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OPTIMUM DESIGN OF SHIELDED DIELECTRIC ROD AND RING RESONATORS FOR OBTAINING THE BEST MODE SEPARATION

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ABSTRACT

Accurate resonant frequencies of shielded dielectric rod and ring resonators are computed by means of the mode-matching technique. For four cases of the rod and ring resonators with $TE_{01\delta}$ and $HE_{11\delta}$ modes, the optimum dimensions are determined to obtain the best separation of the neighboring modes from the interested mode.

INTRODUCTION

Dielectric resonators widely used in the microwave circuits are commonly encased in conducting shields to prevent radiation loss. For such shielded resonators, the lowest-order $TE_{01\delta}$ mode (1)-(3) and the higher-order $HE_{11\delta}$ mode (4) are utilized for constituting compact filters. Hence reliable information for the behavior of any mode is essential to design the resonators.

Recently Zaki and Atia (5) have presented a rigorous method for the computation of the resonant frequencies of any mode excited in a shielded dielectric rod resonator, though the practical computation has been performed only for the $HE_{11\delta}$ mode. For the analysis of resonant modes in a similar configuration, on the other hand, one of the authors (6) has shown that the mode-matching technique is effective not only for accurate calculations of the resonant frequencies and field plots of any mode but also for quantitative estimation of the shielding effects.

In this paper at first resonant modes for a shielded dielectric ring resonator are analyzed by using technique similar to that used in the rod shaped case (6). Then in four cases of the shielded rod and ring resonators with $TE_{01\delta}$ and $HE_{11\delta}$ modes important to filter constitution, optimum dimensions for obtaining the best separation of the neighboring modes from the interested mode are determined from the computation of the resonant frequencies for the various modes.

METHOD OF ANALYSIS

The configuration of a shielded dielectric ring resonator to be analyzed is shown in Fig. 1. Here a dielectric ring with relative dielectric constant ε_r, diameter D, inner diameter D_x, and length L is placed symmetrically in a cylindrical conductor cavity of diameter d and height h. The relative dielectric constant of the air surrounding the dielectric, ε_a=1 is assumed.

The analysis can be performed rigorously by using the mode-matching technique. The main points of the technique are briefly described on account of the limited space. The resonator is divided into homogeneous subregions I, II, III, and IV as indicated in Fig. 1. The electromagnetic fields in each subregion are expanded in eigen functions which satisfy the short-circuit boundary conditions on the conductor surfaces. Then imposing the boundary conditions at the interfaces of the subregions and applying the orthogonality of the eigen functions, we get the homogeneous equations for the infinite number of the expansion coefficients. The resonant frequencies are determined by the condition that the determinant of the coefficient matrix vanishes. In practical computations, a number of the truncated square determinant, N, is chosen to be a value for which the solution converges to desired accuracy.

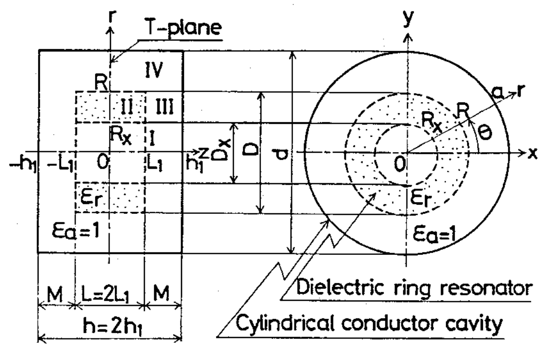


Fig. 1. Configuration of a shielded dielectric ring resonator.

CONVERGENCE OF SOLUTIONS

To examine the convergence of solutions versus N, the resonant frequencies for five principal modes in the ring resonator were computed. The results are shown in Fig. 2. These mode designations follow the method of mode designations used for the rod resonator (6) to maintain continuity of the modes between the rod and ring resonators; that is, as D_x=0, these resonant frequencies coincide to those for the rod resonator. The convergence of solutions for the TM and EH modes is much slower than that for the TE and HE modes.

