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COMPARATIVE STUDY OF THE RESONANT FREQUENCY OF E-PLANE AND H-PLANE COUPLED MICROSTRIP PATCH ANTENNAS

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Abstract—When a microstrip patch antenna is brought closer than 0.2λ to an identical patch the resonant frequency of that antenna changes from the designed frequency. In this paper numerical results for the resonant frequency are presented from a theoretical analysis of the mutually coupled H-plane microstrip patch antennas with confirming experimental results. We have also established the relation between resonant frequency of E-plane coupled and H-plane coupled microstrip patch antennas.

1. SYMBOLS

$a =$ Width of the patch
$b =$ Length of the patch
$h =$ Thickness of the substrate
$\varepsilon_r =$ Relative dielectric constant
$\varepsilon_{eff} =$ Effective dielectric constant
$\lambda =$ Free space wavelength
$d =$ Spacing between the edges of coupled patches
$f_{design} =$ Design frequency
$f_{r-E} =$ Resonant frequency of the E-plane coupled microstrip patch antenna
$f_{r-H} =$ Resonant frequency of the H-plane coupled microstrip patch antenna

2. INTRODUCTION

During the past few decades microstrip antennas experienced a great gain in popularity and have become a major research topic in both theoretical and applied electromagnetics and in the arena of modern communication systems. Microstrip antennas have the attractive features of low profile and light weight. It has a lot of advantages over the conventional antennas like simple and inexpensive to manufacture using modern printed circuit board technology, conformable to planer and non-planer surfaces, and when the particular patch shape and mode are selected they are very versatile in terms of the resonant frequency, polarization and impedance pattern. The analysis of microstrip antennas however is very critical due to presence of fringing field. For the presence of fringing field the resonant frequency of the microstrip antenna shifts from the design resonant frequency. Several techniques have been proposed for determination of the resonant frequency. Krowne [1] analyzed the theoretical and numerical pattern of the resonant frequency for the E-plane and H-plane coupled microstrip antennas. Chair Luk and Lee [2] presented the expression for the frequency considering the fringe field. They also computed how to minimize the resonant frequency by using the multilayer patch. Chang, Long, and Richards [3] also measured the resonant frequency and calculated the bandwidth as a function of electrical thickness. The resonant frequencies in the even and the odd resonance modes of half wave coupled and quarter wave coupled rectangular microstrip resonators were computed by Sharma and Bhatt [4]. Many authors [5–11] have investigated the effect of mutual coupling. But none of these works presents the comparative study for the resonant frequency of the E-plane coupled and H-plane coupled microstrip patch antennas.

The first part of this paper gives the closed form expression for the resonant frequency of the H-plane coupled rectangular patch and the second part gives the relation between the resonant frequency of the E and H-plane coupled antennas.

3. DESIGN AND EXPERIMENTS

3.1. E-plane Coupling

The geometry for the mutually coupled E-plane microstrip antenna is shown in Figure 1. The dimension of the rectangular patch is $a \times b$. The antennas were placed on various dielectric substrates with relative dielectric constant (ε_r) ranging from 2.5 to 10.

The feed mechanism plays an important role in the design of microstrip patch antennas. So many techniques like coaxial probe, microstrip line, aperture coupling, proximity coupling are available for the feeding of microstrip antennas. Here, we used microstrip line feeding techniques with the design frequency ranging from 1 to 10 GHz keeping the patch width to length ratio ranging from 0.2 to 2 and the thickness of the substrate in between the ranges 0.125 cm to 0.305 cm. The spacing (d) between the edges of the two antennas was chosen within the limit 0.02λ to 0.8λ.

For E-plane (end coupled) [1], the patches were kept collinearly along the E-plane and coupled with the direction of propagation perpendicular to the two adjacent antenna coupled end and fed on the middle of the non radiating edge i.e., at the distance of $b/2$ (in the X direction).

