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RESEARCH ON THE EFFECT TO THE EIGEN MODES AND EFFECT OF MINIATURIZATION OF THE METAL CAVITY RESONATORS PARTLY OCCUPIED BY A MAGNETIC-DIELECTRIC COMPOSITE MATERIAL WITH ε_r=10 AND μ_r=10

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This paper discuss the effect to the Eigen frequency of the metal cavity resonator partly occupied by magnetic-dielectric composite material by simulation and comparison, which is then used to assess the effect of miniaturization. Some important properties are found, which are useful for the miniaturization of passive devices for communication.

Key words: magnetic-dielectric composite material; Eigen mode frequency; miniaturization

1 Introduction

The miniaturization of passive microwave devices has become one of the most urgent requirements with the rapid development of wireless communication technology. Especially, the miniaturization of metal cavity resonators, which is widely used in base station filters, has become a bottleneck.

The most conventional method to reduce the size of metal cavity resonator is to fill the cavity with high-dielectric-constant materials [1]. The higher the dielectric constant, the better miniaturization effect is assumed. And to suppress the higher order modes and raise the quality factor, the resonators are always partly occupied rather than fully occupied by high dielectric constant material.

However, the manufacture of high-dielectric-constant material is not an easy work and always not so qualified that the loss cannot be ignored when the dielectric-constant reaches about 45 and above.

So a novel way of miniaturization is urgently needed to meet the challenge of modern communication standards such as LTE, etc.

Recently, a kind of magnetic-dielectric composite material, which has relative permittivity and relative permeability both greater than 1, has arouse people's interest [2, 3]. However, related researches have been focused on the synthesis and manufacture process, while the effect of miniaturization of this kind of material is not detailed.

In the paper, the performance of miniaturization of a magnetic-dielectric material with $\varepsilon_r=10$, $\mu_r=10$ is compared with that of a dielectric material with $\varepsilon_r=100$, $\mu_r=1$, and a magnetic material with $\varepsilon_r=1$, $\mu_r=100$.

2 Experiments on cylindrical metal cavity partly occupied by magnetic-dielectric composite material

The changes of Eigen frequency were investigated to evaluate the capacity of size reducing. A cavity with a 15.3mm radius and a height of 7.5mm were simulated by CST when partly occupied by a block with a 15.3mm radius and a height of 4mm of different materials (shown in fig1). And the results are shown in table1.

It is obvious that the first fifty Eigen modes are mainly consist of TM mode and TE mode when using materials with εr=1, μr=100 and εr=100, μr=1 respectively. This implies that increasing the permittivity and permeability of the material have different effects on the TM mode and TE mode when the cavity is partly occupied. The details of the relation between the partly loaded materials and the frequencies are presented in table 2 and compared with the none-loading situation.

From table 2 (a), (b), the following two features can be seen:

(1) Comparing the reducing multiple of the frequency of different Eigen modes when the cavity partly occupied by the same material, we can see that: The multiple of frequency reduction of TM modes is much larger than that of TE modes when the resonator is partly occupied by magnetic material, versus the frequency of the resonator filled by air. And the multiple of frequency reduction of TE modes is much larger than that of TM modes when the resonator is partly occupied by dielectric material, versus the frequency of the resonator filled by air. When the cavity is partly occupied by magnetic-dielectric composite material, the multiple of frequency reduction of TM modes is relatively close to that of TE modes.

(2) Comparing the reducing multiple of the frequency of the same Eigen mode when the cavity is partly occupied by different materials, we can see that: when the mode belongs to TM modes the high permeability material loading will play a more important role than the high permittivity material while for the TE modes the conclusion is on the contrary. And the loading of magnetic-dielectric composite material is a cross between them.

Because the approximate reducing of the frequencies of TE modes and TM modes, there are more options on choosing the operating mode by which the miniaturization of the cavity resonators can be realize.

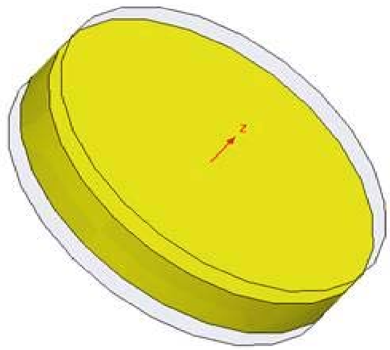

Fig.1 cylindrical metal cavity occupied by medium（yellow for the medium and the outside is the metal cavity）

