ANALYSIS OF DIELECTRIC RESONATORS WITH TUNING SCREW AND SUPPORTING STRUCTURE

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ABSTRACT

The finite Element Method is applied to calculate the resonant frequencies and electromagnetic field distributions of axisymmetric dielectric resonator modes. Analysis of several resonator shapes is made inluding ring resonator, double resonator, and rod resonator with tuning screw and supporting structure.

INTRODUCTION

The application of dielectric resonators in microwave and millimeter circuits requires rigorous and efficient models to calculate resonant frequencies and field distributions. Several methods based in modal development have been presented to analyze rod (1),(2), ring (3), and multilayered cylindrical resonators (4). However these procedures are specifically designed to study determinated structures and may require modifications in their analysis procedures to study others.

Numerical methods can be applied to very different structures entering new data in a general computer program. Some of these are finite differences method (5), the integral surface method (6), and the differential method of Vincent P.(7).

In this paper a numerical procedure based on the finite element method to calculate the resonant frequencies of the TE and TM modes of axisymmetric dielectric resonators is presented. This procedure allows the study of the most common resonators (ring, rod, and double resonators), different environment (supporting structures, tuning mechanisms) and can be also used to design new structures. This method also provides the field distributions useful to design coupling mechanisms and to calculate quality factors.

METHOD OF ANALYSIS

The configuration to be analized consists of an axisymmetric closed metal cavity with an arbitrary number of dielectrics and conductors inside it. A cylindrical dielectric resonator with tuning screw and dielectric support (fig.1) is an example of this kind of structures.

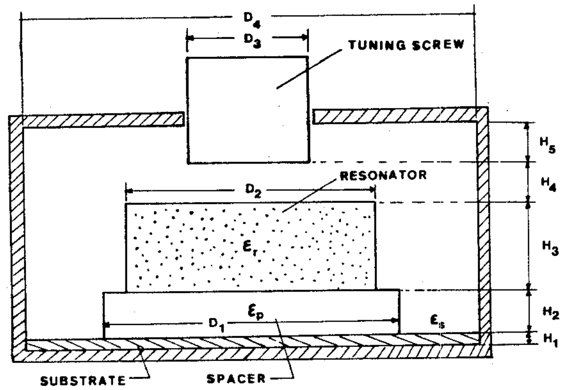

Fig.1 Dielectric rod resonator with tuning screw and supporting structure.

Variational formulation

Finite Element formulation has been made using the variational form proposed by Berk (8). The solution of Maxwell's equations can be derived from the following dual vectorial variational principles for electromagnetic fields:

$$F(\bar{\psi})=\int_{\Omega} p(\nabla\wedge\bar{\psi})\cdot(\nabla\wedge\bar{\psi})^{*}d\Omega - K_0^2\int_{\Omega} q\bar{\psi}\cdot\bar{\psi}^{*}d\Omega \quad (1)$$

$\bar{\psi}$ { Magnetic field $p=1/\varepsilon_r$ $q=\mu_r$

Electric field $p=1/\mu_r$ $q=\varepsilon_r$ }

Considering only axisymmetric structures and modes (TE and TM) the two functionals can be reduced to scalar form using only the ϕ component of the field (Electrical field for TE modes and magnetic field for the TM modes).

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Discretization of the problem

The domain is discretized into a finite number of subregions called elements. Permitivity inside each element must be constant. The size and shape of these regions are important parameters that can be adjusted to optimize the analysis efficiency.

The analysis of dielectric resonators requires generally smaller elements near and inside the resonator because the components of the fields there are more important than in other regions to calculate accurately the resonant frequency.

The field are approximated over each element by polynomials that are defined using the values of the field in some points of the element. The field in each element is expressed as

$$\left.\begin{array}{l} E_\phi \\ H_\phi \end{array}\right\} = \sum_{1}^{r} x_i \cdot N_i \qquad (2)$$

Substituting this aproximate expression of the fields in the variational form and applying stacionariness in the nodes using the Rayleigh-Ritz procedure, the following standart eigenvalue matrix equation is obtained.

$$[A]\ [x] = \lambda [B][x] \qquad (3)$$

$$A_{ij} = \int_\Omega p\left(\frac{\partial N_i}{\partial r}\cdot\frac{\partial N_j}{\partial r} + \frac{\partial N_i}{\partial z}\cdot\frac{\partial N_j}{\partial z} + \frac{N_i \cdot N_j}{r^2} + N_i\frac{\partial N_j}{\partial r} + N_j\frac{\partial N_i}{\partial r}\right) r\,d\Omega$$

$$B_{ij} = \left(\frac{2\pi}{c}\right) \int_\Omega q N_i \cdot N_j \, d\Omega$$

Electric field formulation requires the introduction of perfect electric boundary condition on the metal walls. It is also useful to make the field zero in the symmetric axis for both electric and magnetic formulation. This reduces the size of the system and eliminates some spurious solutions.

The system eigenvalues are the squares of resonant frecuencies and the associate eigenvectors are the polynomial coefficients that describe the field distributions of the modes.