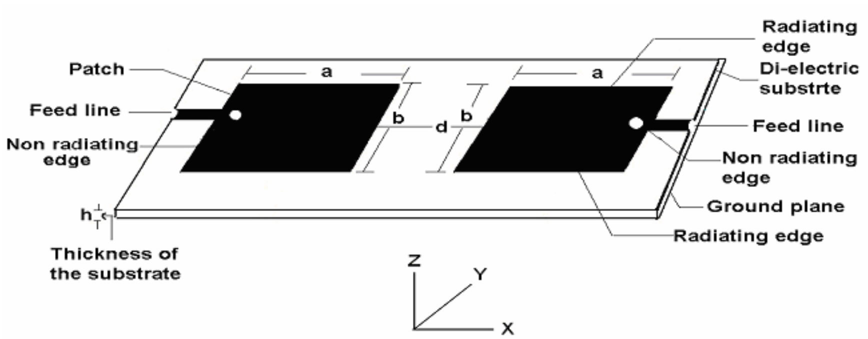


Figure 1. E-plane coupled rectangular microstrip antenna.

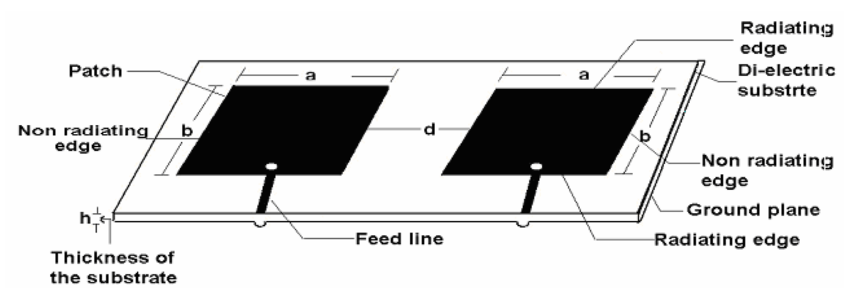


Figure 2. H-plane coupled rectangular microstrip antenna.

3.2. H-plane Coupling

Figure 2 shows the geometry of H-plane coupled rectangular microstrip patch antenna. In case of H-plane (parallel coupling) [1] coupling, the antennas were placed collinearly along the H-plane, and they were coupled with the direction of propagation parallel to the coupled antenna edges. Here, feeding positions were different and they were fed on the radiating edge, which is middle of the patch length i.e., at the distance of $a/2$ (in the Y direction).

The mutually coupled circular microstrip antennas shown in Figure 3 were constructed from the equivalent square ($a = b$) microstrip antennas and fed at their periphery.

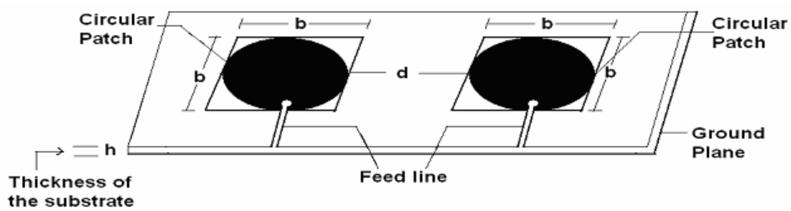


Figure 3. Mutually coupled equivalent circular microstrip antenna.

4. EXPERIMENTAL RESULTS

In H-plane coupling when two microstrip antennas having the same patch width 'a' and the same length 'b' (incase of E-plane coupling length may be different) is brought closer keeping the distance 'd' between the two edges less then 0.2λ, the resonant frequency of the antenna differs from the design frequency. The shift is also pronounced if the distance 'd' is more than 0.2λ due to the presence of the fringing field of the isolated element.

The shift in the resonant frequency was observed from an 8410B network analyzer in an HP-9000 computerized setup with the help of the S_{ij} $(i = j)$ parameter measurement. S_{ij} $(i = j)$ was measured as the reflection coefficient sent at the ith port with the jth port terminated in the $50\,\Omega$ load. The observed resonant frequencies thus obtained were plotted against width (a) and d/λ with a/b and ε_r as parameters. Some typical plots are shown in Figures 4 and 5. Based on these various sets of curves, closed form expressions for the resonant frequencies were developed by the principle of curve fitting techniques, relating it to the design frequencies and various antenna parameters.

