Wireless Personal Communications (2019) 109:1571–1579
https://doi.org/10.1007/s11277-019-06628-z

Design of a Modified Wilkinson Power Divider with Size Reduction and Harmonics Suppression using Triangle-Shaped Resonators

Masoud Heydari[1] · **Parastoo Rostami**[1] · **Saeed Roshani**[2]

Abstract

In this study, a miniaturized microstrip Wilkinson power divider (WPD) with harmonic elimination using low pass filter is proposed. In proposed design, two large conventional quarter wavelength transmission lines are replaced with compact low pass filters. Applied low pass filters are consisted of three triangle resonators, which result in harmonics suppression and size reduction of the proposed WPD. The proposed WPD has 56% size reduction compared to the conventional one. The proposed divider correctly works at 2 GHz and suppresses second to eighth harmonics with more than 20 dB attenuation level. According to the experimental results the insertion loss of the proposed design is less than 0.1 dB n pass band. The return losses at all ports and output ports isolation parameters are better than 20 dB and 26 dB, respectively, which shows good performance of the proposed device.

Keywords Wilkinson power divider (WPD) · Triangle-shaped resonator · Harmonic suppression

1 Introduction

One of the widely used device in the modern wireless circuits and systems is Wilkinson power divider (WPD). Input signals are divided by WPDs into two or more signals [1–3] and used in many systems such as antenna arrays, power amplifiers, feeding networks. A conventional WPD, consists of two quarter wavelength (λ/4) lines and a 100 ohms isolation resistor between two lines.

Relatively large size and presence of unwanted harmonic in the frequency response are the main drawbacks of the conventional divider. So far, various methods are used to suppress unwanted harmonics and decrease the circuit size. In [4] by using a π type structure,

---

✉ Saeed Roshani
s_roshany@yahoo.com

[1] Young Researchers and Elite Club, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

[2] Department of Electrical Engineering, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

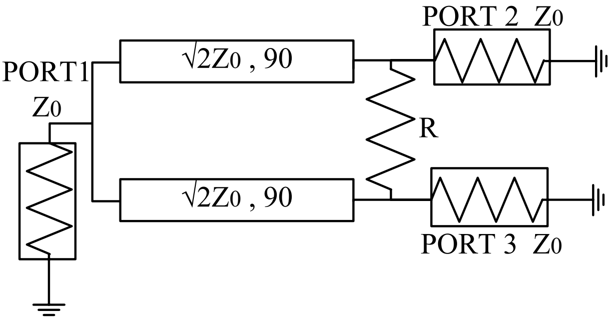


Fig. 1 The conventional Wilkinson power divider

which includes a capacitor between two lines, instead of quarter wavelength transmission line, 3rd harmonic of the power divider is suppressed; however, this design suffers from large size.

In [5], a divider with wide pass-band, using ring resonator is designed, which suppresses the unwanted harmonics. The return loss parameter at the operating frequency is not good. In [6], a simple power divider is presented by using microstrip open stubs, which suppresses 2nd to 6th harmonics. In [7] a compact WPD with anti-coupled line and capacitive load is reported. This divider has good harmonics suppression but, isolation parameter in this design is not very good.

Except using resonators [5] and coupling lines [7], some other methods such as the defected ground structure (DGS) [8], and photonic band gap (PCB) [9], are used to design compact WPD with harmonics suppression. The main drawback of these works is the complex fabrication process.

In this presented paper, a miniaturized WPD using low pass filter instead of large conventional quarter wavelength line is proposed. Furthermore, the proposed WPD has low insertion loss, wide harmonics suppression from 2nd harmonic to 8th and good isolation. In design procedure at first, a low pass filter using triangle-shaped resonators is described step by step. Then, the designed power divider by using the proposed low pass filter, has been presented.

2 Design Process

The structure of the conventional Wilkinson power divider (WPD) is depicted in Fig. 1. In the conventional divider structure an isolation resistor ($R = 100\Omega$) and two quarter wavelength ($\lambda/4$) transmission lines with $\sqrt{2}\, Z_0$ impedance are used, which occupied relatively large size. In the proposed WPD, the relatively long $\lambda/4$ transmission lines, which used in conventional divider, are replaced by low pass filter structure.