Computation

Most of the coefficients of this system are zero so it is convenient to use special sparse matrix algorithms to solve it. Inverse iteration method is applied to solve the system if one eigenvalue is needed or subspace iteration method for several eigenvalues. Numerical integration is used to calculate the coefficients of the system. This simplifies and adds flexibility to the program allowing and easy introduction of different elements and formulations.

Number of nodes by element	Number of elements	Number of equations	Frequency (GHz)	CPU*
4	30	20	10.8086	1
4	120	99	10.5968	2
4	480	437	10.5453	13
8	30	69	10.5307	2
8	120	317	10.5284	13
8	270	745	10.5283	42
9	30	99	10.5302	3
9	120	437	10.5284	13
9	270	1015	10.5283	63
12	30	118	10.5284	6
12	120	535	10.5283	38

TABLE I.Convergence of the method for several elements. $D_2=6.533$, $D_4=1.5*D_2$, $H_1=0.251$, $H_2=H_5=0$ $H_3=2.31$, $H_4=1.5*H_3$, $\varepsilon_r=37$, $\varepsilon_s=2.17$

* CPU time required on a Digital VAX-11/750 computer.

Table I shows the convergence of the method for a dielectric rod resonator on microstrip substrate using several kind of elements. Poor results are obtained with four nodes linear elements because the convergence is very slow. Eight and twelve nodes elements provide better results. High numerical errors have been observed using elements of more than twelve nodes.

RESULTS

Comparison with other theories

A comparison between the results obtained with this method for the resonant frequencies of the lowest TE mode ad those obtained by others autors (2), (3), (4) with rigorous methods for double resonator, ring resonator and rod resonator are show in the tables II-IV. The differences are always smaller than one percent.

To study double dielectric resonators and rod dielectric resonators mounted on structures without lateral walls the distance to those walls in the model is increased until no influence on the resonant frequency is observed. This does not involve too much computational cost for the lowest TE mode because the field decreases very quickly.

Tuning

Curves to design metal screws to adjust the resonant frequency of dielectric rod resonators have been calculated. This is a new result not previously reported and allows to choose the adecuate screw diameter to obtain the desired tuning margin This is specially useful to design filters where diameters must be small, and the aproximation of wide diameter of the screw compared with the resonator diameter is no longer valid. Fig. 2 shows one of these curves.

Another method to adjust the frequency is to change the area of a metal film situated on the resonator. Curves for several distances between the resonator and the metal film are presented (Fig.3). Film thickness has been taken into account. The study of this structure using modal matching methods is difficult.

Field distributions

The eigenvectors associated with the eigenvalues provide the polynomial coefficients of (2) that describe the fields. Using Maswell's equation the other components of the field can be calculated.

Fig.4 shows the magnetic field distribution of a dielectric rod resonator with tuning screw and supporting disk for the $TE_{\gamma\delta}$ and the $TE_{\gamma\delta+1}$ modes. The arrows lenght is lineary prportional to the field amplitude in each point.

Knowledge of the field distributions is useful to design coupling mechanism and to suppres undesired modes.

CONCLUSIONS

Finite Element Method is a useful tool to calculate the TE and TM resonant frequencies and field distributions of axisymmetric dielectric resonators. Many kind of structures can be studied using only one computer program with a moderate computing time and good precision.

This method can be specially interesting to study complex resonators and to design tuning devices and supporting structures.

ACKNOWLEDGEMENT

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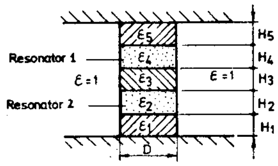
DOUBLE DIELECTRIC RESONATOR

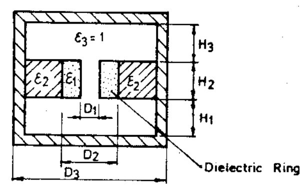


$H_2=H_4=3.52$ mm
$D=14.98$ mm
$\varepsilon_2=\varepsilon_4=34.1$
$\varepsilon_1=\varepsilon_3=\varepsilon_5=2.04$

DIMENSIONS (mm)			RESONANT FREQUENCY (GHz)		
H1	H3	H5	EXPERIMENTAL	Method A	This method
1.92	3.48	8.93	4.182	4.180	4.184
1.92	3.48	2.48	4.433	4.420	4.423
2.48	1.4	4.48	4.061	4.043	4.047

Table II. Comparison with the method proposed by Szymon Maj and Marian Pospieszalski (4) Experimental values take from the same authors.

DIELECTRIC RING RESONATOR

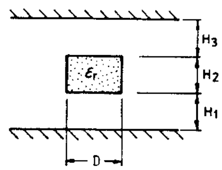


$D_1=3.044$ mm $\varepsilon_1=37.5$
$D_2=9.501$ mm $\varepsilon_2=1.037$
$D_3=14.44$ mm $H_2=4.124$ mm
$H_1=4.$ mm $H_3=4.$ mm

	Method B	This method
Resonant frequency for TE0γδ mode	6.0485 GHz	6.059 GHz
Resonant frequency for TM0γδ mode	9.324 GHz	9.369 GHz

Table III. Method B: mode matching technique used by Yoshio Kobayashi and Masanori Miura (3).