Electromagnetic parameters of filling media.	The first 50 Eigen modes in the cavity（resonant frequency from low to high ranked, the number '2' in the bracket means there are 2 degenerate Eigen modes）
$\varepsilon_r=1$ $\mu_r=100$	$TM_{01\delta}$ $TM_{11\delta}(2)$ $TM_{21\delta}(2)$ $TM_{02\delta}$ $TM_{31\delta}(2)$ $TM_{12\delta}(2)$ $TM_{41\delta}(2)$ $TM_{22\delta}(2)$ $TM_{03\delta}$ $TM_{51\delta}(2)$ $TM_{32\delta}(2)$ $TM_{61\delta}(2)$ $TE_{11(1+\delta)}(2)$ $TM_{13\delta}(2)$ $TE_{21(1+\delta)}(2)$ $TE_{01(1+\delta)}$ $TM_{01(1+\delta)}$ $TE_{31(1+\delta)}(2)$ $TE_{41(1+\delta)}(2)$ $TE_{12(1+\delta)}(2)$ $TM_{42\delta}(2)$ $TM_{71\delta}(2)$ $TM_{11(1+\delta)}(2)$ $TE_{51(1+\delta)}(2)$ $TM_{23\delta}(2)$ $TE_{22(1+\delta)}(2)$ $TM_{04\delta}$ $TE_{02(1+\delta)}$ $TE_{61(1+\delta)}(2)$ $TM_{81\delta}(2)$
$\varepsilon_r=100$ $\mu_r=1$	$TE_{11(1+\delta)}(2)$ 、$TE_{21(1+\delta)}(2)$ 、$TE_{01(1+\delta)}$、$TE_{31(1+\delta)}(2)$ 、$TE_{41(1+\delta)}(2)$ 、$TE_{12(1+\delta)}(2)$ 、$TE_{51(1+\delta)}(2)$ 、$TE_{22(1+\delta)}(2)$ 、$TE_{02(1+\delta)}$、$TE_{61(1+\delta)}(2)$ 、$TM_{01\delta}$、$TE_{32(1+\delta)}(2)$ 、$TE_{13(1+\delta)}(2)$ 、$TE_{71(1+\delta)}(2)$ 、$TM_{11\delta}(2)$ 、$TE_{42(1+\delta)}(2)$ 、$TE_{81(1+\delta)}(2)$ 、$TE_{23(1+\delta)}(2)$ 、$TM_{210}(2)$ 、$TE_{03(1+\delta)}$、$TM_{02\delta}$、$TE_{52(1+\delta)}(2)$ 、$TE_{91(1+\delta)}(2)$ 、$TM_{31\delta}(2)$ 、$TM_{12\delta}(2)$ 、$TE_{33(1+\delta)}(2)$ 、$TM_{41\delta}(2)$ 、$TE_{14(1+\delta)}(2)$

$\varepsilon_r = 10$ $\mu_r = 10$	$TM_{01\delta}$、$TM_{11\delta}(2)$、$TM_{21\delta}(2)$、$TM_{02\delta}$、$TE_{11\delta}(2)$、$TE_{21\delta}(2)$、$TE_{01\delta}$、$TE_{31\delta}(2)$、$TM_{31\delta}(2)$、$TE_{41\delta}(2)$、$TE_{12\delta}(2)$、$TM_{12\delta}(2)$、$TE_{51\delta}(2)$、$TM_{41\delta}(2)$、$TE_{22\delta}(2)$、$TE_{02\delta}$、$TE_{61\delta}(2)$、$TM_{22\delta}(2)$、$TM_{03\delta}$、$TE_{32\delta}(2)$、$TM_{51\delta}(2)$、$TE_{13\delta}(2)$、$TE_{71\delta}(2)$、$TM_{01\delta}$、$TE_{42\delta}(2)$、$TM_{32\delta}(2)$、$TM_{61\delta}(2)$、$TE_{81\delta}(2)$

Table 1 The first 50 Eigen modes in the cavity（resonant frequency from low to high ranked）when occupied by different materials.