2.1 Resonator Design

The layout of the main resonator (triangular shape) is demonstrated in Fig. 2a. In the main resonator structure a high impedance line with short length and a triangle shaped resonator is connected to a high impedance transmission line. The dimensions of the designed resonator

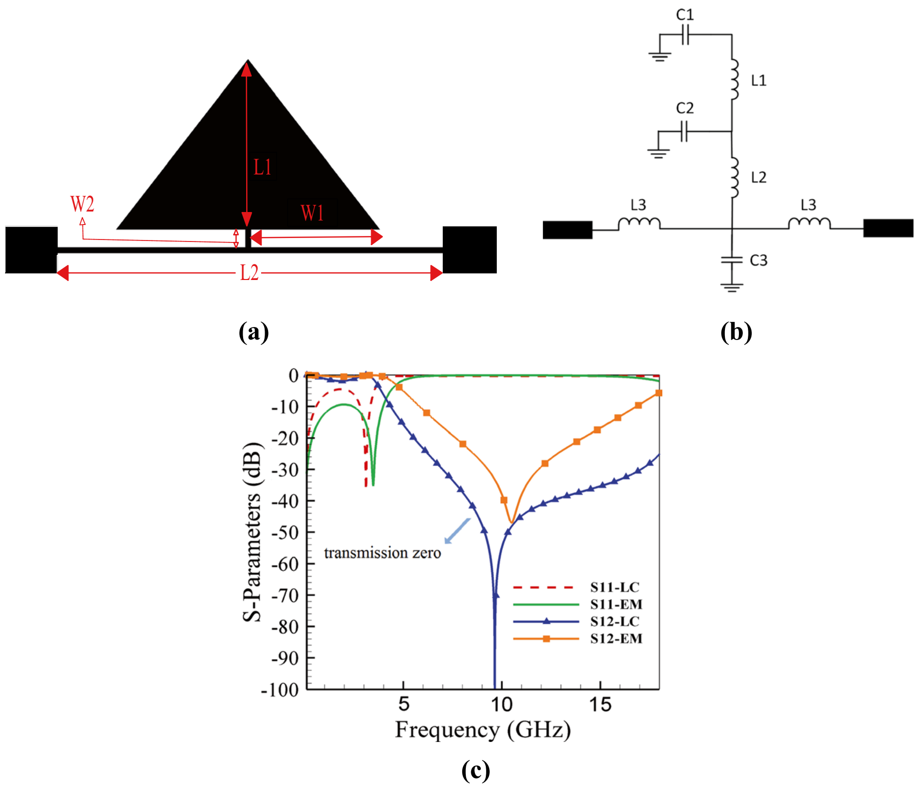


Fig. 2 The main resonator: **a** Layout, **b** LC equivalent circuit, **c** LC and EM simulation results

Table 1 The optimized L-C parameters of the main resonator

Parameter	L_1(nH)	L_2(nH)	L_3(nH)	C_1(pF)	C_2(pF)	C_3(pF)
Value	0.32	0.37	5.72	0.316	0.234	0.158

are as follows: $L_1 = 2.78$ mm, $W_1 = 2.88$ mm, $L_2 = 8.65$ mm, $W_2 = 0.28$ mm. The equivalent LC circuit of the main resonator is depicted in Fig. 2b. According to Eqs. (1) and (2) the low and high impedance transmission lines, are obtained as follows [10]:

$$l_s = \frac{1}{\omega} \times z_s \times \sin\left(\frac{2\pi}{\lambda_g} l\right) \tag{1}$$

$$c_s = \frac{1}{\omega} \times \frac{1}{z_s} \times \tan\left(\frac{\pi}{\lambda_g} l\right) \tag{2}$$

where z_s is the characteristic impedance of the applied transmission line, λ_g is the guided wavelength at the cut-off frequency and l is the physical length of line.

Table 1 shows the optimized L-C parameters, which calculated by ADS software.

