Slotted Dielectric Resonators for Rigorous Design of a Four-Poles Dual Mode Filter

D. Baillargeat, S. Verdeyme, and P. Guillon, *Senior Member, IEEE*

***Abstract*—A new dual mode coupling technique is described. This new method replaces the classical coupling and tuning screws by slotted dielectric resonators. The theoretical analysis uses the three-dimensional finite element method. For the first time, a four-poles dual modes slotted dielectric resonators filter is rigorously designed, taking into account the dielectric losses. The experimental results show excellent agreement with the theoretical ones.**

I. Introduction

Multimodes filters are widely used in telecommunication systems due to their better performance, smaller size, and less mass than classical fundamental mode realizations [1]–[3]. Using a first or second dielectric resonator (DR) hybrid mode, the coupling between the two modes' polarizations is produced by adding a coupling screw at 45° angle with respect to each excitation probe's direction (Fig. 1(a)). By changing the coupling screw penetration in the DR enclosure, the filter response can be adjusted. Two other screws localized in the polarization planes are required to tune the filter resonant frequencies. These tuning mechanisms are not taken into account rigorously by the theoretical methods required to conceive such devices. So, the tuning process requires long and delicate "cut and try" procedures and may increase the cost of dual mode filters production. Recently, some theoretical results have been published for dual mode coupling in planar structures [4] or in waveguide cavities [5]. These studies present a dual mode coupling method developed to suppress coupling and tuning screws.

The objective of the present paper is to replace classical dual modes DR structures (classical cylindrical resonators, metallic screws), by the slotted DR ones excited on the first hybrid mode (Fig. 1(b)). A theoretical analysis using the three-dimensional (3D) finite element method (F. E. M.) is developed to consider the notch 1 (Fig. 1(b)) effects on the device responses. The results obtained are presented in the first paragraph. Finally, to illustrate the application of the new dual mode coupling method, an experimental four-poles dual modes elliptic filter was rigorously designed, taking into account the dielectric losses. The experimental filter with no tuning was tested. Experimental results are compared to the theoretical ones.

Manuscript received May 11, 1994.
The authors are with IRCOM, Faculté des Sciences, Limoges, Cédex, France.
IEEE Log Number 9405081.

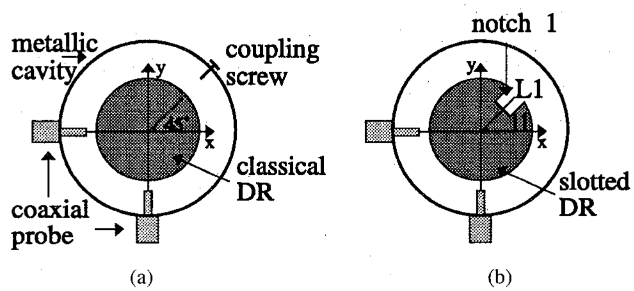

Fig. 1. (a) Classical cylindrical. (b) Slotted cylindrical DR.

II. Analysis

A. Theoretical Analysis of the Structure

This analysis was realized by using the 3D F.E.M. This method has already been presented in several papers [6], and our purpose is not to describe it here. We can, however, notice that a new approximation presented by Nedelec [7] was introduced. Our software permits to compute, applying the free oscillations study, the eigenmode resonant frequencies of closed structures. The forced oscillations F.E.M. is used to compute the scattering matrix parameters in the reference planes of the device. In this article, the presented theoretical results are computed on a HP 755 workstation.

B. A New Dual Mode Coupling Technique

The structure under consideration is given in Fig. 1(b). A classical DR shielded in a cylindrical enclosure and excited on it first hybrid mode (HEM_{11}) presents two orthogonal polarizations at the same frequency (f_0). No energy splits between the polarizations. These two modes can be referred to as HEM_{11}^{x} (frequency f_x) and HEM_{11}^{x} (frequency f_y). The superscripts x and y express the mode polarization.

If we introduce the notch 1 of Fig. 1(b) at a 45° angle with the xy axis, the electromagnetic fields distributions are disturbed, and to satisfy the boundary conditions of field on the notch 1, the two polarizations become nonorthogonal. To verify this hypothesis, the S_{21} modulus parameter is computed (Fig. 2) using the forced oscillations F.E.M. for a classical cylindrical DR and for the slotted cylindrical DR. Fig. 2 shows that a coupling between the two resonant modes can be obtained. So, it is possible to replace the classical coupling screw by the notch 1.

A four-poles dual modes elliptic filter is now developed using this new coupling technique. Its central frequency will be equal to $f_0 = 5.5$ GHz and its bandwidth $\Delta f(-3\text{ dB}) = 55$

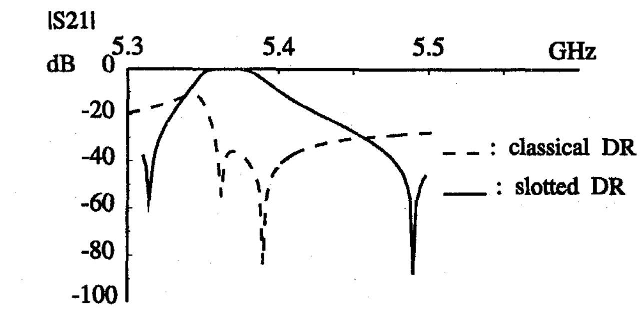

Fig. 2. $|S_{21}|$ for a classical DR and for a slotted DR.

MHz. The scattering parameters in the access planes (P_1, P_2) (Fig. 3) of the structure are established to predict rigorously its experimental responses.

III. Computed and Experimental Results

The geometry of the structure under consideration is given in Fig. 3. We first consider the dielectric materials loss less and isotropic. The metallic walls are considered as perfect conductor.

