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Research Article

A Novel 5G Multi-mode Resonator and Filter with Symmetric Transmission Zeros

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Abstract

5G construction is becoming increasingly important. This paper introduces the theoretical basis of multi-mode filter, and on the basis of theoretical calculation and analysis, a novel 5G cavity multi-mode resonator and filter is designed by using ads/HFSS simulation software. The electric field characteristic of resonator is analyzed, and the mutual coupling between modes is realized by the way of screw perturbation. The electric field distributions of the mode is changed by adding tuning screws, two coupled degenerate modes act as two coupled resonators, so that the numbers of resonator can be reduced while keeping the resonance loop unchanged. For example, the characteristics of 3N section filter can be realized in the physical space of a traditional n-section filter by using three modes of a resonator, thus greatly reducing the volume of the filter. The results show that in the pass-band (3.5 GHz ~ 3.6 GHz): return loss > 17.9 dB, standing wave ratio < 1.29, insertion loss < 0.31 dB, a transmission zero point is introduced at 4 GHz on the right side of the pass-band, which makes the right side out of band attenuation rapidly. The filter has the advantages of small insertion loss, small size and good rejection of out of band, which can be applied to 5G band wireless communication system for better reliability.

Keywords

5G Band, Cavity Filter, Multi-mode Filter, Hfss Simulation and Optimization, Standing-Wave Ratio, Insertion Loss

1. Introduction

Wireless communication has been widely used. Microwave filter plays a key 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 interference signal out of the pass-band and suppress spurious. Therefore, microwave filter has been a research hotspot in the field of wireless communication system [1-24]. However, due to the needs of practical engineering applications, the size of the filter is required to be higher and higher with the development of communication technology, Miniaturization is the inevitable development direction of the filter. The traditional single-mode filter has large size and poor performance. The size of the filter will be smaller and smaller with the high integration of mobile communication technology, Undoubtedly, the multi-mode filter uses the multi-mode resonator to have infinite resonant modes and harmonic frequencies for different field distributions, and the mode with the same resonant frequency is called degenerate mode [2, 3]. In general, some perturbation can be added to a

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single resonator (such as slotting, corner cutting, screw or adding small metal patch, internal tangent angle, etc.), which can change the electric field distribution of the original orthogonal degenerate mode and make a couple of orthogonal degenerate modes coupled. The effect of two coupled degenerate modes is equivalent to that of two coupled resonators. So that the resonant circuit remains unchanged but the numbers of resonator is reduced. For example, a multi-mode resonator can be designed to realize the characteristics of M×N-section filter in the physical space of a traditional N-section filter by using the M-modes of one resonator, thus greatly reducing the size of the filter. Therefore, it is very important to study the multi-mode resonator and filter. The article is based on a multi-mode resonator and studies a 5G frequency band filter with symmetric zero, which has a small volume, low insertion loss, and high return loss.

2. The Design of Dielectric Multi-mode Resonator

2.1. Theoretical Analysis of Multi-mode Resonator and Resonant Frequency

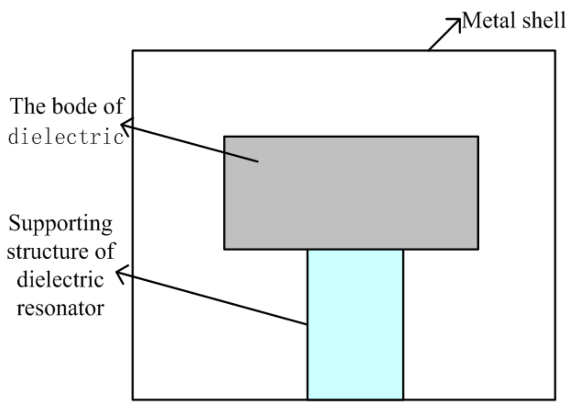


Figure 1. *The structure of dielectric resonator.*

There may be multiple resonant modes in a resonator cavity. Multiple resonant modes can be used to design multi-mode coupling circuits with the same resonant frequency. A multi-mode resonant can replace multiple single-mode resonators. Therefore, it can reduce the size and weight of the filter. The experimental models of dual and multiple degenerate filters have made a lot of progress, and some filtering characteristics have been obtained [3, 4]. Cylindrical, spherical and triangular resonators are used in most literatures. Different structures of resonator have their own characteristics. Generally speaking, the structure of resonator determines the resonant mode of resonator. In order to obtain a suitable resonant mode and the convenience of machining, the resonator is a solid cylindrical dielectric resonator in this paper. A typical dielectric resonator and its metal shell structure are shown in Figure 1. The main material of the resonator is the dielectric material with high dielectric constant, and the main material of the dielectric resonator supporting structure is alumina. Generally speaking, the size of the shielding cavity of the metal shell needs to ensure that the mode frequency works in the evanescent mode.

Most of the field is concentrated in the resonator for dielectric cylindrical resonator, and there is a certain edge field outside of the resonator. Generally, the numerical electromagnetic method is used to calculate the resonant frequency of the resonator. Maxwell equations are used to solve the exact solution. The mixed wall method, variational method, finite element analysis method or open waveguide method can be used to calculate the resonant frequency. Two common calculation methods are as follow.

(1) As shown in Figure 2, the radius of the isolated cylindrical dielectric resonator is *a* and the height is *h*. The electromagnetic environment is relatively simple. The resonant frequency of the lowest mode is usually obtained by using the formula:

$$f_0 = \frac{34}{a\sqrt{\varepsilon_r}}\left(\frac{a}{h}+3.45\right)(\text{GHz}) \quad (1)$$

Where, *a* is the radius and *h* is the height.