DIELECTRIC ROD RESONATOR



$H_1=0$
$H_2=13.37$ mm
$D=8.995$ mm
$\varepsilon_r=34.61$

DISTANCE TO THE TOP METAL WALL (mm)	RESONANT FREQUENCY (GHz)	
H3	Method C	This method
9.03	2.916	2.907
33.03	2.886	2.861

Table IV. Method C: proposed by D. Maystre and and P. Vincent (2).

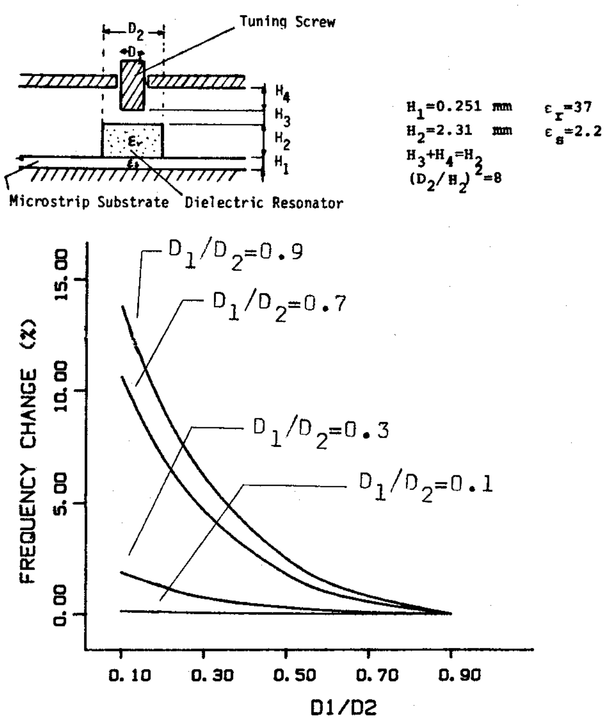


Fig.2 Frequency change of a dielectric rod resonator for several tuning screw diameter.

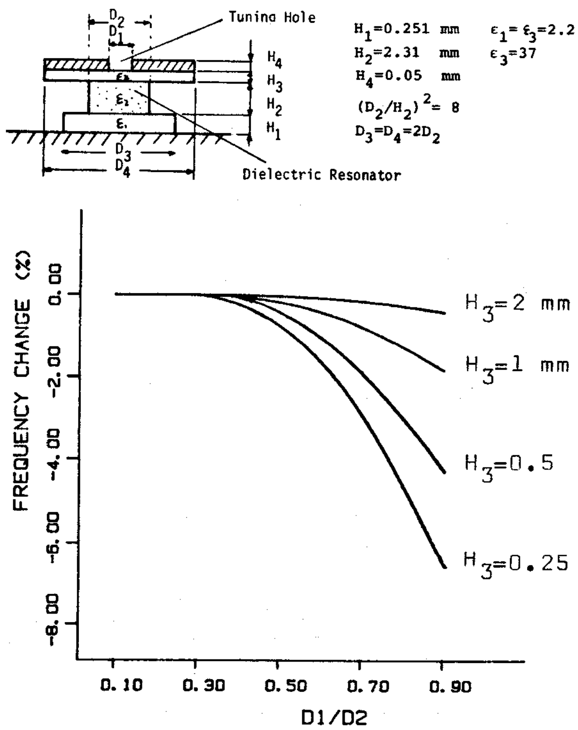


Fig.3 Frequency change of a dielectric rod resonator with metal film tuning.

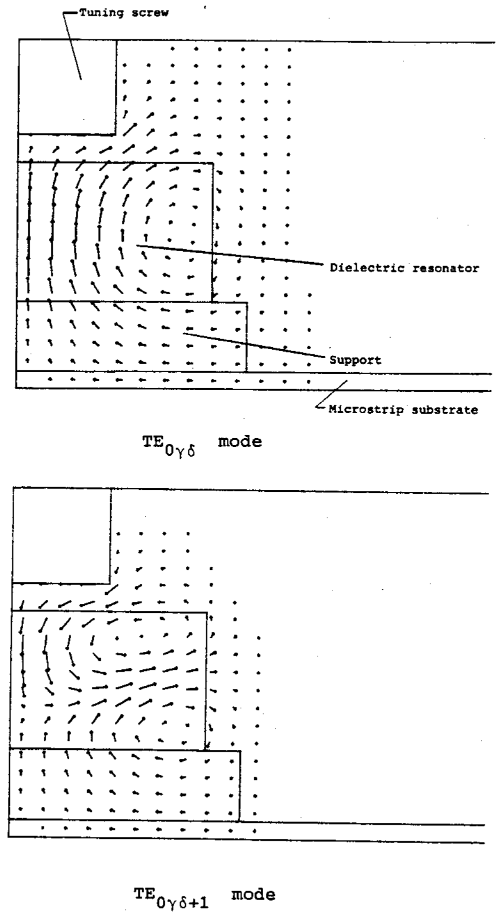


Fig.4 Magnetic field distribution of a dielectric rod resonator with tuning screw and support.

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