WHISPERING GALLERY DIELECTRIC RESONATOR FILTERS

D. CROS - F. NIGON - P. BESNIER - M. AUBOURG - P. GUILLON

I.R.C.O.M. - University of Limoges - 123 Av. A. Thomas - 87060 Limoges Cedex - FRANCE

ABSTRACT

This paper discusses the utilization of whispering gallery mode dielectric resonators for the design of filters at high frequencies. The analysis based on the three dimensional finite element method makes it possible to predict the theoretical responses of filters. Two kinds of filters are presented. The first one is a volumic one and uses two resonators placed in a metallic cavity and coupled to two electric probes. The second one is a planar one and is the association of elementary devices which are composed of a dielectric resonator coupled to two parallel microstrip lines.

INTRODUCTION

Using whispering gallery modes (W.G.M.), the performances of filters are very interesting [1]. In particular, insertion losses are very small because unloaded Q factor of these modes which is very high is only limited by the value of the loss tangent of the resonator material. Moreover, couplings between resonators and input or output access are weak, so bandpass response of these filters are narrow. Finally, W.G.M. dielectric resonator dimensions are relatively large for millimeter wavelengths and permit to realize filters at high frequencies.

Using W.G.M. dielectric resonators, we have designed two types of filter. First a conventional topology is presented. It is composed of two dielectric resonators placed in a metallic cavity and excited by two electric probes. To predict filter response, three dimensional finite element method is used [2]. Theoretical and experimental results of a two pole W.G.M. dielectric resonator is presented. In the second application, an elementary device composed of a dielectric resonator excited on a W.G.M. by two microstrip lines is characterized using finite element method. Then, several elementary devices are put together to realise Butherworth and elliptic filters.

W.G.M. CAVITY TWO POLE FILTER

For this application, the dielectric resonators of diameter 14 mm and thickness 2 mm are made of saphir, because this material has a very large unloaded Q factor [3]. The structure is excited by two electric probes placed in radial planes of each resonator acting on their WGE_{300} mode. For such modes, electric field is essentially radial.

Moreover, as the energy of W.G.M. is confined on the boundary of dielectric resonator, these ones are held in the structure with a dielectric rod placed through their center (figure 1).

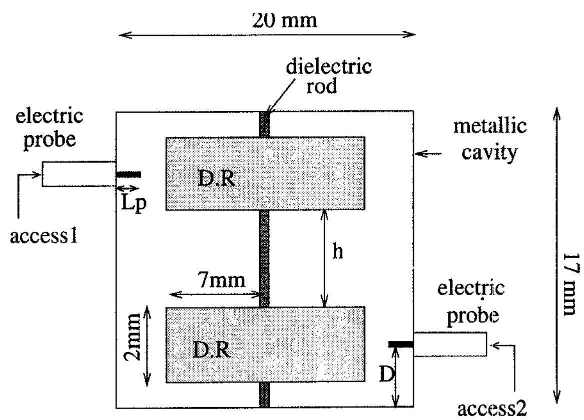

Figure 1 : W.G.M. cavity two pole filter

The coupling coefficient between modes of the structure and electric probe is calculated using only one dielectric resonator excited by two electric probes.

Using finite element method, we compute the transmission and reflexion responses S_{12} and S_{11} of the structure for different distances D between the top of the cavity and the electric probe, and for different lengths of probes Lp. Then, from every value of D and Lp, we obtain loaded Q_l factor. As losses in the resonator are very small, external Q_e factor can be deduced from relation (1)

$$Q_l^{-1} = Q_o^{-1} + Q_{e1}^{-1} + Q_{e2}^{-1} \qquad (1)$$

with $Q_{e1} = Q_{e2}$ (symetric structure) and $Q_o^{-1} = 0$

then $Q_e = 2\,Q_l$

For filter application, theoretical variation of Q_e as a function of probes position are presented on figure 2.
We can see on these figure that the lower limit of external Q_e factor is near 400. So, only narrow band filter can be realized with this type of structure.

0-7803-3246-6/96/$5.00 © IEEE

1996 IEEE MTT-S Digest

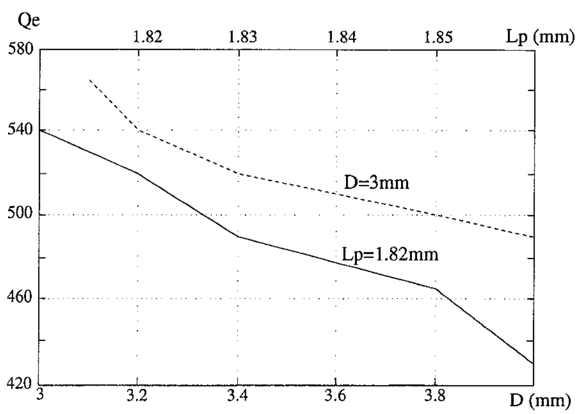

Figure 2 : Qe variation as a function of probes position

The study of coupling between two dielectric resonators is difficult. In fact, as input and output coupling is very small, the probe is placed near the dielectric resonator. So, electromagnetic field of the structure is perturbed by the coupling and the proximity of the probes. For this reason, to determinate coupling coefficient between dielectric resonators we study all the structure taking into account both input and output couplings.

