COUPLING BETWEEN : A MICROSTRIP TRANSMISSION LINE AND A DIELECTRIC RESONATOR AND BETWEEN TWO ADJACENT DIELECTRIC RESONATORS FOR APPLICATION TO BANDPASS FILTER. *

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ABSTRACT

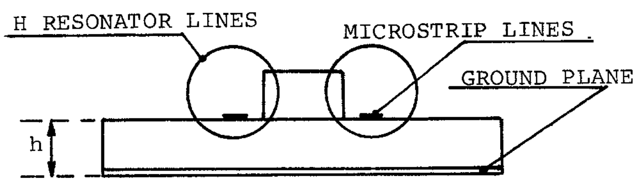
News formulas are derived for the coupling coefficient between a microstrip line and a dielectric resonator, and between adjacent dielectric resonators. A comparison between theoretical and experimental coupling coefficient values show very good agreement. A M.I.C. filter using dielectric resonators is presented.

INTRODUCTION

The development of new ceramics {1} with many advantageous properties at microwave frequency has led to renewed interest in dielectric resonators as microwave circuits elements.
In this paper, we present the analysis of coupling between a line and a resonator by using a low frequency equivalent network and between resonators without any necessity to place them in a waveguide below cut-off. With the results obtained, we have realized a filter. The results are available for rectangular and for cylindrical resonators. Here we use only the cylindrical resonator (permittivity ε_2).

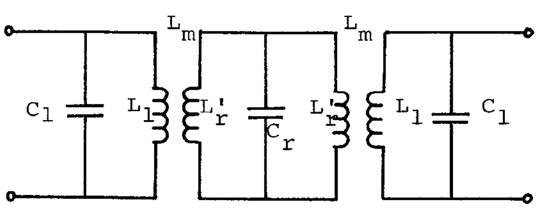
Coupling between a line and a resonator

It was accomplished by orienting the magnetic moment of the resonator acting on the dipolar mode perpendicular to the microstrip plane.



The analysis in terms of equivalent network of such a device requires the association of several two-port junctions which are successively : the two-port junction of the microstrip line, of the coupling between the line and the resonator, of the dielectric resonator. Taking into account the geometrical symmetry, we can get the same distribution of the two-port junctions at the output.

If we assume a parallel representation for the dielectric resonator, and for the half wavelength input and output line, we obtain the equivalent network :



where :
L_L, C_L and L_R, C_R are respectively the equivalent self inductance and capacitor of the microstrip line and of the dielectric resonator. B is the input susceptance of a magnetic wall waveguide ($z = 0$, $z = H_{eff}/2$) H_{eff} is defined in {2} .
The coupling between the line and the resonator is a magnetic coupling which was characterized by the self inductance L_m (K is the mutual inductance coefficient).

Q_u (unloaded quality factor) and Q_e (external quality factor) are sufficient to determinate the coupling as a function of the distance between the line and the resonator :

$$Q_u = \alpha\, Q_e \qquad \text{with } \alpha = \text{V S W R for}$$

undercoupling.

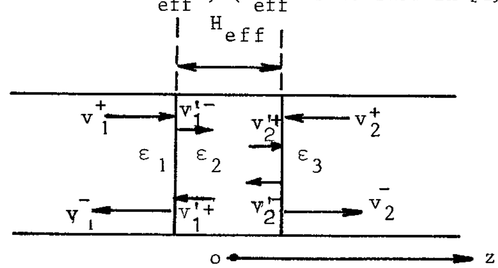
$$\alpha = (1 + |S_{11}|).(1 - |S_{11}|)^{-1} \qquad (1)$$

So we can obtained the coupling coefficient K from the value of S_{11} (first term of the scattering matrix).

To obtain S_{11}, it is first necessary to determinate the elements (A,B,C,D) of the chain matrix $\{Ch\}_t$ of the microwave system including :

- the line chain matrix $\{Ch\}_L$ (the electric length of the line is θ)
- the coupling between the line and the resonator chain matrix $\{Ch\}_C$,-the dielectric resonator chain matrix $\{Ch\}_R$

To obtain the chain matrix of the resonator $\{Ch\}_R$ we suppose that it is contained in a magnetic wall waveguide of radius a_{eff} ; (a_{eff} is defined in {2})



Now we can have the terms of the wave matrix by writing at the boundaries the continuity of the equivalent intensity and voltage respectively proportional to the magnetic and electric field.