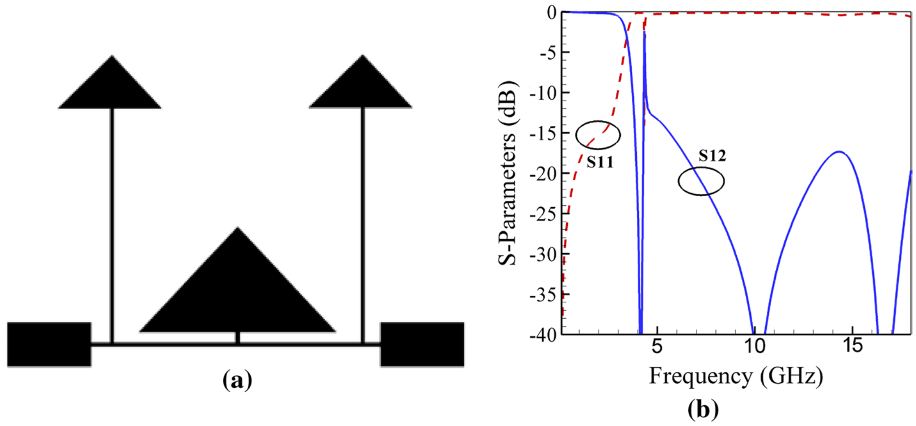


Fig. 3 Primary low pass filter: **a** Layout, **b** EM simulation results

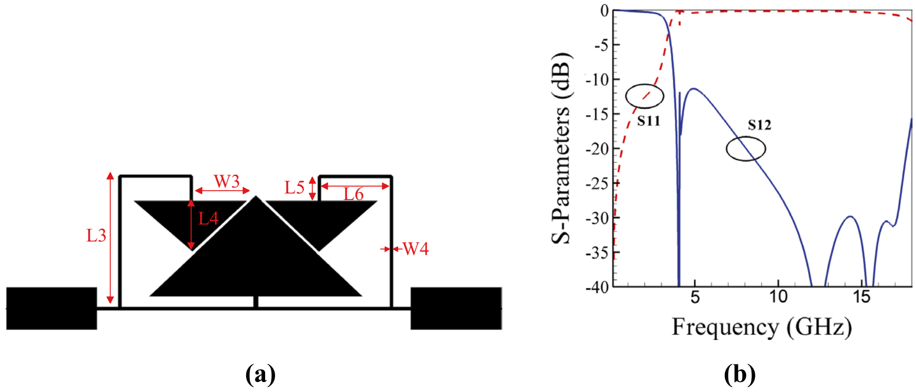


Fig. 4 Proposed low-pass filter: **a** Layout, **b** EM simulation results

S-Parameters simulation of the main resonator are depicted in Fig. 2c. Both of the EM and LC simulations responses are depicted. The agreement between curves are proved the validity of the equivalent LC circuit.

In order to improve the sharpness of transition-band and achieve wide harmonic suppression, two triangle shaped resonators are Inserted in both sides of the main resonator. The layout of the primary low pass filter is illustrated in Fig. 3a. The EM simulation results of the S-parameters for the primary low pass filter is illustrated in Fig. 3b. As seen in Fig. 3b, these three sections, are created three transmission zeroes.

Finally, in order to have better results and also reduce the circuit size of the primary filter, the long lines of symmetrical resonators have been bended. So the layout of the proposed lowpass filter and the EM simulations results of the filter are illustrated in Fig. 4a, b, respectively. The dimensions of the proposed filter are as fallow: $L_3 = 3.63$ mm, $L_4 = 1.4$ mm, $L_5 = 0.72$ mm, $L_6 = 1.89$ mm and $W_3 = 1.5$ mm, $W_4 = 0.1$ mm. As shown in Fig. 4b, the proposed triangle-shaped low pass filter creates three transmission zeroes in 4 GHz, 12.6 GHz and 15.5 GHz frequencies.

