A Parallel Coupling Structure Tai Chi Filter

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Abstract

A Tai Chi filter is designed. The filter circuit is a yin and yang fish Tai Chi pattern, which is composed of yang fish and yin fish resonant circuits through a parallel coupling structure. The circuit is grounded at the head and eye of the yang fish and the yin fish, and the yang fish and the yin fish are connected to the feeder at the body. The yang fish and the yin fish microstrip structure has a gradient step impedance resonator(SIR) characteristic. The working frequency of the filter is 4.38-4.84GHz, the center frequency is 4.61GHz, and the fractional bandwidth is 10%. The filter insertion loss S21 is better than -1.38dB, the return loss S11 is better than -20.32dB, and the in-band performance is good. The overall size of the filter is 22.49mm×16mm×0.508mm, the filter circuit size is small.

Keywords

Parallel coupling structure, Taiji filter, Bandpass filter.

1. Introduction

The microwave filter is an important part of the communication system. Its function is to match the transmission of the signal in the passband frequency range, and the signal in the stopband frequency range is mismatched to transmit and cause reflection attenuation to achieve signal frequency spectrum filtering function[1]. The basic unit of a microwave filter is a microwave resonator, and each resonator is coupled or cascaded to form a complete microwave filter design. Parallel coupled microstrip structure, as a common coupling method, has been widely used in the design of bandpass filters in recent years due to its small size, compact structure, low price, and stable performance.

A typical parallel-coupled microstrip filter circuit cannot provide good filter response and high selectivity due to a single coupled line section unit, and a microwave filter is formed by cascading multiple coupled line section units[2]. Although this design improves the out-of-band suppression of the filter, the design size is larger, which is not conducive to miniaturization. So improve multiple variant structures, such as literature [3] Cui et al proposed a curved parallel fully coupled line broadband band-stop filter and literature [4] proposed a hairpin microstrip line bandpass filter, both of which use the method of bending the parallel coupling structure to achieve filtering. Literature [5] Although the filter is miniaturized and its return loss and insertion loss are good, but the group delay of this design is 0.25ns, the group delay fluctuates in the passband, and the linearity of the filter is poor. Literature [6-7] uses anti-coupling line design and literature [8-9] uses three-line coupling design (that is, three parallel coupled lines are connected in different ways to form four T-shaped filters), obtaining a bandpass filter with simple structure and good out-of-band suppression, but the filter has a narrow pass band.

This paper proposes a deformed structure based on a parallel coupling structure, which uses the shape of the Tai Chi graph to make the shape of the two resonators bend, which is beneficial to increase the coupling area between the two resonators without increasing the design size. The parallel coupling bandpass filter designed by this method has good S-parameter performance, simple design structure and high design efficiency. At the same time, the center frequency and coupling parameters of the filter are adjustable, which increases design flexibility.

2. Filter Theory and Design

2.1. Parallel Coupling Principle

The parallel coupled microstrip is composed of two microstrip lines placed in parallel and close to each other. In the design circuit of a bandpass filter, the microstrip line is not directly connected. It is the coupling between the microstrip lines to allow the radio frequency signal to pass and block the low-frequency signal. Therefore, two similar parallel microstrip lines are commonly used to form the band Pass filter[10].

Located on the same dielectric substrate, the distance between two parallel microstrip lines is S, the thickness of the dielectric substrate is d, and its structure is shown in Figure 1. With the decrease of S, the electromagnetic field interaction between the two parallel microstrips will produce a coupling effect. When the length L of the parallel coupled microstrip line is equal to 1/4 of the wavelength of the center frequency of the filter, the microstrip line of this structure has the characteristics of a bandpass filter. According to the transmission line theory, each microstrip line can be equivalent to a series inductance and a parallel capacitance, with odd mode and even mode characteristics. The basic equations can be established by the even-odd mode analysis method to calculate the odd-mode impedance (Z_{0o}) and even-mode impedance (Z_{0e}).

Suppose the middle part of the parallel coupled microstrip transmission line is the medium, the bottom layer of the medium is a metal ground layer, and the top layer of the medium is two microstrip transmission lines with width W, length L, and spacing S. The characteristics of each microstrip line The impedance is Z_0.

