

Design of Novel Y-shaped Open Stubs with Harmonic Suppression

Jin Guan ^{1, 2, a}, Min Gong ^{1, b} and Bo Gao ^{1, c,*}

¹ Key Laboratory for Microelectronics, College of Physical Science and Technology, Sichuan University, Chengdu, Sichuan 610065, China

² The 10th Research Institute of China Electronics Technology Group Corporation, Chengdu, 610036, China

^a guanjin666@foxmail.com, ^b mgong@scu.edu.cn, ^c gaobo@scu.edu.cn

Keywords: Y-shaped open stubs; miniaturization; harmonic suppression; power divider/combiner.

Abstract. A novel Y-shaped open stubs with harmonic suppression performance is proposed. To obtain the impedances of the open stubs, ABCD matrix analysis and computer aided design (CAD) optimization simulation are used. The proposed Y-shaped open stubs show that not only good match and low insert loss at fundamental frequency, but also high suppression features at 3rd and 5th harmonic frequencies. The proposed Y-shaped open stubs can be used in many microwave circuits, such as impedance matching network, power divider/combiner, coupler, and so on.

1. Introduction

At present, $\lambda/4$ transmission line (TL) is widely used in microwave circuit, such as power divider/combiner (PDC), antenna arrays feeding network, amplifier impedance matching network, and so on. The $\lambda/4$ TL is easy to use, but a major drawback of it is that the presence of spurious response at odd harmonic frequencies [1].

Recently, some achievements have been published in order to analyze and suppress the high harmonic frequencies in microwave circuit. Some papers report using electromagnetic bandgap (EBG) or defected ground structure (DGS) cells to suppress harmonic frequencies [2,3], though these circuits usually require either backside etching or additional lumped reactive element. In paper [1,4,5], T-shaped, Π -shaped stubs or extended line has been used to suppress harmonic frequencies in PDC. In paper [6], computer aided design (CAD) optimization is developed to analyze the microwave circuit performance by using genetic algorithm. Also, some complicated transmission line matching methods are used to achieve harmonic suppression [7,8].

In this paper, we intend to design the Y-shaped open stubs for submitting $\lambda/4$ TL with harmonic suppression characteristic as showing in Fig.1. In Section 2, the analysis basing on ABCD matrix parameter and CAD has been used. In Section 3, an application example of Y-shaped open stub on PDC is given with simulation and measurement results. The following is conclusion in Section 4.

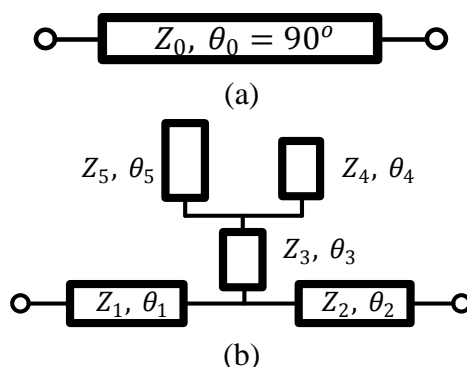


Fig.1 (a) $\lambda/4$ transmission line, (b) the proposed Y-shaped open stubs line.

2. Analysis and optimization of the Y-shaped open stubs

2.1 Analyze the Y-shaped open stubs

The ABCD parameter mode analysis is used to get the some expression of the Y-shaped open stubs, which could help to optimize and get the TLs' exact parameters. Firstly, we introduce the input impedance of one part of Y-shaped open stubs showing in Fig.2.

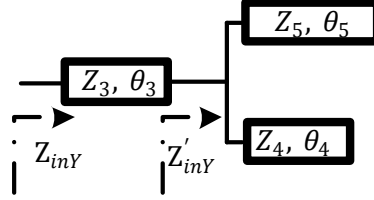


Fig.2 one part of Y-shaped open stubs

We can get the input impedance Z_{inY} from formula (1) as below. For simplify the design, we define that $Z'_{in5} = Z'_{in4}$, so we can get that

$$Z'_{in4} = -j * Z_4 \cot(\theta_4) \quad (1a)$$

$$Z'_{in5} = -j * Z_5 \cot(\theta_5) \quad (1b)$$

$$Z'_{inY} = \frac{Z'_{in4} Z'_{in5}}{Z'_{in4} + Z'_{in5}} \quad (1c)$$

$$Z_{inY} = Z_3 \frac{Z'_{inY} + jZ_3 \tan(\theta_3)}{Z_3 + jZ'_{inY} \tan(\theta_3)} = \frac{jZ_3(2Z_3 \tan(\theta_3) - Z_4 \cot(\theta_4))}{2Z_3 + Z_4 \cot(\theta_4) \tan(\theta_3)} \quad (1d)$$

The ABCD matrix of the original simple quarter-wavelength TL is

$$M_0 = \begin{bmatrix} \cos(\theta_0) & jZ_0 \sin(\theta_0) \\ jY_0 \sin(\theta_0) & \cos(\theta_0) \end{bmatrix} = \begin{bmatrix} 0 & jZ_0 \\ jY_0 & 0 \end{bmatrix} \quad (2)$$

