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COUPLING COEFFICIENT BETWEEN MAGNETIC LOOP AND A DIELECTRIC RESONATOR IN AN EVANESCENT WAVEGUIDE

P. GUILLON*, Y.GARAULT,

Laboratoire d'ELECTRONIQUE MICROONDES
ERA CNRS 535 UER SCIENCES
France 87060 LIMOGES Cédex

* also with
Laboratoire d'OPTOELECTRONIQUE
UER SCIENCES
France 86022 POITIERS Cédex

This paper studies the end coupling between a magnetic loop and a dielectric resonator housed in an evanescent metallic waveguide.

A theoretical and experimental analysis of the variations of the external quality factor as a function of the distance between the loop and the resonator is presented. The influence of the interstage coupling between two dielectric resonators on the end coupling will be also evaluated.

INTRODUCTION.

The bandpass dielectric resonator filter configuration can be generally defined as a section of evanescent mode waveguide in which the dielectric resonators are housed {1}. The orientation of dielectric resonators can either be axial or transverse {2}. The end resonators are either coupled to external sources by means of propagating waveguides {3} or coaxial transmission loops. In this paper the coupling is achieved by the dielectric resonator (at resonance) to the coaxial line, by means of a magnetic loop ; through the evanescent field of the waveguide. In other words, the waveguide magnetic fields excited by the resonator magnetic dipole will be coupled to the loop when threading it, as the plane of the loop is normal to the x, y plane of the guide as shown in figure 1 corresponding to the case of a rectangular wave guide.

EQUIVALENT CIRCUIT. INPUT IMPEDANCE.

The loop resonator cavity system in general, can be representated by the equivalent circuit shown in figure 2. The dielectric resonator is acting on the dipolar TE_{01p} mode. L_m is the mutual self inductance.

Using the equivalent circuit of figure 2. We can evaluate the input impedance Z_{in}.

$$V_1 = j\omega L_p I_p + j\omega L_m I_r$$
$$V_2 = j\omega L_m I_p + j\omega L_r I_r \qquad 1.$$
$$V_2 = -R_r I_r - \frac{1}{j\omega C_r} I_r$$

The indexes p and r refer respectively to the loop and to the dielectric resonator :

$$Z_{in} = \frac{V_1}{I_p}$$

$$Z_{in} = j\omega L_p + \frac{\omega^2 L_m^2}{R_r + j(\omega L_r - \frac{1}{C_r\omega})} \qquad 2.$$

The first term in equation 2 is neglected, considered very small compared to the second term then z_{in} reduces to :

$$Z_{in} = \frac{\omega^2 L_m^2}{R_r + j(\omega L_r - \frac{1}{C_r\omega})}$$

$$\text{at resonance} \quad Z_{in}\Big|_{\omega_o} = \frac{\omega_o^2 L_m^2}{R_r} \qquad 3.$$

Since the unloaded quality factor of the TE_{01p} mode of the dielectric resonator verifies :

$$Q_o = \frac{\omega_o L_r}{R_r}$$
$$Z_{in} = \frac{L_m^2}{L_r}\omega_o Q_o \qquad 4.$$

For $\frac{L_m^2}{L_r}$ factor evaluation in terms of the field contribution to coupling, the TE_{01p} mode of the dielectric resonator is looked at as a magnetic dipole. The voltage V induced in the magnetic loop due to current I_r in the resonator can be expressed by :

$$V = j\omega L_m I_r = j\omega \mu_o H_p A_p \qquad 5.$$

H_p : field values in the magnetic loop due to resonator current. For small magnetic loops H_p can be taken in a first approximation to be the value at the center of the loop of area A_p.

If W_r is the stored energy in the dielectric resonator :

$$W_r = \frac{1}{2} L_r I_r^2 \qquad 6.$$

From 4, 5, 6 we obtain :

$$\frac{L_m^2}{L_r} = \frac{(\mu_o H_p A_p)^2}{2 W_r} \qquad 7.$$

and Z_{in} can be written :

$$Z_{in} = Q_o \frac{(\mu_o H_p A_p)^2}{2 W_r} \qquad 8.$$

EVALUATION OF H_p.

The magnetic field at the center of the loop H_p due to resonator current is taken as the magnetic field of waveguide evanescent modes excited by the resonator dipole at waveguide center where the resonator is located.

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In this paper we only consider the case of the transverse orientation of the dielectric resonator in a rectangular waveguide.

Since transverse orientation is considered, then M_r the equivalent magnetic dipole of the TE_{01p} mode of the dielectric resonator will excite only those modes having H components in the transversal plane, that is those having $h_x \neq 0$ at waveguide center so m must be odd and n even. $^x m\ n$
Among all these modes we only consider this which has the lowest cut off frequency so the TE_{10} mode.