In order to explain this reason, it is necessary to take the feature of the field distributions of the modes into account. For the rod resonator, the field plots of principal modes have been obtained from the numerical calculations (6). Fig. 3

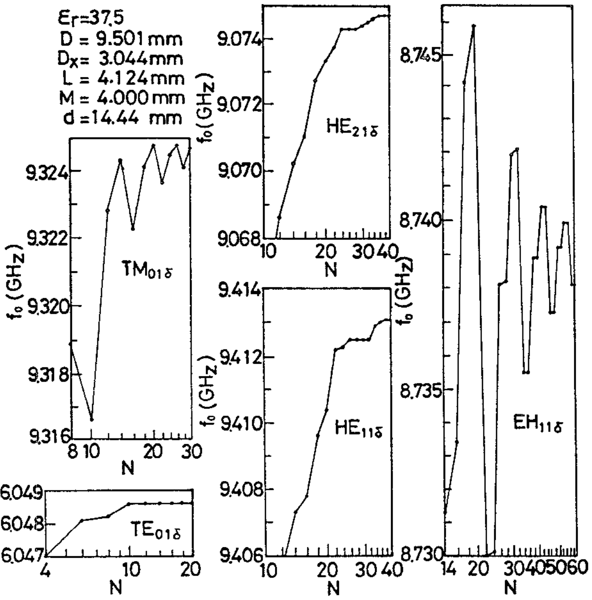


Fig. 2. Convergence of resonant frequencies for a shielded dielectric ring resonator.

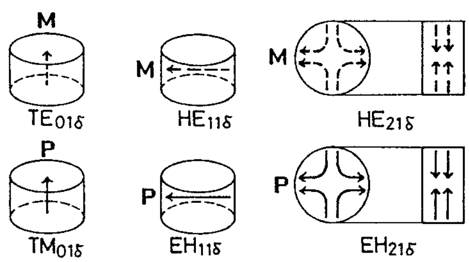


Fig. 3. Orientation of magnetic(M) and electric(P) dipole moments for dielectric rod resonator modes.

shows orientation of the magnetic and electric dipole moments which characterize the modes. For the HE mode the axial component of electric field (E_z) is predominant since the electric lines of force are circles about the magnetic dipole, while for the EH mode the axial component of magnetic field (H_z) is predominant since the magnetic lines of force are circles about the electric dipole. This feature for the hybrid modes is consistent with that described elswhere (7).

As a result, the reason why the convergence of solutions for the TM and EH modes is slow is due to the fact that the electric dipole monents suffer the edge effect on the boundary condition of electric field at the corners of the rod.

COMPUTATION AND EXPERIMENT

The computed results of resonant frequencies for the various modes versus the distance M are shown in Fig. 4 with solid curves. The behavior of the modes is analogous to that for the rod resonator (6). In addition the results measured by using the experimental apparatus shown in Fig. 5 and a (Zr.Sn)TiO_4 ceramic ring (Resomics by Murata Mfg.

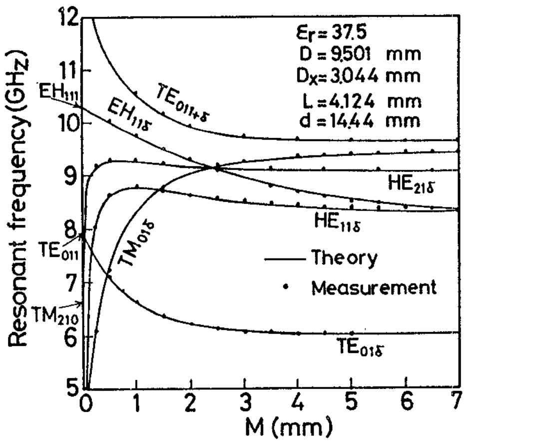


Fig. 4. Theoretical and measured values of resonant frequencies for a shielded dielectric ring resonator.

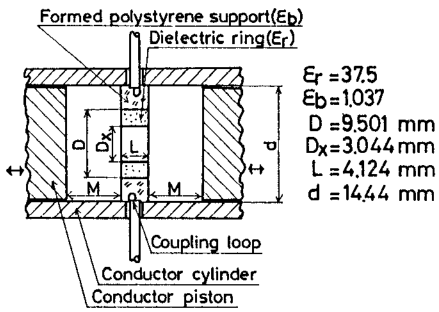


Fig. 5. Sectional view of experimental apparatus.

Co.) are indicated in Fig. 4 with solid dots. All the measured values agree with the computed results to within 1 percent.

OPTIMUM DESIGNS

For the ring resonator with given value of ε_r, the optimum values of dimension ratios, G=M/D, S=d/D, $X=(D/L)^2$, and $S_x=D_x/D$, can be determined to obtain the maximum value of the frequency ratio, $F_r=f_r/f_0$, where f_0 and f_r are the resonant frequencies of the interested mode and of the other modes, respectively. For the rod resonator, S_x=0.

