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FINITE ELEMENT SIMULATION FOR MICROWAVE DEVICES APPLICATIONS TO MICROWAVE D.R. FILTERS

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ABSTRACT

Rigorous numerical analysis of an axis symmetrical $TM_{0,1,\delta}$ dielectric resonators mode filter is presented.

Two dimensional (2D) and three dimensional (3D) finite element method (F.E.M.) is applied to compute the exact scattering matrix parameters (Taking into account the excitation probes) of this device. A sensitivity analysis is also performed and permits easier filter tuning. Experimental results are given and are in good agreement with theoretical ones.

INTRODUCTION

Dielectric resonators (DRs) are widely used in microwave applications, particulary in microwave filters, due to their desirable properties and their commercial availability at reasonable price.

The high electrical performances requiered for microwave filters achievement with DR, need rigorous analysis able to provide their behaviour with high degree of accuracy particularly for several parameters results of the filter synthesis like the coupling between DRs, the input and output coupling coefficients, the proper mode resonant frequency (f_0) or the unloaded quality factor (Q_0).

Up to now [1], [2], [3], [4], the study of each parameters is generally done separately.

In order to take into account all DR influences on each other and then to study the structure completeness, a solution is to use the 2 or 3 dimensional forced oscillations finite element method (F.E.M.).

In this paper, we only present results concerning axis symmetrical DRs structures which necessitate only the use of the two dimensional F.E.M. Section 1 describes succintly this method used to solve electromagnetic forced or free oscillations problems, applied to DRs devices characterization. In section 2, an example of such an analysis is presented. It consists to evaluate the scattering parameters of a $TM_{01\delta}$ DR mode coupled with two coaxial probes. Theoretical and experimental results are given. Then, a sensitivity analysis will be performed to show the geometrical parameters influence on the device responses. The method may be extended to optimize all structures. The analysis is then extended in section 3 to a two DRs axis symmetrical structure excited by two coaxial probes.

I - FINITE ELEMENT ANALYSIS

The two dimensional finite element method previously introduced [5], is used to analyze axis symmetrical structures as shown in figure 1. The structure is composed of N homogeneous, linear, isotropic and loss-less sub mediums, boundered with a circular metallic enclosure. It is excited by two coaxial probes which may support both T.E.M. modes and the first higher order TM_0 modes. Those excitations are represented by magnetic and electric surface currents imposed in the reference planes P_1 and P_2.

In order to calculate the electromagnetic field and the scattering coefficients of this device, we solve the following wave equation deduced from Maxwell ones applied to distributions [5], [6], [7].

$$\iiint_V \left(\frac{1}{\varepsilon_i}\{\mathrm{rot}\}\{H\}\right)\{\mathrm{rot}\}\,\phi\,.\,dV - k^2 \iiint_V H\,.\,\phi\,.\,dV = -j\,\omega\,\varepsilon_0 \sum_{k=1}^{2} J_{mP_k}\,.\,\phi\,dS_{P_k} \qquad (1)$$

where : H is the magnetic field vector

ε_i is the relative dielectric constant of medium i

$k = \omega\sqrt{\varepsilon_0\,\mu_0}$

V is the volume of the structure

S_{P_k} is the surface of port k

J_{mP_k} represent the magnetic current at port k

ϕ is a test function

The second member of the equation (1) represents the excitation of the structure and it can be developped to introduce voltage currents waves a_k and b_k in the formulation. After a numerical processing, we obtain a linear system to solve.

Knowing the frequency at which the structure is acting, the computation of this system yields to :

- the scattering matrix parameters in references planes P_1 and P_2
- the magnetic field vector in each medium of the structure

In the particular case where the references planes are short circuited, $J_{mP_k}=0$ and the second member of (1) cancels. This free oscillation analysis yields to eigen modes resonant frequency and field distribution.