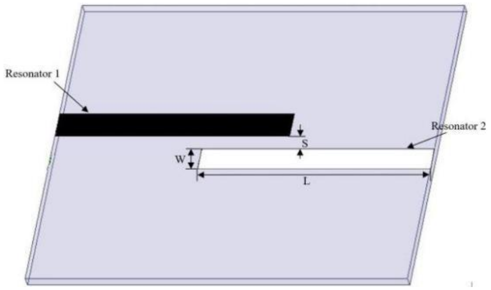

Figure 1: Parallel coupled microstrip structure

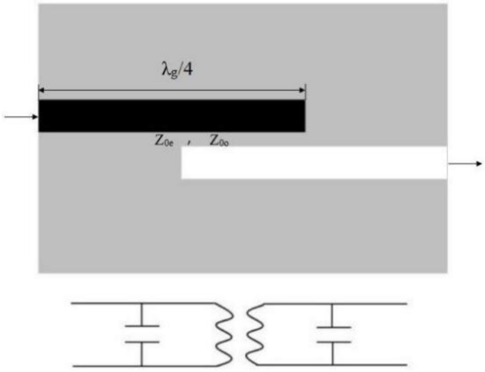

Figure 2: Parallel coupled microstrip structure equivalent circuit diagram

According to the formula in the literature [4, 11], the initial values of the filter parameters and the even mode impedance Z_{0e} and odd mode impedance Z_{0o} can be calculated.

$$L = \frac{\lambda_g}{4} \tag{1}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \tag{2}$$

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}} \tag{3}$$

$$Z_{0o} = Z_0[1 - Z_0 J + (Z_0 J)^2] \tag{4}$$

$$Z_{0e} = Z_0[1 + Z_0 J + (Z_0 J)^2] \tag{5}$$

$$J = \frac{1}{Z_0} \sqrt{\frac{\pi\Delta}{2g_0 g_1}} \tag{6}$$

$$\Delta = \frac{f_2 - f_1}{f_0} \tag{7}$$

Among them, λ_g is the wavelength of the center frequency of the filter, λ_0 is the free space propagation wavelength at the center frequency of the filter, ε_{re} is the effective permittivity, ε_r is the relative permittivity of the dielectric substrate, Δ is the relative bandwidth of the bandpass filter , g is the standard low-pass filter parameter, f_2 is the cutoff frequency at the high frequency of the 3dB bandwidth, f_1 is the cutoff frequency at the low frequency of the 3dB bandwidth, and f_0 is the center frequency of the passband.

Figure 2 is an equivalent circuit diagram of a parallel coupled microstrip structure. The coupling coefficient K between two adjacent resonators can be calculated using the following formula[4] :

$$K = \frac{\Delta}{\sqrt{g_0 g_1}} \tag{8}$$

$$K = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \tag{9}$$

2.2. Design of Parallel Coupling Structure Tai Chi Filter

The designed filter is a single-layer circuit structure, which consists of a dielectric substrate and its top and bottom metal boundaries. The top layer of the dielectric substrate is a microstrip patch metal layer, and the bottom layer is a metal ground plane. The top layer is composed of a 50Ω microstrip feeder, the yin-fish resonator in the Tai Chi pattern is parallel coupled to the yang-fish resonator, and the grounding through hole at the fish-eye of the yin-yang fish head in the resonator. The topology is shown in Figure 3.

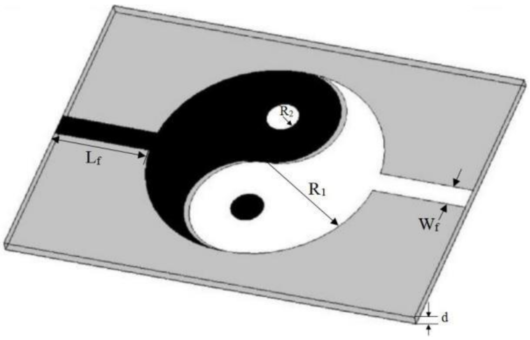

Figure 3: Tai Chi filter

In this paper, a 50Ω microstrip feeder line is laid on the top metal layer to achieve 50Ω impedance matching in the application while taking into account factors such as withstand voltage, large power transmission and small loss. Laying Taichi-shaped microstrip patch is convenient for circuit processing. At the same time, the yin and yang fish resonator in the Taichi-shaped microstrip patch is equivalent to a step impedance resonator (SIR). The frequency range and passband can be adjusted by changing the impedance ratio of SIR. The bandwidth is adjusted to increase design flexibility[12].

2.3. The Influence of Resonator Radius on Filter Working Frequency

When the radius of the resonator changes, the impedance ratio of the yin-yang fish-shaped step impedance resonator also changes. Take the radius of the resonator R_1=6mm, 6.5mm, 7mm for simulation test, the change of the filter working frequency with the radius of the resonator is shown in Figure 4. It can be seen from Figure 4 that as the size of the resonator radius R_1 increases, the operating frequency of the filter gradually decreases.