Knowing the relation of transformation between the wave matrix and the chain matrix, we can obtain the elements (A_1, B_1, C_1, D_1) of the latter

$$\begin{aligned}
A_1 &= \left(\frac{1}{\eta\eta'} - \xi\xi' + \frac{\xi'}{\eta} - \frac{\xi}{\eta'}\right) \cos \beta H_{eff} \\
B_1 &= \left(\frac{1}{\eta\eta'} + \xi\xi' - \frac{\xi}{\eta'} - \frac{\xi'}{\eta}\right) \sin \beta H_{eff} \\
C_1 &= j\left(\frac{1}{\eta\eta'} + \xi\xi' + \frac{\xi}{\eta'} + \frac{\xi'}{\eta}\right) \sin \beta H_{eff} \\
D_1 &= \left(\frac{1}{\eta\eta'} - \xi\xi' + \frac{\xi}{\eta'} - \frac{\xi'}{\eta}\right) \cos \beta H_{eff}
\end{aligned} \qquad (2)$$

with :

$$\eta = \frac{2\sqrt{Z_1 Z_2}}{Z_1 + Z_2} \qquad \xi = \frac{Z_1 - Z_2}{2\sqrt{Z_1 Z_2}}$$

$$\eta' = \frac{2\sqrt{Z_2 Z_3}}{Z_2 + Z_3} \qquad \xi' = \frac{Z_3 - Z_2}{2\sqrt{Z_2 Z_3}}$$

Z_1, Z_2, Z_3 are respectively the wave impedances of the mediums (1), (2), (3). β the propagation constant of the circular magnetic wall waveguide.

According to this value of $(Ch)_R$ to obtain the chain matrix of the structure $(Ch)_t$, we multiply the chain matrix of each of the microwave systems : the input and output line, the coupling, the resonator

$$(Ch)_t = (Ch)_L (Ch)_C \; (Ch)_R \; (Ch)_C \; (Ch)_L = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

Introducing the relation of transformation between the chain and scattering matrix we could obtain S_{11}

$$S_{11} = (A+B-C-D).(A+B+C+D)^{-1}$$

The expression of S_{11} is complicated and we shall not give it here. However S_{11} and also α depend on the value of L_m, but also of the parameters of the dielectric resonator, of the line ; of the substrate (permittivity ε_3, height h)

$$S_{11} = \phi(\varepsilon_2, \varepsilon_3, K, H_{eff}, a_{eff}, h, \theta) \qquad (3)$$

In order to determinate completely the coupling it is necessary to find a relation between the coefficient (α) or K and the distance d between the center of the line and the center of the resonator. On that purpose, the dielectric resonator acting on a dipolar mode is represented by a small conducting loop. The magnetic moment m of this loop defined by COHN {4} is distributed over the volume τ of the resonator. The magnetic field component value at the center of the loop results from two currents : the current flowing in the strip (width w) and the current flowing in the ground plane supposed uniformly distributed over a width 3w. The dielectric substrate is assumed to be lossless. Using these different assumptions we can determinate the relation between K and the distance d, relation which is available for cylindrical and rectangular resonators (W stored energy in the resonator)

$$K = \frac{\mu_o}{8\pi w} \; \frac{1}{\sqrt{L_L W}} \int m \, d\tau \; . \; U \qquad (4)$$

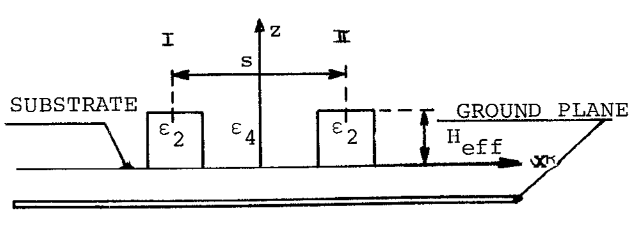
$$U = \text{Log} \frac{\left(d+\frac{w}{2}\right)^2 + \left(\frac{H_{eff}}{2}\right)^2}{\left(d-\frac{w}{2}\right)^2 + \left(\frac{H_{eff}}{2}\right)^2} - \frac{1}{3} \text{Log} \frac{\left(d+\frac{3w}{2}\right)^2 + \left(h+\frac{H_{eff}}{2}\right)^2}{\left(d-\frac{3w}{2}\right)^2 + \left(h+\frac{H_{eff}}{2}\right)^2}$$

Reporting this expression of K in (3) and since K is function of d, S_{11} and also α , Q_e are function of the distance d.

The results of our calculations are given on the curve 1. Measurements show a good agreement with theoretical results. (d' is the distance between the edge of the line and the edge of the resonator).

Coupling between adjacent resonators

The two axis of similar dielectric resonators are parallel.



Such two resonators can exchange energy and the theory of coupling presented here has been developped with the aid of the coupled wave equations for propagating wave along cylindrical rods {3} .

For two modes which have the same constant of propagation β we have :

$$\frac{OE_1}{Oz} = -j\,\beta E_1 + k\,E_2 \; , \; \frac{OE_2}{Oz} = -j\,\beta E_2 + k\,E_1$$

E_1, E_2 are respectively the field's amplitude in system (I) and (II), k is the coupling coefficient.

To determinate k, we solve the Maxwell's equations We also assume that the E and H fields resulting are given by the superposition of the modes of the uncoupled guides :

$$E = \alpha\,E_1 + \gamma E_2 + e$$
$$H = \alpha\,H_1 + \gamma H_2 + h$$

E and H are reported in Maxwell's equation and applying the perturbation method we obtain k by :

$$k = \omega\varepsilon_o \frac{\int_S (\varepsilon_2-\varepsilon_4)\; E_1 . E_2^* \; dx\,dy}{\int_S (E_1 \wedge H_1^* + E_1^* \wedge H_1)\; \vec{u}\; dx\,dy} \qquad (5)$$

$\vec{u}$: unitar vector of the propagation axis

S is the section of the resonator ot volume τ.

