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A Compact Wideband Filtering Power Divider

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Abstract—A compact wideband filtering power divider is presented in this paper, by using coupled transmission lines at two output ports to realize filtering function. The return loss and insertion loss of the design in the passband are improved by inserting fan-shaped open stubs and etching a T-shaped slot at the input port. The central frequency of the power divider is 2.4 GHz. The measured results show a 10-dB fractional bandwidth of 60%, and a wideband filtering response can be obtained. The material object is designed by using FR4, and the size is $0.4\lambda_g * 0.2\lambda_g$. The design is well used in the WiFi band.

1. INTRODUCTION

Power divider is an important component of many RF microwave communication systems, such as power amplifiers, low noise amplifiers, and antennas. Traditional Wilkinson power divider [1] without filtering function cannot effectively prevent the interference from out-of-band signals. In [2], a pair of symmetrical fan-shaped open stubs is inserted into a conventional Wilkinson power divider, and the reflection coefficient of the input port is reduced to -26 dB, but the frequency selectivity is not very ideal. Coupled-line sections are utilized to substitute conventional quarter-wavelength transmission lines [3–5], but the bandwidth of the filtering power divider mentioned above is narrow. A novel structure for designing tunable filtering power dividers is proposed [6], which makes use of multiple miniaturizations to make the whole structure more compact, but it is not to realize the filtering function in the RF band using the lumped parameter. A power divider uses triangular integrated waveguide to compactness [7], but the bandwidth is narrow. Another divider useing triangular cavity integrated waveguide is used for filtering [8], and its filtering performance is good, but the isolation effect is poor. In [9], a power divider with wideband filtering effect is proposed, through a ring resonator by loading an open stub, with fractional bandwidth of 60%, but the insertion loss is large. A rectangular cavity has etched two symmetrical opening resonant rings with equal size to realize the function of filtering [10], but the bandwidth of the passband is narrow, and the insertion loss is relatively large.

In this paper, a compact wideband filtering power divider is proposed by introducing coupled line structures, fan-shaped open stubs, and a T-shaped slot. The design is simulated with the aid of Ansoft high-frequency structure simulator (HFSS). Based on the PCB technology, a prototype is manufactured. Finally, the results of testing and simulation are analyzed and compared.

2. DESIGN THEORY

Figure 1 shows the schematic diagram of the power divider. The input port 1 of the circuit reaches the beginning of the coupled transmission line by a staircase impedance transmission line [11], and then passes through two quarter wavelength coupled transmission lines to output ports 2 and 3, and isolation resistors R_1, R_2 and R_3 are loaded on the beginning of the first coupled line, the ending of the first

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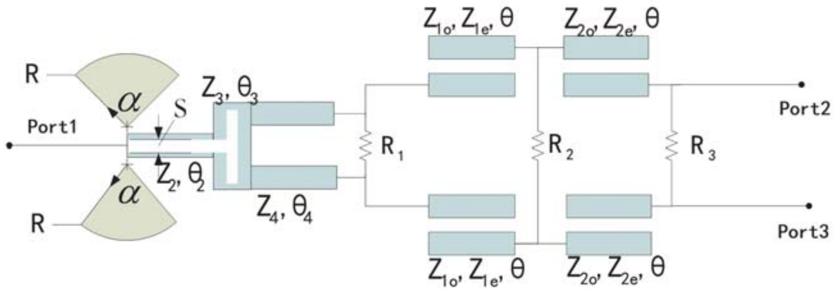


Figure 1. Schematic diagram of the filtering power divider.

coupled line and the ending of the second coupled lines, respectively. In addition, two symmetric fan-shaped open stubs are added to input port 1, and a T-shaped slot is etched on the stepped impedance line. The odd and even mode impedances of the two coupled lines close to the power divider output port are Z_{1o}, Z_{1e} and Z_{2o}, Z_{2e}. The electric length is 1/4 wavelength ($\lambda_g/4$), and λ_g denotes the free space wavelength at their center frequencies. The radius of the fan-shaped open stub is R; central angle is α; and width of the T-shaped slot is S.

