ANALYSIS OF THE COUPLING COEFFICIENT BETWEEN A CYLINDRICAL DIELECTRIC RESONATOR AND A FIN-LINE

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ABSTRACT

The external quality factor of a cylindrical dielectric resonator coupled to a fin-line is evaluated using the finite element method to analyse the transmission line and the resonator. The effects of varying the location of the resonator on the coupling are studied. Experimental results compared with the theoretical ones are presented.

INTRODUCTION

The improvement in the materials used to make dielectric resonators has made them interesting devices to be used in millimeter wave bands [1]. Most of the applications use the dielectric resonators coupled to microstrip lines to stabilize oscillators and to make filters, and several useful approaches have been reported to calculate the coupling to these lines [2]-[5]. Fin-lines have been proved to be an attractive technology to make circuits in Ka band and higher frequencies, whereas little atention has been paid to the study of the coupling to these lines.

In this paper a numerical method to calculate the coupling between a dielectric resonator and a fin-line is presented. The finite element method is used to evaluate the modes in the transmission line and in the resonator. This allows the study of different structures with the same computer program.

Several experimental and theoretical results are presented for the Ka band and the most relevant parameters which affect the coupling are studied. These results can be useful to make oscillators, filters, and others devices with cylindrical dielectric resonators.

METHOD OF ANALYSIS

The coupling to microstrip lines has been usually calculated considering the resonator field intensity in the line and calculating the energy induced by this field [2]-[4]. Other models evaluate the energy induced by the line in the resonator and model it as a magnetic loop [5]. It is more rigorous to consider both field distributions as done by Skalicky [6] to calculate the coupling to microstrip line. This last method should provide better accuracy than the others but requires the calculation of both field distributions and the evalution of a volume integral inside the resonator. This method does not require the evalution of the fin-line impedance, which is not always clearly defined.

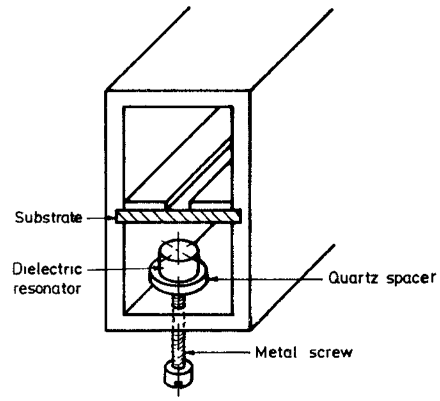

Fig.1 Cylindrical dielectric resonator coupled to a unilateral fin-line.

The structure to be analysed is shown in fig.1. A cylindrical dielectric resonator is located under the gap of a unilateral fin-line and is supported by a metal post. A spacer is under the resonator to reduce the losses. The metal post with the spacer can be substituted by a plastic screw.

External quality factor

The external quality factor of a resonator coupled to a transmission line is the ratio between the power dissipated in the line and the stored electromagnetic energy in the resonator.

$$Q_{ext} = w_o \frac{W_R}{P_d} \qquad (1)$$

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The power excited in the line by the resonator for the mode n can be calculated expanding the resonator field into transmission line modes according to Collin [7]. Considering the polarization current in the resonator the power dissipated in the line is

$$P_d = |C^n|^2 \, Re \, [\int_S e_n \times h_n^* \cdot \hat{z} \, dS \,] \quad (2)$$

$$C_n = -1/P_n \int_V (e_n + e_{zn}).J_p \, e^{-\gamma_n z} \, dV \quad (3)$$

$$P_n = 2\int_S e_n \times h_n \cdot dS \quad (4)$$

$$J_p = jw_0 \, \varepsilon_0 \, (\varepsilon_r - 1) \, E_R \quad (5)$$

E_R : Resonator electric field

$(e_n + e_{zn})$: Electric field of the n mode of the line

The stored electromagnetic energy in the resonator at the resonant frequency is

$$W_R = 0.5 \int_V \varepsilon \, \overline{E}_R.\overline{E}_R^* \, dV \quad (6)$$

To evaluate the external quality factor using the expressions (1)-(6) the following calculations must be done.

- resonant frequency of the resonator
- electric field distribution in the resonator
- propagation constant of the line at the resonant frequency
- electric field distribution of modes above cutoff in the line.
- a volumen and a surface integral.

Analysis of the dielectric resonator

To analize the dielectric resonator the structure which contains the resonator should be considered axisymmetric to reduce the problem to two coordinates. This can be made if it is supposed that the waveguide lateral walls and the slot of the fin-line have little effect on the field distribution and on the resonant frequency.

The analysis of the dielectric resonator has been made using the finite element method decribed in [8]. This method allows to take into account the effect of the supporting structure in the resonator.

Fig.2 shows the field distribution for a dielectric resonator. The arrows length is linearly proportional to the field amplitude. As it can be seen, the field intensity decreases very quickly outside the resonator and has a small value in the lateral walls and in the fin-line

Analysis of the fin-line

The finite element method has been also used to calculate the modes of the fin-line. This allows to use the same computer code and adds flexiblity to the method.

