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Modified Wilkinson Power Divider for Multiple Harmonics Suppression

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Abstract : *A new structure of the Wilkinson power divider that can suppress multiple harmonics output is presented. The power divider consists of T-type or π-type capacitive loads and shunt resistors. Experimental results show that this power divider suppresses the second and the third harmonic components to less than -38dB, while maintaining the characteristics of a conventional Wilkinson power divider, featuring an equal power split, a simultaneous impedance matching at all ports and a good isolation between output ports.*

Key words : *Power divider, Wilkinson power divider, Harmonic suppression*

1. Introduction

The Wilkinson power divider and combiner play an important role in design of microwave circuits and applications(Pozar, 1990 ; Wilkinson, 1960). They match all input and output ports simultaneously with isolation between the input ports for the power combiner and between the output ports for the power divider. The power divider and combiner have been applied to handle the nonlinear devices such as mixer, high power amplifier, and high efficiency power amplifier with switching mode. In this case, the filter is needed to suppress the harmonics, which are generated from nonlinear devices. If the harmonics are suppressed in the power divider or combiner structure, we can eliminate separate harmonic rejection filters from the circuit.

The modified Wilkinson power divider for the nth harmonic suppression is introduced using capacitive load(Bahl & Bhartia, 2003). As shown in that paper, the second harmonic is suppressed by placing a λ/8 open stub at center of each λ/4 branch of the power divider and shunting the output ports with a parallel connection of a resistor and an inductor. However, the total electrical length including two λ/8 transmission lines and an open stub is longer than quarter-wavelength. The longer electrical length gives rise to complex matched impedance for the even-mode excitation(Bahl & Bhartia, 2003). So the inductor is indispensable used in order to match the complex impedance. The design of lumped inductor must be somewhat empirical and the circuit demonstrations have been confined to frequencies up to a few GHz due to the low quality factor Q and low resonant frequencies. In addition, this kind of power divider can suppress only one harmonic, the nth harmonic.

In this paper, the T-type or π-type capacitive load flexible to the length is presented to suppress multiple harmonics. This method also plays a role to reduce the generalized transmission line. By using T-type or π-type capacitive loads equivalent to the λ/4 transmission line, we can remove lumped inductor and the multiple harmonics can be suppressed.

2. Modified Power divider for multiple harmonics suppression

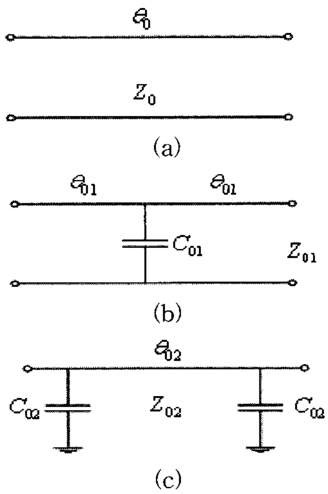

Fig. 1 (a) The arbitrary length transmission line. (b) The equivalent T-type circuit (c) The equivalent π-type circuit.

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Fig. 1 (a), (b) and (c) show the arbitrary transmission line, the equivalent T-type and π-type representation, respectively. Conventional transmission line can be replaced by the shunt capacitive load(Yi & Kang, 2003).

2.1 T-type capacitive load

As shown in Fig. 1 (b), the T-type transmission line can be described by

$$Z_{01} = -\frac{t}{2} + \sqrt{(Z_0)^2 + \frac{1}{4}t^2} \quad (1)$$

$$\omega C_{01} = \frac{\sin\Theta_0}{Z_{01}Z_0}\, t \quad (2)$$

$$t = 2\frac{Z_0}{\sin\Theta_0}\,\frac{\cos 2\Theta_{01} - \cos\Theta_0}{\sin 2\Theta_{01}} \quad (3)$$

where Z_0, Z_{01}, Θ_0, Θ_{01} and ω are the characteristic impedance of the arbitrary transmission line, the characteristic impedance of T-type equivalent capacitive load, the electrical length of the arbitrary transmission line, the electrical length of T-type equivalent capacitive load, and the operating angular frequency, respectively.

2.2 π-type capacitive load

In Fig. 1 (c), the π-type transmission line is expressed as follows:

$$Z_{02} = \frac{\sin\Theta_0}{\sin\Theta_{02}} Z_0 \quad (4)$$

$$\omega C_{02} = \frac{1}{Z_{02}\sin\Theta_{02}}(-\cos\Theta_0 + \cos\Theta_{02}) \quad (5)$$

where Z_{02} and Θ_{02} are the characteristic impedance of π-type equivalent capacitive load and the electrical length of π-type equivalent capacitive load. The transmission line can be miniaturized simultaneously by using capacitive load in the case that Θ_{02} is smaller than Θ_0.

2.3 The open stub equivalent circuit

The open stub equivalent to capacitive load is shown in Fig. 2.