The two slotted DR's are coupled through a crossing rectangular iris. $k_{12} (= k_{34} = 7,18\ 10^{-3})$ express the coupling coefficient between the two DR_1 (DR_2) polarizations. The coupling coefficient between the two DR's referred to k_{14} $(= 2,44\ 10^{-3})$ and k_{23} $(= -6,55\ 10^{-3})$. To obtain an elliptic function k_{23} is negative, so notch 1a and notch 1b are at 90° from each other (Fig. 3).

A. Synthesis Method

- The external quality factor Q_e $(= 108)$ due to the input output coupling coefficient between a coaxial probe and a classical DR is computed as a function of the probe's depth penetration using the forced oscillation F.E.M.
- To obtain $k_{12} = k_{34}$, we calculate the notch 1a and b dimensions from a free oscillations F.E.M. computation. The coupling coefficient k, is given by [5]: $k = \left|\frac{f_x^2 - f_y^2}{f_x^2 + f_y^2}\right|$ and for $k = 7,18\ 10^{-3}$, $|\ 1(a,b) = 1$ mm; $L1(a,b) = 0.95$ mm.
- The coefficients k_{14} and k_{23} are computed using the same F.E.M. technique as a function of the iris dimensions and the distance between two classical cylindrical DR's.

These three steps are independent from each other. Then, the scattering parameters in the access planes are established. The first theoretical results show that the filter must be tuned. In fact, the segmentation approach is too approximative for this complex structure. So, we introduce two notches (2a and 2b). These notches must compensate for the influence of the probes on the two resonant polarizations frequencies. This study proves that f_x increases if notch 2 is located at 90° angle with the polarization axis. This frequency is not disturbed if notch 2 is located in the polarization axis. The boundary conditions on the notch 2 applied to the electromagnetic fields explain this phenomena. The theoretical response presented in Fig. 4 is obtained for the following dimensions of notches $2(|(a,b) = 1$ mm; $L2(a,b) = 0.63$ mm.

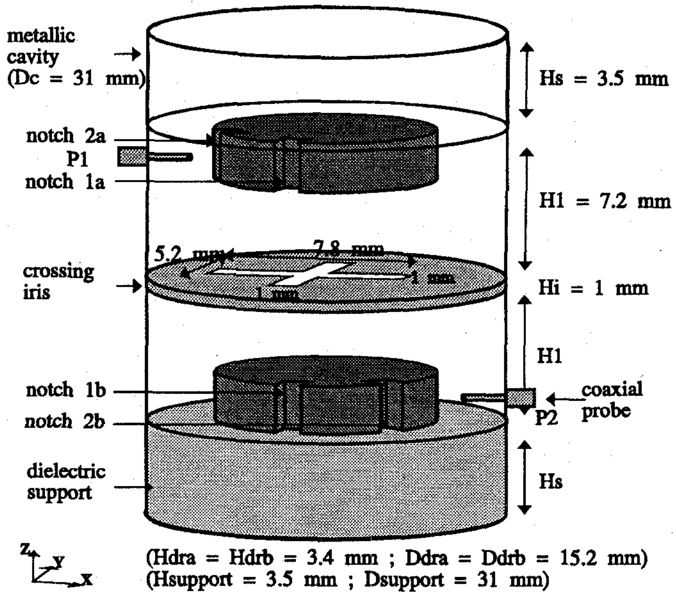

Fig. 3. Structure under consideration: four-poles filter.

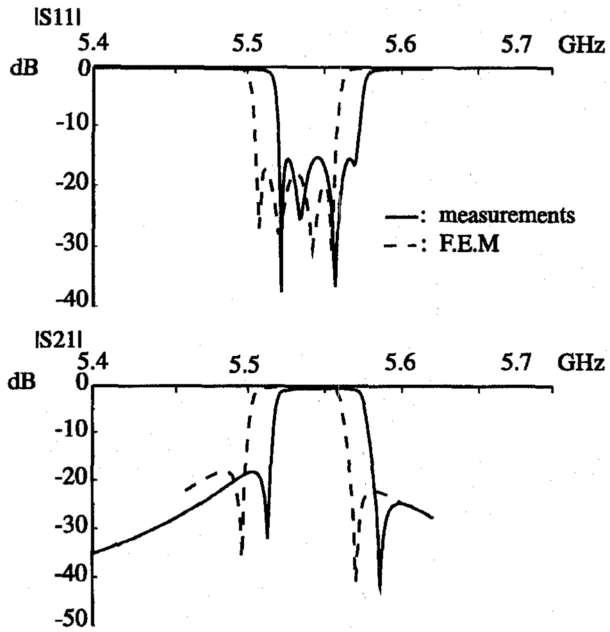

Fig. 4. Four-poles elliptic filter response.

B. Results

Our software permits to take into account the filter dielectric losses. So, for this last computation we consider:

- the DR's permittivity: $\varepsilon_{DR} = \varepsilon'_{DR} - j(\varepsilon'_{DR} tg\delta)$ with

$$\begin{cases} tg\delta & = \frac{f_0(\text{GHz})}{40\ 000} \\ \varepsilon' & = 37 \end{cases}$$

- the support permittivity: $\varepsilon_s = 2,1 - j2\ 10^{-4}$

The first measurements are presented in Fig. 4. The comparison between the theoretical results and the experimental ones show encouraging agreement. In fact, the same bandwidth is obtained, and the difference between the computed central frequency and the measured one is less than 0.2%.

IV. CONCLUSION

In this letter, a new dual mode coupling technique has been introduced. Slotted DR's replace the classical DR's tuning and coupling screws in dual mode filters. A four-poles dual modes elliptic filter was rigorously designed, taking into account the dielectric losses. An experimental filter with no tuning was tested and the measurements show excellent agreement with theory.

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