Resonant modes	Medium and its parameters						
	Air $\varepsilon_r = 1$ $\mu_r = 1$	Magnetic material $\varepsilon_r = 1$、$\mu_r = 100$ partly occupied		dielectric material $\varepsilon_r = 100$、$\mu_r = 1$ partly occupied		Composite material $\varepsilon_r = 10$、$\mu_r = 10$ partly occupied	
	f (GHz)	f (GHz)	multiples of the reduced	f (GHz)	multiples of the reduced	f (GHz)	multiples of the reduced
$TM_{010}(TM_{01\delta})$	7.499	1.0094	7.42899	3.3309	2.25136	2.0099	3.73098
$TM_{110}(TM_{11\delta})$	11.948	1.5799	7.56227	3.7236	3.20862	2.8027	4.26293
$TM_{210}(TM_{21\delta})$	16.011	2.0742	7.71888	3.9455	4.05795	3.3106	4.83616
$TM_{020}(TM_{02\delta})$	17.209	2.2155	7.76786	4.0071	4.29416	3.4359	5.00886
$TM_{310}(TM_{31\delta})$	19.890	2.5229	7.88379	4.1482	4.79486	3.6896	5.39073
$TM_{120}(TM_{12\delta})$	21.869	2.7434	7.97145	4.2555	5.13899	3.8614	5.66344
$TM_{410}(TM_{41\delta})$	23.653	2.9379	8.05103	4.3556	5.4304	4.0090	5.89995
$TM_{220}(TM_{22\delta})$	26.229	3.2114	8.16751	Not appear in the first 50 Eigen modes		4.2142	6.22407
$TM_{030}(TM_{03\delta})$	26.969	3.2900	8.19727	Not appear in the first 50 Eigen modes		4.2728	6.31184
$TM_{510}(TM_{51\delta})$	27.337	3.3283	8.21347	Not appear in the first 50 Eigen modes		4.3015	6.35525
$TM_{320}(TM_{32\delta})$	30.415	3.6449	8.34471	Not appear in the first 50 Eigen modes		4.5402	6.699
$TM_{610}(TM_{61\delta})$	30.962	3.7002	8.36763	Not appear in the first 50 Eigen modes		4.5823	6.7567

Table2 (a) The effects to TM modes when partly occupied by different materials.(multiples of the reduced is versus the frequency when the cavity is occupied by air)

Resonant modes	Medium and its parameters						
	Air $\varepsilon_r=1$ $\mu_r=1$	Magnetic material $\varepsilon_r=1$, $\mu_r=100$ partly occupied		dielectric material $\varepsilon_r=100$, $\mu_r=1$ partly occupied		composite material $\varepsilon_r=10$, $\mu_r=10$ partly occupied	
	f(GHz)	f(GHz)	multiples of the reduced	f(GHz)	multiples of the reduced	f(GHz)	multiples of the reduced
$TE_{111}(TE_{11\delta})$	20.774	3.7298	5.5697	2.2407	9.27125	3.4831	5.96426
$TE_{211}(TE_{21\delta})$	22.119	3.8068	5.81040	2.3852	9.27324	3.5692	6.19718
$TE_{011}(TE_{01\delta})$	23.268	3.8748	6.0049	2.5080	9.27739	3.6449	6.38366
$TE_{311}(TE_{31\delta})$	23.878	3.9119	6.10384	2.5733	9.27912	3.6860	6.47782
$TE_{411}(TE_{41\delta})$	25.945	4.0419	6.41898	2.7935	9.28750	3.8295	6.775
$TE_{121}(TE_{12\delta})$	25.979	4.0437	6.42457	2.7965	9.28983	3.8315	6.78049
$TE_{511}(TE_{51\delta})$	28.257	4.1938	6.73786	3.0374	9.30324	3.9957	7.07196
$TE_{221}(TE_{22\delta})$	28.906	4.2380	6.82067	3.1051	9.30929	4.0438	7.14938
$TE_{021}(TE_{02\delta})$	29.612	4.2860	6.90912	3.1795	9.31418	4.0959	7.22981
$TE_{611}(TE_{61\delta})$	30.742	4.3648	7.04320	3.2981	9.32119	4.1812	7.35251

Table2 (b) The effects to TE modes when partly occupied by different materials.(multiples of the reduced is versus the frequency when the cavity is occupied by air)

3 Conclusions

A novel way to realize the miniaturization of metal cavity resonators by introducing partly magnetic-dielectric composite material loading is presented in this paper. Researches were carried out by simulation by CST. Comparisons, on the condition that the cavity geometric dimension was identical, were made to investigate the effects of varied kinds of loading materials. The magnetic-dielectric composite material loading can reduce the frequencies of both TE modes and TM modes, while the high permittivity and high permeability loading alone largely reduce the frequencies of TE modes and TM modes respectively. So the magnetic-dielectric composite material loading can provide more freedom to choose the low-frequency operating mode. Moreover, the magnetic-dielectric composite material loading can achieve the same degree of size reducing when the permittivity and permeability are not so large; therefore the loss of the material is easier to control than the high permittivity or high permeability material, which provides high quality factor.

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