Combined with the analysis method of coupled line power divider in [3] and [12], the high frequency and the low frequency points in the passband of the power divider are denoted by f_H and f_L, and the center frequency is f_0. Assuming that the input impedance of the microstrip coupled line is Z_{lin}, the relationship below should be satisfied.

$$Z_{lin0} = \frac{\sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} + Z_{0o})^2 \cos^2(\theta)}}{2\sin(\theta)} \tag{1}$$

According to the principle of the filter characteristics of the microstrip coupled line

$$\begin{cases} Z_{0o} = Z_0 \left(1 - \sqrt{\frac{\pi \text{BW}}{1.4}} + \frac{\pi \text{BW}}{1.4}\right) \\ Z_{0e} = Z_0 \left(1 + \sqrt{\frac{\pi \text{BW}}{1.4}} + \frac{\pi \text{BW}}{1.4}\right) \\ \text{BW} = \frac{f_H - f_L}{f_0} \end{cases} \tag{2}$$

The input impedance of input port 1 is Z_A, and the odd mode input impedance of output port 2 and 3 is Z_B, even mode input impedance is Z_C, then the reflection coefficient of the input port is

$$S_{11} = \Gamma_{in} = \frac{Z_A - Z_0}{Z_A + Z_0} \tag{3}$$

The odd and even mode reflection coefficients of the output ports respectively are

$$\Gamma_{out}^e = \frac{Z_C - Z_0}{Z_C + Z_0}, \quad Gamma_{out}^o = \frac{Z_B - Z_0}{Z_B + Z_0} \tag{4}$$

The reflection coefficient of the output ports is

$$S_{22,33} = \frac{\Gamma_{out}^o + \Gamma_{out}^e}{2} \tag{5}$$

where

$$S_{23} = \frac{\Gamma_{out}^e - \Gamma_{out}^o}{2} \tag{6}$$

The resistance values of the three isolation resistors are

$$\begin{cases} R_1 = 2\left(Z_{in1} + Z_0\right) \\ R_2 = 2\left(Z_{in2} + Z_0\right) \\ R_3 = 2Z_0 \end{cases} \tag{7}$$

where

$$\begin{cases} Z_{in1} = Z_{lin1} \dfrac{Z_{in2} + jZ_{lin1} \tan\theta}{Z_{lin1} + jZ_{in2} \tan\theta} \\ Z_{in2} = Z_{lin2} \dfrac{Z_0 + jZ_{lin2} \tan\theta}{Z_{lin2} + jZ_0 \tan\theta} \end{cases} \tag{8}$$

According to Equations (1)–(5), the passband of the wideband filtering power divider and the odd and even mode impedance values of microstrip coupled transmission lines can be determined, and the length, width of coupled lines and the resistance value of each isolation resistor can be confirmed. The power divider is described in this paper, which inserts fan-shaped open stubs and etches a T-shaped slot at the input port, and the reflection coefficient of the input port can be reduced and the bandwidth range widened. The actual reference values of each part are obtained, as shown in Table 1.

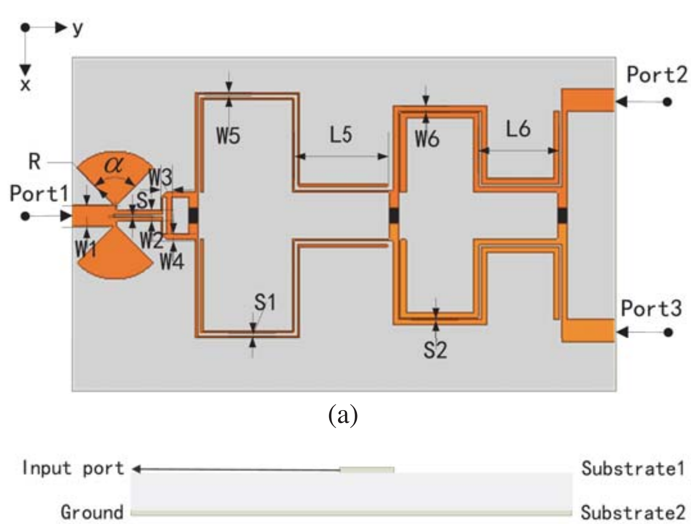
Table 1. The parameters of the wide-band filtering power divider.

Impedance	Z_{1e}	Z_{1o}	Z_{2e}	Z_{2o}	Z_2	Z_3	Z_4	R_1	R_2	R_3
Size (Ω)	181.8	88	132.5	52.6	71.4	71.4	96	350	240	100
Angle	α	θ	θ_2	θ_3	θ_4					
Size (°)	92.8°	90°	12°	10°	10°					

Table 2 shows the actual size of the wide-band filtering power divider, and the width, length and coupling values of the coupled lines are expressed separately by W, L and S.

