A DIELECTRIC RESONATOR BANDSTOP FILTER

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ABSTRACT

This paper presents a new analysis predicting accurately the external quality factor and scattering matrix parameters S_{ij} of the TE_{01p} cylindrical resonator mode, coupled with a microstrip line for arbitrary locations of the resonator and the line. The results obtained are used to realize a Tchebyscheff bandstop filter. Experimental and theoretical results are also included.

Introduction

Interest in the utilization of high dielectric constant resonators has been revived recently because of the availability of low pass temperature stable materials {1} , {2} .

Dielectric resonators used in communication satellites or in earth stations as filters or oscillators elements permit to reduce weight and volume of these devices {3} , {4} .

In this paper, we first describe a new technique for the calculation of coupling coefficient between a microstrip line and a dielectric resonator (assuming TE_{01p} mode) which consider the substrate material, the ground plane, the dielectric supports, the metallic boundaries surrounding the resonator, the distance between the line and the resonator. Secondly we present a new effective synthesis of a microstrip bandstop filter using a dielectric resonator. A realization of such a filter is also given.

Coupling coefficient between a microstrip line and a dielectric resonator.

1. External quality factor

It is well known that to couple a TE_{01p} dielectric resonator mode (assumed to be a magnetic dipole) with a microstrip line it is necessary to place the dielectric resonator on the plane of the substrate as the magnetic lines of the resonator link those of the microstrip line (fig. 1).

An equivalent low frequency network of this system has been analyzed and is shown in Fig. 2. The coupling is characterized by the mutual inductance L_m. L_r, C_r, R_r, L_1, R_1, C_1 are respectively the equivalent parameters of the resonator and the line

$$L_m = \mu_o M \sqrt{\frac{L_r}{2W}} \cdot \frac{H}{I} \quad \ldots\ldots \quad 1$$

W and M are stored energy and magnetic moment of the dipolar TE_{01p} mode of the resonator. I the current flowing through the microstrip line, H the magnetic field produced by the current anywhere in the metallic structure.

After few calculations the circuit of Fig.2 can be transformed in an another equivalent form easier to use (Fig.3). In this new representation Z verifies :

$$Z = \frac{R}{1 + jX} \quad \ldots\ldots \quad 2$$

$$R = \frac{\omega_o L_m^2 Q_o}{L_r} \quad \ldots\ldots \quad 3$$

$$X = 2 . \frac{\Delta\omega}{\omega_o} Q_o \quad \ldots\ldots \quad 4$$

Q_o is the unloaded quality factor of the dielectric resonator placed on the microstrip substrate.

It may be noted that when $\omega = \omega_o$ (at resonance) Z=R. The coupling coefficient characterized by the external quality factor Q_e is :

$$Q_e = \frac{R_{ext}}{R} Q_o \quad \ldots\ldots \quad 5$$

R_{ext} symbolizes the internal resistance of the generator and the loaded impedance of the line(Fig.3).

$$R_{ext} = R_g + R_L \quad \ldots\ldots \quad 6$$

when the generator and the line are matched

$$R_g = R_L = Z_o \quad (Z_o \text{ characteristic impedance}).$$

With this last assumption and taking into account 1,3,5,6 we obtain :

$$Q_e = \frac{4 Z_o W}{\omega_o \mu_o^2 M^2 (\frac{H}{I})^2} \quad \ldots\ldots \quad 7$$

2. Computation of $\frac{H}{I}$

For that computation we use the finite element method. Using the quasi TEM approximation for the mode propagation in the microstrip line we can evaluate the current density in the strip and in the lower and upper plane of the metallic structure.

From these values we deduce the amplitude of the magnetic field H at any point (P) of the structure due to these current densities.

The value of the ratio $\frac{H}{I}$ depends on substrate permittivity and thickness and on the distance d between P and the line. An example of this variation is given in Fig.4.

3. Computation of W and M

To determinate the stored energy W and the magnetic dipole moment M we solve Helmoltz equation expressed in cylindrical coordinate (available for revolution sy-

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metrical mode) by means of the finite difference method.

$$\frac{\partial^2 \psi}{\partial r^2} + \frac{1}{r}\frac{\partial \psi}{\partial r} + \frac{\partial^2 \psi}{\partial z^2} + (k^2 - \frac{1}{r^2})\ \psi = 0 \ \ldots\ldots \quad 8$$

$\psi = E_\theta$ for the considered dipolar TE_{01p} mode.

