

Theoretical study of 2×2 element planar array of equilateral triangular patch microstrip antenna in plasma medium

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Abstract. The radiation properties of 2×2 element planar array of equilateral triangular patch microstrip antenna in plasma medium are studied. The array factor and far-zone EM-mode and P-mode radiation fields of the array geometry are derived using vector wave function techniques and pattern multiplication approaches. The total field patterns and various characteristics of pattern such as half power beam width (HPBW), first null beam width (FNBW) and direction of maximum radiation are computed for two different values of progressive phase excitation difference between the elements. The results of this array geometry are obtained both in plasma medium and in free space and compared with those of single element equilateral triangular patch microstrip antenna.

Keywords. Microstrip planar array; radiation properties; plasma.

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1. Introduction

Due to many unique and attractive properties like light weight, flat profile, low manufacturing cost, compatibility with integrated circuit and better aerodynamics, microstrip antennas and their arrays are becoming increasingly popular in high-performance aircraft, spacecraft, satellite and missile applications [1–4].

The planar array antennas find wide applications in tracking radar, search radar, remote sensing, communications and many others. Planar arrays are more versatile and can provide more symmetrical patterns with lower side lobes. In addition, they can be used to scan the main beam of the antenna toward any point in space. Microstrip planar array antennas mounted on such aerospace vehicles encounter plasma medium during their travel in space, as a result of which radiation properties are altered significantly. This change is caused due to the generation of electroacoustic waves in addition to electromagnetic waves [5,6].

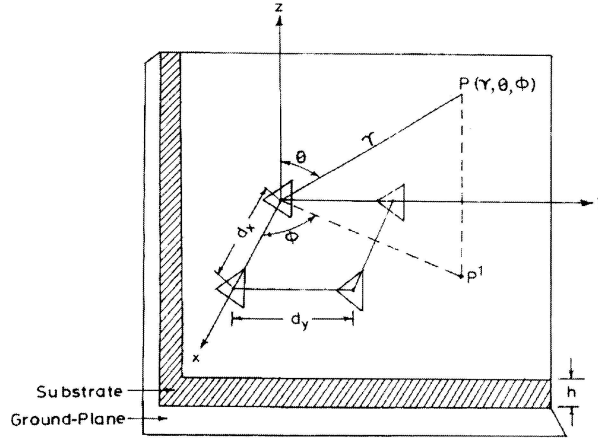


Figure 1. Configuration and coordinate system of 2×2 element planar array of equilateral triangular patch microstrip antenna.

2. Radiation field expressions

The geometry and coordinates system of planar array antenna are shown in figure 1. It consists of four identical triangular microstrip patch element of arm length a , on a dielectric substrate of thickness h and substrate permittivity ϵ_r . The array element which are positioned along x -axis are separated by a distance d_x and, those along y -axis are separated by a distance d_y . Each patch can be excited by a co-axial feed line from its corner. Among the various modes that may be excited in such disc resonators, we have considered TM_{nm} mode with respect to z -axis. Here n and m are the mode numbers associated with the x and y directions respectively. The E_z component of field inside the cavity for dominant mode is given as

$$E_z = A_{1,0,-1} [2 \cos(2\pi x/\sqrt{3}a + 2\pi/3) \cdot \cos(2\pi y/3a) + \cos(4\pi y/3a)]. \quad (1)$$

For the case of 2×2 element planar array of equilateral triangular patch microstrip antenna, the EM- and P -mode fields are given as

EM-mode

$$E_{\theta t} = -i\eta_0\omega_0 \cdot [F_x \cdot \cos \theta \cdot \cos \phi + F_y \cdot \cos \theta \cdot \sin \phi] \\ \times \frac{1}{4} \times \frac{\sin(\psi_x)}{\sin(\psi_x/2)} \times \frac{\sin(\psi_y)}{\sin(\psi_y/2)}, \quad (2)$$

$$E_{\phi t} = -i\eta_0\omega_0 \cdot [-F_x \cdot \sin \phi + F_y \cdot \cos \phi] \\ \times \frac{1}{4} \times \frac{\sin(\psi_x)}{\sin(\psi_x/2)} \times \frac{\sin(\psi_y)}{\sin(\psi_y/2)}. \quad (3)$$

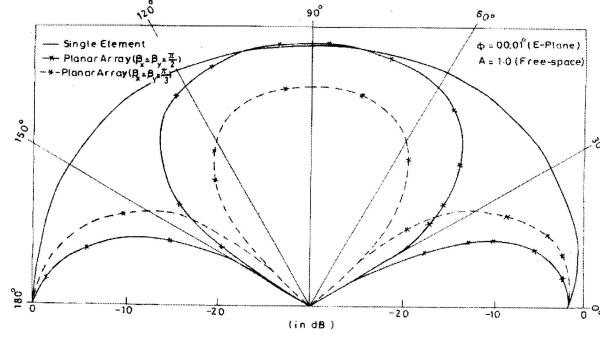


Figure 2. *E*-plane radiation patterns of 2×2 element planar array and single element equilateral triangular patch microstrip antennas for $A = 1.0$.

