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EFFECT ON RESONANT FREQUENCY FOR E-PLANE MUTUALLY COUPLED MICROSTRIP ANTENNAS

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Abstract—The resonant frequency of a microstrip patch (rectangular, square, and circular) changes as soon as an identical patch is brought closer than 0.2λ. Closed form expressions are presented for the E-plane coupled configuration from which this altered resonant frequency may be easily computed. These expressions may be readily used in the computer aided design of microstrip antenna arrays.

1. INTRODUCTION

The essentiality of microstrip antenna is a well known fact in telecommunication and radar systems. To this end, microstrip antennas on dielectric substrates have been an interesting subject of study for the last two decades due to their many advantages over conventional antennas, such as low cost, low weight, ease of fabrication, reproducibility, and reliability. The analysis of microstrip antennas, however, is very complex due to the presence of the fringing field. Because of this fringing field, the resonant frequency of the microstrip antenna is always shifted from the design resonant frequency. Wheeler's work on microstrip impedance analysis considered this fringing effect for a very wide line [1]. Hammerstad also analyzed fringing effect and suggested the length correction model for design of these antennas [2]. The shift in the resonant frequency is more pronounced if the patch is closely coupled to another parasitic patch. This shift in the resonant frequency is to be taken into account while designing a microstrip antenna array because the microstrip patch antenna is a narrow band device.

Krowne [3] presented theoretical and numerically coupled results for mutual coupling between two rectangular microstrip antenna patches for both E-plane and H-plane coupling. Results were also given for resonant frequency, resonant impedance behaviour, and radiation pattern at resonance. The resonant frequencies in the even and odd resonant modes of half-wave-coupled and quarter-wave-coupled rectangular microstrip resonators were computed by Sharma and Bhat [4] with hybrid mode formulation of the spectral domain technique. Several authors [5–9] have carried out many interesting works on coupling. The aim of this paper is to derive a closed form expression for the resonant frequency of E-plane mutually coupled rectangular, square and circular microstrip antennas involving various antenna parameters along with a range of certain distances between the adjacent edges of the patches.

2. DESIGN AND EXPERIMENTS

A number of mutually coupled half wavelength ($\lambda_g/2$) rectangular microstrip antennas were constructed on various dielectric substrates with dielectric constant values (ε_r) ranging from 2.1 to 10. E-plane-coupled configurations for rectangular, square and circular microstrip antennas were chosen in Figures 1 and 2. The guide wavelength (λ_g) was calculated from Schneider's formula [10]. These antennas were fed at the center of one of the non-radiating edges by coaxial connectors with a frequency (f_{design}) ranging from 1 to 10 GHz. The thickness h of the substrate was chosen from 0.127 to 0.3048 cm and the spacing between the edges (s) was chosen from 0.025λ to 0.8λ, where λ is the free space wavelength. The circular microstrip antennas were constructed from the equivalent square microstrip antennas (Figure 3) and were fed by coaxial connectors at their periphery (Figure 2). The resonant frequencies of these mutually coupled rectangular (f_{rect}), square (f_{square}), and circular (f_{circle}) microstrip antennas were observed from an 8410B Network Analyzer tied with an HP-9000 computerized set up with the help of the $S_{ij}\,(i = j)$ parameter measurement. $S_{ij}\,(i = j)$ was measured as the reflection coefficient seen at the ith port with the jth port terminated in the 50-Ω load.

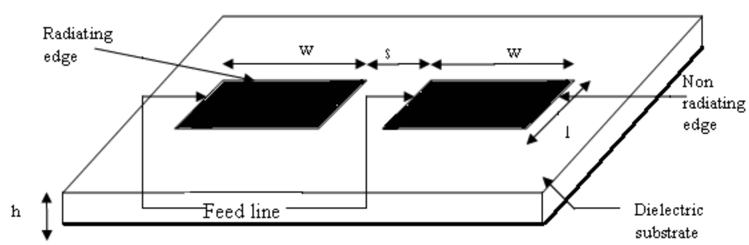

Figure 1. E-plane coupled rectangular microstrip antenna.

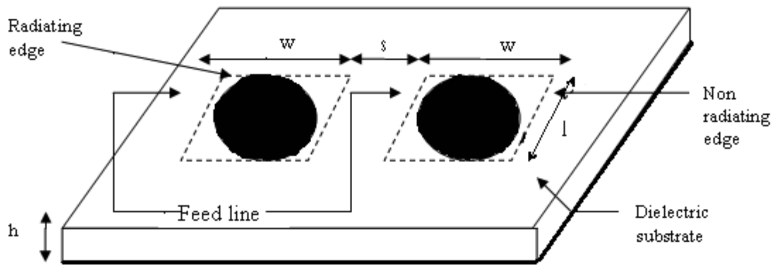

Figure 2. E-plane coupled equivalent circular microstrip antenna.