Taking into account boundary conditions on metallic planes, and continuity conditions at the dielectric interfaces we obtain a linear system {6} , the resolution of which permits to determine the frequency of the resonant system and the electromagnetic fields at any points of the composite structure.

Substituting the electrical field value E into equations 9 and 10 we obtain the stored energy W and the magnetic moment M.

$$W = \frac{1}{2}\varepsilon_o \int_V \varepsilon_i \ E.E^{\star}\ dV \ \ldots\ldots \quad 9$$

$$M = j\omega\ \varepsilon_o\ \varepsilon_i \int_V \vec{R} \wedge \vec{E} \ \ dV \ \ldots \quad 10$$

ε_i relative permittivity of the medium $(\varepsilon_i = \varepsilon_r, \varepsilon_a, \varepsilon_s)$.

4. Coupling coefficient values

We have already stated that the coupling is characterized by the external quality factor Q_e.

Reporting the value of M and W computed from 9 and 10 and those of H/I computed at the center of the resonator from finite element method into 7, we obtain Q_e variation as a function of the distance between the line and the resonator.

In fig. 5 we have drawn the theoretical and experimental variations which agree well.

Dielectric resonator bandstop filter

The dielectric resonator coupled with the microstrip line is identical to a resonant parallel circuit placed in serie with the line. So it is a localized element for which we have established the equivalent network shown in fig.6.

θ being the electrical length of the line, the scattering parameters S of this system verify.

$$S_{11} = \frac{Z/Z_o}{Z/Z_o + 2}\ e^{-2j\theta} \ \ldots\ldots \quad 11$$

$$S_{12} = \frac{2}{Z/Z_o + 2}\ e^{-2j\theta} \ \ldots\ldots \quad 12$$

In fig.7 we have presented an example of S_{11} variation as the distance between the line and the resonator (Z is given by equation 3 at resonance).

The low pass prototype filter corresponding to the desired bandstop filter is obtained by applying the P.I. Richards frequency transformation {5}

$$p = j\Omega = j\ tg\ \frac{\pi\omega}{\pi\omega_o} \ \ldots\ldots\ldots \quad 13$$

Ω : localized constant pulsation filter.

This low pass prototype is a structure containing two units elements and a self L_p (fig.8).

$$L_p = \frac{\pi}{4}\ L\ \omega_o \ \ldots\ldots \quad 14$$

$$L = \frac{\mu_o^2 M^2}{2W} (\frac{H}{I})^2 \ldots\ldots \quad 15$$

To calculate the parameters of the bandstop filter of Tchebyscheff type it is necessary to evaluate the value of the circuit elements, values which depend on the characteristics of the filter which are :

equaripple : 0.2 db
bandwitch at 0.2 db : 120 MHz
center frequency : 6 GHz

The synthesis is derived from the low pass prototype of bandstop microwave filter presented in fig.8. The different elements are derived from the input impedance $Z_e(p)$ by applying P.I. Richards theorem {7} :

Evaluating successively $Z_e\ Z_e^{(1)}\ Z_e^{(2)},\ Z_e^{(3)}$, we obtain :

$$Z_e^{(1)}\ (p) = L_p p + Z_e^{(2)}(p) \ \ldots\ldots \quad 16$$

$$Z_1 = Z_2 = Z_0$$

Now from (14), (15) and (16) we deduce the expression of L_p

$$L_p = \frac{Z_e^{(1)}(p) - Z_e^{(2)}(p)}{p} = \frac{\mu_o^2\ M^2 \mu\omega_o}{8W} (\frac{H}{I})^2 \ldots \quad 17$$

This value of L_p gives the external quality factor to be realized for obtaining the characteristics of the bandstop filter.

$$Q_e = \frac{\pi}{L_p} \ \ldots\ldots\ldots\ldots \quad 18$$

From Fig.6 we note that Q_e = 350.

Such a filter is then realized. The unit elements are represented by quarter wavelength line, the dielectric is placed between them, such as its coupling coefficient with the microstrip line verify Q_e = 350 (fig.9).

Experimental and theoretical characteristics of the filter are drawn in Fig.10.

The T.O.S. is about 1.25, the insertion loss 0.4 db

Conclusion

Using a new approach we have computed the coupling coefficient between a microstrip line and a dielectric resonator. Then we have realized a complete synthesis of a bandstop filter using a method derived from P.I. Richards transformation. Experimental and theoretical results agree well.

