Resonant Characteristics of Triple-Mode Dielectric Resonators

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Abstract

This paper discusses the resonant characteristics, such as the resonant frequencies and Q factors, as well as tuning methods of the resonant frequency of the triple-mode dielectric resonators, for their possible application to compact bandpass filters for mobile communication systems. The resonators include spheres and cylindrical rods that can be applied to compact bandpass filters. These high Q ceramic resonators can replace the conventional coaxial type resonators, which are large sized and also have relatively low Q values. Both simulated and measured results show that the Q values of the sphere and rod reach 27,000 and 24,000, respectively. Decoupling of degenerate modes is also briefly discussed.

Key Words: Dielectric Resonator, Dielectric Rod, Dielectric Sphere, High Q , Triple-Mode.

I. INTRODUCTION

Mobile communication systems support multiband/multi-mode operation, which requires several bandpass filters and which becomes inevitably bulky with conventional cavity type resonators. The base station as well as the remote radio head now requires compact multiband bandpass filters with high performance. This high performance and compactness of the bandpass filters can be accomplished by replacing conventional cavity resonators with ceramic resonators, which have been widely used in satellite communication systems. This paper examines the use of these ceramic resonators in mobile communication systems.

The conventional dielectric resonator used for satellite transponders is a dielectric disk in which the two resonant modes are degenerate. A bandpass filter made with this resonator has good stability against temperature variations and has been applied to many satellite communication systems [1

– 3]. In 1997, a triple-mode dielectric rod resonator was proposed to reduce the size of the bandpass filter [4]. Since this resonator has triple modes, a 3-pole bandpass filter can be designed by one triple-mode resonator. Using two triple-mode resonators, a 6-pole elliptic function bandpass filter was successfully demonstrated for a satellite transponder in [5].

The ceramic resonators analyzed in this paper are dielectric spheres and rods in which triple modes exist. The resonant characteristics are essential to the design of bandpass filter. The electromagnetic fields in these resonators are well known [6]; therefore, only their resonant characteristics, including the tuning method, will be discussed.

II. TRIPLE-MODE RESONATORS

Triple modes can also be supported in a dielectric cube. However, because of the Q values, two types—sphere and rod—will be discussed. The dielectric resonator must be

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Fig. 1. A spherical dielectric resonator with alumina support in a metallic enclosure.

placed inside the metallic housing or cavity; therefore, the dimensions of the metallic cavities and mounts for the dielectric sphere and rod are determined in such a way that they do not affect the resonant characteristics of dielectric resonators very much.

1. The Spherical Dielectric Resonator

As illustrated in Fig. 1, a spherical dielectric resonator with radius a_1 is placed at the center of a spherical metallic cavity with radius of b by an alumina support with permittivity of ϵ_{as} , height h_{as} , and radius a_{as} . This dielectric sphere can support three orthogonal degenerate modes: $TE_{01\delta X}$, $TE_{01\delta Y}$, and $TE_{01\delta Z}$ along the x-, y-, and z-direction, respectively. The electric field configurations of the three modes plotted in Fig. 2 show that the three resonant electric fields have a rotational symmetry. The bandpass filter should be designed by splitting the resonant frequencies in such a way that the three resonant modes constitute three distinct reflection zeroes within the passband.

We can introduce the circumferential chamfering of the sphere as shown in Fig. 3, so that the resonant frequency of the $TE_{01\delta Z}$ mode is shifted upward, while that of the other two modes are not affected. The sphere surface along the z-axis is chamfered, so the radius is reduced from a_1 to a_2 as shown in Fig. 3, for the fine frequency tuning of $TE_{01\delta Z}$ mode without appreciably affecting the other two modes. The bottom of the dielectric sphere is also chamfered slightly in order to mount it onto the hollow cylindrical alumina support. This bottom surface chamfering can also be used for fine control of the resonant frequencies of the $TE_{01\delta X}$ and $TE_{01\delta Y}$ modes. The dimension of the metal cavity is set as $b = 2a_1$ in order not to affect the resonant frequencies of the dielectric resonator. The modified resonator in Fig. 3 has the following dimensions for HFSS simulation at 800 MHz, using the equation given by Kajfez and Guillon [7]: $a_1 = 29.4$ mm, $a_2 = 27.3$ mm, $a_3 = 22.5$ mm, and $b = 44.76$ mm and the dimensions of the alumina support in Fig. 3 is given as

$$\epsilon_{ras} = 9, a_{as} = 13 \text{ mm}, h_{as} = 20 \text{ mm}, t_{as} = 5 \text{ mm}.$$

Fig. 2. Top view of E-field distribution along the axes: (a) $TE_{01\delta X}$ at 845.66 MHz, (b) $TE_{01\delta Y}$ at 845.69 MHz, and (c) $TE_{01\delta Z}$ at 852.76 MHz.

Fig. 3. Chamfered spherical resonator.

The corresponding resonant frequencies are $f_1(TE_{01\delta X}) =$

Fig. 4. The resonant frequency change due to circumferential chamfering in Fig. 3.

Fig. 5. Dielectric rod located inside the metallic cavity.

845.66 MHz, $f_2(\text{TE}_{01\delta Y}) = 845.69$ MHz, and $f_3(\text{TE}_{01\delta Z}) = 852.76$ MHz. The relative permittivity of spherical dielectric resonator is 46 and the calculated unloaded Q value, Q_U , is 19600. The chamfering of the circumferential area affects the resonant frequency $f_3(\text{TE}_{01\delta Z}$ mode) as shown in Fig. 4, while the effect of the chamfering at the bottom of the sphere is not pronounced.

