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Design of Narrow Band High Suppression Cavity Filter

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Abstract: With the development of satellite communication and ground mobile communication system, the compatibility between them has aroused widespread concern. In this paper, a narrow-band cavity filter with high suppression is designed, which aims to suppress the passage of 5G interference signals in the frequency band of Beidou RDSS receiver. According to the constraint conditions, the order, zero configuration and topological structure of the filter are determined by CoupleFil software, so as to obtain the coupling bandwidth and quality factor, and then the filter is modeled and simulated by HFSS software combined with parameters. Finally, the simulation and physical test results meet the requirements, and have a good suppression effect on 5G mobile signals.

Keywords: Cavity filter; Coupling coefficient; Out of band suppression

1. INTRODUCTION

In the wireless microwave communication system, the filter, as a passive device, is an essential core device, which mainly has the function of frequency selectivity[1]. With the increasing demand and functions of wireless communication systems, the available spectrum resources are becoming more and more tense[2]. Each system requires a high degree of isolation between adjacent resource bands to ensure that the systems will not interfere with each other[3]. At present, the requirements are mainly met by improving the indicators of filters. Microwave filters can be divided into LC filters, surface acoustic wave/bulk acoustic wave filters, spiral filters, dielectric filters, cavity filters, high temperature superconducting filters, and planar structure filters[4]. Among them, compared with other filters, the transmission medium of cavity filter is air, which has firm structure, stable and reliable performance, high Q value and good heat dissipation, and its high-end parasitic passband is far away[5].

In this paper, a bandpass cavity filter with narrow band and high rejection is mainly designed. In the design process, the design of the filter is realized by combining HFSS simulation results with parameter extraction, and then it is optimized. Finally, it is manufactured and tested, and the test results show that it meets the performance requirements.

2. PRINCIPLE OF FILTER

When designing microwave filters, we usually start with lumped parameter low-pass filters, get lumped parameter circuit models by frequency transformation, and finally realize them by using distributed parameters[6]. According to the design characteristics of the filter, it can be divided into Butterworth filter, Chebyshev filter and elliptic function filter. Among them, Chebyshev filter is widely used in filter design because of its in-band equal ripple characteristics and controllable transmission zero[7].

In the process of filter comprehensive design, because the generalized Chebyshev filter needs to solve the recursive relation of polynomials, the matrix of coupled microwave network can be deduced according to the cavity filter function through the corresponding recursive technology[8].

If there are n resonant cavities, the coupling normalization matrix of the resonators is shown in the following formula (1).

$$[M] = \begin{bmatrix} 0 & m_{s1} & \cdots & m_{sn} & m_{sl} \\ m_{s1} & m_{11} & \cdots & m_{1n} & m_{1l} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ m_{sn} & m_{1n} & \cdots & m_{nn} & m_{nl} \\ m_{sl} & m_{1l} & \cdots & m_{nl} & 0 \end{bmatrix} \tag{1}$$

In formula (1), m_{s1} represents the coupling coefficient between the input port and the first resonant cavity; m_{nl} represents the coupling coefficient between the output port and the last resonant cavity. m_{ii} ($i \neq 0$) represents the resonant frequency of the i-th resonant cavity; m_{ij} ($i \neq j$, and $i,j \neq 0$) represents the coupling between the i-th resonator and the j-th resonator.

The admittance matrix can be deduced by reflection polynomial and transmission polynomial, and then the coupling matrix can be simplified[9]. Because of the complexity of the formula, the coupling coefficient can be extracted by auxiliary software. In this paper, the coupling of resonators adopts spatial coupling structure, and a fifth-order comb cavity filter is designed[10].

3. DESIGN METHOD OF CAVITY FILTER

In the design of cavity filter, firstly, the order, coupling coefficient and topological structure of the filter are determined according to the design index, secondly, modeling and simulation are carried out by using HFSS software, and finally, optimization is carried out to meet the required index requirements.

In order to make Beidou S-band signal pass smoothly and suppress the strong interference of 5G signal, The design indexes of the filter are shown in the following table 1.

Parameter	Index Requirements
Central frequency	2491.75MHz
Bandwidth	16MHz
Insertion loss	< 5dB
Voltage standing wave ratio	1.5
Out-of-band rejection	-50dB@2515MHz

Firstly, through the auxiliary software CoupleFil, input the corresponding frequency band range and the required out-of-band suppression performance, check the frequency response curve of the filter in the ideal state, and debug the order and transmission zero. It can be seen that the out-of-band suppression at 2515MHz can meet the required out-of-band suppression conditions when the filter is selected as the fifth order[11].