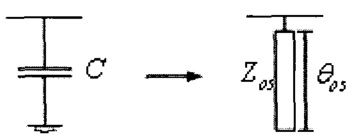

Fig. 2 The open stub equivalent to the lumped capacitor C.

In the case of open stub, the input impedance is expressed as follows,

$$Z_{in}(d) = -jZ_{os}\frac{1}{\tan(\beta d)} \quad (6)$$

where Z_{os}, d are the characteristic impedance and the length of the open stub, respectively. It would be equivalent to a capacitive behavior if the length of the open stub is less than quarter-wavelength of the transmission line.

$$Z_{in}(d) = -j\frac{1}{\omega C} \quad (7)$$

from (6), (7), we obtain

$$\omega C = \frac{\tan\Theta_{os}}{Z_{os}} \quad (8)$$

where Θ_{os} is the electrical length of the open stub. Upon using (1) - (5) to replace ωC_{01} and ωC_{02}, we obtain,

$$Z_{os} = \frac{Z_{01}\tan\Theta_{os}\sin 2\Theta_{01}}{\cos 2\Theta_{01} - \cos\Theta_0} \quad \text{T-type} \quad (9)$$

$$Z_{os} = \frac{\tan\Theta_{os} \cdot Z_{02}\sin\Theta_{02}}{-\cos\Theta_0 + \cos\Theta_{02}} \quad \pi\text{-type} \quad (10)$$

As we know, at the fundamental frequency f_0, the $\lambda/4$ open stub shorts the circuit and no transmission from the input to output ports. We use this fact to suppress harmonics by making the length of the open stub to $\lambda/4n$. In this case, at the nth harmonic frequency n f_0, the $\lambda/4n$ open stub shorts the circuit and the nth harmonic component is suppressed without sacrificing the characteristics of the conventional Wilkinson power divider at the operating frequency. Compared with the modified power divider proposed by Yi(Bahl & Bhartia, 2003), this method removes unnecessary inductor, which makes the circuit much simpler. Also, we can use T-type circuit to suppress one harmonic and π-type circuit to suppress two harmonic components. If we divide the transmission line into several parts and use equivalent T or π-type capacitive loads to replace it separately, multiple harmonics will be suppressed at the same time.

3. Simulation and Experimental results

T-type and π-type capacitive loads can be used to suppress multiple harmonics. As a result, the capacitance of π-type circuit is larger than that of T-type circuit at the same electrical length. So the π-type circuit is more convenient to be fabricated for the open stub will be longer or wider as the capacitance is larger. In this paper, we suppress two harmonics with equivalent π-type capacitive loads. A schematic diagram of proposed power divider, which suppresses the second and the third harmonic components using a λ/8 and a λ/12 open stubs, is shown in Fig. 3.

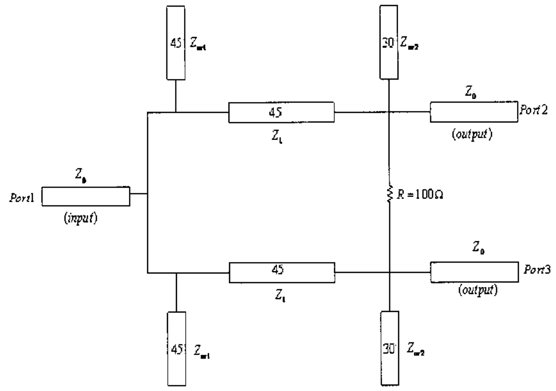

Fig. 3 Schematic diagram of the Wilkinson power divider for the second and third harmonic suppression

Considering the effects of the junctions, the lengths of transmission lines are reckoned like that shown in Fig. 4. The power divider for f_0=1GHz and Z_0=50 Ω is fabricated on a 0.762mm-thick teflon substrate with a relative permittivity of 3.5 and a conductor thickness of 35um. The λ/4 branch of the original Wilkinson power divider is replaced by π-type capacitive load with the electrical length θ_1=45°, and the characteristic impedance Z_1=100 Ω. For the second and the third harmonic suppressions, two kind of open stubs are designed with the characteristic impedance Z_{os1}=100 Ω and Z_{os2}=57.7 Ω. A photograph of the fabricated Wilkinson power divider with an area of 5×5cm 2 is shown in Fig. 5.

