FULL -WAVE ANALYSIS OF THE GAP COUPLED MICROSTRIP ANTENNAS

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ABSTRACT

Full-wave analysis of a gap is carried out using Galerkin's method in the Fourier transform domain (FTD). In the formulation of the problem, we consider two types of resonators. The analysis is carried our for both electric and magnetic walls at the planes of symmetry. The equivalent length Δl_e and Δl_m for electric and magnetic walls respectively· are determined from the respective resonance frequencies of resonators. From Δl_e and Δl_m the discontinuity capacitances of the Pi- equivalent circuits are determined.

The equivalent circuit of a microstrip gap is calculated for different gap spacing.

1. INTRODUCTION

Applications of microstrip antenna are limited mainly because of their narrow bandwidth [1],[2]. A method for increasing the bandwidth of microstrip patch antenna by incorporating two additional resonators which are gap coupled to the radiating edges of a rectangular patch was developed by Gupta [3]. In this method [3], a two dimensional approach using impedance Green's function and the segmentation method has been used to analyze the proposed antenna configuration shown in Fig. 1-a, the antenna configuration is thus considered as a multiport network. The coupling gap between the two opened - rectangular microstrip patchs were modeled as two-dimensional capacitive pi-network as shown in Fig. 1-b. The values of these capacitances were obtained from the formulas for even and odd capacitances of coupled microstrips of unequal width [4]. Quasi-static characterization of capacitances with microstrip discontinuites are valid with sufficient accuracy, only up to few gigahertz. For a complete characterization of discontinuties, it is required to determined the frequency dependence of various parameters. This information is obtained from full-wave analysis which is presented in this paper.

2. FORMULATION OF THE PROBLEM

Full-wave analysis of a gap between two antennas can be carried out by using Galerkin's method in FTD . In this case, one considers two types

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of resonators. First, an analysis is carried out with conducting planes (electric walls) at z= ± D in the configuration shown in Fig. 2 . A second computation is carried out for magnetic walls at z= ± D. The dimension L is chosen such that (2D - 2L) is equal to the gap spacing,

2.1. Analysis of Microstrip Resonator with Two Electric Walls:

As the fields existing in the structure shown in Fig. 2 can be considered as superpositions of TE (to z) and TM(to z) Fields, they can be expressed in terms of two types of scalar potentials $\psi(x,y,z)$ and $\varphi(x,y,z)$. Accordingly, the fields existing in the structure are given by:

$$E_{zi}\ (x,y,z) = K_i^2\ \varphi_i + \frac{\partial^2 \varphi_i}{\partial z^2} \tag{1a}$$

$$H_{zi}\ (x,y,z) = K_i^2\ \psi_i + \frac{\partial^2 \psi_i}{\partial z^2} \tag{1b}$$

$$H_{xi}\ (x,y,z) = j\omega\varepsilon_1 \left(\frac{\partial \varphi_i}{\partial y}\right) + \frac{\partial^2 \psi_i}{\partial x\,\partial z} \tag{1c}$$

$$E_{xi}\ (x,y,z) = \frac{\partial^2 \varphi_i}{\partial x\,\partial z} - j\omega u_i \left(\frac{\partial \psi_i}{\partial y}\right) \tag{1d}$$

where i=1,2 designates the substrate or the air region respectively

$$K_1 = (\varepsilon_r\ u_r)^{1/2}\ k_o \qquad \varepsilon_1 = \varepsilon_o \cdot \varepsilon_r \qquad u_1 = u_o\ u_r \tag{2a}$$

$$K_2 = k_o = \omega(\varepsilon_o\ u_o)^{1/2},\ \varepsilon_2 = \varepsilon_o \qquad u_2 = u_o \tag{2b}$$

ω is the operating frequency and ε_o and u_o are the free-space permittivity and permeability, respectively. The boundary value problem associated with the structure is solved in the Fourier transform or the spectral domain.The original form of this method was first developed by Itoh and Mittra [6],[7]. Formulation of the problem for determining the resonant frequency is basically the same as that found by Itoh [5]. The essential difference here is that, discrete variable transform in z-direction k_z is used in the formulation of the problem which is determined from the solution of cavity resonator for instance.

$$k_z = (m - \tfrac{1}{2})\frac{\pi}{D} \qquad \text{for } E_x \text{ even - } H_x \text{ odd (in z) modes} \tag{3a}$$

$$= m\frac{\pi}{D} \qquad \text{for } E_x \text{ odd - } H_x \text{ even (in z) modes} \tag{3b}$$

where m = 1,2,.....

