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Design of Three-Mode Filtering Power Divider for Ship Anti-Signal Interference

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Abstract—This paper presents a novel microstrip three-mode filtering power divider (FPD) with high frequency selectivity and high isolation, which integrates only a single resonator and a resistor to realize the dual functions of the power division and filtering. In order to further improve its frequency selectivity and obtain wide upper stop band, three open stubs are loaded into the input and output ports of the filter power divider. The measured and simulated results show that the range of $S_{11} < -10\,\mathrm{dB}$ is $1.86 \sim 2.1\,\mathrm{GHz}$; the relative bandwidth of 3 dB is 17.9%; the in-band isolation is higher than 26 dB; and it has a relatively simple topology.

1. INTRODUCTION

The signal power transmitted by the Global Position System (GPS) satellite, the weak signal reaching the ground, the unpredictable harsh environment, and the emergence of special GPS jammers [1] will directly cause GPS signals to be interfered, even unable to work normally in serious cases. Therefore, in order to enable the GPS receiver to cope with more complex environments and improve its own anti-jamming capability, the research on GPS anti-jamming technology has received extensive attention [2, 3].

Power divider and bandpass filters are indispensable passive components in modern wireless communication systems [4–9]. By convention, these two devices take up too much space in the RF transmitting front-end system. In order to overcome this difficulty, an effective way is proposed, which is integrating the power divider and band pass filter into a single component, that is, filtering the power divider to achieve power distribution/combination and frequency selectivity at a specific frequency. In recent years, many scholars and researchers have studied and reported on filtering power divider.

A filtering power divider is proposed in [10] by replacing the quarter-wavelength converter in the traditional Wilkinson power divider with two filtering structures. However, the designed circuit exhibits poor insertion loss and isolation of the two output ports. In order to better improve performance, the folded quarter-wave resonator is applied to the cross-coupled resonator, but the coupling between them is not easy to control [11]. In [12], a coupled filter divider with a two-pole bandpass response is proposed. In [13], an asymmetric coupling structure in dual modes using an E-shaped resonator is proposed to realize a high-performance filter power divider. In addition to the designs listed above, [14] reports a filter divider that utilizes a substrate-integrated waveguide resonator. The above-described filter divider design requires a two-way resonator to achieve both filter response and power divider distribution, which always results in a relatively large planar structure and a complicated design. However, there is too little literature on filter dividers based on only one open resonator.

In the proposed letter, a new three-mode filtering power divider design is proposed, which uses only a single open-circuit T-type resonator and a resistor to achieve high isolation and frequency selectivity. In order to achieve high isolation performance of the filtering power divider, a resistor is loaded between

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the output ports. In addition, two open-circuit microstrip lines are integrated into the two output ports to generate multiple transmission zeros, improving frequency selectivity and harmonic rejection. The prototype three-modes filter power divider is realized by simulation verification, and the operating frequency $1.86 \sim 2.1$ GHz is applied to the ship anti-signal interference.

2. THE PRINCIPLE OF RESONATOR DESIGN AND BASIC STRUCTURE

The proposed three-modes filtering power divider consists of a single T-shaped resonator, an isolation resistor, and a coupled microstrip input port and two outputs, as shown in Fig. 1. Since the two outputs are symmetrically distributed on both sides of the resonator, the coupling between two outputs and the resonator has the same amplitude and phase characteristics. At the same time, a resistor is introduced between the two output lines to enhance the isolation of output port 2 and port 3. The detailed theoretical derivation will be described later.