The transmission and reflexion coefficients are computed for different distances h between dielectric resonators (figure 1). Then, we have calculated reflexion coefficient of the odd mode (S_{11o}) and even mode (S_{11e}) with the relation given by (2) and (3) [4] :

$$S_{11e} = S_{11} + S_{12} \qquad (2)$$
$$S_{11o} = S_{11} - S_{12} \qquad (3)$$

As we consider the structure without losses, modulus of S_{11o} and S_{11e} are equal to unity. However, with phases of S_{11o} and S_{11e} we can deduce resonant frequencies of the odd mode (f_{0o}) and the even mode (f_{0e}) of the structure. Then, the coupling coefficient k between both modes of the structure is given by (4) :

$$k = \frac{f_{0o}^2 - f_{0e}^2}{f_{0o}^2 + f_{0e}^2} \qquad (4)$$

The coupling coefficient k as a function of the distance h between resonators is given on figure 3.

Using previously computed values of Q_e and k we have calculated dimensions of a Butherworth two pole filter. Its center frequency is 18.3 GHz with 50 MHz of bandpass. The position of the probes is D = 3.3 mm, Lp = 1.82 mm and the spacing between the dielectric resonators is h = 7.25 mm.

The results are shown on the figure 4. We can see a good agreement between experimental measurements and theoretical results. The experimental bandpass is equal to 51 MHz, the frequency center is f_0 = 18.2 GHz, and the insertion losses are lower than 1.5 dB.

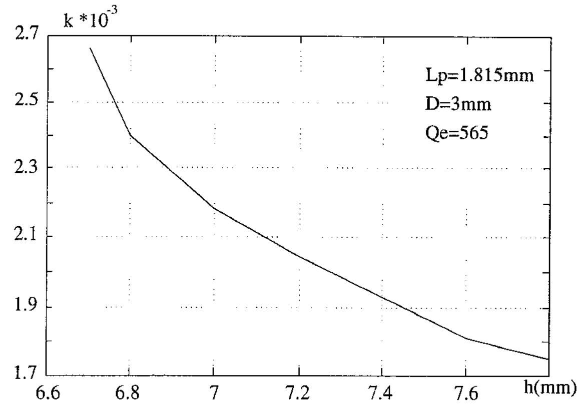

Figure 3 : Coupling coefficient as a function of distances between resonators

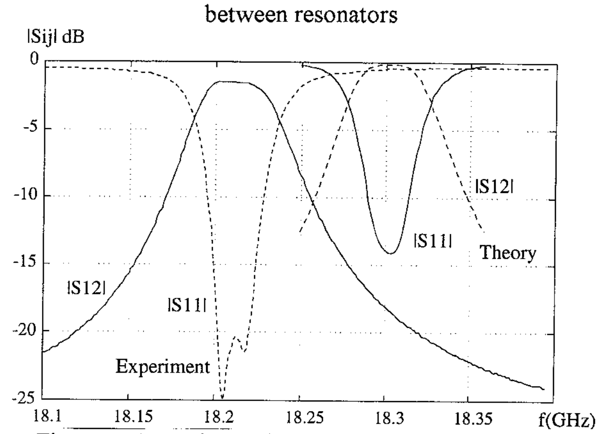

Figure 4 : Experimental and theoretical results of the two pole filter

PLANAR FILTERS

The elementary structure is composed of a W.G. dielectric resonator coupled to two parallel microstrip lines and placed in a metallic enclosure. The access planes (I and II) of the structure are constitued of two parallel microstrip lines on a dielectric substrate (figure 5).

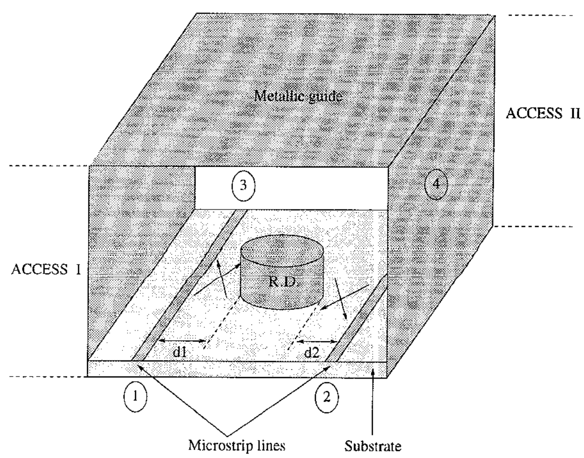

Figure 5 : Whispering Gallery dielectric resonator coupled to two parallel microstrip lines

Since the W.G.M. is running essentially in the azimuthal direction, a directive response is obtained. Indeed, most of the incident wave at port 1 is shared towards port 2 and 3 (respectively pass band and stop band responses). The scattering parameters depend on the coupling coefficients between the dielectric resonator and the lines and on the unloaded Q factor of the structure.