Fig. 5 The layout of the proposed compact WPD

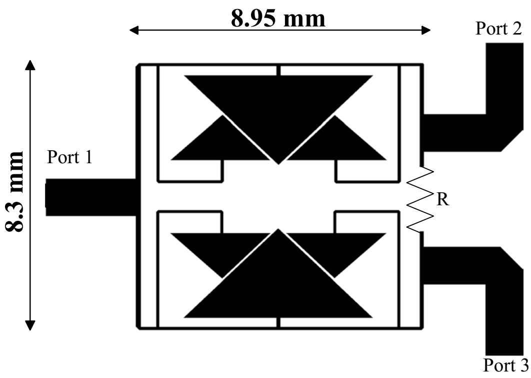
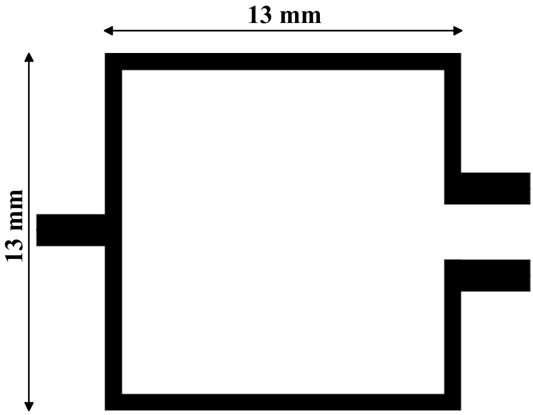


Fig. 6 The layout of the conventional WPD at 2 GHz



2.2 Power Divider Design

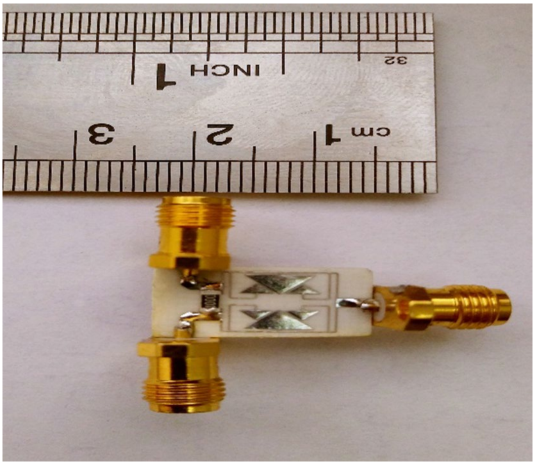
By inserting two proposed LPFs symmetrically instead of quarter wavelength lines in conventional power divider, a compact WPD is proposed as illustrated in Fig. 5. In this structure the 100 Ω isolation resistor is used.