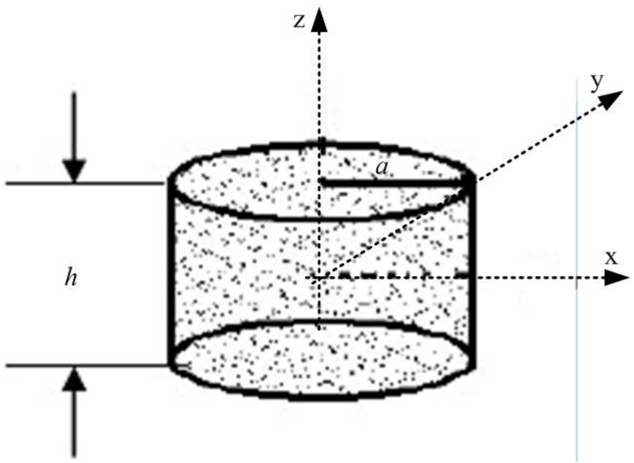


Figure 2. *Isolated dielectric resonator.*

(2) Dielectric resonator in metal shielding box.

The dielectric resonator is placed in the metal shielding box. The open waveguide method is used for analysis because of the complex electromagnetic. The circuit diagram of the dielectric resonator is shown in Figure 3, the area within the metal plate of the resonator is divided into six areas, the area of 1, 2, 3 and 4 have electromagnetic field distribution. The area of 5, 6 have weak electromagnetic field, which can be ignored and regarded as zero-field.

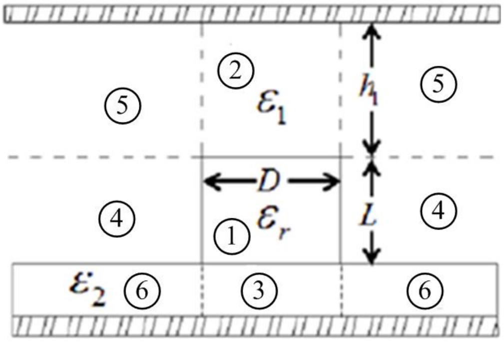


Figure 3. *The diagram of dielectric resonator.*

TE wave and TM wave exist inside of dielectric resonator. Taking TE wave as an example (TM wave can be analyzed by similar method), the Hz magnetic field component which does not change with δ in each region in Figure 3 is obtained by solving Helmholtz equation:

$$H_{Z1} = A_1 J_0(K_0 r)\cos(\beta z + \varphi) \tag{2}$$

$$H_{Z2} = A_2 J_0(K_0 r) sha_1(\frac{L}{2} + h_1 - z) \tag{3}$$

$$H_{Z3} = A_3 J_0(K_0 r) sha_2(z + \frac{L}{2} + h_2) \tag{4}$$

$$H_{Z4} = A_4 J_0(K_0 r)\cos(\beta z + \varphi) \tag{5}$$

Among them, A_1, A_2, A_3, A_4, φ are constants, and at the same time:

$$\beta^2 = \varepsilon_1 k_0^2 - k_0^2 = k_0^2 + \alpha_3^2 \tag{6}$$

$$\alpha_1^2 = k_0^2 - \varepsilon_1 k_0^2 \tag{7}$$

$$\alpha_2^2 = k_0^2 - \varepsilon_2 k_0^2 \tag{8}$$

If H_Z are known, then the components of other fields can be calculated as follows:

$$E_r = \frac{-j\omega_r \mu_0}{k^2 - k_z^2} - \frac{\partial Hz}{r\partial\theta} \tag{8}$$

$$H_r = \frac{1}{k^2 - k_z^2} \cdot \frac{\partial^2 Hz}{\partial r \partial\theta} \tag{9}$$

$$E_\theta = \frac{j\omega_r \mu_0}{k^2 - k_z^2} \cdot \frac{\partial Hz}{r\partial\theta} \tag{10}$$

$$H_\theta = \frac{1}{k^2 - k_z^2} \cdot \frac{\partial^2 Hz}{r\partial z \partial\theta} \tag{11}$$

Where, k is the wave numbers in (8)-(11), the propagation constants are β in the regions of 1 and 4, and are $j\alpha_i (i = 1, 2)$ in the regions of 2 and 3, the propagation constants are zero for those TE modes independent of θ. Since the interface of the resonator is continuous, so (2) - (5) can be written as:

$$H_{Z1} = A_1 J_0(k_0 r)\cos(\beta z + \varphi) \tag{12}$$

$$H_{Z2} = A_1 \frac{\cos(\beta L/2 + \varphi)}{sh\alpha_1 h_1} J_0(k_0 r) sha_1(\frac{L}{2} + h_1 - z) \tag{13}$$

$$H_{Z3} = A_1 \frac{\cos(\beta L/2 - \varphi)}{sh\alpha_2 h_2} J_0(k_0 r) sha_2(\frac{L}{2} + h_2 + z) \tag{14}$$

$$H_{Z4} = A_1 \frac{J_0(k_c r)}{K_0(\alpha_3 a)} K_0(\alpha_3 r)\cos(\beta z + \varphi) \tag{15}$$