The normalized x directed field component within the rectangular guide is :

$$h_x = \left\{ \frac{\lambda_{10}\,\Gamma}{j\ ab\ \pi z_o} \right\}^{1/2} \sin \pi \frac{x_1}{a} \qquad 9.$$

For resonator located at guide center $x_1 = \pm \frac{a}{2}$

$$h_x = \left\{ \frac{\lambda_{10}\,\Gamma}{j\ ab\ \pi\ z_o} \right\}^{1/2} \qquad 10.$$

$$\Gamma : \text{evanescent constant} = \alpha_{10} = \frac{2\pi}{\lambda_{10}} \left[1 - \left\{ \frac{\lambda_{10}}{c}\ 2\pi\omega_o \right\}^2 \right]^{\frac{1}{2}}$$

λ_{10} wavelength of TE_{10} mode in rectangular guide
$\lambda_{10} = 2a$

$Z_o = 377\ \Omega$

The total field H_x at a distance S between the centers of the loop and the resonator is given by :

$$H_x = a_{t_{10}}\ h_x\ e^{-\alpha_{10} s} \qquad 11.$$

The amplitude $a_{t_{10}}$ of forward directed TE_{10} wave excited by an x oriented magnetic dipole M_r is defined by the following equation :

$$a_{t_{10}} = \frac{-\omega_o\ \mu_o\ M_r}{2} \left\{ \frac{j\ \lambda_{10}\ \alpha_{10}}{a\ b\pi\ z_o} \right\}^{1/2} \qquad 12.$$

Relating equation (8) (10) (11) (12) the input impedance is expressed by :

$$Z_{in} = Q_o\ \omega_o\ \frac{\mu_o^2 A_p^2}{2\ W_r} \left\{ a_{t_{10}}\ h_x\ e^{-\alpha_{10} s} \right\}^2 \qquad 13.$$

If Z_c is the terminating characteristic impedance of the coaxial line evaluated at 50 Ω being the interior source of dissipation and Z_{in} is the exterior impedance looked at from the coaxial line :

$$Q_{ext} = \frac{Q_o}{\beta} \qquad \beta = \frac{Z_{in}}{Z_c}$$

$$Q_{ext} = \frac{2\ W_r\ Z_c}{\omega_o\ \mu_o\ A_p^2\ H_x} \qquad 14.$$

In this expression H_x is evaluated from (11) taking into account (12). W_r and M_r are evaluated by using the finite difference method {4} . Q_{ext} is computed by the equation (14) for loop diameter of 3.5 mm and 5 mm. Graphs of curves 3 show the variations of Q_{ext} as a function of spacing s.

Practical measurement of Q_e is determined for a 3.5 mm loop as well a 5.0 mm in the graphs of curve 4 and in curve 5. Loop thickness is also considered in curve 5 where Q_{ext} is calculated for (5 ± 0.2) mm and (3.5 mm ± 0.2 m) loop diameter.

INFLUENCE OF THE INTERSTAGE COUPLING ON THE END COUPLING.

The coupling coefficient between a pair of dielectric resonators is expressed by the equation {2} :

$$k(s) = \frac{\mu_o\ H_x\ M_r}{2\ W_r} \qquad 15.$$

The external Q given by (14) can be related to k(s), through the magnetic field H_x which is assumed the same in keeping the spacing between loop and resonator equal to the spacing between the dielectric resonators (s) and assuming the loop surface comparable to the dielectric resonator :

$$Q_{ext} = \frac{F\ Z_c}{\mu_o\,\omega_o\ A_p^2\ k(s)^2} \qquad 16.$$

$$F = \frac{\mu_o M_r^2}{2\ W_r}$$

Graphs of curve 6 shows the variations of Q_{ext} computed taking into account or not the coupling between the pair of dielectric resonators.

CONCLUSION.

The coupling between a magnetic loop and a dielectric resonator contained in a evanescent waveguide has been evaluated. Theoretical and experimental results agree well. The influence of the interstage coupling on the coupling coefficient between the loop and the resonator has been computed.

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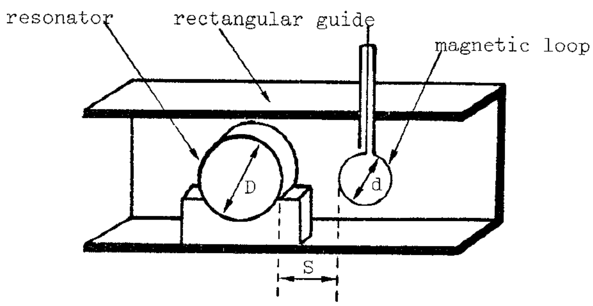

Figure 1 : Resonator in a rectangular evanescent waveguide.

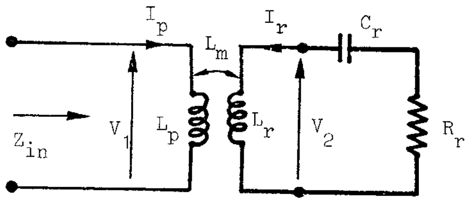

Figure 2 : Equivalent circuit of the coupling loop resonator.