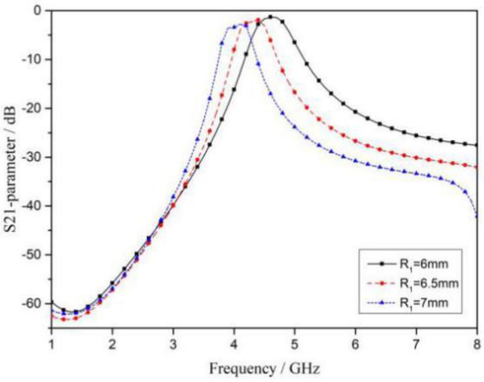

Figure 4: The influence of resonator radius on filter working frequency

2.4. The Influence of Coupling Spacing on Filter Bandwidth

Analyze the influence of coupling spacing on the working bandwidth of the filter. It can be seen from formulas (7)-(9) that when the coupling distance S decreases, the coupling between the two resonators increases and the coupling coefficient K increases. As the coupling coefficient increases, the relative working bandwidth of the filter increases. Take the coupling spacing S=0.1mm, 0.15mm, 0.2mm for simulation test, the simulation result is shown in Figure 5.

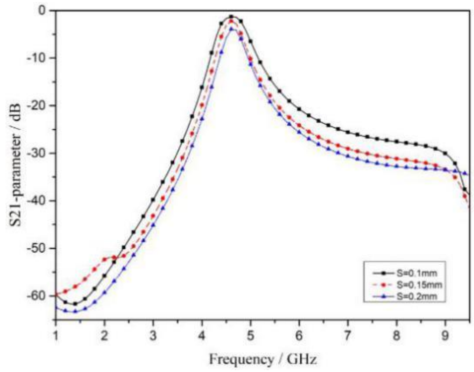

Figure 5: The influence of coupling distance S on the working bandwidth of filter

It can be seen from Figure 5 that when the coupling distance S=0.1, the working bandwidth of the filter is the widest and the coupling effect is the best. This conclusion can be verified in the electric field intensity distribution diagram of the filter in Fig. 6. The electric field intensity at the gap between the two resonators in Fig. 6 is relatively large, and the coupling distance between the two resonators can be controlled to control the coupling coefficient, thereby meeting the design requirements.

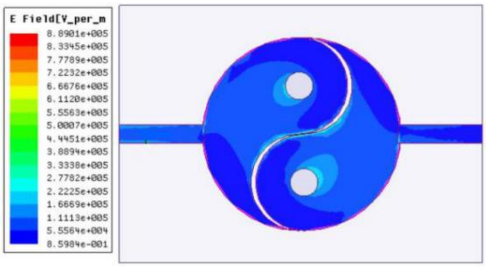

Figure 6: Filter electric field intensity distribution map

2.5. Influence of Resonator Ground Through Hole on Resonant Frequency

During the simulation process, it was found that the resonator grounding via would affect the resonant frequency of the resonator. Using ANSYS company's three-dimensional high-frequency electromagnetic simulation software HFSS-15 simulation, in the weak coupling feed mode, the simulation experiment of the resonator grounding hole radius. Figure 7 shows the change of the resonant frequency of the resonator when the radii of the resonator ground vias are R_2=0.71mm, 0.86mm, 1mm. It can be seen from Figure 7 that when the radius of the resonator ground via increases, the resonant frequency of the resonator increases.

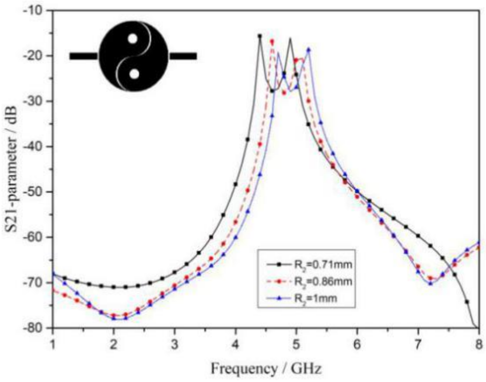

Figure 7: Influence of resonator ground through hole on resonant frequency

Through the optimization of the filter circuit, the design parameters of the Tai Chi filter are finally obtained as follows: The circuit uses a single layer of RO4003 dielectric substrate with a thickness of d=0.508mm, its dissipation factor is 0.0027, and the overall circuit size is 22.49mm× 16mm×0.508mm. The microstrip parameters of the top layer of the circuit are L_f=5.15mm，W_f=1.15mm，R_1=6mm，S=0.1mm，R_2=0.86mm.