For simplify the design, we define that $Z_2 = Z_1$ and $\theta_2 = \theta_1$. The ABCD matrix of the equivalent Y-shaped open stubs transmission line, M_Y , at fundamental frequency can be written as below.

$$M_Y = M_1 * M_{inY} * M_2 = \begin{bmatrix} \cos(\theta_1) & jZ_1 \sin(\theta_1) \\ jY_1 \sin(\theta_1) & \cos(\theta_1) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/Z_{inY} & 1 \end{bmatrix} \begin{bmatrix} \cos(\theta_2) & jZ_2 \sin(\theta_2) \\ jY_2 \sin(\theta_2) & \cos(\theta_2) \end{bmatrix} = \begin{bmatrix} \cos(2\theta_1) + \frac{jZ_1 \sin(2\theta_1)}{2Z_{inY}} & -\frac{Z_1^2 \sin^2(\theta_1)}{Z_{inY}} + jZ_1 \sin(2\theta_1) \\ \frac{\cos^2(\theta_1)}{Z_{inY}} + \frac{j \sin(2\theta_1)}{Z_1} & \cos(2\theta_1) + \frac{jZ_1 \sin(2\theta_1)}{2Z_{inY}} \end{bmatrix} \quad (3)$$

2.2 CAD arithmetic optimization

We know that the Y-shaped TL should achieve perfectly impedance matching at the center frequency f_0 . To make the original TL equal to the Y-shaped TL ($M_Y = M_0$) at the fundamental frequency, we can make

$$\begin{cases} M_Y(1,1)|_{f=f_0} = M_Y(4,4)|_{f=f_0} = M_0(1,1)|_{f=f_0} = 0 \\ M_Y(1,2)|_{f=f_0} = M_0(1,2)|_{f=f_0} = jZ_0 \\ M_Y(2,1)|_{f=f_0} = M_0(2,1)|_{f=f_0} = jY_0 \end{cases} \quad (4a)$$

To make the proposed Y-shaped open-stub TL structure get two harmonic suppression zeros at $3f_0$ and $5f_0$, the input impedance of open stubs Z_{inY} should be zero at $3f_0$ and $5f_0$.

$$\begin{cases} Z_{inY}|_{f=3f_0} = 0 \\ Z_{inY}|_{f=5f_0} = 0 \end{cases} \quad (4b)$$

For the final design and optimization of the Y-shaped TL, an error function is constructed as formulas (5), which depends on the above parameters.

$$\varepsilon = \sum_{i=1}^5 \omega_i \varepsilon_i \quad (5a)$$

$$\begin{cases} \varepsilon_1 = |M_Y(1,1)|_{f=f_0} - 0| \\ \varepsilon_2 = |M_Y(1,2)|_{f=f_0} - jZ_0| \\ \varepsilon_3 = |M_Y(2,1)|_{f=f_0} - jY_0| \\ \varepsilon_4 = |Z_{inY}|_{f=3f_0} - 0| \\ \varepsilon_5 = |Z_{inY}|_{f=5f_0} - 0| \end{cases} \quad (5b)$$

Where ω_i ($i=1, 2, 3, 4, 5$) are weighting functions. The weighting factors ω_i depend on the requirements and convergence of the problem. The minimization of error function ε determines optimum values of parameters. Here, we use CAD to minimize of the error function to get the suitable parameters of Y-shaped TL. In this paper, we will not introduce the CAD optimization in detail because of the limit of the paper.

The Fig.3 shows the simulation results of the Y-shaped TL for submitting the $50\Omega - \lambda/4$ transmission line. The proposed Y-shaped TL is not only low loss at fundamental frequency, but also high harmonic suppression at 3rd and 5th harmonic frequencies.

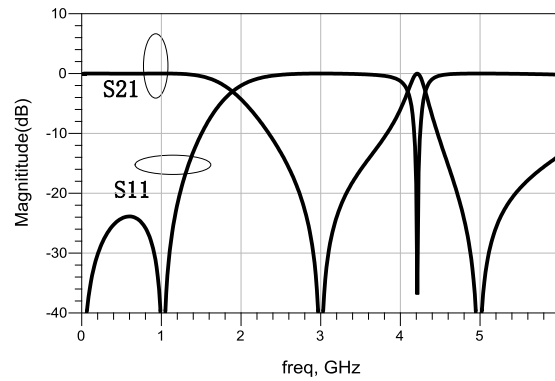


Fig.3 The simulation results of the Y-shaped TL

3. Application of the Y-shaped TL

In this section, an example of the application of Y-shaped TL in Wilkinson PDC, which manufacture on PCB (fundament @ $f_0 = 1GHz$, and harmonic suppression @ $3f_0$, @ $5f_0$), is presented for demonstration, as showing in Fig.4. Here, we use the CAD to get the parameters of PDC. The S-parameter performances of the designed PDC are obtained by EM simulation software, and the measurement results are collected from a network analyzer.



Fig.4 Application of the Y-shaped TL in PDC

Table.1 lists the CAD optimization results of this example PDC without consider parasitic effect and finally PCB slightly tuning.

