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NUMERICAL ANALYSIS OF THE TUBULAR DIELECTRIC RESONATOR WITH A DIELECTRIC TUNING ROD

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Abstract - This paper presents the results of the numerical analysis of a resonant cavity containing a tubular dielectric resonator and a dielectric tuning rod. For the given set of dimensions, the analysis indicates that the resonant mode TM_{01} can be tuned over 14 % of the frequency range. Higher-order modes, which could interfere with the desired TM_{01} mode, are also evaluated.

INTRODUCTION

Dielectric-resonator oscillators (DROs) have become popular building blocks of microwave systems. The mechanical tuning of a typical DRO operating in TE_{01} mode is limited to a few percent of the carrier frequency [1, p.164]. Theoretical studies show that the TE_{01} resonator can be tuned with a metal screw for more than ten percent [2], but the associated degradation of the Q factor is too severe for practical applications.

It has been found experimentally that a considerably larger useful tuning range, of about ten percent [3], can be obtained by using the TM_{01} mode. This paper presents the results of the numerical analysis of such a resonant cavity containing a tubular TM_{01} dielectric resonator and a dielectric tuning rod. The procedure provides the resonant frequencies of the desired and undesired modes as functions of the penetration of the tuning rod, and the associated Q factors. The computer-generated field plots provide an additional understanding of the tuning details.

NUMERICAL SOLUTION PROCEDURE

The numerical solution utilizes the Finite Integration Technique [4,5], specialized to the rotational cavities filled with inhomogeneous dielectrics. A definite advantage of the computer code based on this procedure is the fact that several of the lowest resonant modes of the same azimuthal mode number are determined in a single matrix eigenvalue operation, and that an arbitrary distribution of dielectric regions within the cavity can be specified by a simple change of the input data.

The cavity cross section is subdivided into an equidistant grid of elements, with the electric field vectors defined on each grid side. The matrix equation is formulated with the help of the zero-divergence condition, which provides an insurance against the appearance of the parasitic modes. In an E-field formulation, the matrix equation looks as follows [5]:

$$\left\{ \begin{bmatrix} \underset{\sim}{A}^e_{rr} & \underset{\sim}{A}^e_{rz} \\ \underset{\sim}{A}^e_{zr} & \underset{\sim}{A}^e_{zz} \end{bmatrix} - \omega_n^2 \begin{bmatrix} \underset{\sim}{D}^e_{rr} \underset{\sim}{D}_{\epsilon r} & \underset{\sim}{0} \\ \underset{\sim}{0} & \underset{\sim}{D}^e_{rz} \underset{\sim}{D}_{\epsilon z} \end{bmatrix} \right\} \begin{bmatrix} |e_r> \\ |e_z> \end{bmatrix} = 0 \quad (1)$$

Matrices $\underset{\sim}{A}$ are sparse, and matrices $\underset{\sim}{D}$ are diagonal. Vectors $|e_r>$ and $|e_z>$ contain the radial and axial components of the electric field. The above equation is a standard eigenvalue problem, for which eigenvalues ω_n are the natural resonant frequencies of the cavity. Equation (1) constitutes the electric field formulation of the problem. An analogous magnetic field formulation has also been carried out. For m=0 modes, the matrix eigenvalue problem is formulated without the use of the divergence equations, and the resulting matrix is approximately half smaller.

The solutions for the hybrid modes are denoted here as HEM_{mn}, in accordance with the IRE 1953 standard [6]. This standard has obviously gone unnoticed by a number of authors, who have since introduced various combinations of letters E and H, in a multitude of permutations, to denote the hybrid modes. Only two integer subscripts, m and n, are used here. The first subscript, m, as it is generally agreed, denotes the azimuthal variation. The second subscript, n, identifies the modes counted in the growing order of their resonant frequencies. While such a notation is simpler than most of the proposed ones, it must be understood that the same two subscripts in a shallow and wide cylindrical cavity may result in a distinctly different field pattern than in a long and narrow cavity. However, once the cavity is fully specified, the notation used here provides an unambiguous identification of individual modes.