The theoretical method of characterization consists in calculating all the electromagnetic modes present in the acces planes (I and II) of the structure. These modes are typically the odd and even modes of the coupled microstrip lines [4] and the higher order modes of the rectangular metallic guide such as TE_{01}, TE_{02} ...

Then, the scattering parameters relative to each previous mode are computed. This is a 3D calculation using the finite element method and taking into account the dielectric and metallic losses of the materials.

As the experimentation takes only into account the quasi T.E.M. microstrip line modes, the higher order modes are rigorously short circuited in the input planes of the structure. Finally, we obtain the scattering matrix of the four port device in the access planes by a linear combination of the odd and even mode S parameters.

Theoretical and experimental results for several elementary devices have been compared to validate this method of characterization. We present on figure 6 the results obtained with a D.R. of relative permittivity 29.6 , thickness 1.8 mm and diameter 10 mm, acting on the $W.G.E._{300}$ mode. The spacings between the D.R. and the lines are equal to 0.8 mm. The microstrip lines use a substrate of permittivity 9.8 and thickness 0.254 mm. This figure clearly shows the characteristics of the W.G.M. : directive response ($|S_{21}|>>|S_{41}|$) and low entrance reflexion ($|S11|\approx 0$). The shift frequency is lower than 0.5 %.

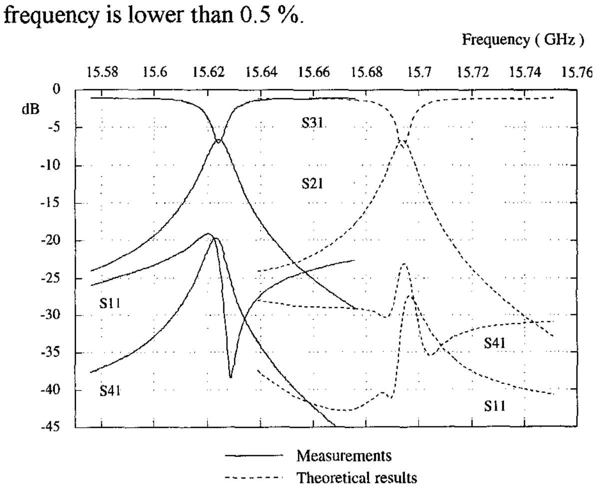

Figure 6 : Comparison between theoretical and experimental results for a symetric structure (d = 0.8 mm)

To improve the selectivity of the filter, several elementary devices are put together so we have defined two kinds of topology. The first one is the chain topology and is composed of two elementary devices. Two dielectric resonators spaced by an odd number of quater guided wavelength are placed between two parallel microstrip lines (figure 7).

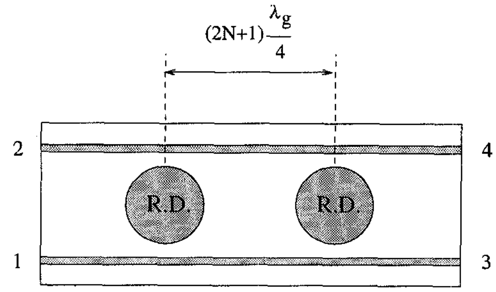

Figure 7 : Chain topology

In order to obtain the theoretical response of this structure, the scattering matrix of the fundamental and the higher order modes of each elementary structure are chained. We obtain the S parameters of each mode for the whole structure. Then, like for the elementary device, the higher order modes are short circuited in the access planes and we obtain the response of the filter with a combination of odd and even mode scattering parameters. The theoretical results presented on figure 8 are obtained with a spacing between the D.R. and the lines equal to 0.1 mm. In this calculation, the losses of the materials are not taken into account.