P-mode

$$\begin{aligned}
 E_{pt} &= 2h\beta_p\omega_p^2/3a\omega_0\varepsilon_0(\omega_0^2 - \omega_p^2) \\
 &\times \exp(-i\beta_p r)/r \times \exp(-i\beta_p a \sin \theta \cos \phi / \sqrt{3}) \\
 &\times \frac{1}{4} \times \frac{\sin\{\beta_p \cdot d_x \cdot \sin \theta \cdot \cos \phi + \beta_x\}}{\sin\{0.5(\beta_p \cdot d_x \cdot \sin \theta \cos \phi + \beta_x)\}} \\
 &\times \frac{\sin\{\beta_p \cdot d_y \cdot \sin \theta \cdot \sin \phi + \beta_y\}}{\sin\{0.5(\beta_p \cdot d_y \cdot \sin \theta \cdot \sin \phi + \beta_y)\}} \times [E_{px} + E_{py}], \quad (4)
 \end{aligned}$$

where

$$\begin{aligned}
 \psi_x &= \beta_e \cdot d_x \cdot \sin \theta \cdot \cos \phi + \beta_x, \\
 \psi_y &= \beta_e \cdot d_y \cdot \sin \theta \cdot \sin \phi + \beta_y.
 \end{aligned}$$

M and N are the elements placed along the x -axis and y -axis respectively, β_x and β_y are the progressive phase excitation difference along the x - and y -directions, $E_{\theta t}$ and $E_{\phi t}$ are the components of total electric field vectors for EM-mode, E_{pt} is the total electric field vector for P-mode, F_x and F_y are the vector electric potentials for x - and y -components, respectively, E_{px} and E_{py} are the P-mode electric field vectors for x - and y -components, β_e is the phase propagation constant for EM-mode given by $2\pi A/\lambda_0$, β_p is the phase propagation constant for P-mode given by $\beta_e c/v$, where c is the velocity of light and v is the root mean square thermal velocity of electron. A is the plasma frequency parameter given by $(1 - \omega_p^2/\omega_0^2)^{1/2}$, where ω_0, ω_p are the angular source and plasma frequency, η_0 is the free space impedance equal to 120π ohms.

3. Field patterns

The expression for total field pattern $R(\theta, \phi)$ is obtained as

$$R(\theta, \phi) = |E_{\theta t}|^2 + |E_{\phi t}|^2. \quad (5)$$

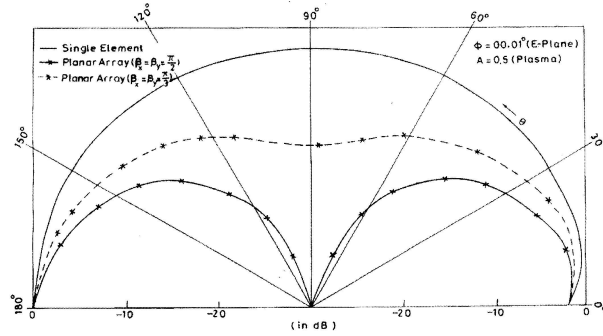


Figure 3. *E*-plane radiation patterns of 2×2 element planar array and single element equilateral triangular patch microstrip antennas for $A = 0.5$.

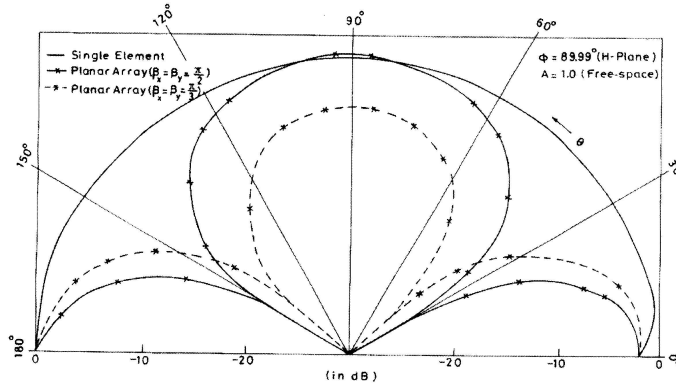


Figure 4. *H*-plane radiation patterns of 2×2 element planar array and single element equilateral triangular patch microstrip antennas for $A = 1.0$.

