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Radiation from a Triangular Microstrip Antenna Surrounded by an Isotropic & Homogeneous Plasma

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The radiation properties of a triangular microstrip antenna in an ionized plasma medium are investigated. Hydrodynamic theory with vector potential function approach is used to derive expressions for the far-zone electromagnetic and plasma mode radiation field patterns. The results are plotted in plasma medium as well as in the free space. A comparison is made with the radiation patterns of a square-patch microstrip antenna.

1 Introduction

Due to their light weight and better aerodynamic properties, microstrip antennas of different configurations are being increasingly used on-board aerospace vehicles, satellites and portable system applications[1-3]. An antenna mounted on a space vehicle encounters ionized plasma during their travel in space and its radiation properties are modified to a great extent. Gujar and Gupta[4,5] and Bhatnagar and Gupta[6-8] studied the radiation properties of microstrip antennas in ionized plasma medium and noticed considerable plasma effect.

In this paper, the radiation properties of a microstrip triangular antenna in an ionized isotropic warm plasma are studied. The far-zone field expressions for electromagnetic as well as for electroacoustic modes are obtained using well known hydrodynamic theory and potential function techniques. The field pattern factors are computed and compared with the corresponding field pattern factors of a square-patch microstrip antenna. By substituting plasma frequency to zero, the free space field patterns are also derived. It is concluded that microstrip triangular antenna is suitable for hemispherical coverage applications.

2 Radiation Field Expressions

A triangular microstrip antenna in its simplest shape comprises an equilateral triangular conductor on a dielectric substrate backed by a ground plane. The geometry and coordinate system of the antenna are shown in Fig. 1.

It can be considered as a triangular resonator with magnetic side walls, filled with a dielectric material. Amongst the various TM_{mn} modes that may be excited in such antenna, the fields inside the cavity for dominant mode are as follows[9]

$$E_z = A_{1,0,-1}\left[2\cos\left(\frac{2\pi x}{Ka}+\frac{2\pi}{3}\right)\times\cos\frac{2\pi y}{3a}+\cos\frac{4\pi y}{3a}\right] \quad \ldots(1)$$

$$H_x = \frac{j}{\omega_0\mu}\frac{\partial E_z}{\partial y} \quad \ldots(2a)$$

$$H_y = \frac{-j}{\omega_0\mu}\frac{\partial E_z}{\partial x} \quad \ldots(2b)$$

$$H_z = E_x = E_y = 0$$

By image theory the ground plane is replaced by doubling of the equivalent magnetic surface current

$$\bar{M} = 2\,\bar{E}\times\hat{n} \quad \ldots(3)$$

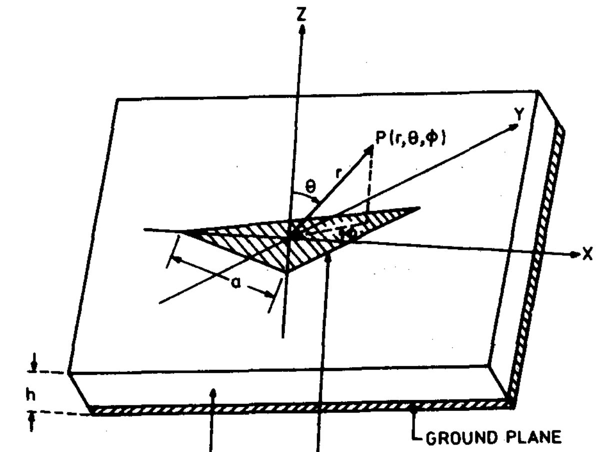

Fig. 1—Geometry and coordinate system of a triangular microstrip antenna

where $\hat{n}$ is a unit vector normal to the aperture. Using the method followed earlier by Bhatnagar and Gupta[6-8], radiation fields for EM-mode and P-mode are derived by evaluating the vector electric potential[10]. The EM-mode and P-mode fields can be expressed as follows:

EM-mode

$$E_r=0 \quad \ldots(4a)$$

$$E_\theta=-\mathrm{j}\,\eta\,\omega_0[-F_x\sin\phi+F_y\cos\phi] \quad \ldots(4b)$$

$$E_\phi=\mathrm{j}\,\eta\,\omega_0[F_x\cos\theta\cos\phi+F_y\cos\theta\sin\phi] \quad \ldots(4c)$$

where

$$\begin{aligned}F_x=&A_{1,0,-1}\,KC_{xy}\left[\frac{X_1}{4b^2-X_1^2}\left\{\left[0.5\sin(0.5KaX_1)\right.\right.\right.\\&\left.-\frac{Kb}{X_1}\cos(0.5KaX_1)\right]-\mathrm{j}\left[0.5\cos(0.5KaX_1)\right.\\&\left.\left.+\frac{Kb}{X_1}\sin(0.5KaX_1)+1\right]\right\}\\&+\frac{X_1}{b^2-X_1^2}\{[\cos(0.5KaX_1)\\&\times(0.5Kb/X_1+0.5)+1]\\&+\mathrm{j}[\sin(0.5KaX_1)(0.5Kb/X_1+0.5)]\}\\&+\frac{X_2}{4b^2-X_2^2}\left\{\left[0.5\sin(0.5KaX_2)\right.\right.\\&\left.-\frac{Kb}{X_2}\cos(0.5KaX_2)\right]\\&-\mathrm{j}\left[0.5\cos(0.5KaX_2)\right.\\&\left.\left.+\frac{Kb}{X_2}\sin(0.5KaX_2)+1\right]\right\}\\&+\frac{X_2}{b^2-X_2^2}\left\{\left[\cos(0.5KaX_2)\right.\right.\\&\left.\times\left(\frac{0.5Kb}{X_2}+0.5\right)+1\right]\\&\left.\left.+\mathrm{j}\left[\sin(0.5KaX_2)\left(\frac{0.5Kb}{X_2}+0.5\right)\right]\right\}\right]\end{aligned} \quad \ldots(5)$$

$$\begin{aligned}F_y=&A_{1,0,-1}\,C_{xy}\left[\frac{X_3}{4p^2-X_3^2}\left\{\left[0.5\sin(0.5aX_3)\right.\right.\right.\\&\left.-\frac{Kp}{X_3}\cos(0.5aX_3)\right]-\mathrm{j}\left[0.5\cos(0.5aX_3)\right.\\&\left.\left.+\frac{Kp}{X_3}\sin(0.5aX_3)+1\right]\right\}+\frac{X_3}{p^2-X_3^2}\\&\times\left\{\left[\cos(0.5aX_3)\left(\frac{0.5Kp}{X_3}+0.5\right)+1\right]\right.\\&\left.+\mathrm{j}\left[\sin(0.5aX_3)\left(\frac{0.5Kp}{X_3}+0.5\right)\right]\right\}\\&+\frac{X_4}{4p^2-X_4^2}\left\{\left[\frac{Kp}{X_4}\cos(0.5aX_4)\right.\right.\\&\left.-0.5\sin(0.5aX_4)\right]-\mathrm{j}\left[0.5\cos(0.5aX_4)\right.\\&\left.\left.+\frac{Kp}{X_4}\sin(0.5aX_4)+1\right]\right\}\\&+\frac{X_4}{p^2-X_4^2}\left\{\cos(0.5aX_4)\right.\\&\times\left(0.5-\frac{Kp}{X_4}\right)-\mathrm{j}\sin(0.5aX_4)\\&\left.\times\left(0.5-\frac{Kp}{X_4}\right)\right\}+\frac{3a}{\pi}\exp(\mathrm{j}\,0.5Ka\sin\theta\cos\phi)\\&\times\left\{\frac{\sigma\sin\left(\frac{\pi\sigma}{3}\right)+2K\cos\left(\frac{\pi\sigma}{3}\right)}{4-\sigma^2}\right.\\&\left.\left.+2\,\frac{\sigma\sin\left(\frac{\pi\sigma}{3}\right)-K\cos\left(\frac{\pi\sigma}{3}\right)}{1-\sigma^2}\right\}\right]\end{aligned} \quad \ldots(6)$$

$$C_{xy}=\frac{\varepsilon_0 h}{4\pi r}\exp(-\mathrm{j}\,\beta_e r)\exp(\mathrm{j}\,a/K\beta_e\sin\theta\cos\phi) \quad \ldots(7)$$