Similarly, H_r, E_θ is written as:

$$H_{r1} = \frac{\beta A_1}{k_c} J_1 k_c r \sin(\beta z + \varphi) \tag{16}$$

$$H_{Z2} = A_1 \frac{\cos(\beta L/2 + \varphi)}{sh\alpha_1 h_1} J_0(K_0 r) sh a_1 (\frac{L}{2} + h_1 - z) \quad (17)$$

$$H_{r3} = \frac{\alpha_1 A_1}{k_c} \frac{\cos(\beta L/2 - \varphi)}{sh\alpha_2 h_2} J_1(K_c r) ch\alpha_1 (\frac{L}{2} + h_2 + z) \quad (18)$$

$$H_{r4} = -\frac{\beta A_1}{k_c} \frac{J_0(k_c r)}{K_0(\alpha_3 a)} K_1(A_3 r) \sin(\beta z + \phi) \quad (19)$$

$$E_{\theta 1} = \frac{-j\omega_r \mu_0 A_1}{k_c} J_1(k_c r) \cos(\beta z + \varphi) \quad (20)$$

$$E_{\theta 2} = \frac{-j\omega_r \mu_0 A_1}{k_c} J_1(k_c r) \frac{\cos(\beta L/2 + \varphi)}{\mathrm{sh}\alpha_1 \mathrm{h}_1} \mathrm{sh}\alpha_1 (L/2 + \mathrm{h}_1 - z) \quad (21)$$

$$E_{\theta 3} = \frac{-j\omega_r \mu_0 A_1}{k_c} J_1(k_c r) \frac{\cos(\beta L/2 - \varphi)}{\mathrm{sh}\alpha_2 \mathrm{h}_2} \mathrm{sh}\alpha_2 (L/2 + \mathrm{h}_2 + z) \quad (22)$$

$$E_{\theta 4} = \frac{-j\omega_r \mu_0 A_1}{\alpha_3} \frac{J_0(k_c r)}{K_0(\alpha_3 a)} K_1(\alpha_3 r) \cos(\beta z + \varphi) \quad (23)$$

$J_0(x)$ and $J_1(x)$ are the first kind of Bessel functions in (10)-(21), and $K_0(x)$ and $K_1(x)$ are the second kind of modified Bessel functions. On the boundary of $r = a = \frac{D}{2}$, according to the boundary conditions of $E_{\theta 1} = E_{\theta 4}$, it can be gotten that:

$$\frac{J_1(k_0 a)}{k_c J_0(k_0 a)} = -\frac{K_1(\alpha_3 a)}{a_3 K_0(\alpha_3 a)} \quad (24)$$

On the boundary of $z = \frac{L}{2}$, according to the boundary conditions of $H_{r1} = H_{r2}$, the following conclusions can be obtained:

$$\beta tg(\frac{\beta L}{2} + \varphi) = \alpha_1 cth\alpha_1 h_1 \quad (25)$$

Similarly, On the boundary of $z = -\frac{L}{2}$, according to the boundary conditions of $H_{r1} = H_{r2}$, the following conclusions can be obtained,

$$\beta tg(\frac{\beta L}{2} - \varphi) = \alpha_2 cth\alpha_2 h_2 \quad (26)$$

From formulas (25) - (26), the following results can be gotten:

$$\beta L = \tan^{-1}(\frac{\alpha_1}{\beta}\coth\alpha_1 h_1) + \tan^{-1}(\frac{\alpha_2}{\beta}\coth\alpha_2 h_2) \quad (27)$$

$$\varphi = \tan^{-1}(\frac{\alpha_1}{\beta}\coth\alpha_1 h_1) - \tan^{-1}(\frac{\alpha_2}{\beta}\coth\alpha_2 h_2) \quad (28)$$

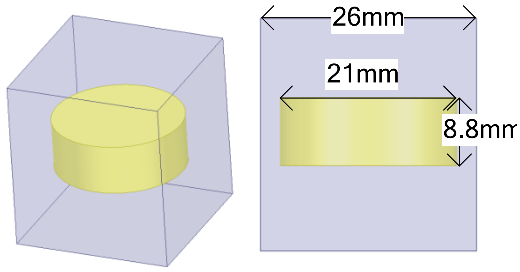
Equation (26) has many discrete roots, k_{01} is the smallest root after arrange according to the size. Therefore, in modules independent of θ, $TE_{01\delta}$ is the lowest module, and which is the main module.

The accurate numerical calculation method of the resonant frequency of cylindrical dielectric resonator in different modes needs to solve a large number of mathematical differential equations, which is cumbersome and time-consuming. With the development of IT technology, the use of computer software simulation has become a mainstream way, and empirical formula is only used as auxiliary design.

2.2. Simulation Design of Resonator

A dielectric material with permeability μ = 1 and dielectric constant = 24 is selected when the actual resonator is designed. According to the theory in the previous section, the cavity size is initially set as 28 mm x 28 mm x 28 mm, and the cavity material is plated with silver. HFSS (high frequency structure simulator) software is used to preliminarily build the dielectric resonator model, as shown in Figure 4. The diameter of cylindrical dielectric resonator is 21 mm and the height is 8.8 mm. HFSS is set as the eigen mode simulation, and calculate six modes. After simulation and analysis, the resonant frequency and Q value of dielectric resonator are finally obtained. The results are shown in Figure 5. It can be seen from the results that the resonant frequencies of modes 1, 2 and 3 are in the range of 3.3 Ghz ~ 3.6 Ghz in 5G frequency system.

The 5G band filter designed in this paper is Unicom band 3.5 Ghz ~ 3.6 Ghz, 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 Figure 6 and Figure 7.