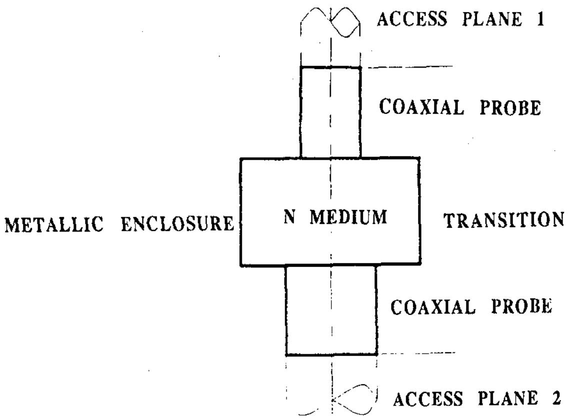

Figure 1 : Transition between coaxial probes

II - ANALYSIS OF A STRUCTURE COMPOSED OF A D.R. COUPLED WITH TWO PROBES

A) - Structure presentation

The first structure we are going to study is shown in figure 2. A DR of radius r=11 mm, height L=7 mm and permittivity ε_r=36,8 is enclosed in a perfectly conducting cylindric cavity of radius r'=2r and height L'=3L. This DR is supported by a concentric low relative dielectric constant material ring (e.g. Teflon).

The DR is excited in its electrical dipolar $TM_{0,1,\delta}$ mode, excitation which can be achieved by mean of coaxial probes mounted axially in the center of the metallic cavity. The reference planes P_1 and P_2 are chosen far enough from the discontinuities, so that the higher TM modes of the probes vanished in those planes.

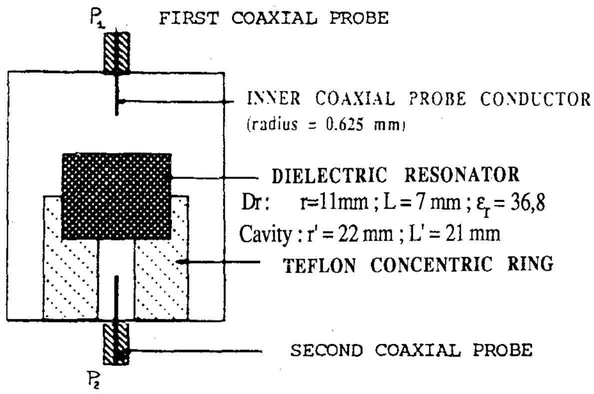

Figure 2 : A dielectric resonator coupled with two coaxial probes

B) - Theoretical and experimental results

The F.E.M. described previously is used to compute the scattering matrix parameters in the reference planes P_1 and P_2 of the structure shown in figure 2.

The theoretical S_{21} modulus variation as a function of the frequency for a 6 mm depth penetration probes is presented in figure 3. Since the DR is supposed loss-less, the theoretical external quality factor Qe can be obtained from the pass band response of the one pole DR filter (figure 3), applying :

$$Q_e = \frac{\omega_0}{\Delta\omega} \tag{2}$$

where ω_0 is the resonant pulsation, $\Delta\omega$ is the pass band width.

Then, to evaluate the loaded quality factor Q_L, we first evaluate the unloaded quality factor Q_0 by solving the free oscillation equation and knowing Q_e from the theoretical response, we deduce Q_L from :

$$Q_L^{-1} = Q_0^{-1} + Q_e^{-1} \tag{5}$$

A computation of theoretical and experimental Q_L factor for different coaxial probe depth penetration values is presented in figure 4. We can see a good agreement between those theoretical results and experimental ones. Figure 5 shows the $|S_{21}|$ parameter variations as a function of the frequency for varius probe depth penetrations.

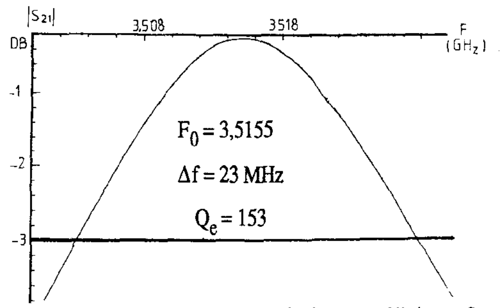

Figure 3 : Modulus of the transmission coefficient S_{21} as a function of the frequency for a 6 mm depth penetration probes