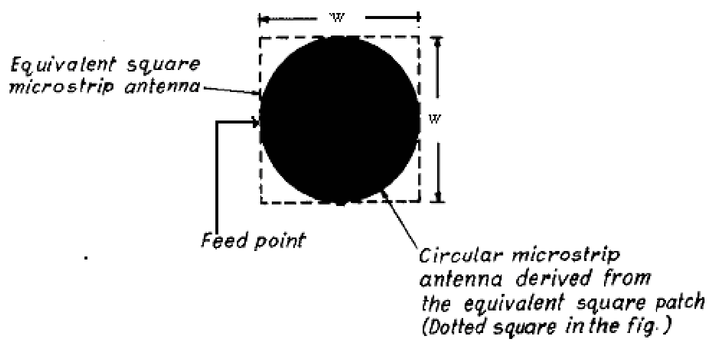

Figure 3. Circular microstrip antenna derived from equivalent square microstrip antenna.

3. DERIVATION OF THE CLOSED FORM EXPRESSIONS

The values of the resonant frequencies (f_{rect}, f_{square}, and f_{circle}) observed from the Network Analyzer were different from the resonant frequencies at which the antennas were designed (f_{design}) because of the fringing field. This shift in the mutually coupled configuration was found to exist upto a spacing (s/λ) of 0.2 between the edges for all antennas (i.e., rectangular, square and circular). Beyond the distance of 0.2λ between the edges, no shift of resonant frequency was observed. However, in that case, the resonant frequency observed was different from the design frequency. In the former case the shift was due to the mutual coupling effect (variable shift with the spacing between the edges) between the two in addition to the normal fringing effect of the antennas. In the latter case, the deviation of the design frequency from the observed one was due to the fringing effect of the isolated element. The observed resonant frequencies thus obtained were plotted against

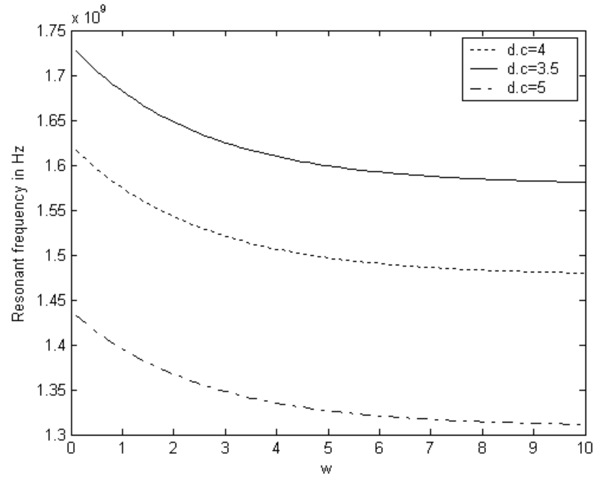

Figure 4. Resonant frequency versus width plot for various d.c $= \varepsilon_r$ for rectangular microstrip antennas, $h = 0.3048$, $f_{design} = 3\,\text{GHz}$.

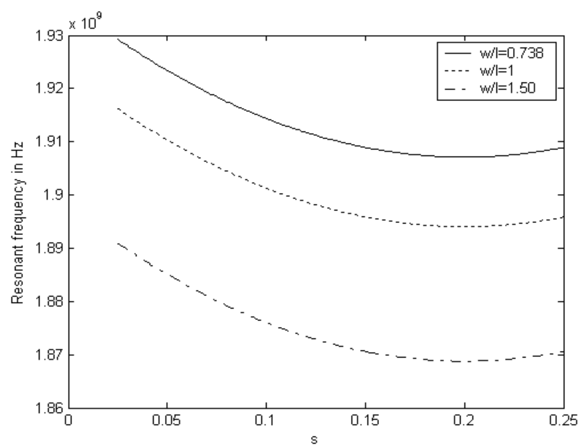

Figure 5. Resonant frequency versus s/λ = s plots for various w/l ratios for rectangular microstrip antennas, $f_{design} = 3\,\text{GHz}$, $h = 0.3048$, $\varepsilon_r = 2.5$ and considering s/λ = s.

w and s/λ with w/l and ε_r as parameters. Some typical plots are shown in Figures 4, 5 and 6. Based on these various sets of curves, closed form expressions for the resonant frequencies were developed by the principle of curve fitting, relating it to the design frequencies and various antenna parameters.

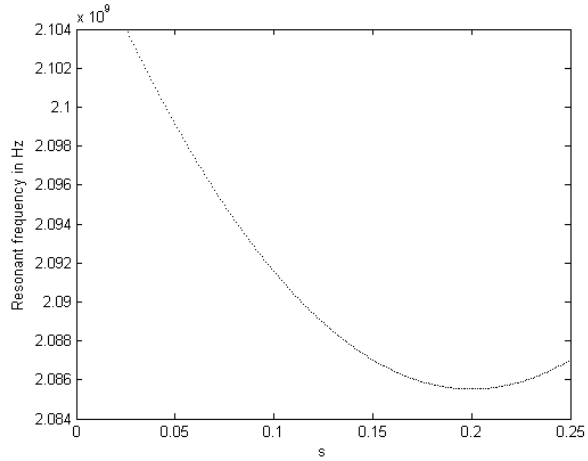

Figure 6. Resonant frequency versus s plots for circular microstrip antennas, $\varepsilon_r = 2.55$, $f_{design} = 3\,\text{GHz}$, $w/h = 10$ and considering $s/\lambda = \text{s}$.