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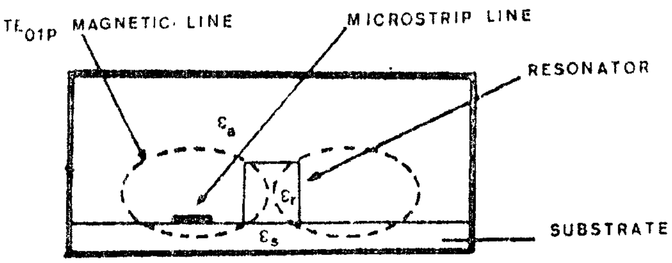

Fig.1 : Coupling between a line and a dielectric resonator.

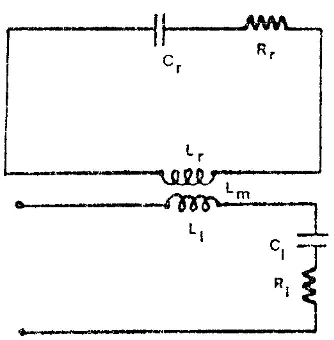

Fig.2 : equivalent network.

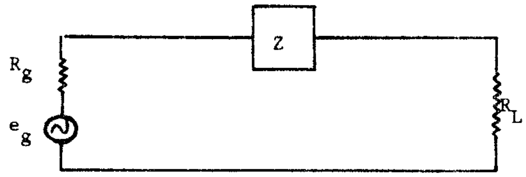

Fig.3 : equivalent network

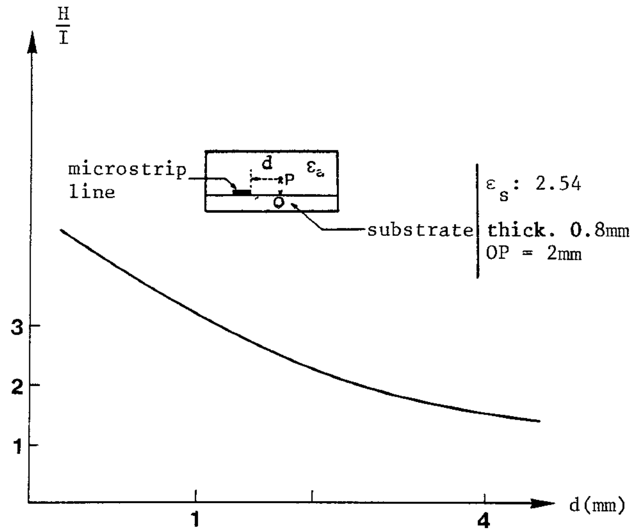

Fig.4 : $\frac{H}{I}$ variations as the distance between a point P and the line.

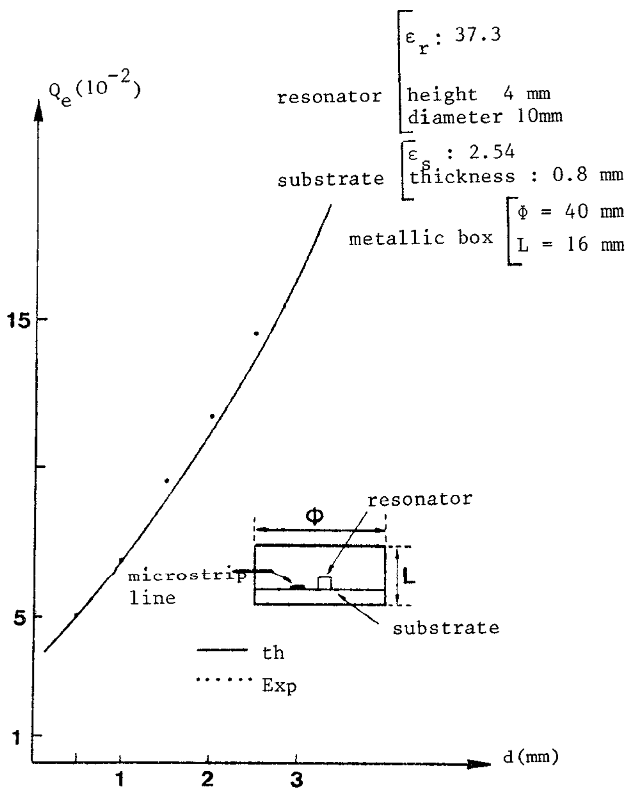

Fig.5 : Q_e variations as the distance between the line and the resonator.

