A Dual-Mode Dielectric Filter for 5G System

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Abstract. Based on 5G system, a cylindrical dual-mode resonator and filter are designed. The electric field distribution characteristics of each mode of the dual-mode resonator are analyzed by using high-frequency electromagnetic field simulation software. Based on the designed dual-mode resonator, through theoretical calculation and analysis, a 5G system dielectric dual-mode filter is designed by using the RF / microwave simulation software ADS/HFSS. The coupling between modes is realized by setting metal screw perturbation on surfaces. The effect of two coupled degenerate modes is equivalent to that of two coupled resonators, so that the number of resonators can be reduced while the resonant circuit remains unchanged. For example, two modes of a resonator can be used in a traditional n-section filter, the same physical space realizes the characteristic of 2n section filter, which greatly reduces the size of the filter. A 5G system dielectric filter is designed based on dual-mode resonator. The results show that in the pass-band (3.4 ~ 3.5GHz), the return loss is more than 18dB, the insertion loss is less than 0.3dB, the zero on the left side of the pass-band is 3.1716GHz, the zero on the right side of the pass-band is 3.8537GHz, the VSWR is less than 1.28. Transmission zeros are introduced on both sides of the pass-band, which improves the suppression ability out of pass-band. The 5G system dielectric filter has the advantages of low insertion loss, small size and good suppression performance out of pass-band. When applied to 5G wireless communication system, the anti-interference ability and stability of the system can be improved.

Keywords: 5G System, Cavity Filter, Dual-mode Filter, Return Loss

1. Introduction

In the past few decades, wireless communication has been widely used. As one of the key RF devices in wireless communication, RF filter plays an important role in wireless communication and is an indispensable part of wireless communication system. Microwave filter with excellent performance can play a role in selecting frequency band and channel, and can filter harmonics out pass-band and suppress spurious. Therefore, microwave filter has been a research hotspot in the field of wireless communication system [1-10]. However, with the development of communication technology, due to the needs of practical engineering applications, the size of the filter is required to be smaller and smaller, and the filter will inevitably develop in the direction of miniaturization. The traditional single-mode cavity filter has a large size and poor performance. With the high integration of mobile
communication technology, the size of the filter will be smaller and smaller. Undoubtedly, the dual-mode filter uses infinite resonant modes and resonant frequencies for different field distributions in the resonator, and the mode with the same resonant frequency is called degenerate mode [2-3]. Generally, some perturbations (such as slotting, chamfering, screw or adding small metal patch, undercut, etc.) can be added to a single resonator to change the electric field distribution of the original orthogonal degenerate modes, so that a couple of orthogonal degenerate modes are coupled. The effect of two coupled degenerate modes is equivalent to two coupled resonators, so that the resonant loop remains unchanged and the number of resonators is reduced. For example, a dual-mode resonator can be designed to realize the characteristics of a 2 x n-section filter in the physical space of a traditional n-section filter by using the two modes of a resonator, thus greatly reducing the size of the filter. Therefore, it is very important to study dual-mode resonators and filters based on dual-mode resonators.

2. The Design of Dielectric Dual-Mode Resonator

2.1 Theoretical Analysis of Dual-Mode Resonator and Its Resonant Frequency

There may be multiple resonant modes in a resonator. Multi-modes can be used to design multi-mode coupling circuits with the same resonant frequency. A dual-mode resonator can replace two single-mode resonators. Therefore, it can reduce the overall size of the filter. The experimental models of dual and multiple mode filters have made a lot of progress, and some filtering characteristics have been obtained [3-4]. Different shapes of resonators have own characteristics. Generally, the shape of resonators determines the resonant mode of resonators. In order to obtain a suitable resonant mode and the convenience of machining, the resonator used in this paper is a solid cylindrical dielectric resonator. As shown in Fig.1, the material of the body is the dielectric material with high dielectric constant, and the material of the supporting dielectric resonator structure is alumina.

The resonant frequency of the resonator is usually calculated by numerical electro-magnetic method and Maxwell equations, or by mixed wall method, finite element method or open waveguide method. For the isolated cylindrical dielectric resonator, the electromagnetic environment is relatively simple. Thus, the following formula may be calculated the lowest frequency of the resonator.

\[ f_0 = \frac{34}{a} \sqrt{\varepsilon_r \left( \frac{a}{h} + 3.45 \right)} \text{(GHz)} \]  

(1)

Where, as shown in Fig.1, \( a \) is the diameter of the isolated cylindrical dielectric resonator and \( h \) is the height.

Due to the complex electromagnetic environment, the open waveguide method is used usually to analyze the dielectric resonator placed in the metal shielding box.

