ELLIPTIC FILTER RIGOROUS DESIGN AND MODELLING APPLYING THE FINITE ELEMENT METHOD

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ABSTRACT

This paper describes a new dual mode coupling technique wich permits to replace classical dielectric resonators, coupling and tuning screws commonly used in dual mode filters, by slotted dielectric resonators. The theoretical analysis is performed applying the three dimensional finite element method. For the first time, a synthesis method is developped to design rigorously a four and a eight pole dual mode slotted dielectric resonators filter. The theoretical responses show good agreement with the experimental ones.

INTRODUCTION

Dual mode filters offer better performances, smaller size and less mass than classical fundamental TE or TM mode filters [1-2]. Moreover, this configuration may simplify the achievement of elliptic responses to increase the filter rejection slope. It is well known that coupling between the two modes polarizations of the first dielectric resonator (DR) hybrid mode is produced by adding a coupling screw at 45° angle with respect to each excitation probe direction (figure 1-a). The filter response can be adjusted by changing the penetration in the DR enclosure of the coupling screw and of the two tuning screws located in the polarization planes. But these coupling and tuning systems are not taken into account rigorously by actual theoretical methods. So each experimental realization requires long and delicate tuning which may increase the cost of dual mode DR filters production. Recently, some studies about mode coupling in planar structures [3] or waveguide cavities [4] have been developped to suppress coupling and tuning screws.

This paper introduces a new dual mode coupling technique which replaces classical dual mode DR structures (classical DR, metallic screws) by slotted DR ones excited on the first hybrid mode (HEM_{11}) (figure 1-b). Using the three dimensional finite element method (F.E.M.) we first present the notch 1 effect on the coupling between the two resonant dual modes. A comparison between the unloaded Q_0 factor obtained for a slotted DR and for a classical one with metallic screw is presented. Then, to illustrate the application of the new coupling technique a theoretical method is developped to analyze dual mode filter responses. Two elliptic filters with four and eight poles are rigorously designed. Dielectric and metallic losses are taken into account for the four pole filter. The theoretical results are compared to measurements.

NEW DUAL MODE COUPLING METHOD

❑ The analysis is realized using the 3D. F.E.M. . This method has been already explained in several papers [5] and our purpose is not to describe it here. We can however notice that the free oscillations study permits to compute the eigen mode resonant frequencies and the unloaded Q_0 factor of closed structures. The scattering parameters in the reference planes of the device is computed by using the forced oscillations 3D. F.E.M. .In this article, the computations are performed on a HP 755 workstation.

❑ A classical cylindrical DR shielded in a metallic cavity (figure 1-a) and excited on the HEM_{11} mode presents two orthogonal polarizations at the same frequency (f_0) . But for the slotted cylindrical DR (figure 1-b) where notch 1 is located at 45° angle with the excitation axis the electromagnetic fields distribution of the two polarizations are modified and then, two resonant modes are excited [6]. The resonant frequencies are f_x and f_y. The S_{21} parameter is computed using the forced oscillations 3D. F.E.M. for a classical DR without coupling screw and for a slotted one (figure 2). This computation verifies

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that the coupling screw can be replaced by the notch 1.

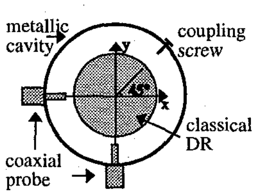


Figure 1a :
Classical cylindrical DR

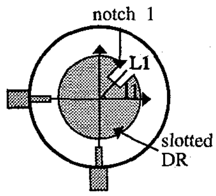


Figure 1b :
Slotted cylindrical DR

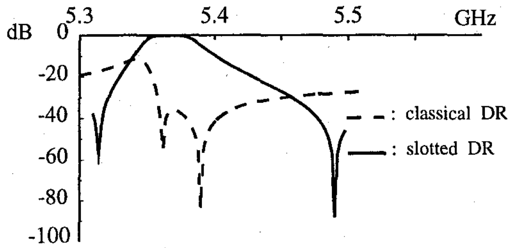


Figure 2 : $|S_{21}|$ for a classical and for a slotted DR

❑ The coupling coefficient K between the two polarizations is computed applying the free oscillations F.E.M. for different notch 1 dimensions (figure 3). For this analysis, the presence of the coaxial probes is considered. K is defined in [7].