The magnetic field variational formulation with the divergence condition imposed by the penalty method [9] was first used. However poor results were obtained in this case because the penalty term produces an important error. This effect was also observed by Hara [11] for structures with corners. Another problem of this formulation is the singularities of the field in the fin corners.

Better results were obtained using a formulation with the longitudinal components of the field [10]. In this formulation the effective permittivity is a parameter, the frequency is the eigenvalue of a linear system and the eigenfunctions are the field distributions of the modes. Third order serendipity polynomials were used to approach the field.

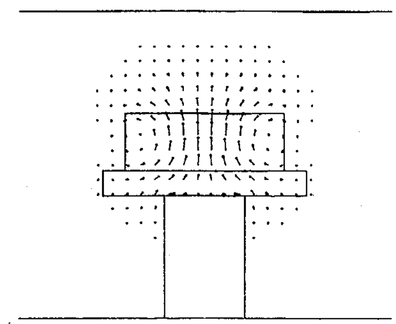


Fig.2 Magnetic field distribution for the $TE_{0\gamma\delta}$ mode in a cylindrical dielectric resonator.

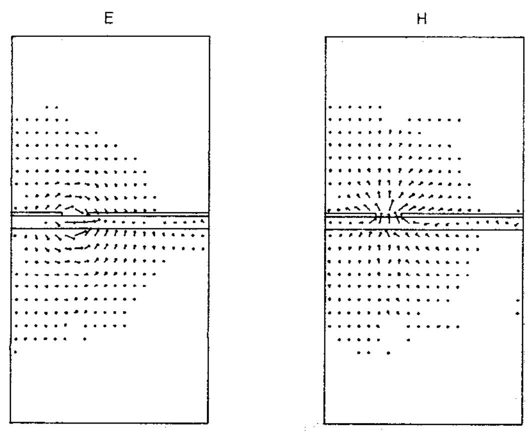


Fig.3 Transversal field distribution in a unilateral fin-line

This formulation is ill conditioned if the relative permittivity of the structure is equal to the efective permittivity of the line [10]. The modes in these points were interpolated from the whole curve.

COMPUTATION

A computer program in FORTRAN-77 to calculate the coupling was written. This program takes into account the sparsity of the matrices which arise in the finite element method. The integrals which appear in the finite element formulation and in the calculation of the coupling (1)-(6) are evaluated numerically. The geometry of the line and the resonator are entered in the program as input data files. This allows to study several kinds of lines and resonators.

The computer time required to calculate the coupling depends much on the desired precision and on the complexity of the structure to be analyzed. The total computer time for a typical case varies between 10 and 30s on a VAX11/785.

RESULTS

Experimental results

The structure used to measure the coupling between a fin-line and a dielectric resonator is shown in the fig.4a. The height of the resonator in the waveguide can be varied with a screw. The fin-line is terminated with two transitions to waveguide at both ends.

Fig.4b shows the measured and the theoretical values of the external quality factor for the $TE_{0\gamma\delta}$ mode of a resonator in Ka band varying the height of the resonator in the waveguide. As it can be seen the slope of the curve of the theoretical values is greater than that of the measured curve. Fig.4c shows the theoretical resonant frequency and the measured values. The value of the permittivity provided by the manufacturer was used to calculate the frequency.

The $TE_{0\gamma\delta}$ mode is the most coupled to the line and only two modes were observed in the 26.5-40 GHz band. The difference in the resonant frequency for the two first modes is always greater than 5 Ghz.

Variation of the coupling

The height of the resonator in the waveguide is the parameter which affects more strongly the external quality factor of the resonator. Values between 10 and 10^4 can be obtained varying this parameter. However strong variation of the resonant frequency is observed if the resonator is near the fin-line or the waveguide wall. So it is not very useful to be used as a parameter to adjust the coupling.