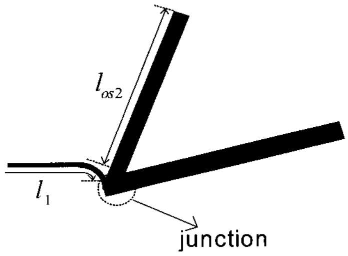

Fig. 4 Layout of the junction part

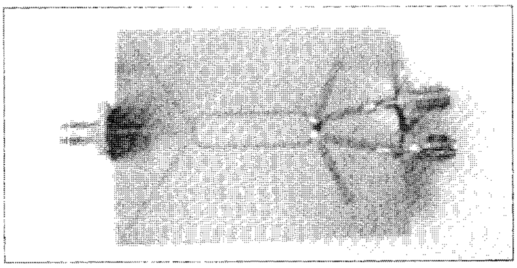

Fig. 5 Photograph of the fabricated Wilkinson power divider

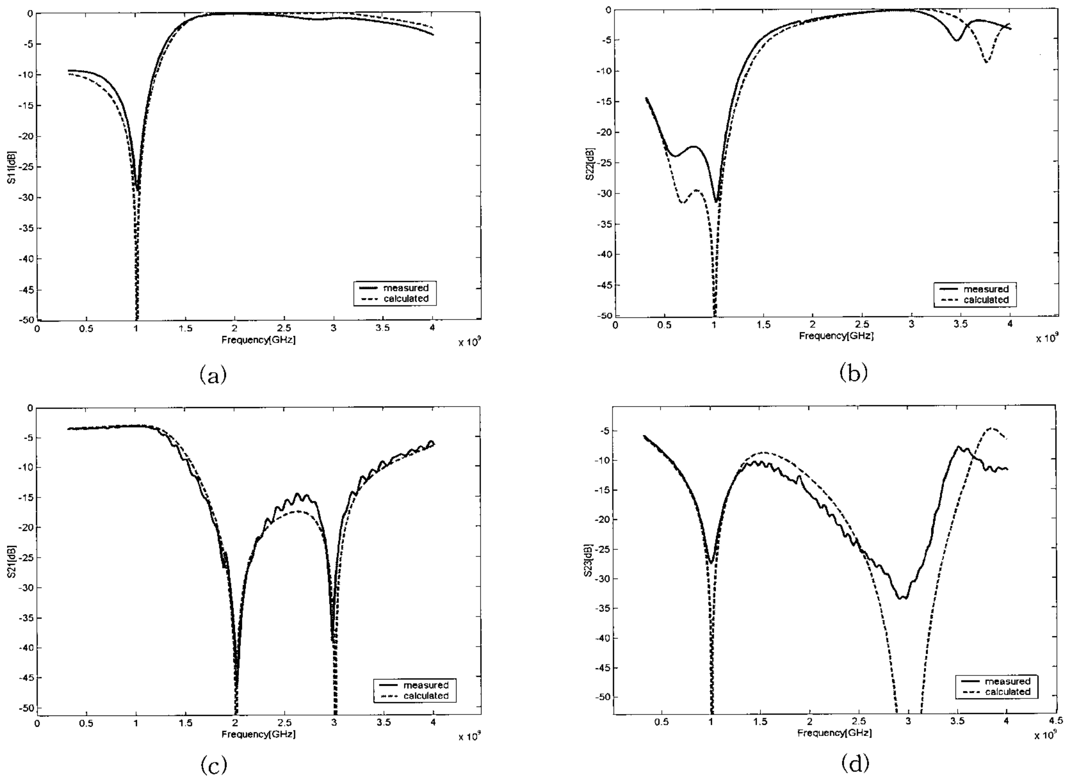

Fig. 6 Calculated and measured S-parameters of Wilkinson power divider (a) S_{11}, (b) S_{22}, (c) S_{21}, (d) S_{23}

The measured S-parameters using an HP8722ES network analyzer and calculated results using ADS software from Agilent Technologies are shown in Fig. 6. We can see from the figure that the measured S-parameters agree quite well with the calculated ones. In Fig. 6 (a) and (b), the measured S_{11} and S_{22} are 29dB and-31dB at the operating frequency 1 GHz. In Fig. 6 (c), the measured S_{21} is 3.1dB at 1 GHz, which shows that the signal at port 1 is equally divided at operating frequency. Also, at the frequencies 1.99GHz and 2.94GHz, S_{21} shows a second and a third harmonic suppression 46dB and 38dB, respectively. The measured S_{23} shown in Fig. 6 (d) is 28dB at the operating frequency 1GHz which shows a good isolation between the output ports. However, steps in width existing at junctions of microstrip lines that have different impedances give rise to discontinuity. In addition, open-ends and T junctions also result in discontinuity that leads to inaccuracy of the measured results.

4. Conclusion

A modified Wilkinson power divider that suppresses multiple harmonics is proposed in this paper. The π-type capacitive loads using open stubs, which can suppress harmonic component, are mathematically expressed. The measured results show that the power divider has an equal power split, a simultaneous impedance matching at all ports and a good isolation between the output ports. It operates well as a conventional Wilkinson power divider at the operating frequency of 1GHz, while suppressing the 1.99GHz second and 2.94GHz third harmonics. The microwave circuit using this kind of power divider can be applied to marine communication system.

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