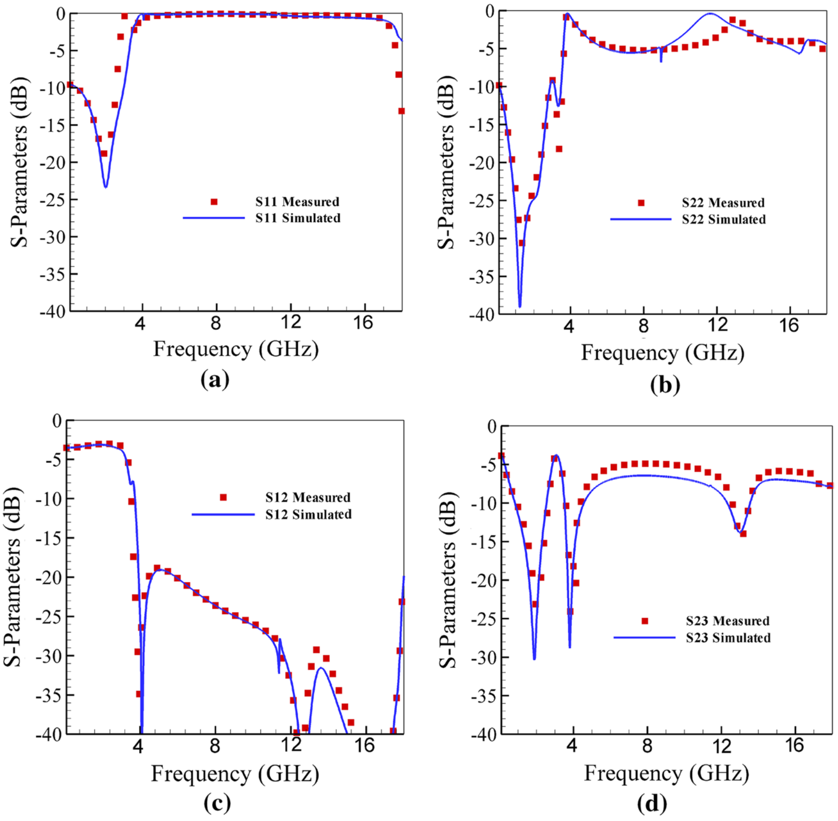
3 Simulated and Measured Results

The proposed WPD is fabricated on the Rogers4003c substrate with a dielectric constant of 3.38, thickness of 20 mil and loss tangent of 0.0022. The overall dimension of the fabricated device is 8.3 mm × 8.95 mm (0.09 λg × 0.097 λg), where λg is the guided wavelength of the center frequency (2 GHz). The proposed divider has about 56% size reduction compared to the conventional 2 GHz WPD, which shown in Fig. 6. The fabricated image of the designed WPD is illustrated in Fig. 7.

Figure 8 shows the measured and simulated S-parameters of the proposed WPD. According to the Fig. 8a, b, the experimental results show that at the operating frequency of 2 GHz the input (S_{11}) and output ($S_{22} = S_{33}$) return losses are better than 20 dB. From the

Fig. 7 The fabricated image of the proposed divider





(a) (b) (c) (d)

Fig. 8 EM simulation and experimental scattering parameters results: **a** the input return loss **b** the output return loss **c** the insertion loss **d** the isolation response

Table 2 A comparison among some reported works and the proposed WPD

References	FBW (%)[a]	Center frequency (GHz)	Harmonic suppressions (dB)								Size reduction (%)
			2nd	3rd	4th	5th	6th	7th	8th	9th	
[11]	48	2.65	–	29	–	34	–	–	–	–	36.5
[12]	–	2	–	53	25	56	20	–	–	–	29.3
[13]	–	0.9	–	22	–	–	–	–	–	–	47
[14]	34	1	31	50	20	31	45	21	15	–	45
[15]	21	1	30	30	20	20	–	–	–	–	55
This work	59	2	22	20	23	25	31	33	42	21	56

[a] $\mathrm{FBW}(\%) = \frac{f_2 - f_1}{0.5(f_1 + f_2)} \times 100$

measurement results in Fig. 8c could be observed that, the insertion loss at the 2 GHz frequency is less than 0.1 dB ($S_{12}=S_{13}=3 \pm 0.1$). As seen in Fig. 8d the output ports isolation (S_{23}) parameter is better than 26 dB.

As seen in Fig. 8a, from Eq. (3) 59% fractional bandwidth (1.44–2.66 GHz) was observed from measured results by considering $|S_{11}|$ greater than 15 dB.

Moreover, as seen in Fig. 8c the proposed divider features a wide range of harmonics suppression from 2nd up to 9th harmonic (4–18 GHz) with better than 20 dB attenuation level.

A performance comparison among some reported works and the proposed WPD are listed in Table 2. The results show that the proposed divider has very good specifications compare to others works.

$$FBW\,(\%) = \frac{f_2 - f_1}{0.5\left(f_1 + f_2\right)} \times 100 \tag{3}$$

4 Conclusion

In this paper, a compact Wilkinson power divider (WPD) with ultra wide stop band (4–18 GHz) and low insertion loss with 2 GHz operating frequency is designed and fabricated. By using a low pass filter based on triangle-shaped resonators instead of quarter wavelength lines of a conventional divider, not only the unwanted harmonics from 2nd to 9th are suppressed, but also the size of the divider is reduced over 56% compared with the conventional divider. Moreover the proposed WPD has 59% fractional bandwidth (1.44–2.66 GHz). Good agreement are observed among simulation and experimental results.

References

1. Tang, C., Lin, X., Fan, Y., & Song, K. (2016). A wideband power divider with bandpass response. *International Journal of Microwave and Wireless Technologies, 8*(3), 583–590.
2. Burdin, F., Podevin, F., & Ferrari, P. (2016). Flexible and miniaturized power divider. *International Journal of Microwave and Wireless Technologies, 8*(3), 547–557.