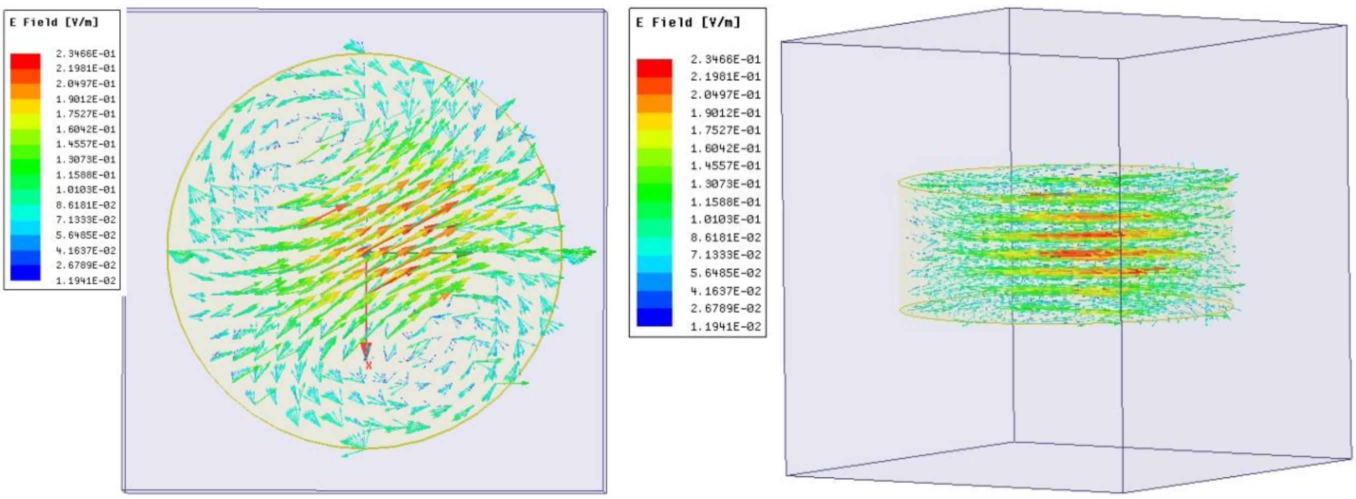


(a) The stereogram (b) The front view

Figure 4. *The mode of dielectric resonator.*

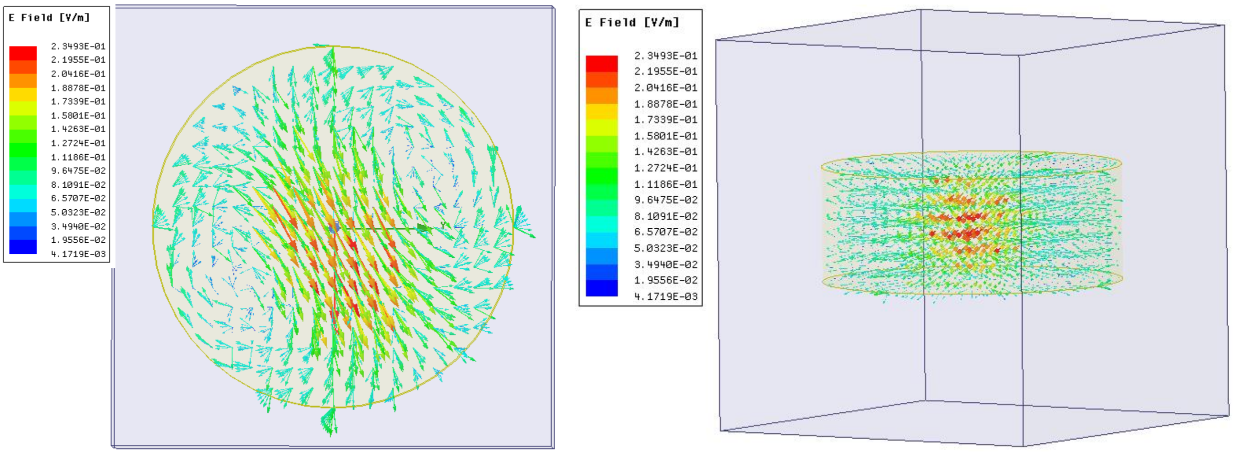
Eigenmode	Frequency (GHz)	Q
Mode 1	3.31991 +j 0.000112069	14812.0
Mode 2	3.56607 +j 0.000153470	11618.1
Mode 3	3.57034 +j 0.000153614	11621.1
Mode 4	4.27747 +j 7.08260e-05	30197.1
Mode 5	4.28899 +j 7.13846e-05	30041.5
Mode 6	4.47104 +j 4.77945e-05	46773.6

Figure 5. *The results of eigen mode simulation.*



(a) The top view (b) The side view

Figure 6. *The electric field pattern of HEE11 degenerate two mode along the radial clockwise 45 °polarization mode.*



(a) The top view (b) The side view

Figure 7. *Electric field diagram of HEE11 degenerate two mode along radial counter clockwise 45 °polarization mode.*

From the electric field diagram of Figure 6 to Figure 7, it can be seen that the electric field of the HEE11 dual-mode is the surrounding field from the side view, and the energy is concentrated in the middle of the cylindrical resonator. From the top view, it can be seen that the field distribution of the degenerate two modes of HEE11 can be affected by the interference applied to the upper part of the resonator, so as to realize the coupling between the two modes.

In cylindrical dielectric resonator, the main parameters affecting the resonant frequency of each mode are the diameter D and thickness H of the dielectric resonator. As shown in Figure 8 and Figure 9, the resonant frequencies of the eight main modes in the dielectric resonator are shown in relation to the diameter D and height H respectively.

