Compact Wilkinson power divider with modified T-types impedance transformers for harmonics suppression

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\textbf{Abstract:} This paper presents a compact Wilkinson power divider with enhanced harmonics suppression. By replacing the quarter-wavelength impedance transformers in the traditional Wilkinson power divider with modified T-type impedance transformers (MTITs), three transmission zeros can be created at the second, third and fourth harmonic frequencies. The impedance transformers are folded to reduce the size of the power divider. For validation, a power divider operating at 1 GHz is implemented. Results indicate that the proposed structure can effectively be used for high order harmonics suppression while maintaining a good in-band performance and compact size.

\textbf{Keywords:} power divider, Wilkinson divider, harmonic suppression

\textbf{Classification:} Microwave and millimeter wave devices, circuits, and systems

\textbf{References}

[1] E. Wilkinson: IEEE Trans. Microw. Theory Techn. 8 (1960) 116. DOI:10.1109/TMTT.1960.1124668
[2] C. M. Lin, H. H. Su, J. C. Chiu and Y. H. Wang: IEEE Microw. Wireless Compon. Lett. 17 (2007) 700. DOI:10.1109/LMWC.2007.905595
[3] F. Zhang and C. F. Li: Electron. Lett. 44 (2008) 422. DOI:10.1049/el:20083693
[4] M. Gil, J. Bonaiche, I. Gil, J. García-García and F. Martín: IET Microw. Antennas Propag. 1 (2007) 73. DOI:10.1049/iet-map:20050302
[5] D. J. Woo and T. K. Lee: IEEE Trans. Microw. Theory Techn. 53 (2005) 2139. DOI:10.1109/TMTT.2005.848772
[6] H. W. Liu, Z. F. Li, X. W. Sun and J. F. Mao: IEEE Microw. Wireless Compon. Lett. 15 (2005) 55. DOI:10.1109/LMWC.2004.842809
[7] K. H. Yi and B. Kang: IEEE Microw. Wireless Compon. Lett. 13 (2003) 178. DOI:10.1109/LMWC.2003.811670
[8] J. Zhang, L. Li, J. Gu and X. Sun: IEEE Microw. Wireless Compon. Lett. 17 (2007) 661. DOI:10.1109/LMWC.2007.903453
[9] H. Liu, Z. Shi, A. Boutejdar, R. H. Knoechel and K. F. Schuenemann: Microw. Opt. Technol. Lett. 50 (2008) 601. DOI:10.1002/mop.23172
1 Introduction

Power dividers are widely used in microwave and millimeter-wave systems for signal splitting or combining. The Wilkinson power divider is considered as one of the most popular used power divider [1]. However, the quarter-wavelength transmission-line sections in the Wilkinson power dividers result in the presence of the spurious passbands. Thus, techniques to achieve harmonics suppression are continually being studied [2, 3, 4, 5, 6, 7, 8].

Some structures such as electromagnetic bandgap (EBG), defected ground structure (DGS), and periodic photonic bandgap (PBG) have been used for harmonics suppression due to their slow wave and bandstop effect [2, 3, 4, 5, 6]. However, they introduce complication in the fabrication of such circuits. In [7], an open stub of length $\lambda/4n$ is placed at the center of each $\lambda/4$ branch to suppress the nth harmonic and its odd multiples, but an additional inductor is required. In [8], a pair of anti-coupled lines in series with a low impedance line are used for harmonic suppression, which results in poor return loss at all ports. Spur-line is used in [9] to suppress the high order harmonics. The method using high-low impedance resonator cells is presented in [10] to reduce the size and suppress high order harmonics.

In this letter, a compact power divider with enhanced second, third and forth harmonic suppression is proposed. Two modified T-type impedance transformers (MTITs) are used in the design to achieve high order harmonics suppression. To achieve compact size, meander lines are adopted. As an advantage, only a single resistor is needed for isolation. Measurements indicate that the fabricated power divider has an input return loss better than 18 dB, and less than 3.4 dB insertion loss at 1 GHz. The output return loss as well as the isolation are greater than 23 dB. The design also has about 28, 37, and 34 dB suppression for the second, third, and forth harmonics, respectively. Furthermore, the size of the power divider is only $15.3 \times 7.2$ mm$^2$, which corresponds to a compact electrical size of $0.086 \lambda_g \times 0.041 \lambda_g$, where $\lambda_g$ is the guided wavelength at 1 GHz.

2 Circuit design

Fig. 1 shows the configuration of the proposed power divider. The MTIT consists of two parallel coupled-lines and an open stub. In addition to the transmission zero introduced by the open stub [5], the coupled-line sections will excite two more transmission zeros in the stopband. In order to illustrate the design theory, simulated S-parameters with different dimensions of L1, L3, W1 and W3 have been studied.