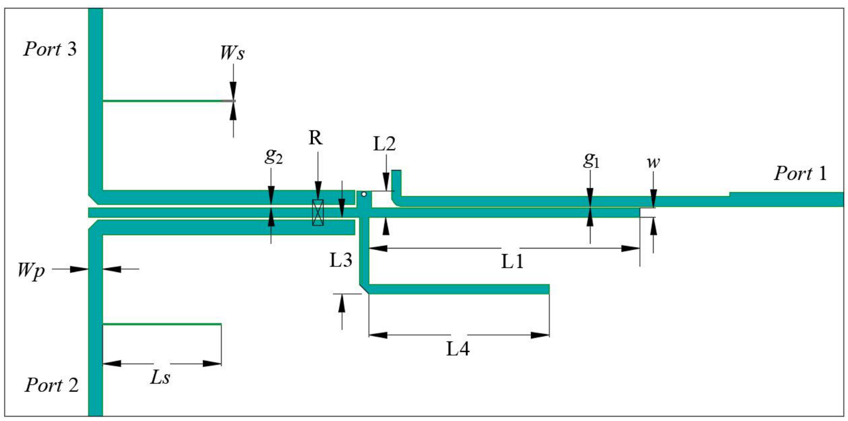

Figure 1. The structure diagram of three-mode resonator.

The structure of the three-mode resonator used in this paper is shown in Fig. 2(a), which is composed of a conventional half-wave microstrip resonator, a bent open branch, and a shorted branch. In this design, the substrate is Rogers RO4003c, with a relative dielectric constant of 3.38, a dielectric loss tangent of 0.0027, and a thickness of 0.508 mm. Since the structure is symmetrically distributed, the resonator can be decomposed into an odd-mode excitation and two even-mode excitations by the method of odd-even mode analysis [15]. For the odd-mode excitation, the middle of the resonator where the voltage is zero constitutes the electric wall. As shown in Fig. 2(b), when the input admittance of the odd-mode is $Y_{odd} = 0$, the resonant frequency of the odd-mode can be obtained as:

$$f_{odd} = \frac{c}{4L_1\sqrt{\varepsilon_{eff}}} \tag{1}$$

where c is the light speed in free space, L_1 the length of odd mode, and $\varepsilon_{eff} = (\varepsilon_r + 1)/2$ the effective dielectric constant of the substrate.

As shown in Fig. 2(c), for the even mode, the central symmetry plane can be equivalent to a magnetic wall. The even mode is decomposed into an open circuit and a short circuit resonant circuit, as shown in Figs. 2(d) and (e), which are a quarter-wavelength terminal short-circuit resonator and a half-terminal open-circuit resonator, respectively. Their resonant frequencies are:

$$f_{even1} = \frac{c}{2(L_1 + L_3 + L_4)\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$f_{even2} = \frac{c}{4(L_1 + L_2)\sqrt{\varepsilon_{eff}}} \tag{3}$$

Figure 3 shows the corresponding coupling scheme of the filtering power divider, where $E1$, $E2$, and O represent the even and odd modes of the three-mode filter response resonator. The input signal from

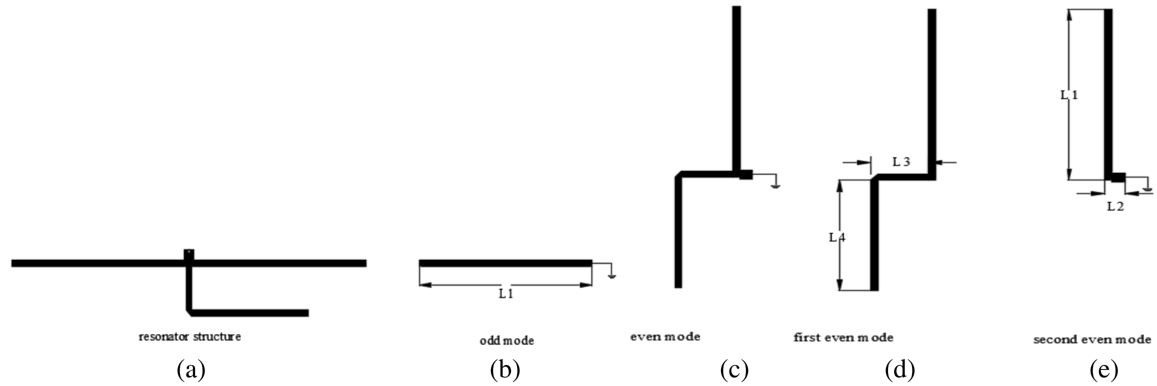

Figure 2. (a) The front of the resonator structure; (b) the equivalent circuit of odd-mode; (c) the equivalent circuit of even-mode; (d) the equivalent circuit of first even-mode; (e) the equivalent circuit of second even-mode.