$$K = \frac{f_x^2 - f_y^2}{f_x^2 + f_y^2}$$

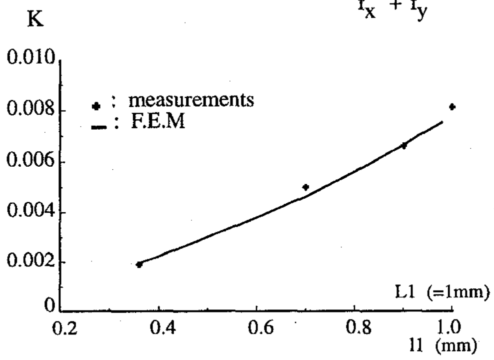


Figure 3 : Coupling coefficient between the two polarizations

❑ Figure 4 presents a comparison between the unloaded Q_0 factor computed as a function of K for a classical DR with coupling screw and for a slotted one. The same polarization in considered. A slotted DR advantage compared to the classical DR is to preserve Q_0 constant for K values commonly used for dual mode DR filter.

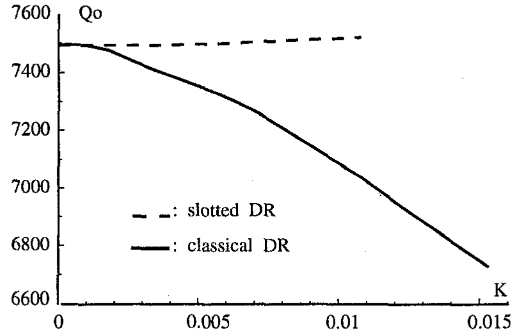


Figure 4 : Unloaded Q_0 factor for a classical DR and for a slotted one as a function of K

SYNTHESIS METHOD

To compute the dimensions of the structure which satisfy the electric characteristics of a band-pass DR filter (f_0, bandwidth, insertion losses, rejection slope) a segmentation approach is first developped.

❑ Applying the free oscillations 3D. F.E.M., we compute :

- the DR and metallic cavity dimensions (part A1)
- the coupling coefficients K as a function of the notch 1 dimensions (figure 3) (part A2)
- the coupling coefficients C between two classical DRs as a function of a rectangular iris dimensions (part A3)
- the notch 2 dimensions introduced to tune the filter response (part A4). This notch must compensate for the influence of the probe on the resonant frequency of the excited polarization. This frequency increases if notch 2 is located at 90° angle with the excitation axis (figure 5). But if notch 2 is located in this axis, the excited frequency is not disturbed by this notch. The boundary conditions on notch 2 applied to the electromagnetic fields explain this phenomena.

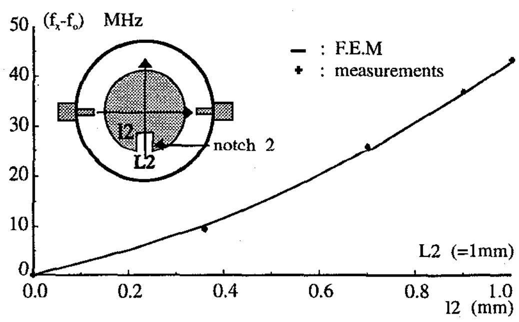


Figure 5 : Frequencies difference between f_0 (classical DR) and f_x (notch 2 DR)

❑ Then an analysis using the forced oscillations 3D. F.E.M. defines the external quality factor Q_e due to the input/output coupling coefficient between a coaxial probe and a classical DR (part A5). Q_e depends on the probe penetration depth.