ε_4 is the permittivity of the medium surrounding the resonators. The formula (5) available for all the resonators has been applied to dipolar mode of circular resonator.

r^I_{II} being the distance between the running point and the center of the resonators I and II, the fields are :

inside the resonator : $H_{z\,iII}^{\;I} = B\,J_o(k_i\,r^I_{II})$

outside the resonator: $H_{z\,e\,II}^{\;I} = D\,K_o\,(k_e\,r^I_{II})$

$$k_o = \omega\sqrt{\varepsilon_o\,\mu_o} \qquad \beta = \frac{P\Pi}{H_{eff}}$$

$$k_i^2 = k_o^2\,\varepsilon_2 - \beta^2 \qquad k_e^2 = \beta^2 - k_o^2$$

To calculate k, we must express the field in a commun coordinate system Oxyz and we assume that the argument of the Bessel's function of the second kind is very large. Thus we obtain the coupling (k) as a function of the distance (s) between the center of the two adjacent resonators :

$$k = \frac{\omega\mu \qquad P}{4\,\frac{k_e^2}{k_i^2} + \Pi^2\,\frac{J_o^2(k_i a)}{K_o^2\,(k_e a)}} \; \frac{J_o^2(k_i a)}{K_o^2(k_e a)} \sqrt{\frac{\Pi}{2k_o s}} \; e^{-k_o s} \qquad (6)$$

P is a term which contains products of Bessel's function of the first and secund kind. Solving the equation (6) by means of a computer we have obtained the curve 2 suitable for the coupling between two dielectric disk resonators. (s' is the distance between the edges of resonators).

Filter synthesis

A Butterworth filter using two-dielectric resonators was designed with the following parameters.

Center frequency : 4.51 GHz
3db bandwidth : 60 MHz
Substrate Rexolite : ε_3 = 2,54 h = 1,6 mm
Resonator parameters : a = 4,5 mm, H = 2,7 mm
Resonator material ε_2 = 66

For this filter the appropriate distance between resonators was calculated to be s = 14 mm, and the distance between the microstrip line and the resonator to be d = 7,8 mm.

The theoretical and experimental responses are given on curve 3.

CONCLUSION

Accurate expressions have been presented which allow the calculation of the parameters of coupling between a microstrip line, and a dielectric resonator and between two resonators for the design of microwave filters containing dielectric resonators.

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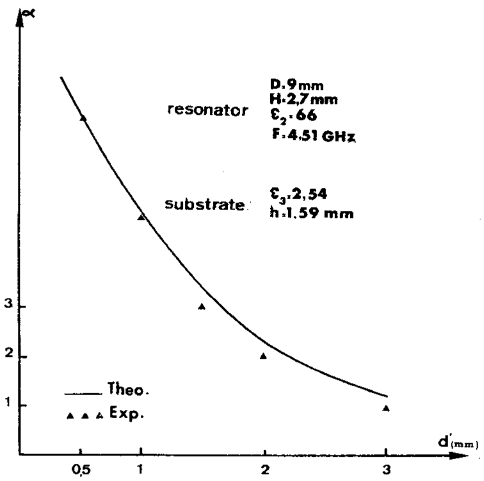

Fig.1 : Coupling between a line and a resonator.

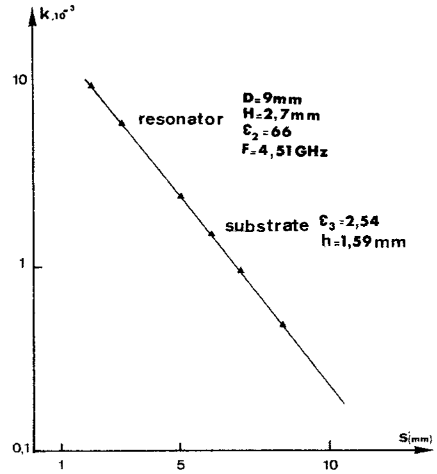

Fig.2 : Coupling between two adjacent resonators.

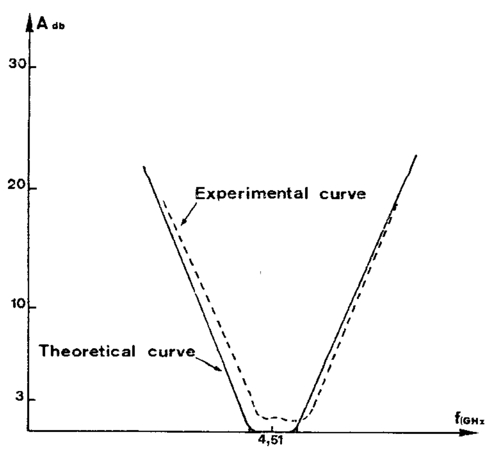

Fig.3 : "Butterworth" filter.