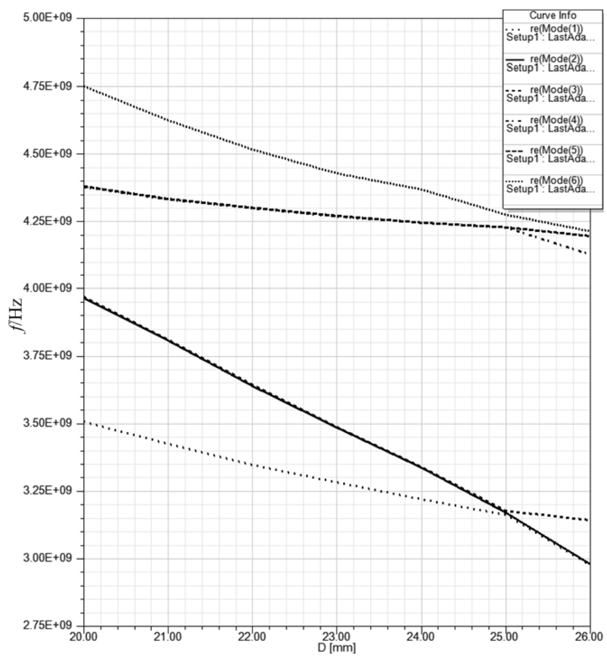


Figure 8. *Relationship between resonant frequency and diameter D of eight modes in dielectric resonator.*

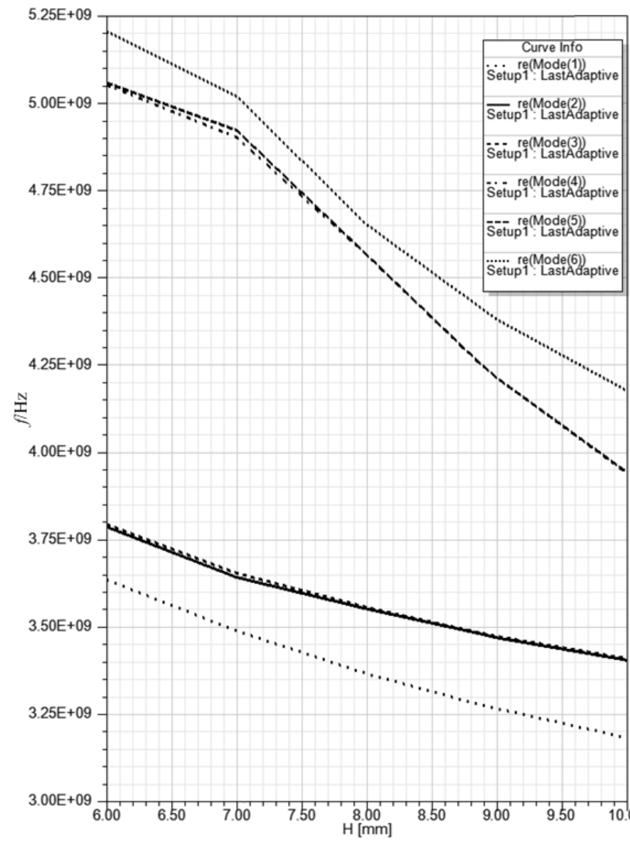


Figure 9. *Relationship between resonant frequency and height H of eight modes in dielectric resonator.*

According to the above analysis, the appropriate size can be selected from the rules in Figure 8 and Figure 9. When the diameter D of dielectric resonator is about 23 mm and the thickness H is about 8.5 mm, the resonant frequency of HEE11 degenerate dual-mode (mode 2 and mode 3) is close to 3.5 GHz, which can be used to design 5G system filter in Unicom band.

3. Theoretical Design of 5G Band Dielectric Filter

3.1. Design Parameters of 5G Band Dielectric Filter

According to the latest commercial planning of frequency band, China Unicom has been allocated the frequency band of 3500 MHz-3600 MHz with a total of 100 MHz. Therefore, the index performance of the designed 5G system filter is shown in Table 1, and the dimensions of dielectric resonator and metal external cavity are shown in table 2.

Table 1. *The design parameter of 5G band dielectric filter.*

The parameter of filter	
Center frequency (f_0)	3550 MHz
Absolute bandwidth (*ABW*)	100 MHz
Relative bandwidth (*RBW*)	2.81%
Standing wave ratio (*VSWR*)	1.3
bandpass ripple (ε)	0.6 dB

Table 2. *Specification of 5G band dielectric filter.*

Filter design size parameters	
Unit	**mm**
Rectangular metal external cavity	26x26x28
Diameter/height of cylindrical dielectrics	21/8.8
Diameter/height of supporting structure	3/11

Based on the above design indicators and 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. In the cavity, there are several paths for the signal to be transmitted from the input to the output. Therefore, by using the multipath transmission of the signal, the phase reversal and mutual cancellation can be realized at the finite frequency. The design of transmission zero point can be realized by using the appropriate optimization design, so as to improve the out of band suppression ability of the dielectric filter.

The main difficulty of designing 5G band dielectric filter with multi-mode resonator is the design of port coupling and coupling between modes. The design of transmission zero is mainly optimized by tuning screw.

3.2. Design of Port Coupling

The coupling of port is realized by the action of electric field, and use of the way that the probe is inserted into the cavity wall hole. The common SMA port which is convenient for manufacturing and processing is used. The SMA connector is fixed on the metal shell, and the SMA inner core is connected with the coupling probe. As shown in Figure 10, the coupling between input and output port and corresponding mode is realized by two coupling probes extend into the bottom of the cylindrical resonator.