These parts (A1, A2, A3, A4 and A5) are independent from each other.

At last, applying the forced oscillations 3D. F.E.M., the whole structure is analyzed to establishe the scattering parameters in the acces planes (part A6). To eliminate the degradations of the filter responses due to the dependence between the elements of the device, an optimization is applied to fine-adjust the filter dimensions.

COMPUTED AND EXPERIMENTAL RESULTS

A four and a eight pole elliptic dual mode slotted DR filters are now designed using the synthesis method. For these filters, the external Q_e is equal to 108. The central freqency is 5.53 GHz and the bandwidth (-3dB) is 1%.

A. A four pole elliptic filter

The filter geometry is given in figure 6a.

The value of the coupling coefficients K_{12} (DR1) and K_{34} (DR2) are : $K_{12}=K_{34}=7.8\ .10^{-3}$. The two slotted DRs are coupled through a crossing rectangular iris. These coupling coefficients C are referred to C_{14}= -2.44 $.10^{-3}$ and C_{23} = 6.55 $.10^{-3}$. To obtain an elliptic function C_{14} is negative, so notch 1a and notch 1b are at 90° angle from each other.

The four pole filter theoretical response presented in figure 6b is obtained taking into account the dielectric and the metallic losses :

- for the DRs $\varepsilon_{DR} = 37 - j\ 37.tg\delta$
  with $tg\delta = f_0(GHz)/40000$

- for the supports $\varepsilon_s = 2.1 - j\ 4.2\ .10^{-4}$

- for the metallic walls $\sigma = 1.57\ .10^7$ mhos/m

An experimental structure without correction on dimensions defined in part A6 is built and tested without tuning. Comparisons between theoretical and experimental results show encouraging agreement (figure 6b).

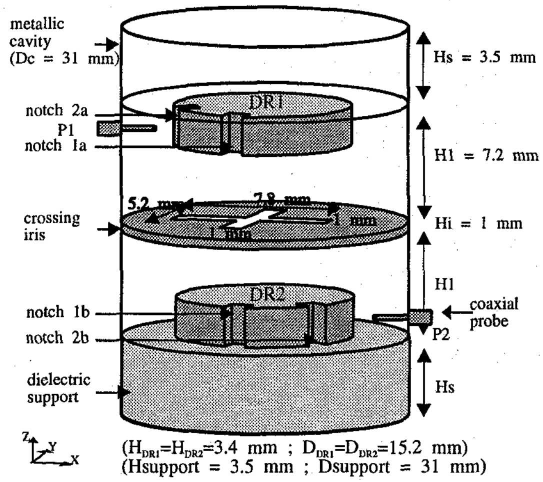


Figure 6a : Four pole filter design

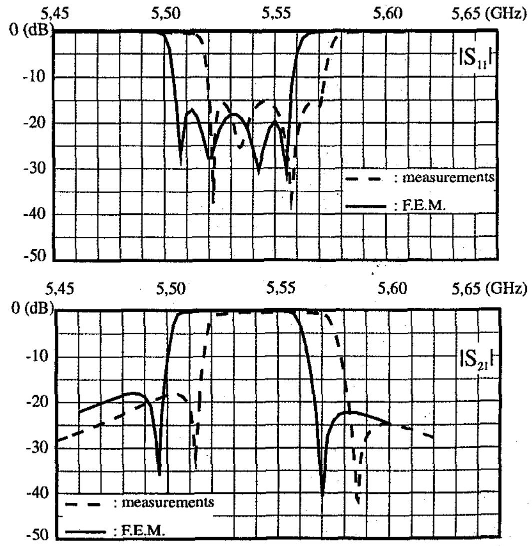


Figure 6b : Four pole elliptic filter : computed and experimental responses

B. A eight pole elliptic filter

Figure 7a presents the device under consideration. The value of the coupling coefficients are :

- $K_{12}=K_{78}$= 7.505 $.10^{-3}$ and $K_{34}=K_{56}$= 4.875 $.10^{-3}$
- C_{14}= -4.68 $.10^{-4}$ and C_{23}= 5.61 $.10^{-3}$
- C_{45}= 4.839 $.10^{-3}$ and C_{36}= 0

The synthesis method permits to define the device dimensions. The first theoretical eight pole elliptic filter response is presented in figure 7b. For this filter, the permittivities are $\varepsilon_r = 37$ for the DRs and $\varepsilon_s = 2.1$ for the supports.