2. Dielectric Rod

The cylindrical dielectric rod shown in Fig. 5 can also support triple resonant modes. However, in this structure, only two $\text{TE}_{01\delta X}$ mode and $\text{TE}_{01\delta Y}$ mode are degenerate. The third mode, $\text{TE}_{01\delta Z}$ mode, which has a very similar electric field distribution along the cross section, has different resonant frequencies depending on the length H . By setting the diameter of the rod nearly equal to the length of the rod, H , one can observe that the resonant frequency of the $\text{TE}_{01\delta Z}$ mode is located very close to that of two degenerate modes ($\text{TE}_{01\delta X}$ and $\text{TE}_{01\delta Y}$ modes). The electric field distributions of three modes are plotted in Fig. 6; they are not much different from those of sphere resonators. The three modes are orthogonal to each other and designated as the $\text{TE}_{01\delta X}$,

Fig. 6. E-field distributions of three orthogonal modes: (a) $\text{TE}_{01\delta X}$ at 842.70 MHz, (b) $\text{TE}_{01\delta Y}$ at 842.85 MHz, and (c) $\text{TE}_{01\delta Z}$ at 846.85 MHz.

Table 1. Resonant frequency (MHz) variations as a function of rod length H

H (mm)	$H/R = 0.49$			$H/R = 0.51$		
	$\text{TE}_{01\delta X}$	$\text{TE}_{01\delta Y}$	$\text{TE}_{01\delta Z}$	$\text{TE}_{01\delta X}$	$\text{TE}_{01\delta Y}$	$\text{TE}_{01\delta Z}$
42.5	991.02	991.07	995.73	968.33	968.36	966.94
45	936.45	936.72	940.74	914.34	914.40	913.17
47.5	886.78	886.81	890.93	866.53	866.63	864.82
50	842.95	843.09	846.56	823.33	823.37	821.59
52.5	803.00	803.08	806.24	784.26	784.31	782.53
55	766.22	766.25	769.37	749.52	749.67	747.49
57.5	732.98	732.99	735.85	716.04	716.09	714.44
60	702.67	702.69	705.40	687.08	687.18	685.06

$\text{TE}_{01\delta Y}$, and $\text{TE}_{01\delta Z}$ modes, respectively, as shown in Fig. 6. Therefore, we simulate the variation of resonant frequency at 850 MHz range as a function of rod radius and rod length as shown in Table 1. The resonant frequency of the $\text{TE}_{01\delta Z}$ mode is greatly affected when H/R is less or greater than 0.5. In the simulation, the dimension of the outer metallic cavity was determined in such a way that the triple resonant frequencies were not affected.

Fig. 7. Fabricated triple-mode resonators: (a) sphere and (b) rod.

Fig. 8 The measured resonant characteristics of the triple-mode dielectric rod.

3. Discussion

The dielectric sphere, as well as the dielectric rod, was fabricated in the metal housing as shown in Fig. 7. The calculated Q values of the resonant dielectric sphere lie between 27,000 and 29,000, depending on the modes, while those of dielectric rod resonator are between 24,000 and 27,000. The quality factors, Q , were measured as in [7]. The measured resonant frequencies and their behaviors are not much different from the simulated results. Measured Q values of the dielectric sphere are over 27,000 depending on the input/output coupling structures within the metal housing. Chamfering the sides of the sphere permits easy separation of the resonant frequencies of TE_{016X} and TE_{016Z} modes. The measured resonant frequencies, including the cross coupling in the dielectric rod resonator, are 855.19 MHz (TE_{016X} mode), 855.24 MHz (TE_{016Y} mode), and 855.86 MHz (TE_{016Z} mode); the inhomogeneity of the dielectric can introduce a small discrepancy from the simulated results. However, separation of the resonant frequency of degenerate mode TE_{016X} and TE_{016Y} modes for 3-pole bandpass filter applications requires other decoupling schemes. The internal cross coupling can create the transmission zero. For the dielectric rod, the Q values are over 24,000 when it is evaluated

Fig. 9. The dimension of the dielectric rod for the simulation and fabrication.

from the measured results shown in Fig. 8. The dimension of the dielectric rod for the simulation is given in Fig. 9, where the three modes are separated as in Fig. 8. The resonant frequency of the TE_{016Z} mode in the dielectric rod can be moved upward by adjusting its length along the z -direction compared to its diameter. As is the case for the sphere, separation of the resonant frequency of TE_{016X} mode and TE_{016Y} mode needs other decoupling structures because the separation of the resonant frequency of the degenerate mode is not sufficiently large for the design of a bandpass filter. We obtained very similar behavior in the frequency response for the dielectric sphere as discussed in the simulated results.

III. CONCLUSION

Novel triple-mode high- Q spherical dielectric loaded cavity resonators are analyzed for application to bandpass filters for mobile communication systems. Two types of dielectric resonators—spheres and rods—are analyzed and simulated in order to obtain their resonant characteristics. The frequency responses of the two types of resonators behave in the similar way when the resonant frequencies of triple modes are concerned. We also studied the change in the resonant frequencies as a function of the structural parameters of the resonators so that we can use them in the design of bandpass filters.

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