Following the same steps, which was developed in [5], the wave length λ_e corresponding to the resonant frequency f_{re} can be determined and λ_e is given by

$$\lambda_e = \frac{C}{f_{re}\sqrt{\varepsilon_{re}}} \tag{4a}$$

where

C is the velocity of light in free space

ε_{re} is the effective dielectric constant [8], where

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\ F\ (W/h) \tag{4b}$$

$$F(W/h)=\left[\begin{array}{lll}(1+12h/2W)^{-1/2} & +\,0.04(1-2\,W/h)^{2} & 2W/h\leqslant 1\\ (1+12h/2w)^{-1/2} & & 2W/h\geqslant 1\end{array}\right. \qquad (4c)$$

2.2 Analysis of Microstrip Resonator with Two Magnetic Walls:

Following the same procedures stated in section 2.1, after replacing the two electric walls by two magnetic walls, and the only difference will be in the value of K_z
where,

$K_z = m\ \pi/D$ for $E_x$even - H_x odd (in z) modes (5a)

$= (m-\frac{1}{2})\frac{\pi}{D}$ for $E_x$odd - H_x even (in z)modes (5b)

By the same way, the wave length λ_m corresponding to the resonant frequency f_{rm} of this structure can be determined and λm is given by

$$\lambda_m = \frac{c}{f_{rm}\sqrt{\varepsilon_{re}}} \qquad (6)$$

2.3 Calculation of the Equivalent Circuit of the Gap:

The end effect of the open-ended microstrip patch can be represented by an extension in the length Δl_e and Δl_m for the two cases 2.1 and 2.2 respectively, where

$$2(L+\Delta l_e) = \lambda_e/2 \qquad (7a)$$

$$2(L+\Delta l_m) = \lambda_m/2 \qquad (7b)$$

From Δl_e and Δl_m, two equivalent capacitances C_e and C_m [8] are calculated

$$C_e = \frac{\sqrt{\varepsilon_{re}}}{c\,Z_o}\,\Delta l_e \qquad (8a)$$

$$C_m = \frac{\sqrt{\varepsilon_{re}}}{c\,Z_o}\,\Delta l_m \qquad (8b)$$

$$Z_o = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ \mathrm{Ln}\left(\frac{8h}{2W} + 0.25\,\frac{2W}{h}\right) \qquad (2W/h\leqslant 1) \qquad (8c)$$

$$= \frac{\eta}{\sqrt{\varepsilon_{re}}}\left(\frac{2W}{h} + 1.393 + 0.667\ \mathrm{Ln}\left(\frac{2W}{h} + 1.444\right)\right)^{-1} \qquad (8d)$$

$$(2W/h\geqslant 1)$$

where $\eta = 120\,\pi$ ohm

where, Z_o is the characteristic impedance of the microstrip which is evaluated using work of Wheeler and Schneider [6]. These capacitances C_e and Cm are related to the discontinuites of the Pi- equivalent circuit of a gap by the following equations

$$Cg= (C_e - C_m)/2 \tag{9a}$$

$$Cp= C_m \tag{9b}$$

3. RESULTS AND DISCUSSIONS

Numerical Computations have been Carried out for the resonant frequencies and the equivalent circuit of the gap Coupling

Fig. 3shows the resonant frequency f_{re} and f_{rm} versus the gap spacing. This Figure shows that as the spacing increases, the resonant frequency f_{re} decreases, f_{rm} increases.

The imaginary part in the computed resonant frequency is due to the energy Lost by radiation from the fringing fields at the open ends.