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The accuracy of the solution decreases as the modal index n increases. Suppose the meridian plane is discretized into 10 lines and 10 columns, which give, approximately, 100 nodal values for the radial component of the field, and 100 nodal values for the axial component. An eigenvalue solver applied to equation (1) will provide about 200 eigenvalues and eigenvectors. Obviously, only the lowest few eigenvalues can be interpreted as acceptable modal resonant frequencies, while the remaining high eigenvalues are superfluous, and should be ignored.

The field patterns were obtained with the use of an interactive program for plotting the vector fields with a personal computer [7]. The program had to be modified because, due to the nodal discretization used in the formulation, the horizontal components of the field are located at physically different points than the vertical components.

MODE TUNING CHART

The cavity used for numerical study is shown in Fig. 1. The tubular dielectric resonator has outer radius 5.06 mm and length 4.60 mm. The relative dielectric constant of the resonator is ϵ_r = 37.7. The tuning rod, made of the same dielectric material, has a radius 0.92 mm and its length is varied from zero to 9.66 mm. A spacer made of the material with ϵ_r = 2.55 serves to hold the dielectric resonator in its place.

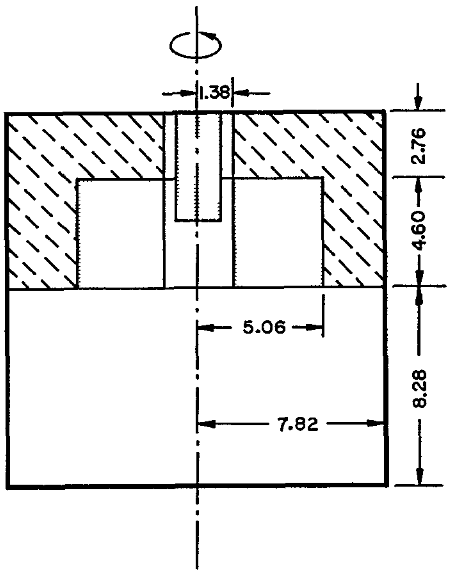
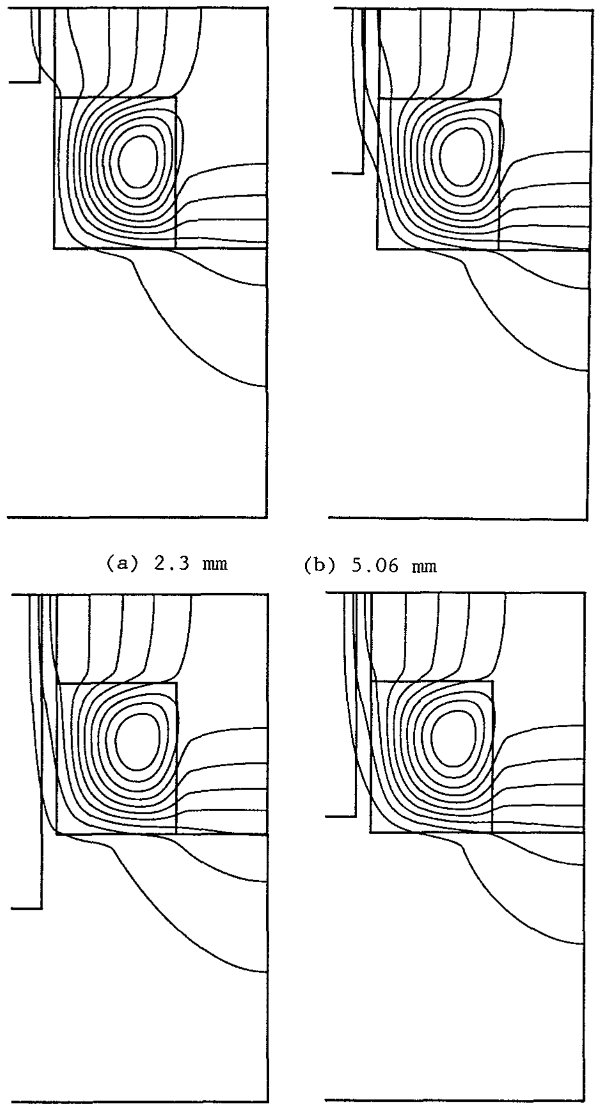