As shown in Fig. 2(a), when L1 increases from 3 to 5 mm with steps of 1 mm, the transmission zero at lower band will move from 2.5 to 1.7 GHz, which has no significant effect on the locations of other two transmission zeros. Similarly, in Fig. 2(b), by increasing L3 from 4.2 to 6.2 mm, the frequency of the transmission
zero at upper band will decrease and the locations of other two transmission zeros are not affected. Thus, the transmission zeros can be added at the desired position by choosing the lengths of two coupled-line sections and the open stub properly. From Fig. 2(c) and (d) it can be seen that the different characteristic impedances of the coupled-line sections only affect the return loss at the operating frequency.

From the above analysis, if we can choose the dimensions of three sections properly, three transmission zeros at desired positions and good inband return loss can be achieved. In addition, to realize a compact size, meander lines are adopted.

Fig. 1. Configuration of the proposed power divider.

Fig. 2. Simulated S-parameters of proposed power divider with different dimensions of L1, L3, W1 and W3: (a) Simulated $S_{21}$ with different L1, (b) Simulated $S_{21}$ with different L3, (c) Simulated $S_{11}$ with different W1, (d) Simulated $S_{11}$ with different W3
3 Simulation and measured results

The fabricated power divider is implemented on Rogers RO4350 with thickness 0.508 mm and dielectric constant 3.66. Fig. 3 shows the photograph of the fabricated power divider. The dimensions are: $W_1 = 0.2$ mm, $S_1 = 0.33$ mm, $L_1 = 4.3$ mm, $g_1 = 0.25$ mm, $W_2 = 1.1$ mm, $S_2 = 0.3$ mm, $W_3 = 0.2$ mm, $S_3 = 0.12$ mm, $L_3 = 5.2$ mm, $g_3 = 0.25$ mm, $d = 0.41$ mm. The isolation resistor is $R = 100$ $\Omega$, which is similar to the traditional Wilkinson power divider. Fig. 4 illustrates the measured S-parameters and the full EM simulation (ANSOFT HFSS12) results.

The measured insertion loss is less than 3.4 dB from DC to 1.22 GHz, while the return loss is better than 10 dB. The insertion loss and return loss are 3.39 dB and 18.29 dB at 1 GHz. The return loss and isolation of both output ports are better than 23 dB. The 15 dB attenuation band from 1.9–4.47 GHz has been achieved attributed to those transmission zeros. Furthermore, the fabricated power divider has a small electrical size of $0.086 \lambda_g \times 0.041 \lambda_g$, where $\lambda_g$ is the guided wavelength at 1 GHz. Table I shows the comparisons with some former designs. The dimensions of each divider is measured without 50 $\Omega$ transmission lines at input and output ports. It has been shown that the performance of the proposed power divider is comparable with other modified structures. Meanwhile, it has the properties of smaller size and enhanced high order harmonics suppression.

![Photograph of the fabricated power divider.](image_url)
Conclusion

The implementation of a compact Wilkinson power divider, which can suppress the 2nd, 3rd and 4th harmonic outputs, is described in this letter. The proposed structure can achieve a good inband performance and wide stopband bandwidth without backside etching or lumped reactive component. The measurements show good agreement with the simulations, which confirms the feasibility of the design method. In addition, the proposed power divider may be a preferred option for some applications which require high order harmonics suppression and compact size.

Table 1. Comparisons with previous works.

| Ref. | Freq. (GHz) | Insertion Loss (dB) | Return Loss (dB) | Harmonic Suppression (dB) | Size ($\lambda_e \times \lambda_g$) |
|------|-------------|---------------------|------------------|---------------------------|-----------------------------|
| [2]  | 2.4         | 3.4                 | 23               | 32.5@3rd 12@5th          | 0.39 × 0.33                 |
| [3]  | 1.8         |                     |                  | 26@2nd 25@3rd           | 0.16                        |
| [4]  | 1.5         |                     | 40               | 18@2nd 15@3rd          | 0.9                         |
| [7]  | 2.05        | 3.3                 | 34               | 44@3rd                  | 0.33 × 0.33                 |
| [8]  | 1.8         | 3.67                | 12               | 57@3.4 GHz 52@6.2 GHz    | 1.26                        |
| [9]  | 3.12        | 3.7                 | 36.3             | 30.8@2nd 37.6@3rd       |                             |
| [10] | 2.65        | 3.3                 | 27               | 29@3rd 34@5th          | 0.36                        |
| This work | 1           | 3.4                 | 18               | 28@2nd 37@3rd 34@4th    | 0.086 × 0.041               |

Fig. 4. Simulated and measured S-parameters of proposed power divider. (a) $S_{11}$ and $S_{21}$ (b) $S_{22}$ and $S_{32}$