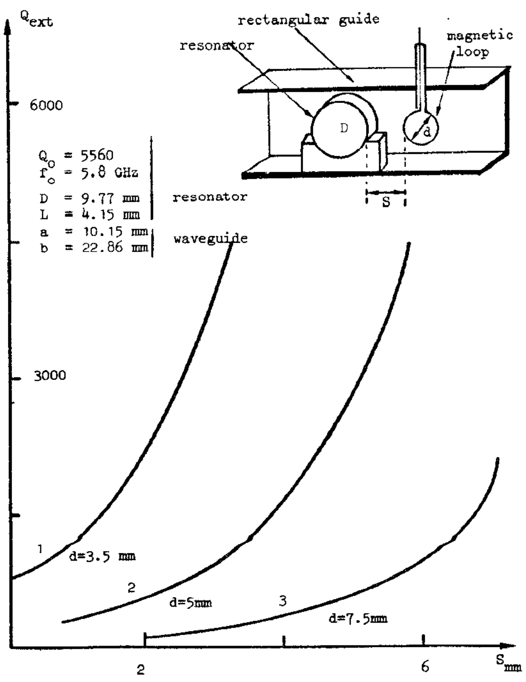

Figure 3 : Distance S in mm between loop and resonator.

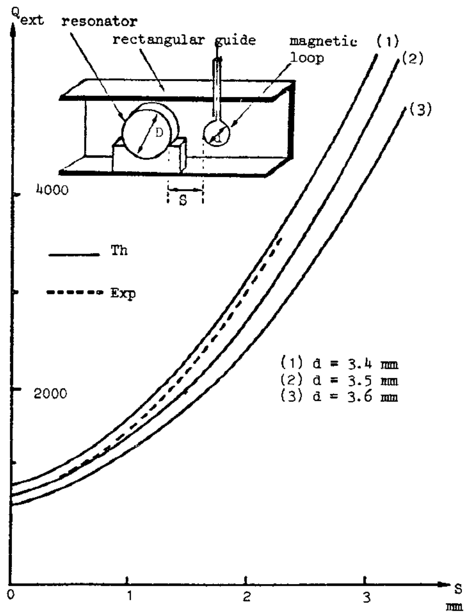

Figure 4 : Q_{ext}/spacing (S) for 3.5mm loop diameter.

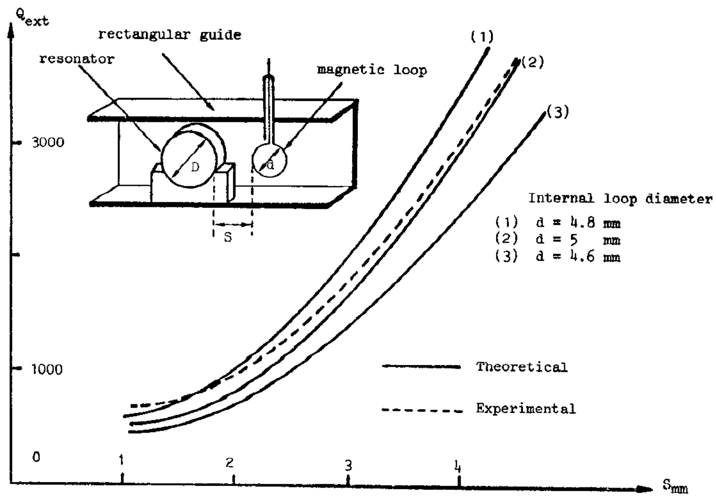

Figure 5 : Q_{ext}/spacing (S) for loop of 5.0mm diameter

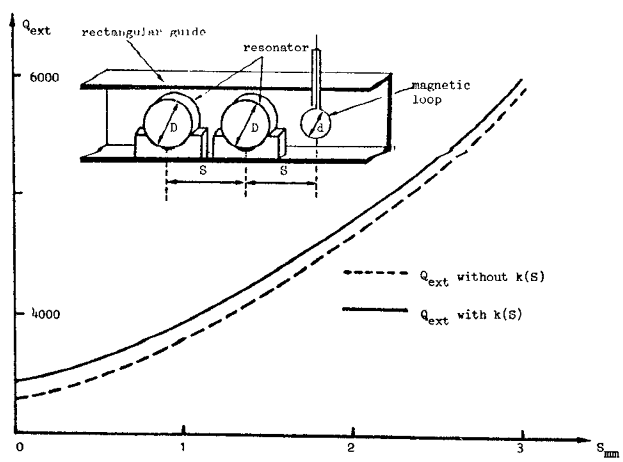

Figure 6 : Q_{ext} for loop of 3.5 mm diameter