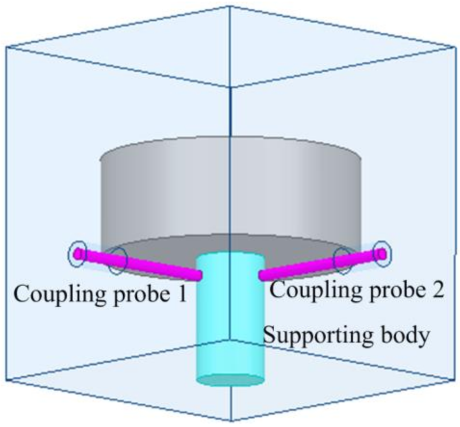


Figure 10. *Coupling probe extending into the bottom of resonator.*

The port coupling is generally expressed by the loaded Q_e value, that is, the position of the input and output ports is generally determined by the loaded Q_e value, and the relationship between Q_e and the coupling coefficient k_{01} is

$$Q_e = \frac{1}{k_{01}} \tag{29}$$

On the above equation (29), k_{01} is the coupling coefficient between input port/output port and mode 2/mode 3. According to the electric field pattern of figure 6 to figure 7, a coupling probe is inserted at the bottom of the cylindrical medium, and the coupling probe is electrically coupled with the corresponding resonant mode. The coupling strength is directly proportional to the depth of the coupling probe penetrating into the bottom of the medium. After comprehensive consideration, the coupling probe length is 15.3 mm.

3.3. Coupling and Tuning Design Between Modes and Modes

The coupling coefficient can be calculated according to the formula

$$k = \frac{f_1^2 - f_2^2}{f_1^2 + f_2^2} \quad (30)$$

Where, k is the coupling coefficient between the two modes, f_1 is the resonant frequency of the first mode, and f_2 is the resonant frequency of the second mode.

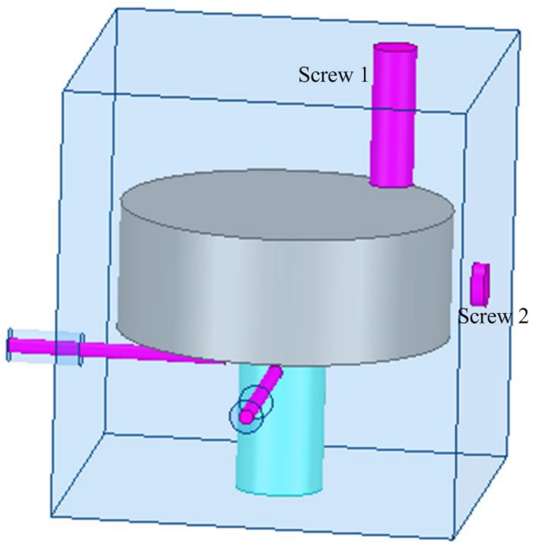


Figure 11. *Location of perturbation coupling screw.*

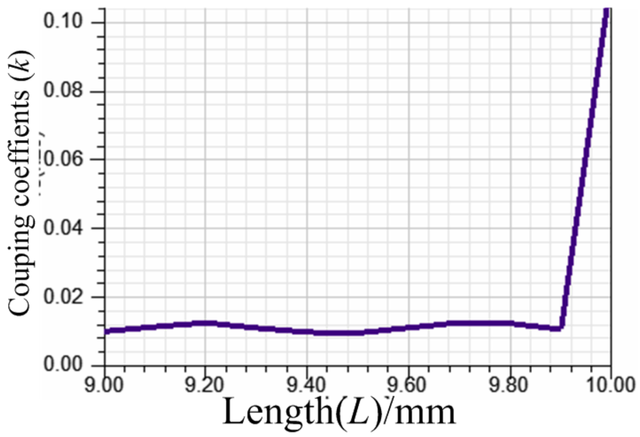


Figure 12. *Relationship between the length of screw 1 and coupling coefficient.*

The electric field distribution of each mode is shown in Figure 6 and Figure 7. The distribution of HEE11 field can be changed by inserting metal screws above the cylindrical medium to realize the coupling of the two modes. From reference, it can be seen that the position of screw 1 affects the change direction in coupling coefficient. Therefore, it is necessary to find an appropriate position so that the coupling coefficient changes proportionally to the length of screw 1. Through simulation analysis, it was found that the relationship between the length of screw 1 and coupling coefficient is shown in Figure 12 and the relationship between the diameter of screw 1 and coupling coefficient is shown in Figure 13. Therefore, the coupling coefficient can be changed by changing the length or radius of screw 1. In Figure 11, screw 1 is mainly used to adjust the coupling strength, and screw 2 is used to tune the overall performance of the filter.

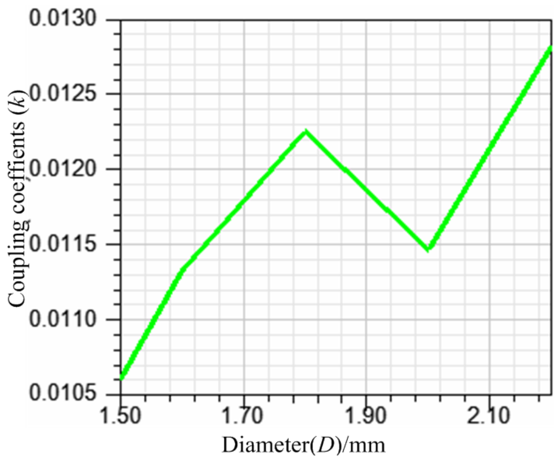


Figure 13. *Relationship between the diameter of screw 1 and coupling coefficient.*

4. Design and Simulation of Filter Based on Multi-mode Resonator

Based on the analysis of port coupling and mode coupling, the three-dimensional electromagnetic field simulation software is used to simulate the filter. As has been analyzed in this paper, the length of coupling probe will affect the performance of the filter, and the parameters such as the radius and height of the resonator also have a great impact on the performance of the filter. For the structure in Figure 11, the performance of the coupling probe on the filter is analyzed in detail. It can be seen that the length of the coupling probe (T) can change the return loss of the filter, as shown in Figure 14. After several optimization analysis, the final structure parameters of 5G band dielectric filter are shown in Table 2.