Fig. 1 Cross section of the cavity with the tuning rod

Figure 2 shows the electric field lines of the TM_{01} mode for various positions of the tuning rod. The solution has been obtained by using 17×34 grid elements. Because of the limited number of elements, the electric field lines appear to have



(a) 2.3 mm (b) 5.06 mm

(c) 6.9 mm (d) 9.66 mm

Fig. 2 Electric field lines of the TM_{01} mode for several rod penetrations

an overly smooth transition between the dielectric and the interface. It has to be kept in mind that the field plot is obtained by interpolating the field values between the discrete points. Therefore, a sudden change in the field direction becomes apparent only over a distance larger than one grid cell in any direction.

It is apparent from Fig. 2 that the electric field at the center of the cavity is relatively strong, and oriented mainly in the axial direction. For that reason, the mechanical tuning with the centrally located tuning rod is quite effective. It is seen in Fig. 3 that the tuning range of the TM_{01} mode is about 14 % of the carrier frequency.

Figure 3 is a tuning chart of all the modes which have the resonant frequency lower than 10 GHz. It can be seen that only the modes TM_{01} and TM_{02} have their resonant frequency affected by the position of the tuning rod, whereas the other modes are influenced by less than one percent. It is also seen that three of the modes (TE_{02}, HEM_{13}, and HEM_{22}) have their resonant frequencies clustered closely around 8.7 GHz. Finally, the chart also shows that the mode HEM_{12} interferes with the tuning range of the TM_{01} mode.

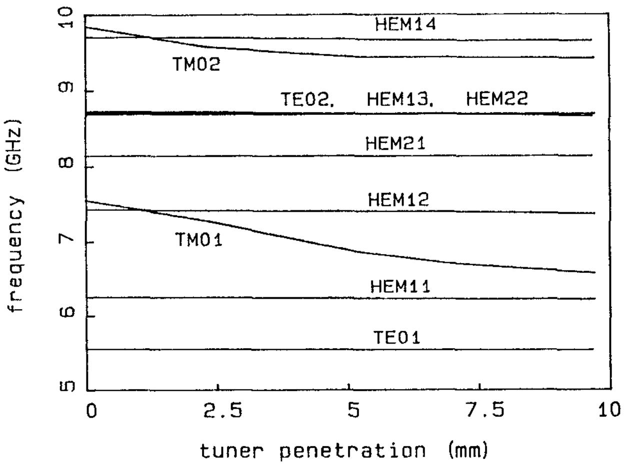


Fig. 3 Tuning chart

There are several possible solutions of this interference problem. First, the coupling mechanism of the cavity to the external circuit should be made such as to be invisible to the HEM_{12} mode. The field pattern of the undesired mode, shown in Fig. 4, could be helpful in selecting an appropriate coupling mechanism.

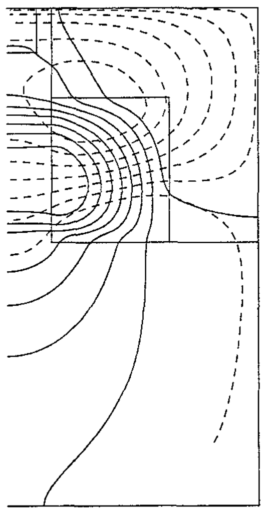


Fig. 4 Electric (solid) and magnetic (dashed) field lines of the HEM_{12} mode

Second, the resonant frequency of the HEM_{12} mode can be shifted by a proper mode trap (e.g. a metal ring, like in [1, p. 302]). The third, and the most appropriate, solution would be to optimize the resonator dimensions so that the tuning range of the TM_{01} mode becomes clear of any interference with other modes. For the tubular dielectric resonator operating in the TE_{01} mode, an optimization of resonator dimensions has been described in [8]. The computer code used here would be well suited for a similar optimization study, which would also take into account the size and the shape of the tuning rod.