Its normalized coupling matrix M is:

$$[M]=\begin{bmatrix} 0 & 0.0065 & 0 & 0 & 0 & 0 & 0 \\ 0.0065 & 0 & 0.0056 & 0 & 0 & 0 & 0 \\ 0 & 0.0056 & 0 & 0.0041 & 0 & 0 & 0 \\ 0 & 0 & 0.0041 & 0 & 0.0041 & 0 & 0 \\ 0 & 0 & 0 & 0.0041 & 0 & 0.0056 & 0 \\ 0 & 0 & 0 & 0 & 0.0056 & 0 & 0.0065 \\ 0 & 0 & 0 & 0 & 0 & 0.0065 & 0 \end{bmatrix}$$

The corresponding relationship between the elements in the matrix and the coupling coefficient is shown in formula (1), the input port coupling coefficient and the output port coupling coefficient $m_{s1} = m_{5l} = 0.0065$, the resonant frequency coupling coefficient $m_{11} = m_{22} = m_{33} = m_{44} = m_{55} = 0$, and the coupling coefficient $m_{12} = m_{21} = 0.0056$ between the first and second resonant cavities. The coupling coefficient $m_{23} = m_{32} = 0.0041$ between the second resonator and the third resonator, $m_{34} = m_{43} = 0.0041$ between the third resonator and the fourth resonator, and $m_{45} = m_{54} = 0.0056$ between the fourth resonator and the fifth resonator[12].

The ideal filter frequency response curve is shown in Figure 1 below.

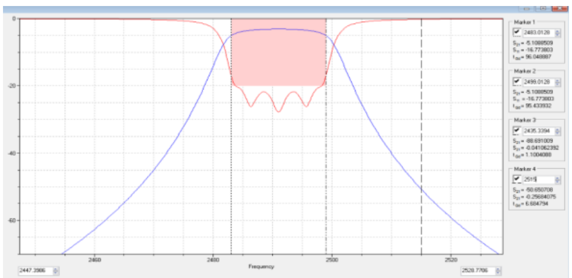

Fig 1 Frequency response of ideal filter

As can be seen from Figure 1 above, the out-of-band rejection at 2515MHz is 50dB, and the insertion loss of the filter is about 5dB.

According to the required index requirements, the filter is realized in the form of 5-order comb line. Firstly, using HFSS simulation software, combined with the required parameters, the structure of the designed single-cavity filter is shown in Figure 2 below.

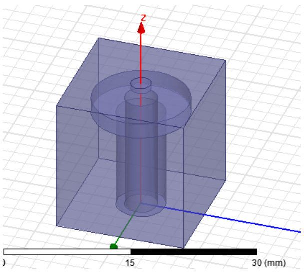

Fig. 2 Single-cavity filter model

In Figure 2 above, we can see that the single-cavity filter adopts the structure of adding a resonant rod in the resonant cavity. The ratio of the inner diameter of the conductor to the side length of the outer cavity is aimed at making the Q value of the cavity higher. Secondly, the diameter of the resonant rod, the width of the resonant cavity and the height of the resonant cavity are 2mm, 6mm and 15mm respectively. d/a≈0.33

The coupling model of port and resonator is calculated by time delay method here. The port design model in the simulation is shown in Figure 3 below.

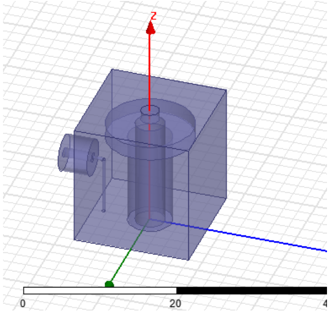

Fig. 3 resonator simulating port delay

The optimized delay simulation parameters are shown in Figure 4 below.

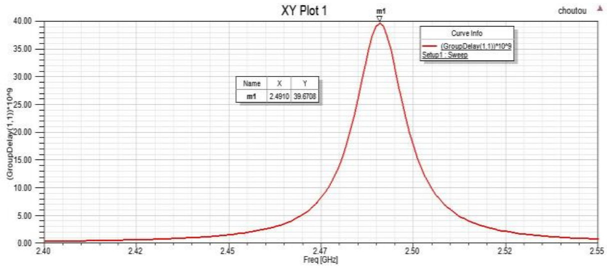

Fig. 4 Final optimized time delay simulation curve

The coupling between resonators is calculated by eigenmode frequency separation method, and its coupling model is shown in Figure 5 below.