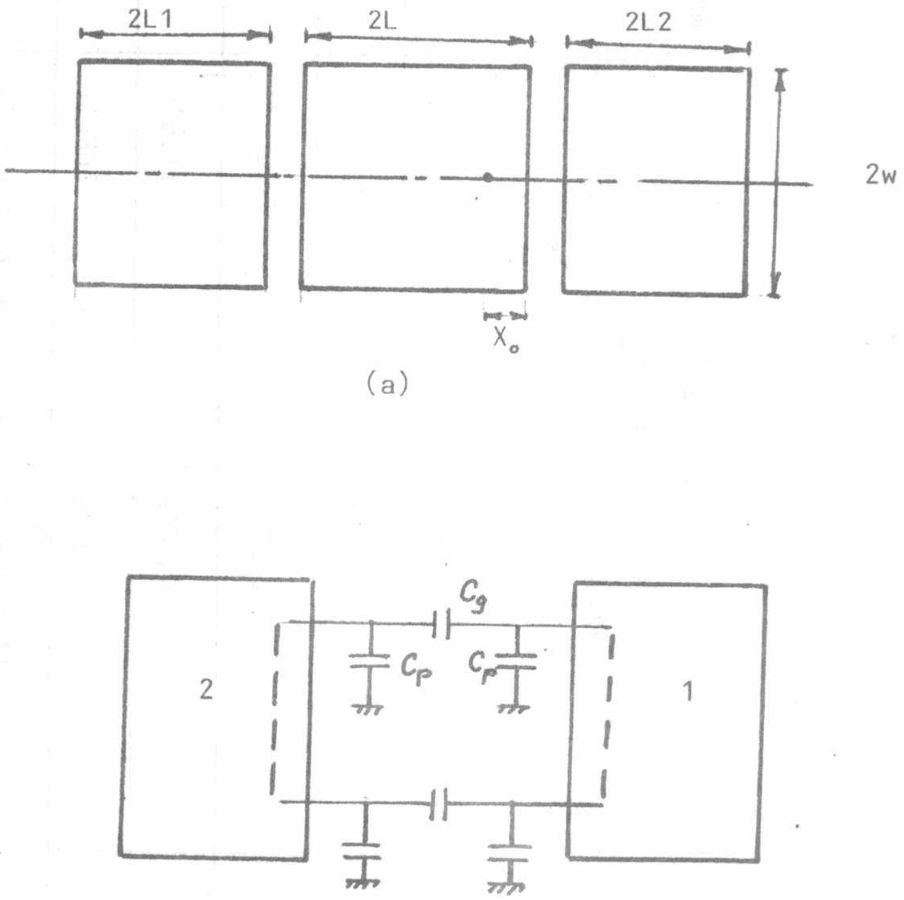
The equivalent circuit for the gap, as referred to the center Line of the gap, will include series capacitance and some negative shunt capacitance to account for the fact that the gap reduces the shunt capacitance in the vicinity of the center Line, O Liner [9].

Fig.4 shows the equivalent Capacitances Cg and Cp which decrease as the spacing increases. Table 1- Sumarizes the different results.

4. CONCLUSION

The Capacitive network model which was used [3] to represent the coupling between the main resonator and the additional resonators is Considered as very approximate . Thus, the full-wave analysis which is presented in this paper for determining the gap Coupling to improve the accuracy of representing the Coupling.

It is planned in the future to obtain the equivalent Circuit of the gap Coupling for radiating edge gap Coupled micro strip antennas (REGCMA).



(a)

(b)

Fig.1.(a) Radiating edge gap coupled microstrip antenna with different parasitic element
(b) Lumped element network for modeling of coupling gaps

TABLE 1
Summary of the results (versus gap spacing)

Spacing (CM)	0.15	0.165	0.18	0.19
f_{re} [GHZ]	$4.84411-j.2506 \times 10^{-6}$	$4.84553-j.2849 \times 10^{-6}$	$4.84696-j.3301 \times 10^{-6}$	$4.84791-j.3690 \times 10^{-6}$
f_{rm} [GHZ]	$4.99190-j.9158 \times 10^{-8}$	$4.98628-j.1577 \times 10^{-7}$	$4.98078-j.2276 \times 10^{-7}$	$4.97716-j.27651 \times 10^{-7}$
λ_e (CM)	3.9892	3.9880	3.9869	3.9861
λ_m (CM)	3.8711	3.8755	3.8798	3.8826
Δl_e(CM)	-0.35268	-0.35297	-0.35327	-0.35346
Δl_m(CM)	-0.38221	-.038112	-0.38005	-0.37934
C_g (PF)	0.08842	0.0842811	0.080201	0.077504
C_p (PF)	-2.2893	-2.2828	-2.27639	-2.27217