Q FACTOR

When the numerical solution of the matrix eigenvalue problem is obtained, the eigenvectors of each resonant mode contain the values of the electric (or magnetic) fields at each node of the cavity cross section. The values of the magnetic field tangential to the metal surface are then used to find the conductor losses of the cavity. Similarly, the values of the electric field over the dielectric regions are used to compute the dielectric losses. The unloaded Q factor of the cavity is then obtained by adding these two loss mechanisms.

The computed Q factors of the TM_{01} and TM_{02} modes are shown in Fig. 5. It was assumed that the cavity is made of brass ($\sigma = 1.45\ 10^{-7}$ S/m), and that the loss tangent of the dielectric resonator material is a function of frequency as follows:

$$\tan \delta = 0.45 \cdot 10^{-4} + 0.166 \cdot 10^{-4} f_{GHz} \qquad (2)$$

For the largest penetration of the tuning rod, the Q factor of the TM_{01} mode drops to about 83 % of its maximum value, which is a very modest degradation.

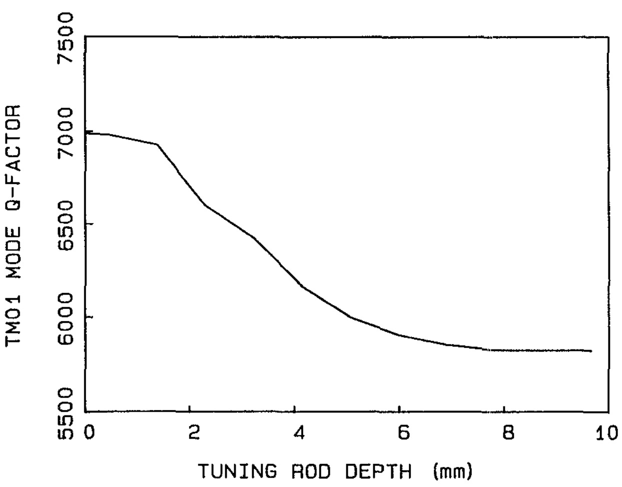


Fig. 5(a) Q factor of TM_{01} mode

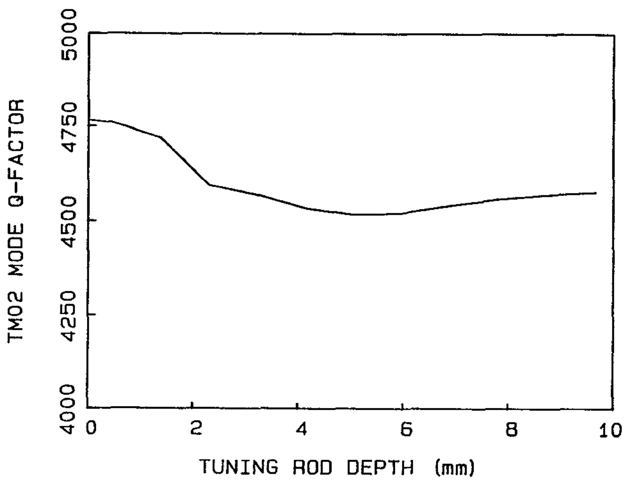


Fig. 5(b) Q factor of the TM_{02} mode

SUMMARY AND CONCLUSIONS

In summary, the tubular dielectric resonator operating in TM_{01} mode appears to have a good potential for mechanical tuning, and the tuning range appears to be possible beyond ten percent of the carrier frequency. The numerical procedure based on the Finite Integration Technique is well suited for studying the tuning properties of the cavity. By using this procedure, it should be further possible to optimize the dimensions of the resonator and its surroundings, so that a maximum tuning range, free of the interference with other modes, will be achieved. Study of the temperature stability is also possible with the same procedure, because the procedure provides accurate information on the resonant frequency as a result of any change in cavity dimensions.

ACKNOWLEDGEMENTS

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