Table 2. The size of the wideband filtering power divider.

Parameter	W_1	W_2	W_3	W_4	W_5	W_6	S	S_1	S_2
Size (mm)	1.2	0.6	0.6	0.3	0.1	0.3	0.2	0.2	0.1
Parameter	L_1	L_2	L_3	L_4	L_5	L_6	R		
Size (mm)	3	2.4	2	2	5	4	2		



(a)

(b)

Figure 2. Layout of the filtering power divider. (a) Top view. (b) Lateral view.

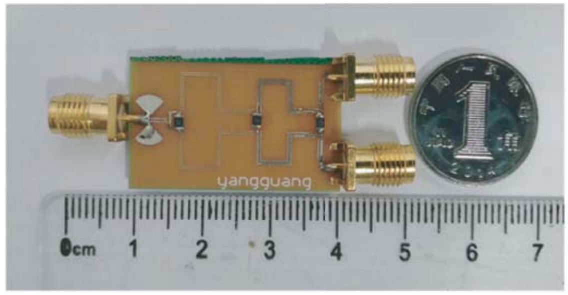


Figure 3. The wideband filtering power divider physical photos.

The layout of the filtering power divider by HFSS is shown in Figure 2, and a physical photo is displayed in Figure 3. It can be seen that the size of the filtering power divider is small.

3. SIMULATION AND MEASUREMENT

The modeling and simulation of the wideband filtering power divider are performed in electromagnetic simulation software HFSS. The center frequency is $f_o = 2.4$ GHz, and the dielectric substrate is low cost FR4 plate, with the relative dielectric constant of $\varepsilon_r = 4.4$, thickness of 0.6 mm, and low dielectric loss factor of $\tan\delta = 0.02$. Table 2 lists actual dimensions of the power divider.

The prototype is tested by using an Agilent E5071C vector network analyzer. The comparison between measured and simulated results is shown in Figure 4.

Figure 4(a) shows the comparison between simulated and measured results,. It can been seen that the passband of the power divider is from 1.6 to 3.04 GHz, and the relative fractional bandwidth is 60%. In the passband, the measured isolation is slightly less than the simulation, and the insertion losses of measurement and simulation are basically concentrated at around 3.65 dB. Compared with the simulation, the measured return loss is slightly shifted to lower frequency, and the maximum return loss in the passband is 26 dB. On the whole, the measured results of the power divider are in good agreement with the simulation ones.

As shown in Figure 4(b), the maximum value of return loss is only 13 dB, without the fan-shaped open stub, but with it, the return loss will be improved to 23 dB. Comparing S_{21} of the two cases, we know that the bandwidth in the second case is obviously better than the first one. It is shown that loading a fan-shaped open stub not only improves the waveform performance of the passband, but also broadens the bandwidth of the wideband filtering power divider.

As shown in Figure 4(c), the maximum value of return loss is 23 dB without a T-shaped slot. The maximum value of return loss reaches 26 dB, and the average can reach 22 dB, if etching a T-shaped slot. It can be seen that etching a T-shaped slot can further improve the passband performance.

In summary, combining with a fan-shaped open stub and T-shaped slot can reduce the return loss and improve bandwidth of the power divider.

Table 3. Performance comparison of existing power dividers.

Ref.	FBW	IL	Isolation	Size
[3]	52.5%	3.8 dB	18 dB	$0.53\lambda_g \times 0.52\lambda_g$
[4]	4%	4.6 dB	12 dB	$0.28\lambda_g \times 0.66\lambda_g$
[9]	60%	4.3 dB	20 dB	$\approx 0.6\lambda_g \times 0.4\lambda_g$
[13]	87%	3.6 dB	17 dB	$0.8\lambda_g \times 0.5\lambda_g$
[14]	62%	4.4 dB	15.8 dB	$\approx 0.8\lambda_g \times 0.7\lambda_g$
[15]	32.1%	3.45 dB	22.5 dB	$0.4\lambda_g \times 0.4\lambda_g$
This paper	60%	3.65 dB	15 dB	$0.4\lambda_g \times 0.2\lambda_g$