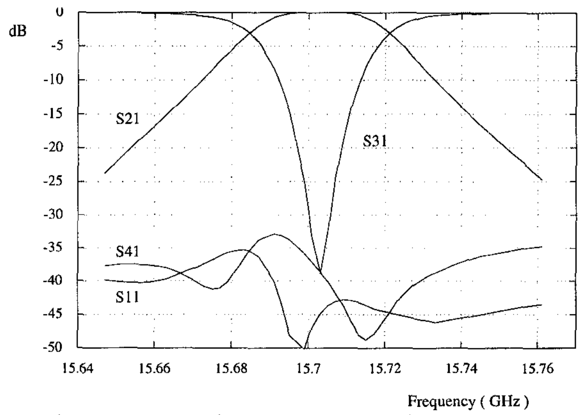

Figure 8 : Scattering parameters of chain topology

The second type of association is the cascade topology (figure 9) which is composed of two distinct elementary devices

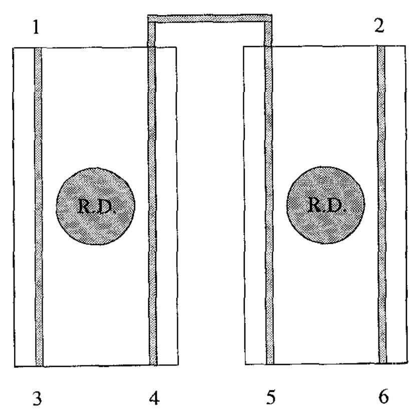

Figure 9 : Cascade topoloy

The theoretical response of this topology is obtained by using only the final scattering parameters of the elementary structure. The results obtained with this topology are presented on figure 10.

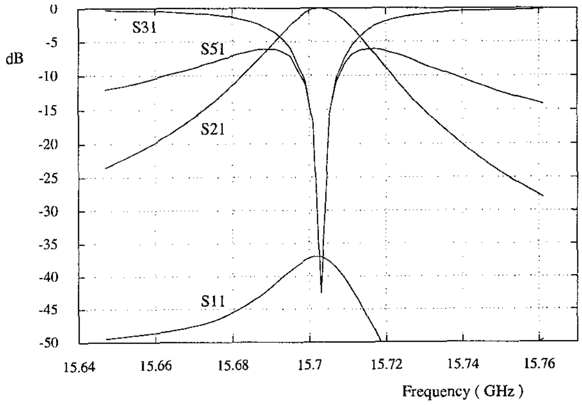

Figure 10 : Scattering parameters of the cascade topology

Finally, a cascade of two chained structures is presented on figure 11.

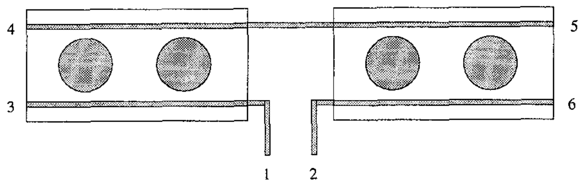

Figure 11 : Cascade of two chain topologies

In that case, the spacings between the dielectric resonators are adapted in order to obtain an elliptic filter response. The theoretical transmission parameter is shown on figure 12. Like previously, the losses of the materials are not taken into account.

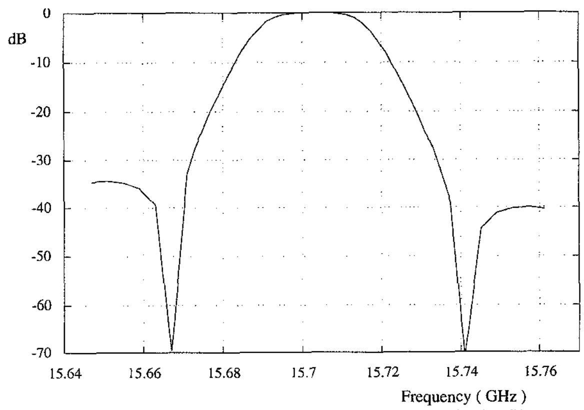

Figure 12 : Theoretical response of the elliptic filter

CONCLUSION

We have presented the design of different microwave filters using the whispering gallery modes of dielectric resonators. All these designs of filter have been computed by finite element method to predict experimental responses.
In the future, the purpose is to realize millimeter filters using the same topologies. Indeed, the design of these filters with W.G.M. can be easily adapted in millimeter wavelength band.

REFERENCES

[1] X.H. Jiao - P. Guillon - L.A. Bermudez - P. Auxemery "Whispering-Gallery Modes of Dielectric Structures : Application to Millimeter-Wave Bandstop Filters" IEEE MTT, Vol 35, No 12, Dec 1987, pp 1169-1175

[2] M. Aubourg - P. Guillon "A Mixed Finite Formulation for Microwave Devices Problems : Application to MIS Structure" Journal of Electromagnetic Waves and Applications, Vol 5, No 4/5, 1991, pp 371-386

[3] M.E. Tobar - A.G. Mann "Resonant frequencies of higher order modes in cylindrical anisotropic dielectric resonators" IEEE MTT-S Digest, 1991, pp 143-146

[4] G.L. Matthaei - L. Young - E.M.T. Jones "Microwave filters, impedance matching network and coupling structures" Mac Graw Hill, pp 172-180