Table.1 Optimization results of proposed PDC

	<i>parameters</i>	<i>values</i>
Optimization results	Z_1, Z_2	119.1Ω
	Z_3	66.2Ω
	Z_4	57.8Ω
	Z_5	120.3Ω
	θ_1, θ_2	26.0°
	θ_3	5.8°
	θ_4	26.3°
	θ_5	13.4°

From the Fig.5, showing the simulation and measurement S-parameter performance of proposed PDC. By using the Y-shaped, we can get that the PDC not only has similar S-parameter with the traditional Wilkinson PDC at around fundamental frequency, but also has harmonic suppression performance at 3rd and 5th. The insertion loss of modified Wilkinson PDC is below about -3.4dB covering a fractional bandwidth of about 40%, depending on ports return loss and ports isolation below -15dB. The measured S-parameter performances reveal the modified PDC has been achieved attenuation below -30dB at 3rd and 5th harmonic frequencies. The small discrepancies between the simulated and measured results were mainly caused by the fabrication tolerances and discontinuities. Also, Table.1 shows that $\theta_1 + \theta_2 < 90^\circ$, which means that the modified Wilkinson PDC could have smaller size than traditional Wilkinson PDC.

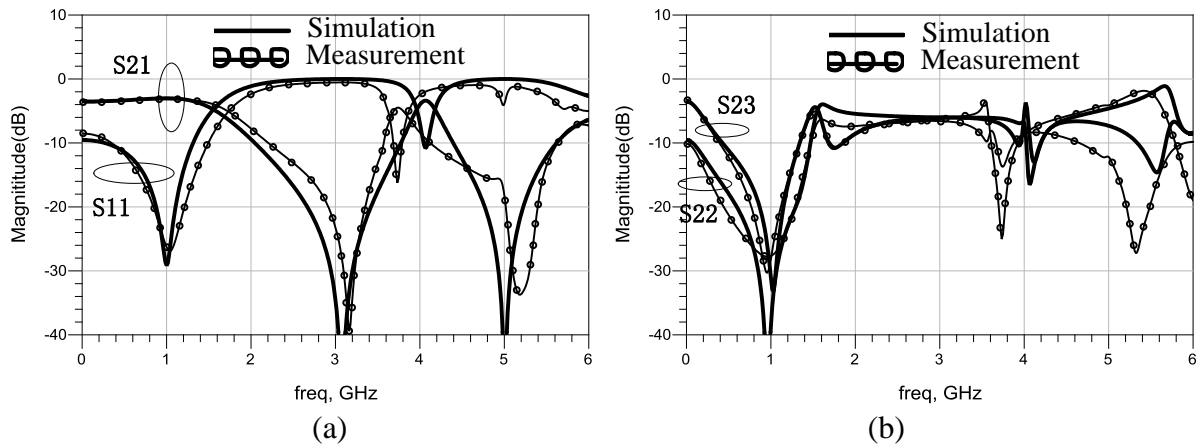


Fig.5 The simulation and measurement of modified PDC

4. Conclusion

In this paper, the design and the optimization of the Y-shaped TL with harmonic suppression features are reported. The analysis and design procedure is based on ABCD matrix and CAD optimization. In the application, a modified PDC with Y-shaped TL is given. The Y-shaped TL is valuable not only with low loss at fundamental frequency and high suppression at harmonic frequencies, but also with size minimization.

References

- [1]. Guan J, Zhang L, Sun Z, et al. Modified Gysel Power Divider with Harmonic Suppression Performance [J]. 31, (2012), 2012, 31:255-269.

- [2]. Lin C M, Su H H, Chiu J C, et al. Wilkinson Power Divider Using Microstrip EBG Cells for the Suppression of Harmonics[J]. IEEE Microwave & Wireless Components Letters, 2007, 17(10):700-702.
- [3]. Woo D J, Lee T K. Suppression of harmonics in Wilkinson power divider using dual-band rejection by asymmetric DGS [J]. IEEE Transactions on Microwave Theory & Techniques, 2005, 53(6):2139-2144.
- [4]. Wang X, Ma Z, Yoshikawa M, et al. Mixed π type structure in Wilkinson power divider design with 3rd harmonic suppression [J]. Microwave & Optical Technology Letters, 2017, 59.
- [5]. Nouri S, Nourinia J, Valizade N, et al. Novel Compact Branch-Line Coupler Using Non-Uniform Folded Transmission Line and Shunt Step Impedance Stub With Harmonics Suppressions[J]. Applied Computational Electromagnetics Society Journal, 2016, 31(4):401-409.
- [6]. Oraizi H, Sharifi A R. Optimum Design of Asymmetrical Multisection Two-Way Power Dividers with Arbitrary Power Division and Impedance Matching [J]. IEEE Transactions on Microwave Theory & Techniques, 2011, 59(6):1478-1490.
- [7]. Nai J K, Hsiao Y H, Wang Y S, et al. A 2.8–6 GHz high-efficiency CMOS power amplifier with high-order harmonic matching network[C]// Microwave Symposium. IEEE, 2016:1-3.
- [8]. Ma R, Chung S W, Teo K H. Output matching network for wideband power amplifier with harmonic suppression [J]. 2016.