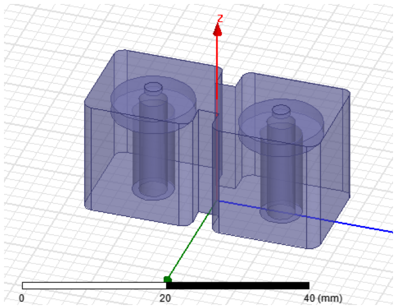

Fig. 5 resonator coupling model

Through the above design, the single-cavity resonator, port and coupling model are obtained. Finally, the full-wave filter is modeled, and its model is shown in Figure 6 below.

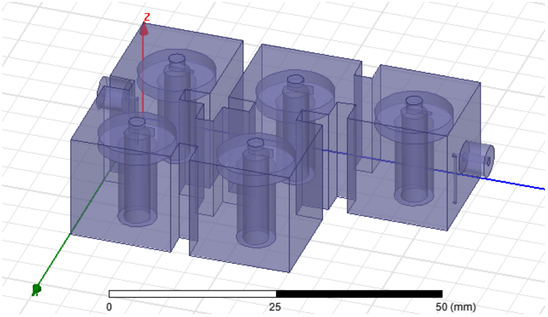

Fig. 6 The established fifth-order filter resonance model.

The model is analyzed, and the simulation results are shown in Figure 7 below.

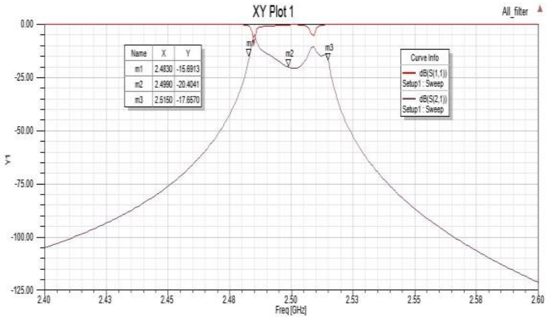

Fig. 7 Initial simulation results of integral filter

As can be seen from the curve in Figure 7 above, the simulation results have not achieved the desired effect. At this time, it is necessary to optimize and adjust according to the relative size and size of the coupling coefficient, and the final optimization result is shown in Figure 8 below.

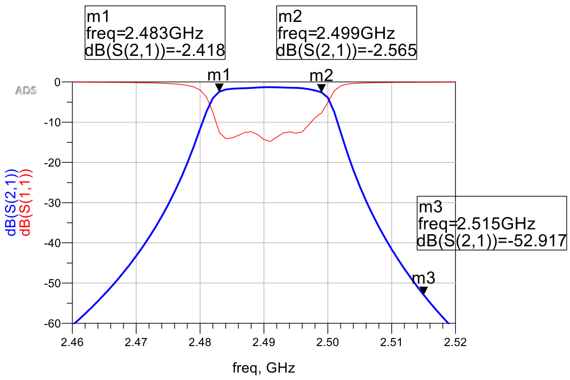

Fig. 8 Simulation results after optimization

Through the above simulation results, we can see that the design of the filter meets the index requirements.

4. PHYSICAL TEST

According to the satisfied index requirements after simulation, the layout is derived and the physical object is made. The physical object of the uncovered filter is shown in Figure 9 below. The test diagram of the capped filter is shown in Figure 10 below.

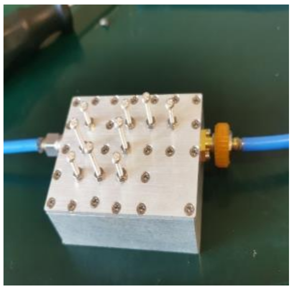

Fig. 9 Uncovered filter in kind

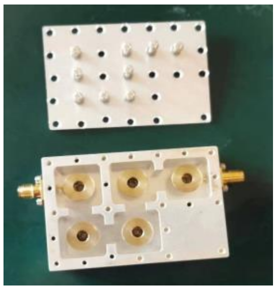

Fig. 10 Filter test object

The filter test results are shown in Figure 11 below.

Fig 11 Filter Test Results

It can be seen from the above figure 11 that the actual bandwidth of the filter is 16MHz, the insertion loss is about 5dB, and the suppression at 2515MHz is about 50dB.

5. CONCLUSION

In this paper, a fifth-order comb cavity filter is designed by using HFSS software. The return loss in the passband is more than 20dB, the in-band interpolation loss is about 5dB, and the out-of-band rejection is 50dB at 2515MHz, and the physical test and simulation results are basically consistent. The cavity filter can realize that Beidou signal has a good suppression effect on 5G adjacent frequency strong interference signal in S band, and it has certain effectiveness.

6. REFERENCES

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