stub loaded resonators," *Electronics Letters*, Vol. 44, 747–749, 2008.