2.2 Simulation Design of Dual-mode Resonator

A dielectric material with permeability \( \mu = 1 \) and dielectric constant = 24 is selected. The cavity size is initially set as 27mm x 27mm x 27mm. HFSS (high frequency structure simulator) software is used to preliminarily build the model of dielectric resonator. The cylindrical dielectric resonator has a diameter of 20mm and a height of 8.7mm. After simulation and analysis, the resonant frequency and Q value of dielectric resonator are finally obtained. The results are shown in Fig.2. It can be seen from the results that the resonant frequencies of modes 2 and 3 are in the range of 3.4GHz-3.5GHz in 5G frequency band.
The 5G system filter designed is Unicom band 3.4~3.5GHz, so mode 2 and mode 3 are selected. In order to further analyze the characteristics of the resonator, HFSS is used to analyze the electric field of mode 2 and mode 3 of the resonator. The analysis results are shown in Fig. 3 and Fig. 4.

![Fig. 3 Electric Field Pattern of HEE11 Dual-mode Along the Radial Clockwise 45° Polarization](image)

![Fig. 4 Electric Field Pattern of HEE11 Dual-mode Along the Radial Anti-clockwise 45° Polarization](image)

### 3. Theoretical Design of 5G System Dual-mode Dielectric Filter

The performance index of the designed 5G system filter is shown in Table 1.

| The Index of Filter          | The Index of Filter          |
|------------------------------|------------------------------|
| Center frequency($f_0$)      | 3450MHz                      |
| Absolute bandwidth(ABW)      | 100MHz                       |
| Relative bandwidth(RBW)      | 2.89%                        |
| Return Loss                  | 15dB                         |
| Insertion Loss               | 0.6dB                        |
| VSWR                         | 1.3                          |

Based on the above design indicators, in order to facilitate tuning and design, the HEE11 degenerate coupled dual-mode is used to realize the coupling between the two resonators, and the input and output are coupled with the two modes respectively.

Port coupling refers to the coupling between the input and the first resonator, and the output coupling with the last resonator. The common SMA port which is easy to manufacture and process is used to fix the SMA connector on the metal shell and connect the SMA inner core with the coupling.
probe. As shown in Fig.5, the two coupling devices extend into the bottom of the cylindrical resonator to realize the correspondence port coupling between the input and output ports and the modes respectively.

**Fig.5** The Coupling and Tuning Devices

For symmetrical resonator, the coupling coefficient is calculated by calculating only half of the structure. When PEC and PMC boundary conditions are applied respectively in the middle of the structure, the two resonant frequencies can be obtained, and then the coupling coefficient will be given, that is, the calculation of coupling coefficient can be based on the formula

\[ k = \frac{f_1^2 - f_2^2}{f_1^2 + f_2^2} \]  \hspace{1cm} (2)

Where, \( k \) is the coupling coefficient between the two modes, \( f_1 \) is the resonant frequency of the first mode when \( f_2 \) the resonant frequency of the second mode. For HEE11 degenerate mode, the two modes are symmetrically distributed. Therefore, the coupling coefficient can be calculated by using the formula of coupling coefficient between symmetrical resonators. The relationship is shown between \( L \) and \( k \) in Fig.6.

**4. Design and of Filter based on the Dual-mode Resonator**

Based on the analysis of port coupling and mode coupling, the final filter structure is simulated by 3D electromagnetic simulation software. After accurate simulation, the designed filter bandwidth is 3.4–3.5GHz, return loss > 18db, insertion loss < 0.3db, the zero point on the left side of the pass-band is 3.1713ghz, and the zero point on the right side of the pass-band is 3.8537ghz, as shown in Figure 7, and the VSWR < 1.28, as shown in Figure 8.

**Fig.7** Return Loss and Insertion Loss of Dielectric Filter
5. Conclusion

In this paper, the design method of dielectric filter based on dual-mode resonator is introduced. The electric field distribution of the original orthogonal degenerate mode is changed by adding some perturbation in resonator, there are multiple resonant modes for different field distributions in the single cavity resonator. Two coupled degenerate modes are equivalent to two coupled resonators, so that the number of resonators is reduced by half while the resonant circuit remains unchanged. Thus, the volume of the filter is greatly reduced. Two transmission zeros is introduced on both sides of the pass-band to improve suppression ability out of pass-band of the filter. The results show that in the pass-band (3.4 ~ 3.5GHz), the return loss is more than 18dB, the insertion loss is less than 0.2 dB, the zero on the left side of the pass-band is 3.1713GHz, the zero point on the right side of the pass-band is 3.8537GHz, and the VSWR is 1.28. The filter has the advantages of small insertion loss, small size and good rejection out of pass-band, which can be applied to 5G band wireless communication system with better suppression performance to improve the communication quality of the communication system.

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