The experimental results obtained without tuning, are presented and compared to the theoretical ones in figure 7b.

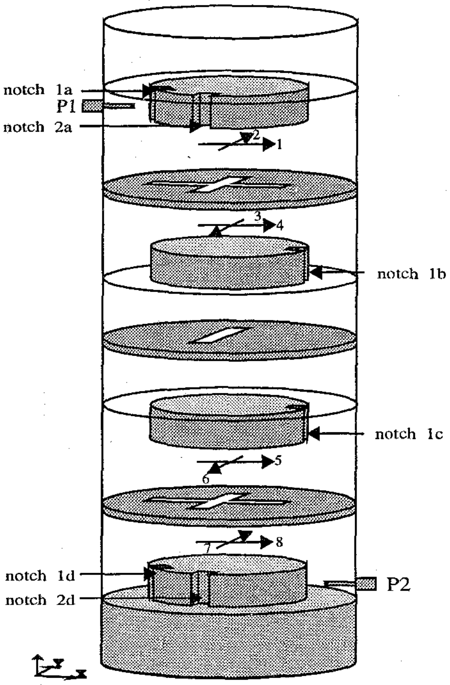
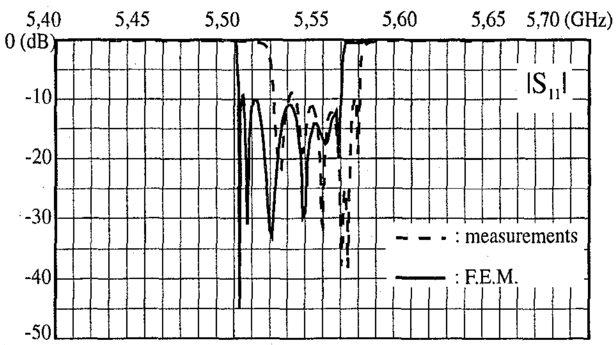


Figure 7a : Eight pole filter design



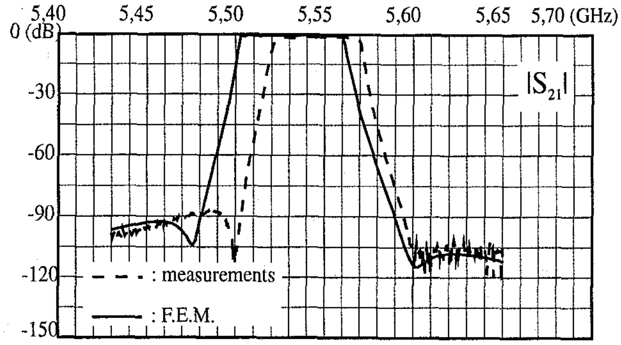


Figure 7b : Eight pole elliptic filter : computed and experimental responses

C. Conclusion

For the two filters, the difference between the computed central frequency and measured one is less than 0.2 %.The difference between the bandwidthes is equal to 5 MHz. The experimental passband return loss verify the theoretical ones.

CONCLUSION

This article introduces a new dual mode coupling technique which permits to replace classical DRs, tuning and coupling screws in dual mode DR filter by slotted DRs. A comparison between the unloaded Q_0 factor obtained for a slotted DR and for a classical one with coupling screw is presented. At last, an analysis method permits to compute rigorously for the first time two experimental elliptic DR filter with no tuning. The measured elliptic four and eight pole filter responses show excellent agreement with theory.

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