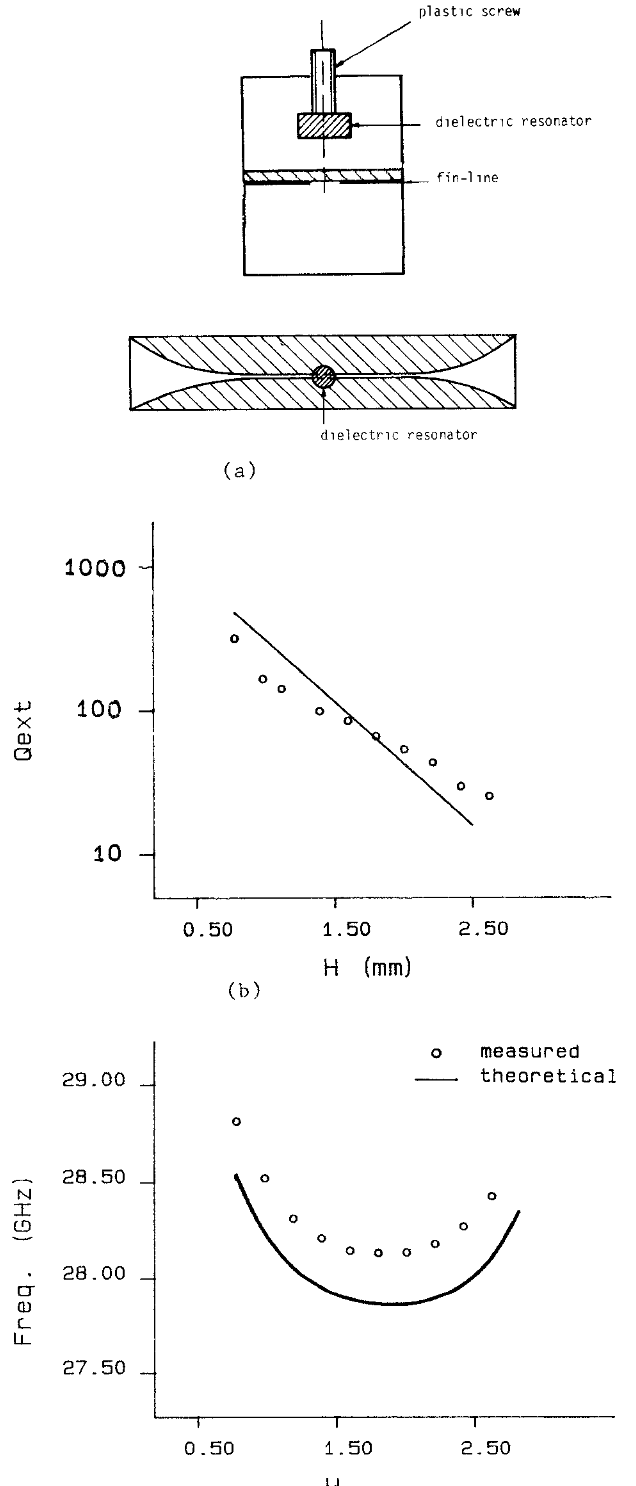


Fig.4 (a) Structure used to measure the coupling. (b) Theoretical and measured coupling. (c) Resonant frequency. A=7.11 mm, B=3.556 mm, b=0.32 mm, D_r=1.888 mm, H_r= 0.844 mm, R_t=1 mm, ε_r=37, R=1.778 mm, H_m=0.034 mm, H_s=0.254 mm, H_f=3.429 mm, ε_t=2.2

Offset of the resonator in the waveguide. This parameter allows to vary slightly the coupling with small variation in the frequency. It can be useful to adjust the coupling. The greatest coupling is obtained when the resonator is just under the fin-line gap. Fig.5 shows the variation of the coupling for a resonator in Ku band.

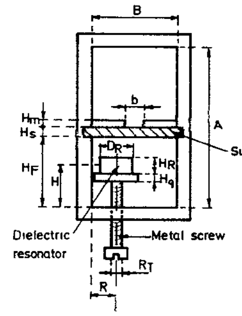
Width of the fin-line. The coupling increases with the width of the fin-line gap. Fig.6 shows the variation of the coupling for several widths of the gap.

CONCLUSION

A numerical method to calculate the coupling between a cylindrical dielectric resonator and a fin-line has been proposed and experimental measures were made to evaluate its precision.

The coupling of a dielectric resonator to fin-lines is generally greater than that obtained with microstrip lines. However a wide margin of values of the external quality factors can be obtained, which is useful to design oscillators and filters.

The finite element formulation used to study the fin-line should be improved in order to avoid the singularities for some values of the effective permittivity.



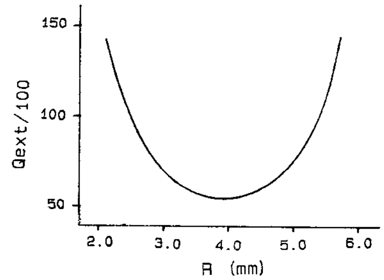


Fig.5 Effect of varying the distance to the lateral waveguide wall on the external quality factor. A=15.6 mm, B=7.8 mm, b=2 mm, D_r=3.912 mm, R_t=1.8 mm, ε_r=37, ε_q=3 mm, H_m=0.3 mm, H_s=0.5 mm,

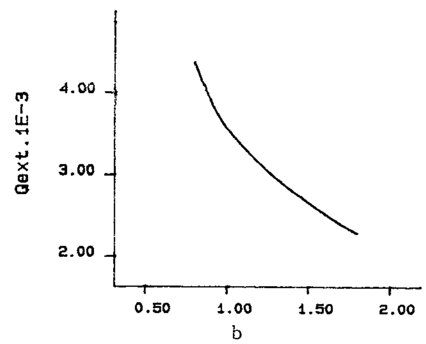


Fig.6 Effect of varying the width of the fin-line on the external quality factor. A=15.6 mm, B=7.8 mm, D_r=3.912 mm, R_t=1.8 mm, ε_r=37, ε_q=3 mm, H_m=0.3 mm, H_s=0.5 mm,

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