These results are for the following structure parameters

$L = 1.35$ cm
$w = 1.95$ cm
$d = 0.159$ cm
$\varepsilon_r = 2.55$

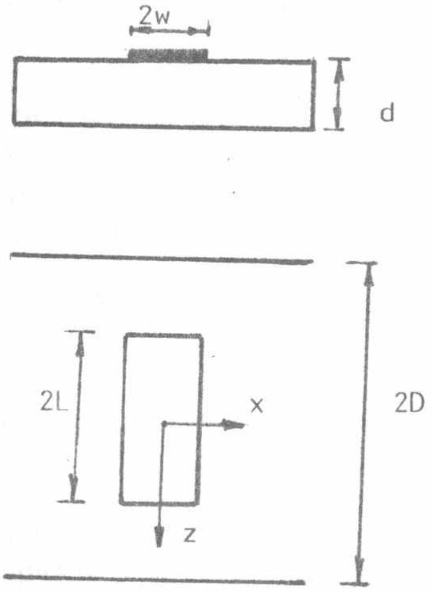


Fig.2. Microstrip resonator

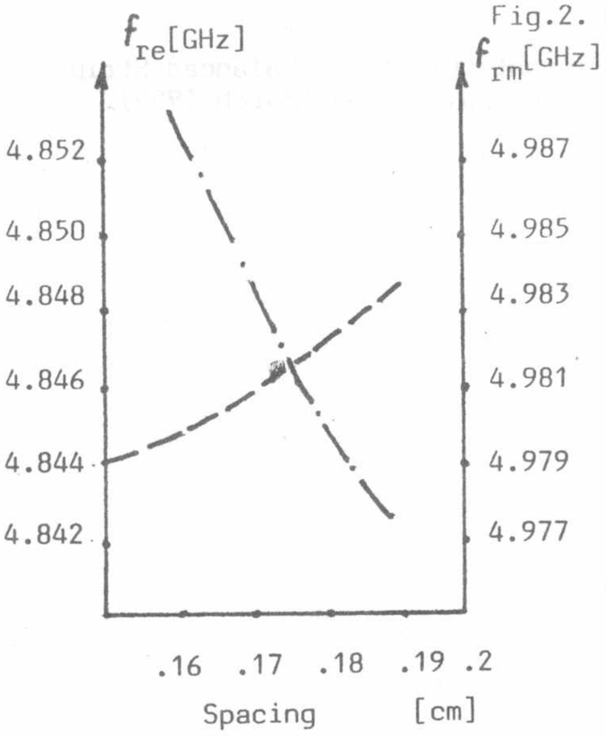


Fig.3 Resonant frequency versus spacing

--- resonant freq with electric walls

-.- resonant freq with magnetic walls

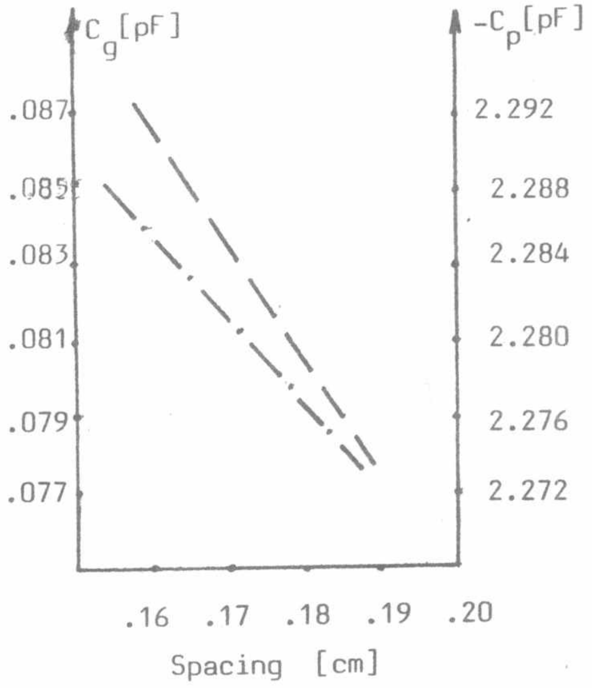


Fig.4 Capacitive network versus specing

-.- $-C_p$

--- C_g

REFERENCES

[1] I.J.Bahj and P. Bhartia."Microstrip Antennas". Dedham, MA: Artch House, 1981.

[2] IEEE Trans. Antennas Propagat., "Special issue on microstrip antenna", Vol. AP-29, 1981.

[3] G.Kumar and Gupta," Broad-Band Microstrip Antennas using Additional Resonators Gap - Coupled to the Radiating Edges," IEEE Trans A&P., Vol. Ap- 32, No. 12, pp. 1375-1379, DEC, 1984.

[4] R.Garg, "Design Equations For Coupled microstrip lines", Int, J.Electron., Vol. 47, No.6, pp. 587-591, 1979.

[5] Itoh, T., "Analysis of Microstrip Resonators," IEEE Trans., Vol. MTT-22, 1974, pp.946-952.

[6] T.Itoh, R. Mittra, and R.D.Ward," A method for Computing Edge Capacitance of Finite and semi-finite Micro-strip lines", IEEE Trans Microwave Theory Tech. (short paper), Vol. MTT-20, pp.847-849, Dec. 1972.

[7] T.Itoh and R.Mittra, "A new Method for Calculating the Capacitance of a Circular Disk for Microwave Integrated circuits," IEEE Trans Microwave Theory Tech. (short paper), pp. 431-432, Jane 1973.

[8] K.C. Gupta, R.Garg, and I.J.Bahl., "Microstrip Lines and Slot Lines", Artch House, Inc, 1979, pp.133-135.

[9] A.A. O Liner, "Equivalent circuit for Discontinuities in Balanced Strip Transmission Line," IRE Trans. PGMTT, Vol. MTT-8, pp.328-339 (March 1955).