Table 1: List of filter circuit parameters

parameter	value	parameter	value
Lf	5.15mm	Wf	1.15mm
R1	6mm	R2	0.86mm
d	0.508mm	S	0.1mm

2.6. Simulation Results

The simulation result is shown in Figure 8. The operating frequency of the Tai Chi filter is 4.38-4.84GHz, the center frequency of the passband is 4.61GHz, the fractional bandwidth is 10%, the insertion loss S_{21} in the passband is better than -1.38dB, the return loss S_{11} is better than -20.32dB. The filter has the advantages of miniaturization, high performance and good design flexibility. It is suitable for filter circuit design requirements.

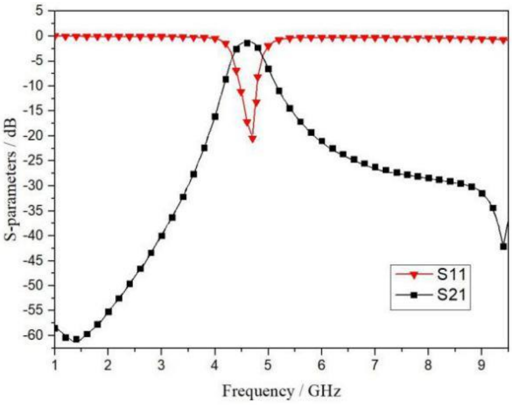

Figure 8: Simulation results

3. Conclusion

This paper designs a parallel-coupled microstrip line bandpass filter based on the basic theory of parallel coupled microstrip line. The working frequency of the filter is 4.38-4.84GHz, the center frequency of the passband is 4.61GHz, the fractional bandwidth is 10%, the insertion loss S_{21} in the passband is better than -1.38dB, and the return loss S_{11} is better than -20.32dB. The filter is a single-layer circuit structure, which has the advantages of low cost, simple and flexible design structure, and small circuit size, which is conducive to miniaturization and integration of the circuit. However, this design still has some shortcomings, such as the narrow 3dB fractional bandwidth at the passband, and its broadbandization needs to be further studied in the future.

Acknowledgements

This work is supposed by the Natural Science Foundation of Tianjin, China (18JCYBJC16400), Graduate Innovation Foundation of Tianjin University of Technology and Education in 2020, China (YC20-3).

References

[1] X.F. Xu: ADS2008 RF Circuit Design and Simulation Examples (Electronic Industry Press, China 2013).

[2] J.G. Zhou, Y.C. Chang, W.Q. Che: Compact Wideband Balanced Band-pass Filter with High Commonmode Suppression based on Cascade Parallel Coupled Lines, IEEE Microwaves Antennas and Propagation, Vol. 8(2014) No.8, p.564-570.

[3] D.N. Cui, Y.N. Liu, S.L Li, et al． A Compact Band-pass Filter based on Two Meandered Parallel-coupled Lines, The Journal of China Universities of Posts and Telecommunications, Vol. 19(2012) No.3, p.33-36.

[4] J.Z. Zhang: Design of Ku-band Hairpin Filter, Guangdong Communication Technology, Vol. 2(2009) No.2, p.76-79.

[5] L. Zhu, H. Wang: Ultra-wideband Bandpass Filter on Aperture-backed Microstrip Line, Electronics Letters, Vol. 41(2005) No. 18, p.1015-1016.

[6] M.Y. Hsieh, S.M. Wang: Compact and Wideband Microstrip Bandstop Filter, IEEE Microwave and Wireless Components Letters，Vol. 15(2005) No.7, p.472-474.

[7] L.M. Liang: Theoretical research and design of broadband filter based on anti-coupling line and signal interference (Ph.D., Beijing University of Posts and Telecommunications, China 2014).

[8] Q. Li, C.H. Liang, J. Chen: Design of Ultra-wideband Bandpass Filter based on Three-wire Coupling Structure, National Microwave and Millimeter Wave Conference (China, 2009). Vol. 1, p.1556.

[9] D.N. Cui, J.H. Wang: Four Types of T-type Filters Composed of Three Parallel Coupled Lines Connected in Parallel, National Microwave and Millimeter Wave Conferenc (China, 2013). Vol. 1, p.1023.

[10] C. Xu, X. Tang: Design Simulation and Test of Parallel Coupled Microstrip Line Bandpass Filter, Modern Electronics Technique, Vol. 36(2013) No.23, p.78-84.

[11] Q.W. Li, P.J. He, D. Jiang, et al. Analysis and Design of Parallel Coupling Bandpass Filter, Fire Control Radar Technology, Vol. 43(2014) No.3, p.83-86.

[12] M. Makimoto, S. Yamashita: Microwave Resonator and Filter in Wireless Communication (National Defense Industry Press, China 2002).