The expressions derived are as follows,

$$f_{rect,square,circle} = f_{design}\beta\left[1 \pm \frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right]\left[\cosh\left\{\left(1-\frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right)\left(0.2-\frac{s}{\lambda}\right)\right\}\right] \tag{1}$$

Where

$$\beta = \frac{e^{-0.4\times(w+2.4)}+3.9}{3.64+\varepsilon_r}$$

and

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\times\frac{1}{\sqrt{1+\frac{10}{(w/h)}}}$$

In equation (1), the negative sign is to be considered for the third term on the right hand side for mutually coupled rectangular and square microstrip antennas. So, for rectangular and square microstrip antennas the equation becomes,

$$f_{rect,square} = f_{design}\beta\left[1 - \frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right]\left[\cosh\left\{\left(1-\frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right)\left(0.2-\frac{s}{\lambda}\right)\right\}\right] \tag{2}$$

For mutually coupled circular microstrip antennas, the positive sign in the third term of equation (1) is to be used, and the expression becomes,

$$f_{circle} = f_{design}\beta\left[1+\frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right]\left[\cosh\left\{\left(1-\frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right)\left(0.2-\frac{s}{\lambda}\right)\right\}\right] \quad (3)$$

Equations (1), (2), (3), are valid for

f (GHz)	s/λ	w/l	h (cm)	ε_r
1 to 10	0.025 to 0.2	0.5 to 2	0.127 to 0.3048	2.1 to 10

Here w = width of the microstrip patch and l = length of the microstrip patch. For spacing between the edges of more than 0.2λ no changes of resonant frequency was observed for rectangular, square and circular microstrip antennas.

4. RESULTS

The theoretical (curve fitted) results obtained from equation (2) for rectangular microstrip antennas were compared with the measured data. One typical plot is given in Figure 7. The agreement was found to be excellent. The theoretical results were also compared with the results obtained by Krowne [3]. The plot is given in Figure 8. For this case also, the agreement was found to be also excellent.

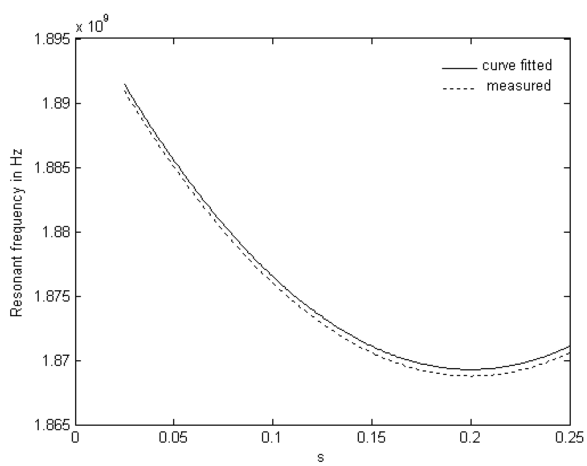

Figure 7. Comparison between curve fitted and measured results for rectangular microstrip antennas for $f_{design} = 3$ GHz, $\varepsilon_r = 2.5$, $w/l = 1.50$, and considering $s/\lambda =$ s.

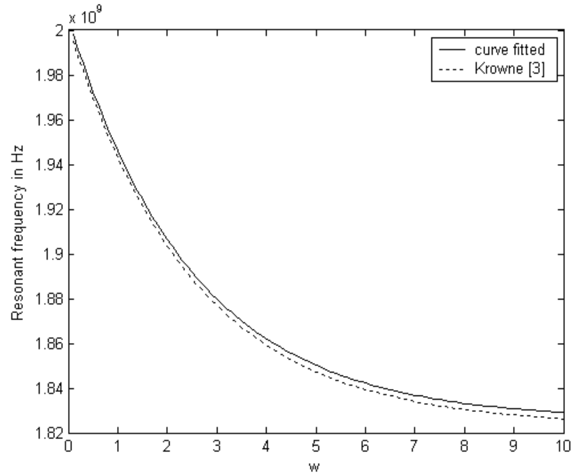

Figure 8. Comparison between curve fitted results and Krowne [3] for $\varepsilon_r = 2.5$.

5. CONCLUSION

Closed form expressions for the prediction of the resonant frequency of mutually coupled rectangular, square and circular microstrip antennas have been derived using curve fitting techniques. The expressions are useful at the time of computing the mutual impedance and input impedance of these antennas when they are placed in an array environment. These expressions are also useful when the fringing effects are to be considered. This is expected to be helpful in the computer-aided deign of microstrip antenna arrays.

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