The values of R_e and R_h are calculated by taking $f = 10$ GHz, $a = 1.3$ cm, $d_x = d_y = \lambda/2 = 1.5$ cm, $n = 1$, $\epsilon_r = 2.32$ and the phase difference $\beta_x = \beta_y = \pi/2$ and $\pi/3$. The results are plotted in figures 2 and 4 for two different planes ($\phi = 0$ and $\phi = \pi/2$) for $A = 1.0$, i.e. in free space and in figures 3 and 5 for two different planes ($\phi = 0$ and $\phi = \pi/2$) for $A = 0.5$, i.e. in a plasma medium. The P-mode fields are plotted in figure 6 for $A = 0.5$ for a limited range of 10° (from 50° to 60°). The field patterns are also compared with single element triangular patch microstrip antenna. The calculated values of different pattern characteristics of array geometry for both the planes, i.e. $\phi = 0$ and $\phi = \pi/2$ and for $\beta_x = \beta_y = \pi/2$ and $\pi/3$ are given in table 1.

4. Conclusions

From the above study, it is observed that there is a significant change in the radiation characteristics of the array geometry under investigation due to (i) variation of progressive phase excitation difference among the elements and (ii) variation of ratio of plasma to source frequency.

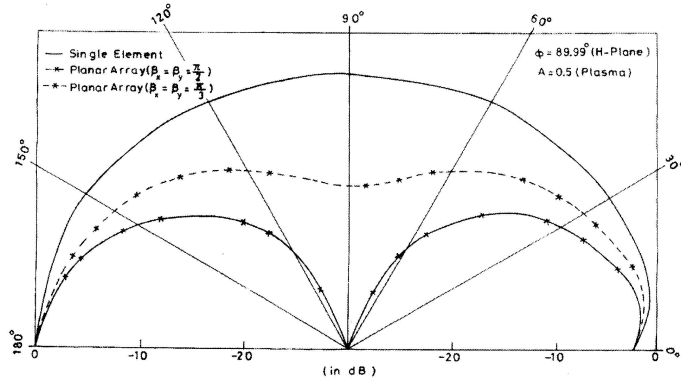


Figure 5. *H*-plane radiation patterns of 2×2 element planar array and single element equilateral triangular patch microstrip antennas for $A = 0.5$.

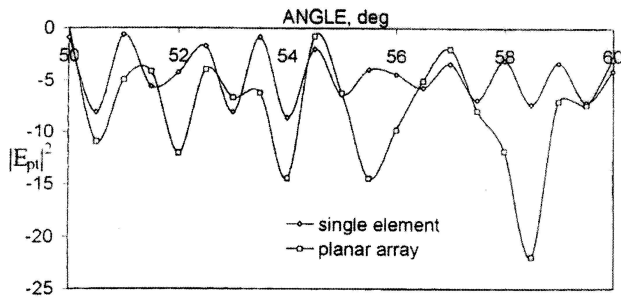


Figure 6. Plasma-mode field pattern of 2×2 element planar array and single element equilateral triangular patch microstrip antennas for $A = 0.5$.

Finally, it is concluded that the 2×2 element planar array of equilateral triangular patch microstrip antenna has unique radiation characteristics and a possible use of the present array geometry may be in search and track applications in radar system due to its unique scanning capabilities. The theoretical results obtained in the present study may be helpful for prospective antenna designers and investigators for several applications. An experimental verification of the present array geometry

Table 1. Calculated values of pattern characteristics of planar array antenna in free space.

	$\phi = 0$ plane		$\phi = \pi/2$ plane	
	$\beta_x = \beta_y = \pi/2$	$\beta_x = \beta_y = \pi/3$	$\beta_x = \beta_y = \pi/2$	$\beta_x = \beta_y = \pi/3$
2×2 Element planar array				
Half-power beam width (HPBW)	80°	60°	80°	60°
First null beam width (FNBW)	120°	100°	120°	100°
Direction of max. radiation	90°	90°	90°	90°

in free space as well as in plasma medium is required which may give additional information about the effect of plasma.

References

- [1] I L Freeston and R K Gupta, *Proc. IEE*, **18**, 633 (1971)
- [2] Y T Lo, D Soloman and W F Richards, *IEEE Trans. Antennas Propag.* **AP-27**, 137 (1979)
- [3] K R Carver and J W Mink, *IEEE Trans. Antennas Propag.* **AP-29**, 2 (1981)
- [4] I J Bahl and P Bhartia, *Microstrip antennas* (Artech House, London, 1980)
- [5] C A Balanis, *Antenna theory – analysis and design* (Harper and Row, New York, 1982)
- [6] J R James and P S Hall, *Handbook of microstrip antennas* (Peter-Peregrinus Ltd, London, UK, 1989)