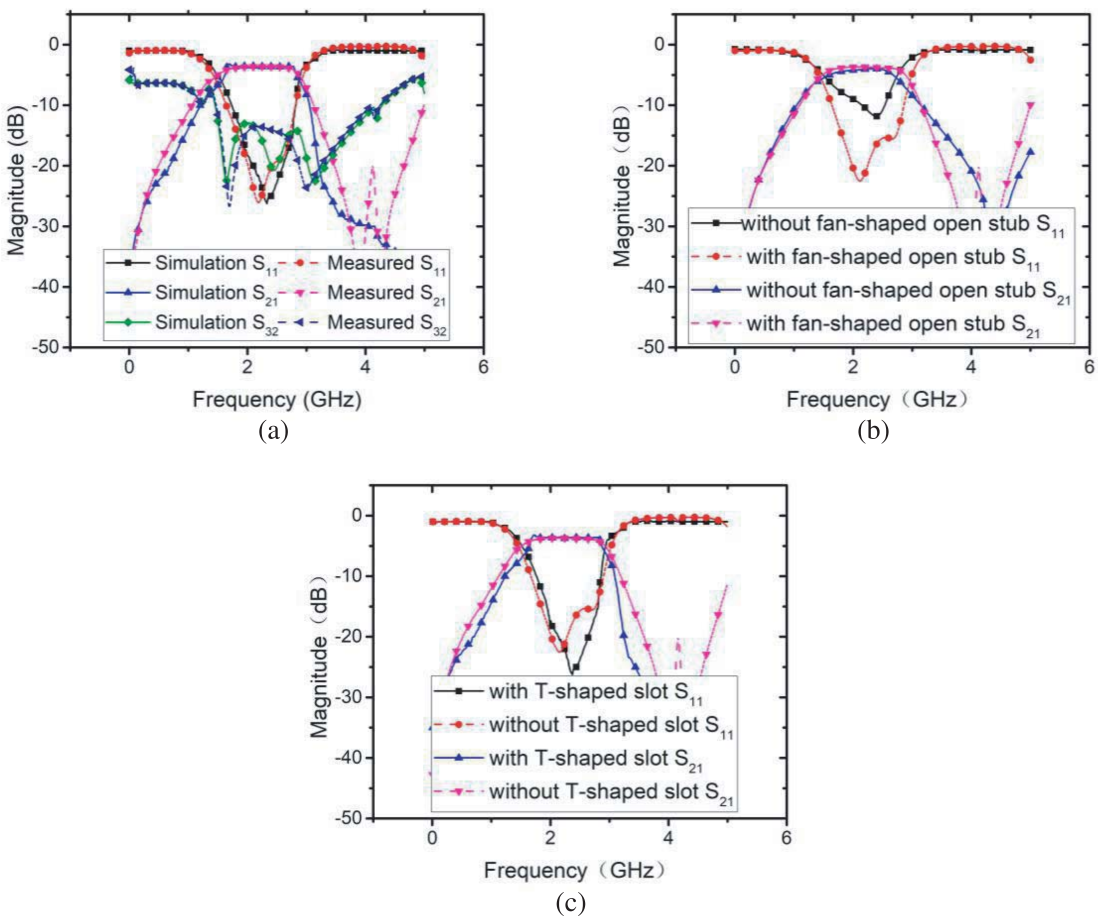


Figure 4. (a) The simulated and measured data, (b) the data comparison of without or with fan-shaped open stub, (c) the data comparison of without or with etch T-shaped slot.

Table 3 shows the performance comparison between this design and existing filtering power dividers. It can be seen that the bandwidth is less than 60% in [3, 4] and [15]. The bandwidth is about 60% in [9] and [14], but the insertion loss is greater than 4.4 dB. In [13], the bandwidth is 87%, larger than this design, but the size is not compact enough of $0.8\lambda_g \times 0.5\lambda_g$. Compared with existing filter power dividers, the design has advantages in terms of bandwidth and size.

4. CONCLUSION

This paper presents a compact wideband filtering power divider by using coupled transmission lines and fan-shaped open stubs and a T-shaped slot. Its fractional bandwidth is 60% with the return loss better than 10 dB. The maximum return loss is 26 dB; the isolation degree is more than 15 dB; and the average insertion loss is 3.65 dB in the passband. Compared with existing filter power dividers, the proposed power divider has wider bandwidth and compact structure. The frequency of this design is 2.4 GHz; therefore, it has good application prospects in modern wireless communication such as RF power amplifiers and WiFi.

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