The expressions derived are as follows,

$$f_{r-H} = f_{design} \times \left[\frac{\exp(-0.4(a+2.4)) + 3.9}{(\varepsilon_r + 3.72)}\right] \times \frac{b}{4.81} \times \left[1 \pm \frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right] \times \cosh\left[\left(1 - \frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right) \times \left(0.2 - \frac{d}{\lambda}\right)\right] \quad (1)$$

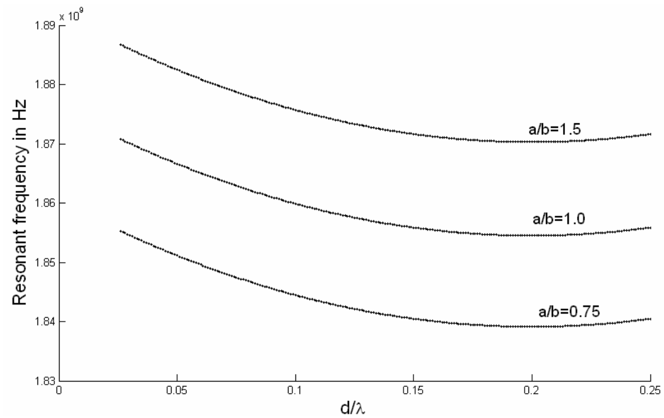


Figure 4. Resonant frequency versus d/λ plot of H-plane coupled rectangular microstrip patches for $\varepsilon_r = 2.5$, $f_{design} = 3\,\text{GHz}$, $h = 3048\,\text{cm}$ and $b = 5\,\text{cm}$.

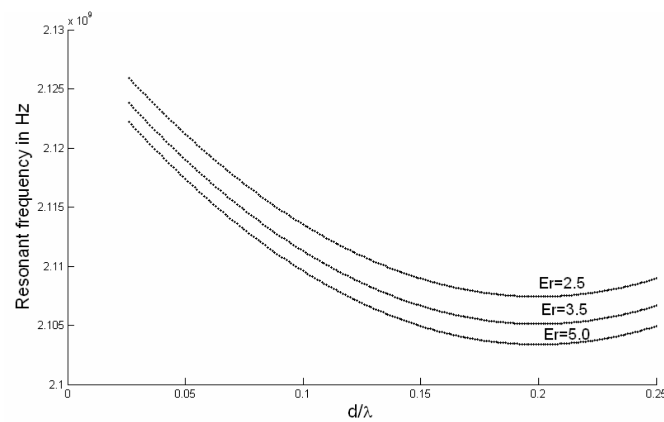


Figure 5. Resonant frequency versus d/λ plot for various $E_r(= \varepsilon_r)$ of H-plane coupled circular microstrip patches for $f_{design} = 3\,\text{GHz}$, $h = 3048\,\text{cm}$ and $a = b = 5\,\text{cm}$.

In the above equation fourth term on the right hand side is considered as negative for mutually coupled rectangular and square ($a = b$) antennas whereas for mutually coupled equivalent circular antennas shown in the Figure 3. the term is considered as positive.

Where

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \frac{(\varepsilon_r - 1)}{2} \times \frac{1}{\sqrt{1 + 10\left(\frac{h}{a}\right)}} \tag{2}$$

The closed form expression for the E-plane coupled microstrip antennas derived by Ray et al. [5] is

$$\begin{aligned} f_{r-E} &= f_{design} \times \left[\frac{\exp(-0.4(a+2.4)) + 3.9}{(\varepsilon_r + 3.64)}\right] \times \left[1 \pm \frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right] \\ &\quad \times \cosh\left[\left(1 - \frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right) \times \left(0.2 - \frac{d}{\lambda}\right)\right] \end{aligned} \tag{3}$$

Here also the third term on the right hand side of the above equation has been considered as negative for mutually coupled square and rectangular microstrip antennas and positive for mutually coupled circular antennas.

Let

$$\begin{aligned} \alpha &= f_{design} \times \left[1 \pm \frac{\varepsilon_{eff}}{14.33\varepsilon_r}\right] \times \cosh\left[\left(1 - \frac{\varepsilon_{eff}}{3.82\varepsilon_r}\right) \times \left(0.2 - \frac{d}{\lambda}\right)\right] \\ \beta &= [\exp(-0.4(a+2.4)) + 3.9] \end{aligned}$$

Then the Equation (1) reduces to

$$f_{r-H} = \frac{\alpha \times \beta}{(\varepsilon_r + 3.72)} \times \left(\frac{b}{4.81}\right) \tag{4}$$