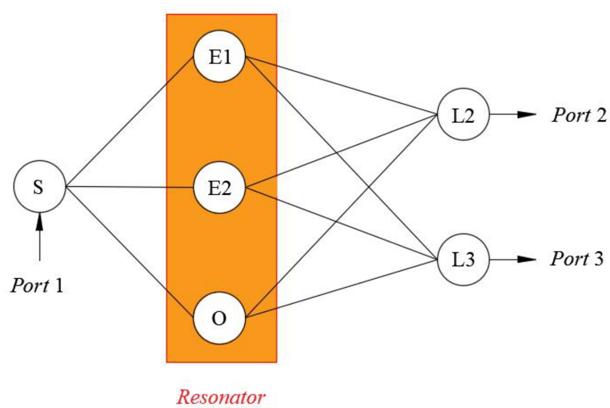

Figure 3. The coupling scheme of three-mode filter power divider.

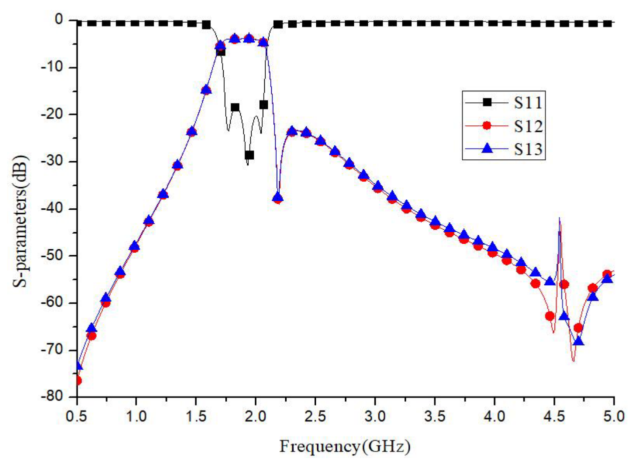

Figure 4. S_{11}, S_{12}, S_{13} of the simulated filtering power divider.

port 1 propagates along the input transmission line, then the energy will be coupled to the three-mode resonator, and finally splits to the two output ports (i.e., port 2 and port 3). Therefore, the coupling coefficient satisfies the relationship of ME1L2 = ME1L3, ME2L2 = ME2L3, and MOL2 = MOL3, as shown in Fig. 3. The effect of the isolation resistance (R) has not been considered, since it hardly affects the three-mode filtering power division responses due to its symmetry property. However, as the coupling strength is changed, the filter response will also be changed. Once the filter response is specified, the isolation of port 2 and port 3 will be achieved primarily by changing the value of resistance.

In this paper, a filtering power divider with a center frequency of 1.9 GHz and a 3 dB relative bandwidth of 18.4% is designed. The design steps are as follows: First, according to the formulas (1)∼(3), the values of the resonator parameters $L1 \sim L4$ can be calculated ($L1 = 22.6$ mm, $L2 = 1.41$ mm, $L3 = 6.4$ mm, $L4 = 15.1$ mm). The odd mode of resonant frequency is obtained of 1.93 GHz. The resonant frequency of the first even mode is 2.04 GHz, and the resonant frequency of the second even mode is 1.77 GHz [16]. Then according to the external Q value of the odd mode and the first and second even modes ($Q_{odd} = 42.32$, $Q_{even1} = 11.82$, $Q_{even2} = 16.41$), the width and slot size of the resonator can be calculated as: $w = 0.78$ mm, the slot size $g1 = 0.12$ mm, $g2 = 0.26$ mm. Then, in order to suppress the higher harmonic components, two open-circuit branches are loaded at the two outputs of the filtering power divider. Finally, the 100 ohm resistance is loaded between the two output ports to achieve higher isolation.