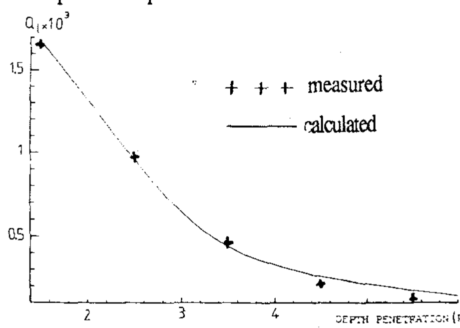

Figure 4 : Loaded quality factor

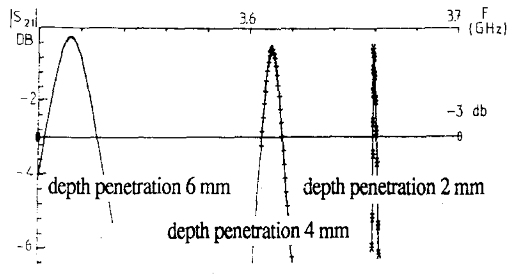

Figure 5 : Modulus of the transmission coefficient S_{21} as a function of the frequency for varius probe depth penetrations

C) - Sensitivity analysis

Filter designers may study the influences of the structures dimensions on the filter responses to know the degree of accuracy required on them. The theoretical sensitivity calculation after the resolution of the linear system has already been presented in [5].

For the structure given figure 2, it yields to the scattering matrix terms derivate as a function of :

- geometrical parameters : cavity height and radius - axis shifting resonators - probe depth penetration
  - resonator height and radius.
- electrical parameters like : RD permittivity - support permittivity

Note that it is also possible to compute sensitivity relative to many parameters at the same time. The computer algorithm permits to obtain in a few seconds accurate results for structures slightly different from the original one.

We only present here a computation example which permit to appreciate the accuracy of the method. Figure 6 presents a interpolated curve for $\Delta\varepsilon_r$=+0,1 and the computed response for $\varepsilon_r = \varepsilon_{r1} + \Delta\varepsilon_r$. We can note a very good agreement between the results obtained by using the interpolation software and those obtained by using a new mesh of the structure and running again the program.

D) - Higher modes analysis

Up to now, we are working with the first TM_0 DR mode. In this chapter, we will see that the same software can also be used to evaluate the electrical parameters of the second TM_0 DR mode. The response obtained in this case is shown in figure 7. We can verify that the coupling factor is lower than the one obtained for the first TM_0 DR mode for the same probes depth penetration, as the first TM_0 mode energy is less concentrated in the DR than thus of the second one.

III - ANALYSIS OF A TWO DIELECTRIC RESONATORS STRUCTURE

A) - Structure presentation

Two dielectric resonators are included in a perfectly conducting cylindric shield. They are supported by a concentric Teflon ring. The excitation is achieved by coaxial probes mounted axially in the center of cavity (figure 8).

B) - Theoretical results

Figure 9 presents some responses obtained for varius distances d between DRs as a function of the frequency. We can verify that the coupling coefficient [1] decreases when d increases. This coefficient solution of the forced oscillation problem can be compared to this obtained by solving the free oscillation equation and evaluate from (4).

$$k_0 = \frac{f_{0e}^2 - f_{0o}^2}{f_{0e}^2 + f_{0o}^2} \qquad (6)$$

where f_{0e} and f_{0o} are respectively frequencies of even and odd modes of the DRs structure (figure 10).

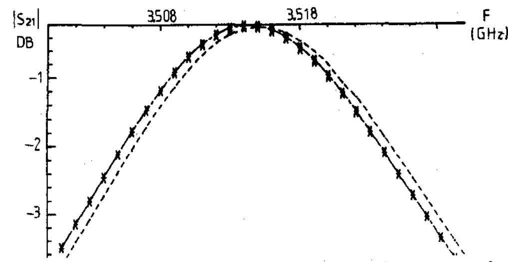

Figure 6 : Modulus of the transmission coefficient S_{21} as a function of the frequency