Table 3. *Initial size and optimizated size of 5G band dielectric filter.*

Paramaters	**Initial value (mm)**	**Optimizated value (mm)**
The length of filter (a)	28	26
The width of filter (b)	28	26
The height of filter (c)	28	28
The diameter/length of screw 1	1.6/9.8	2.0/9.5
The diameter/length of screw 2	1.5	1.5/0.8

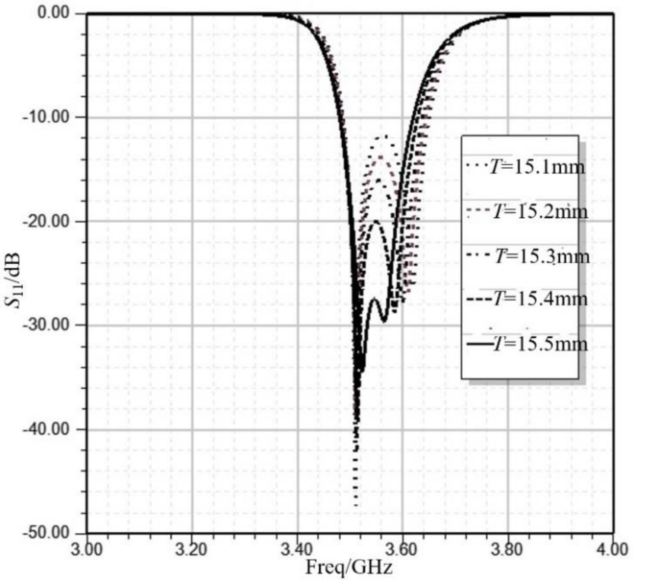


Figure 14*. Influence of coupling screw length on filter parameter S11.*

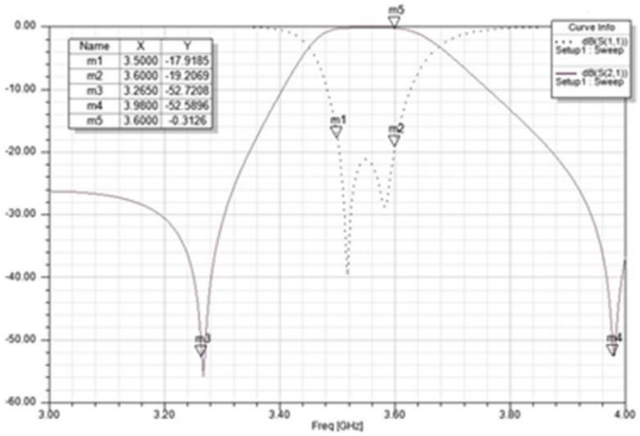


Figure 15*. return loss and insertion loss of dielectric filter.*

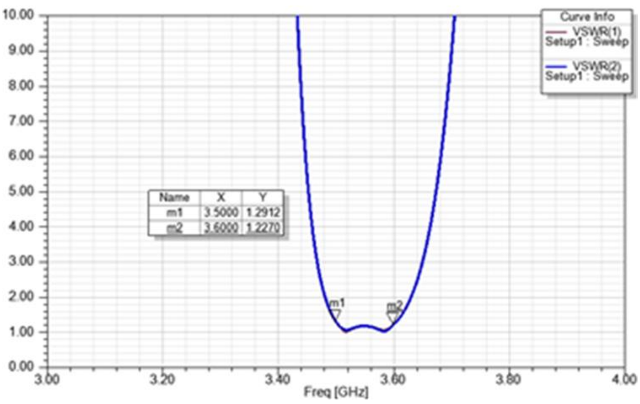


Figure 16*. VSWR of dielectric filter.*

The final filter structure is simulated by 3D electromagnetic simulation software. After accurate simulation, the designed filter bandwidth is 3.5 GHz ~ 3.6 GHz, return loss > 17.9 dB, insertion loss < 0.31 dB, the zero point on the left side of the pass-band is 3.265 GHz, and the zero point on the right side of the pass-band is 3.980 GHz, as shown in Figure 15, and the VSWR<1.29, as shown in Figure 16.

5. Comparison Between Simulation and Measurement of 5G Band Multi-mode Filter

The dielectric cavity filter based on multi-mode resonator is fabricated and shown in Figure 17. Due to some errors in measurement, there are some tolerable differences between measured and simulated data. The physical results is tested and compared with the simulation results. As shown in Figure 18 and Figure 19, the physical test results are basically consistent with the simulation results. From the results of S parameter and standing wave ratio, the deviation between the actual test result and the simulation frequency is about 1 MHz, the main reason is the error of the manufacture of resonator. This assumption is verified by HFSS simulation.