The design process for the $TE_{01\delta}$ ring resonator with ε_r=37.5 is shown in Fig. 6. Here, the values of G, S, X, and S_x were varied one by one to obtain the maximum value, F_{rmax}. After repeating these steps once or twice to converge, we obtained G=0.442, S=2.02, X=8.25, and S_x=0.400 for F_{rmax} =1.58. Similar oputimum designs for the $TE_{01\delta}$ rod-, $HE_{11\delta}$ rod-, and $HE_{11\delta}$ ring-resonators were performed. The results are summerized in Table 1. Here the dimensions relative to D=1 are indicated for each resonator, and the relative sizes of the configurations are illustrated for four resonators having the equal f_0 values. For the $HE_{11\delta}$ resonators the $TE_{01\delta}$ mode appears at the frequency lower than that of the $HE_{11\delta}$ mode; in this case let's define as $F_r=f_0/f_r$; then the neighboring modes $TE_{01\delta}$ and $TM_{01\delta}$ appear at $f_r=f_0/F_{rmax}$ and $f_r=f_0F_{rmax}$, respectively.

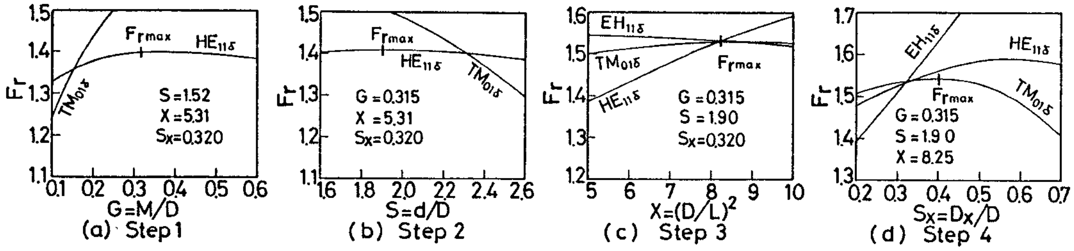
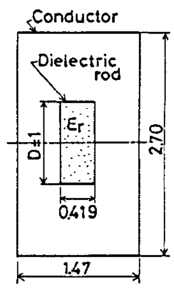
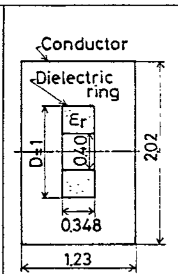
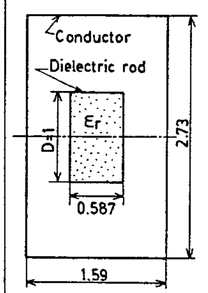
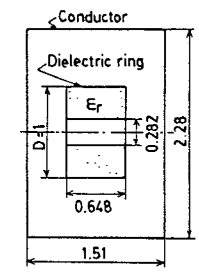


Fig. 6. Design process of determining the optimum dimensions to obtain F_{rmax} for $TE_{01\delta}$ dielectric ring resonator with ε_r=37.5.

Table 1. Shielded dielectric rod and ring resonators having optimum dimension ratios to obtain F_{rmax} for ε_r=37.5.

	$TE_{01\delta}$ resonators		$HE_{11\delta}$ resonators	
relative volumes for equal f_0 values				
D [mm] ($35<\varepsilon_r<40$)	$\frac{53.6}{f_0[GHz]}\sqrt{\frac{37.5}{\varepsilon_r}}$	$\frac{59.5}{f_0[GHz]}\sqrt{\frac{37.5}{\varepsilon_r}}$	$\frac{57.0}{f_0[GHz]}\sqrt{\frac{37.5}{\varepsilon_r}}$	$\frac{59.2}{f_0[GHz]}\sqrt{\frac{37.5}{\varepsilon_r}}$
$F_{rmax}=f_r/f_0$	1.32($HE_{11\delta}$,$EH_{11\delta}$)	1.58($TM_{01\delta}$)	1.15($TE_{01\delta}$,$TM_{01\delta}$)	1.20($TE_{01\delta}$,$TM_{01\delta}$)
resonator volume ratio	1	0.64	1.33	0.987
dielectric volume ratio	1	0.95	1.68	1.92

The $TE_{01\delta}$ ring resonator realizes the higher F_{rmax} value by 20 % compared with the rod shaped case. This verifies the validity of the result obtained from experiment (2). The F_{rmax} value for the $HE_{11\delta}$ ring resonator is higher by only 4 % than that for the rod shaped case.

CONCLUSION

Optimum designs of shielded dielectric rod and ring resonators for obtaining best separation of the neighboring modes have been performed by means of the mode-matching technique. It is seen in Table 1 that reduction of size and improvement of the mode separation can be achieved by using the ring resonators.

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