In order to verify the proposed scheme, the structure of filtering power divider was simulated in the software HFSS. The dimensions of the filtering power divider are as follows: $L1 = 22.6$ mm, $L2 = 2.2$ mm, $L3 = 5.6$ mm, $L4 = 15.6$ mm, $Ls = 9.8$ mm, $Ws = 0.12$ mm, $Wp = 1.2$ mm, $w = 0.78$ mm, $g1 = 0.12$ mm, $g2 = 0.26$ mm. The reflection coefficient S_{11} of the input port and insertion losses S_{12}, S_{13} of the filtering power divider are shown in Fig. 4, . It can be seen that the frequency range of $S_{11} < -10$ dB is $1.72 \sim 2.07$ GHz, and the insertion losses S_{12} and S_{13} are 3.78 dB at the center frequency of 1.9 GHz.

The fabricated filtering power divider is shown in Fig. 5, and Fig. 6 shows the measured result of the S parameters. The range of $S_{11} < -10$ dB is from 1.86 GHz to 2.1 GHz, and the maximum insertion loss in this band is 1.1 dB. The deviation from the simulated results may be due to the additional loss introduced by the SMA connector, and the measured maximum isolation in the passband is 26 dB.

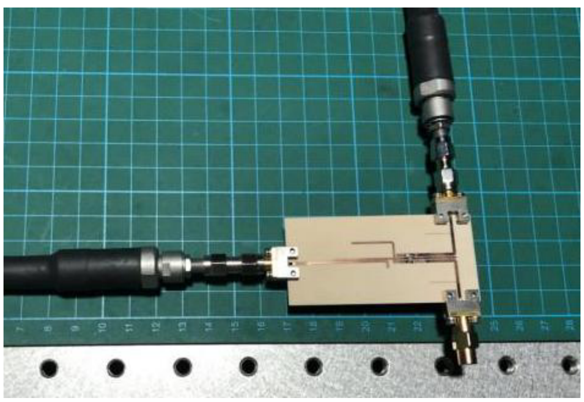

Figure 5. Photographs of the fabricated filtering power divider.

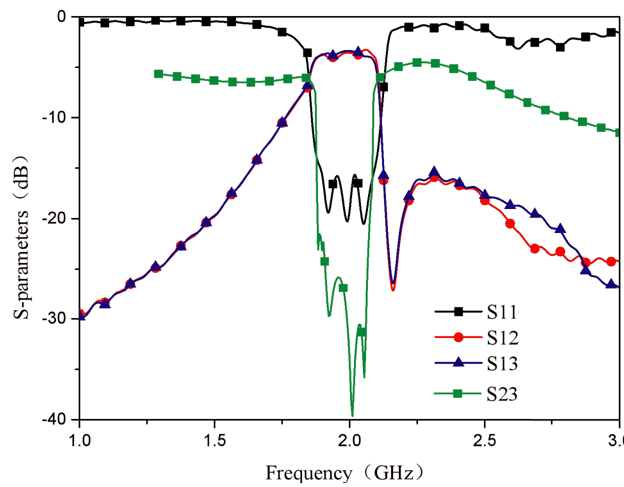

Figure 6. The measured results of S parameters.

Table 1 compares the proposed work with the filter power divider designed in other literatures. It can be seen that the filter power divider designed in this paper not only has higher performance, such as a wider 3 dB relative bandwidth and higher isolation, but also has a relatively simple topology.

Table 1. Comparisons with other previous works.

Refs	3 dB FBW	Insertion loss	Isolation in band	Topology
[11]	6.5%	3.96 dB	> 20 dB	Two way resonators
[12]	10%	4.2 dB	> 17 dB	Two way resonators
[13]	13.3%	3.97 dB	> 22 dB	Two way resonators
This work	17.9%	4.1 dB	> 26 dB	Co shared resonators

3. CONCLUSION

In this paper, a three-mode filtering power divider using an open-circuit resonator is proposed, and its principle and design steps have been analyzed and studied. By using simulation software, the proposed filtering power divider not only has good frequency selectivity and wider stopband range, but also has high isolation between two output ports. The characteristics enable the proposed filtering power divider to be widely used in wireless communication systems.

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