And the Equation (3) reduces to

$$f_{r-E} = \frac{\alpha \times \beta}{(\varepsilon_r + 3.64)} \tag{5}$$

4.1. Relation between the Resonant Frequency of an E-planed Coupled and an H-planed Coupled Microstrip Antennas

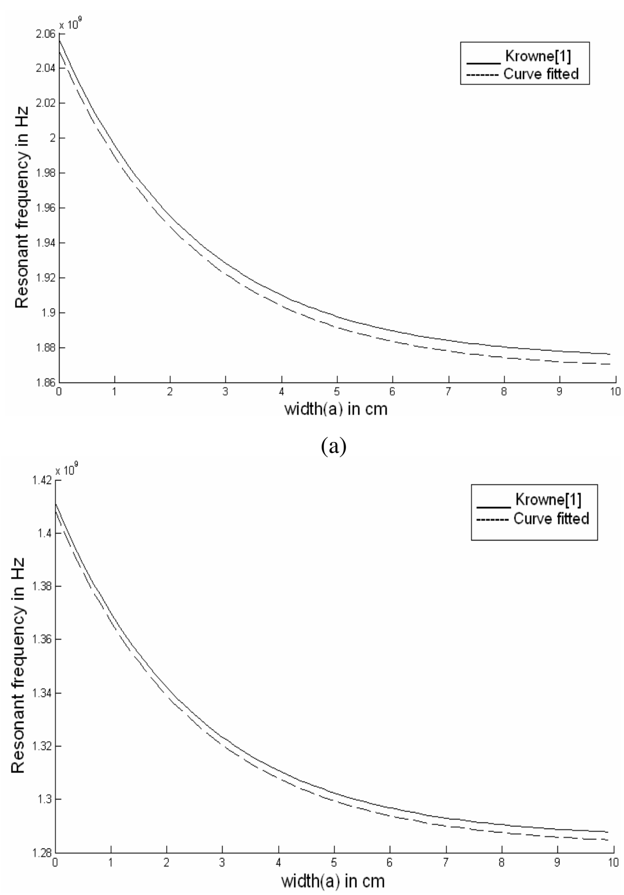
From the above two Equations (4) and (5) we can relate between the resonant frequency of E-plane and H-plane coupled microstrip antennas.

$$\frac{f_{r-E}}{f_{r-H}} = \frac{\alpha \times \beta/(\varepsilon_r + 3.64)}{\alpha \times \beta/(\varepsilon_r + 3.72) \times (b/4.81)}$$

It can be written in the simplified form as,

$$\frac{f_{r-E}}{f_{r-H}} = \left(\frac{4.916}{b}\right) \times \frac{(1 + 0.269\varepsilon_r)}{(1 + 0.275\varepsilon_r)}$$

The theoretical results were compared with C. M. Krowne [1]. The agreement was found to be fairly good. Typical plots are shown in Figures 6(a) and 6(b). The resonant frequency ratios versus length (b) of the patch for various dielectric constants are also shown in Figure 7.



(a)

(b)

Figure 6. Resonant frequency versus width plot for (a) $\varepsilon_r = 2.5$ (b) $\varepsilon_r = 5$ of a H-plane mutually coupled rectangular microstrip patches for $f_{design} = 3\,\text{GHz}$, $d/\lambda = 0.1$, $h = 3048\,\text{cm}$ and $b = 5\,\text{cm}$.

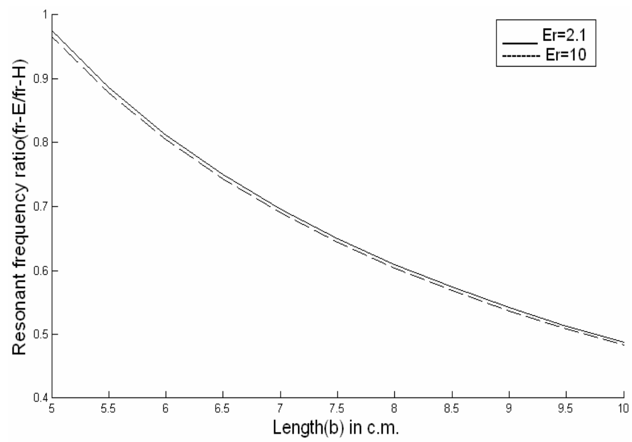


Figure 7. Resonant frequency ratio (f_{r-E}/f_{r-H}) versus length (b) of the patch for various dielectric constant ($E_r = \varepsilon_r$).

5. CONCLUSIONS

The characteristics of mutually coupled H-plane rectangular, square and circular microstrip antennas have been observed. The application of the formula derived here is to design and also to calculate mutual impedance of these antennas when they are placed in an array environment. These expressions are very much useful in the computer aided design of microstrip antenna arrays. The computation time will also be negligibly small.

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