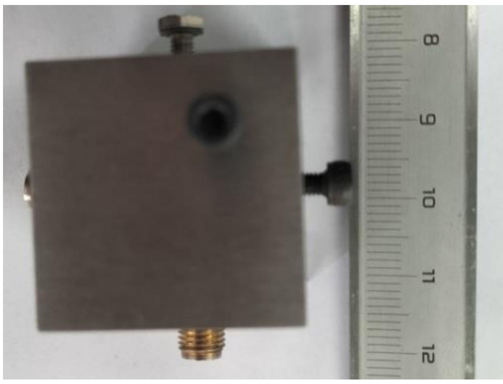


Figure 17*. Fabricated photograph of physical filter.*

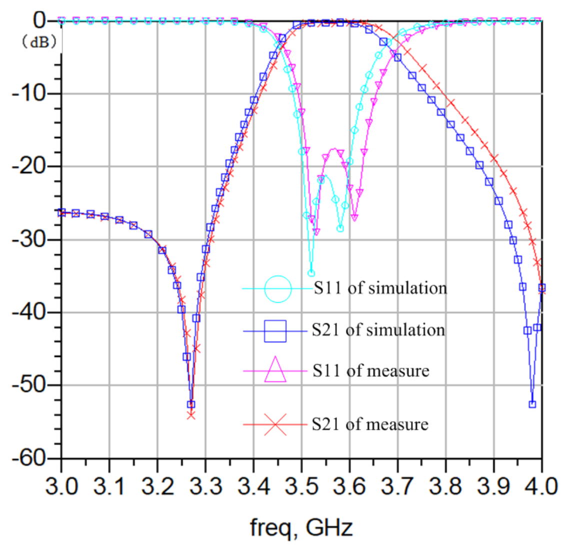


Figure 18*. Comparison between simulated and measured s parameters.*

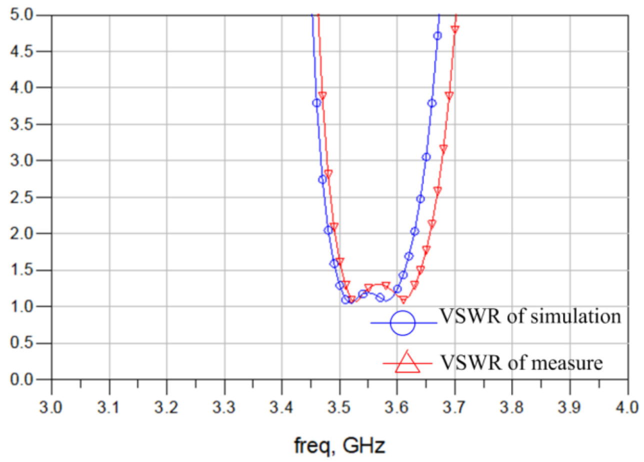


Figure 19. *Comparison between simulated and measured VSWR.*

6. Results and Discussion

In this paper, a design method of symmetrical zero filter based on multi-mode resonator is introduced. By using infinite resonant modes and resonant frequencies in a single cavity resonator for different field distributions, some perturbations (such as screw, slotting, cutting angle or adding small patch, internal tangent angle, etc.) are added to a single resonator. In this paper, the original orthogonal degenerate mode is changed by adding tuning screw. Two coupled degenerate modes are equivalent to two coupled resonators, so that the number of resonators is reduced greatly while the resonant circuit remains unchanged. Thus, the size of the filter is greatly reduced. A transmission zero is introduced on both sides of the pass-band to improve the suppression ability out of band of the filter. A filter with symmetrical zero is designed by using HEE11 degenerate dual-mode. The results show that in the pass-band (3.5~3.6 GHz), the return loss is more than 19 dB, the insertion loss is less than 0.3 dB, the zero on the left side of the pass-band is 3.265 GHz, and the zero point on the right side of the pass-band is 3.98 GHz, and the VSWR is less than 1.26, as shown in Figure 16 and Figure 17.

This paper analyzed the electric field diagram of HEE11 radial clockwise 45° polarization mode and HEE11 radial counter clockwise 45° polarization mode. By using the HEE11 radial clockwise 45° polarization mode and HEE11 radial counter clockwise 45° polarization mode, and inserting screws in the strong electric field of the two modes, it can affects the field distribution and makes the modes coupling. The coupling can be controlled by controlling the screw size and insertion depth. The length of the probe inserted into the bottom of the resonator controls the coupling strength, and then the parameters of the filter are achieved. It is found that the frequency deviation is about 1 MHz. The main reason is the deviation of the manufacture of resonator. The diameter and length of the resonator will affect the resonant frequency of the resonator, thus affecting the central frequency and the coupling strength of the input and output. The results show that the length of the tuning screw will affect the bandwidth of the filter. The longer the length, and the wider the bandwidth. Moreover, the influence of the screw length on the filter bandwidth is linear and controllable.

7. Conclusion

At present, mobile communication technology has been greatly developed, but with the outbreak of a large number of wireless communication applications, frequency resources are becoming more and more important, and the interval between various frequency bands is becoming narrower and narrower. Therefore, it is urgent to improve the communication quality of communication system by using filters with better suppression performance. In addition, in the era of systematization and economization, electronic products are bound to decrease in size. Therefore, the miniaturization of filter is an inevitable trend. This paper designs a filter with symmetrical zeros by using dual-mode resonator, which realizes the size miniaturization of the filter, and introduces a transmission zero on the left and right sides to improve suppression ability of the out of band of the filter. The design results are in the pass-band: return loss > 17.9 dB and insertion loss < 0.31 dB, zero on the left side of the pass-band is 3.265 GHz, and the zero point on the right side of the pass-band is 3.98 GHz, and the VSWR is less than 1.29, which achieves the design goal. However, due to the complexity of the coupling between the modes of the multi-mode resonator, sometimes the coupling of the perturbation to the mode is not linear, and the perturbation not only affects one mode, but also affects other modes. How to control the influence of the perturbation on the modes is the research difficulty of the multi-mode filter. In this paper, based on the dual-mode resonator, a filter with symmetrical zero is designed, which can be used as a reference for the study of multi-mode filters and filters with zeros.

Abbreviations

5G	5th Generation Mobile Communication Technology
TE	Transverse Electric Wave
TM	Transverse Magnetic Wave
HEE	Hybrid Electric Electric
HFSS	High Frequency Structure Simulator

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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Research Fields

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