3. Song, K., Zhou, Y., Fan, M., Zhu, Y., & Fan, Y. (2017). Wide-stopband bandpass-filtering power divider with high-frequency selectivity. *International Journal of Microwave and Wireless Technologies, 9*(10), 1931–1936.
4. Wang, X., Ma, Z., Yoshikawa, M., Kohagura, J., Tokuzawa, T., Kuwahara, D., et al. (2017). Mixed π type structure in Wilkinson power divider design with 3rd harmonic suppression. *Microwave and Optical Technology Letters, 59*(6), 1245–1248.
5. Gao, S. S., Sun, S., & Xiao, S. (2013). A novel wideband bandpass power divider with harmonic-suppressed ring resonator. *IEEE Microwave and Wireless Components Letters, 23*(3), 119–121.
6. Hayati, M., Roshani, S., & Roshani, S. (2013). A simple Wilkinson power divider with harmonics suppression. *Electromagnetics, 33*(4), 332–340.
7. Zhang, J., Li, L., Gu, J., & Sun, X. (2007). Compact and harmonic suppression Wilkinson power divider with short circuit anti-coupled line. *IEEE Microwave and Wireless Components Letters, 17*(9), 661–663.
8. Woo, D. J., & Lee, T. K. (2005). Suppression of harmonics in Wilkinson power divider using dual-band rejection by asymmetric DGS. *IEEE Transactions on Microwave Theory and Techniques, 53*(6), 2139–2144.
9. Yang, F. R., Ma, K. P., Qian, Y., & Itoh, T. (1999). A uniplanar compact photonic-bandgap (UC-PBG) structure and its applications for microwave circuit. *IEEE Transactions on Microwave Theory and Techniques, 47*(8), 1509–1514.
10. Hong, J. S., & Lancaster, M. J. (2001). *Microstrip filters for RF/microwave applications*. New York: Wiley.
11. Wang, J., Ni, J., Guo, Y. X., & Fang, D. (2009). Miniaturized microstrip Wilkinson power divider with harmonic suppression. *IEEE Microwave and Wireless Components Letters, 19*(7), 440–442.
12. Hayati, M., Roshani, S., & Roshani, S. (2013). Miniaturized Wilkinson power divider with nth harmonic suppression using front coupled tapered CMRC. *ACES, 28*(3), 221–227.
13. Karthikeyan, S. S., & Kshetrimayum, R. S. (2011). Compact, harmonic suppressed power divider using open complementary split-ring resonator. *Microwave and Optical Technology Letters, 53*(12), 2897–2899.
14. Siahkamari, H., Yasoubi, Z., Jahanbakhshi, M., Mousavi, S. M. H., Siahkamari, P., Nouri, M. E., et al. (2018). Design of compact Wilkinson power divider with harmonic suppression using T-shaped resonators. *Frequenz, 72,* 253–259.
15. He, J., Feng Chen, Z., Hai Yang, B., & Ying Xiong, M. (2012). Miniaturized microstrip Wilkinson power divider with capacitor loading. *Microwave and Optical Technology Letters, 54*(1), 61–63.

Masoud Heydari was born in Kermanshah, Iran in 1992. He received his B.Sc. and M.Sc. degrees in Electronics Engineering from Islamic Azad University, Kermanshah, Iran in 2015 and 2017, respectively. He joined Young Researchers and Elite Club in 2017. His current research includes microwave passive circuits and RF integrated circuit design.

Parastoo Rostami was born in Kermanshah, Iran in 1992. She received her B.Sc. degree in Electronic Engineering in 2014 from Razi University, Kermanshah, Iran and M.Sc. degree in Electronic Engineering in 2017 from Islamic Azad University, Kermanshah, Iran. She joined Young Researchers and Elite Club in 2017. Her current research interest includes RF and microwave circuit design.

Saeed Roshani received the B.Sc. degree in Electrical Engineering from Razi University, Kermanshah, Iran in 2008, M.Sc. degree in Electrical Engineering from Shahed University, Tehran, Iran in 2011 and Ph.D. in Electrical Engineering from Razi University in 2015. He performed opportunity research program in Amirkabir University of Technology (Tehran Polytechnics) Iran, in 2014–2015. He graduated as the best student of his country among all students of Iran on 2015 and Awarded by the First Vice President and science, research and technology Minister. He is currently an Assistant Professor in the Department of electrical engineering at Islamic Azad University, Kermanshah, Iran. He has published more than 40 papers in ISI Journals and Conferences and two books. His research interest includes the microwave and millimeter wave devices and circuits, low-power and low-size integrated circuit design.