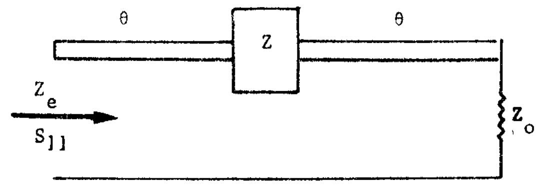

Fig.6 : equivalent network

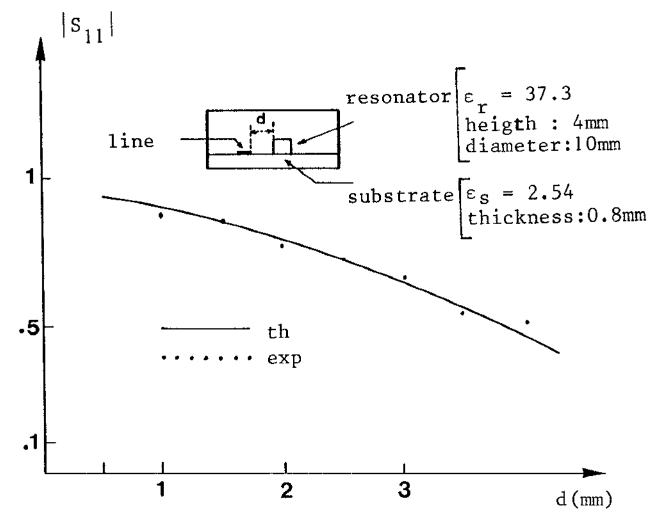

Fig.7 : $|S_{11}|$ variations as the distance between the line and the resonator

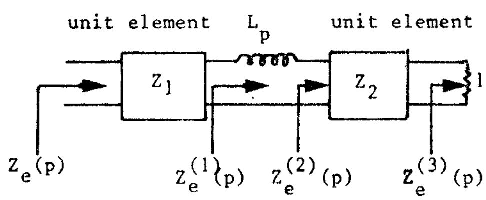

Fig.8 : filter synthesis.

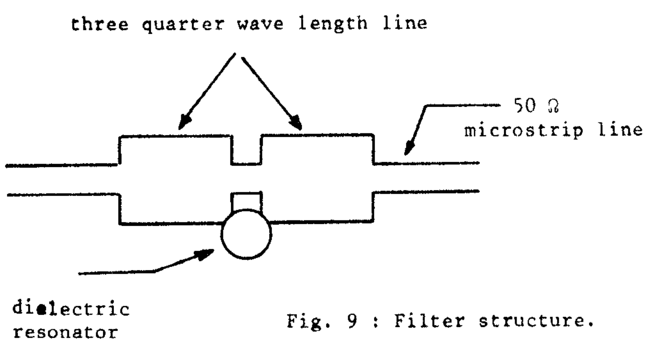

Fig. 9 : Filter structure.

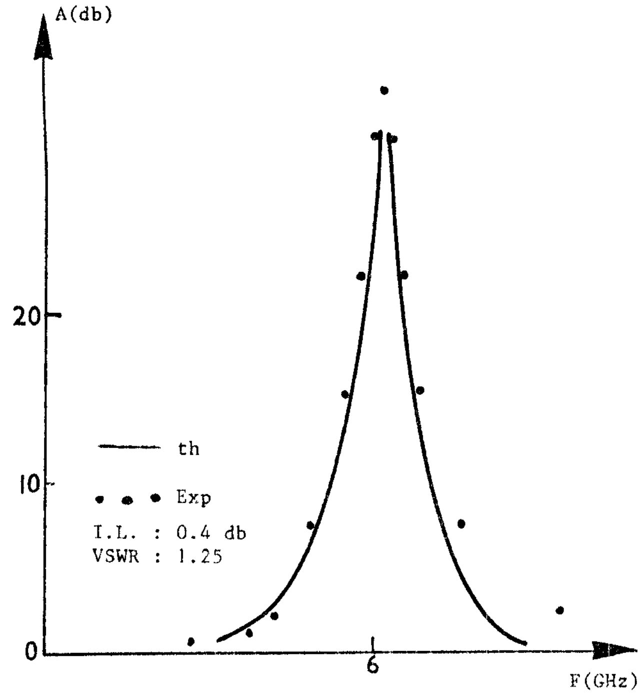

Fig.10 : Tchebyscheff bandstop filter.