- - - - - computed with ε_r = 36,8

——— interpolated with $\Delta\varepsilon_r$ = + 0,01

* * * computed with ε_r = 36,81

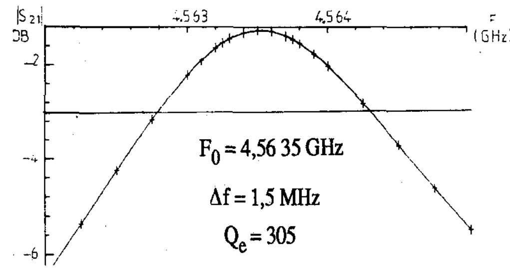

Figure 7 : Modulus of the transmission coefficient S_{21} as a function of the frequency of the second TM_0 mode

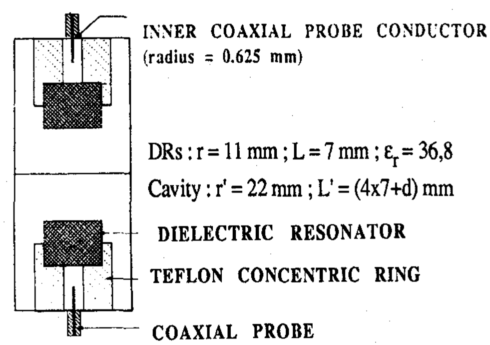

Figure 8 : Two dielectric resonators coupled with two coaxial probes

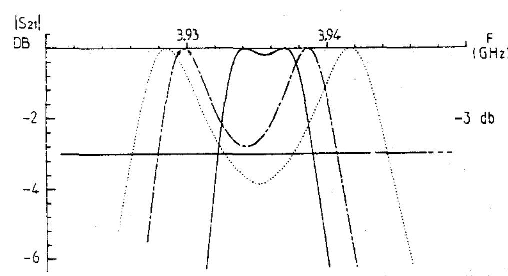

Figure 9 : Modulus of the transmission coefficient S_{21} as a function of the frequency for varius distances d between DR

············——— d = 80 mm

— - - — d = 70 mm

·········- d = 64 mm

Finally, some results concerning the DR height and radius influences on the $|S_{21}|$ responses are presented on figure 11. These results show that a completely analysis sensitivity is very important for filters adjustements and for the experimental response prediction from manufactuer performances.

IV - CONCLUSION

The forced oscillations two dimensionnal F.E.M. presented in this paper leads to the scattering matrix parameters of a cylindrical DR structure excited on the $TM_{0,m,p}$ mode using axial coaxial probes.

The sensitivity analysis is used to observe the geometrical variation influence on those S parameters and can be applied to the structure optimisation. We have now to use the three dimensionnal F.E.M. to analyse asymmetric structures and, for example, the excitation of TE or HEM DR modes achieved by coaxial loops or microstrip lines.

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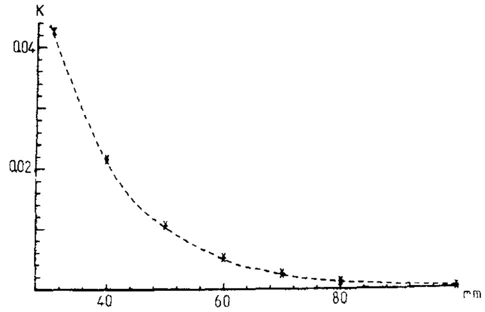

Figure 10 :The inter resonators coupling coefficient as a function of the distance d between DR
free oscillation
forced oscillation

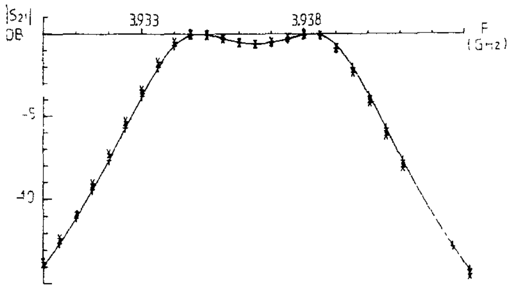

Figure 11 : Modulus of the transmission coefficient S_{21} as a function of frequency
——computed with r = 11 mm and L = 7 mm
* * * interpolated with Δr = +0,01
+ + + interpolated with ΔL = +0.001