$X_1=\beta_e L_1, X_2=\beta_e L_2, X_3=\beta_e L_3, X_4=\beta_e L_4$

$L_1=\sin\theta(\cos\phi+1/K\sin\phi)$

$L_2=\sin\theta(\cos\phi-1/K\sin\phi)$

$L_3=\sin\theta(K\cos\phi+\sin\phi)$

$$L_4 = \sin\theta(-K\cos\phi + \sin\phi)$$

$$\sigma = \frac{3\beta_e a \sin\theta \sin\phi}{2\pi} \qquad \ldots(8)$$

P-mode

$$E_p = \frac{2h\beta_p \omega_p^2 \exp(-j\beta_p r)}{3a\omega_0 \varepsilon_0(\omega_0^2 - \omega_p^2) r} \times \exp(-j a/K\beta_p \sin\theta\cos\phi) \times [E_{px} + E_{py}]\hat{r} \qquad \ldots(9)$$

where

$$\begin{aligned} E_{px} = {} & \frac{1}{\bar{X}_1 - 4b^2}[-\{0.5K\bar{X}_1 \sin(0.5Ka\bar{X}_1) + b\cos(0.5Ka\bar{X}_1) + 2b\} + j\{0.5K\bar{X}_1\cos(0.5Ka\bar{X}_1) - b\sin(0.5Ka\bar{X}_1)\}] \\ & - \frac{1}{\bar{X}_1 - b^2} \times [\{b\cos(0.5Ka\bar{X}_1) - 0.5K\bar{X}_1\sin(0.5KaX_1) + b\} + j\{b\sin(0.5Ka\bar{X}_1) + 0.5K\bar{X}_1\cos(0.5Ka\bar{X}_1)\}] \\ & + \frac{1}{\bar{X}_2^2 - 4b^2}[-\{0.5K\bar{X}_2\sin(0.5Ka\bar{X}_2) + b\cos(0.5Ka\bar{X}_2) + 2b\} + j\{0.5K\bar{X}_2\cos(0.5Ka\bar{X}_2) - b\sin(0.5Ka\bar{X}_2)\}] \\ & - \frac{1}{\bar{X}_2^2 - b^2}[\{b\cos(0.5Ka\bar{X}_2) - 0.5K\bar{X}_2\sin(0.5Ka\bar{X}_2) + b\} + j\{b\sin(0.5Ka\bar{X}_2) + 0.5K\bar{X}_2\cos(0.5Ka\bar{X}_2)\}] \end{aligned} \qquad \ldots(10)$$

$$\begin{aligned} E_{py} = {} & \frac{1}{\bar{X}_3^2 - 4p^2}[-\{0.5K\bar{X}_3\sin(0.5a\bar{X}_3) + p\cos(0.5a\bar{X}_3) + 2p\} + j\{0.5K\bar{X}_3\cos(0.5a\bar{X}_3) - p\sin(0.5a\bar{X}_3)\}] \\ & - \frac{1}{\bar{X}_3^2 - p^2}[\{p\cos(0.5a\bar{X}_3) - 0.5K\bar{X}_3\sin(0.5a\bar{X}_3) + p\} + j\{0.5K\bar{X}_3\cos(0.5a\bar{X}_3) - p\sin(0.5a\bar{X}_3)\}] \\ & - \frac{1}{\bar{X}_3^2 - p^2}[\{p\cos(0.5a\bar{X}_3) - 0.5K\bar{X}_3\sin(0.5a\bar{X}_3) + p\} + j\{p\sin(0.5a\bar{X}_3) + 0.5K\bar{X}_3\cos(0.5a\bar{X}_3)\}] \\ & + \frac{1}{\bar{X}_4^2 - 4p^2}[-\{0.5K\bar{X}_4\sin(0.5a\bar{X}_4) + p\cos(0.5a\bar{X}_4) + 2p\} + j\{0.5K\bar{X}_4\cos(0.5a\bar{X}_4) - p\sin(0.5a\bar{X}_4)\}] \\ & - \frac{1}{\bar{X}_4^2 - p^2} \times [\{p\cos(0.5a\bar{X}_4) - 0.5K\bar{X}_4\sin(0.5a\bar{X}_4) + p\} + j\{p\sin(0.5a\bar{X}_4) + 0.5K\bar{X}_4\cos(0.5a\bar{X}_3)\}] \\ & - \frac{1}{\bar{X}_5^2 - p^2}\{jK\bar{X}_5\cos(0.5a\bar{X}_5) - p\sin(0.5a\bar{X}_5)\} - \frac{1}{\bar{X}_5^2 - p^2/4} \times \{jK\bar{X}_5\cos(0.5a\bar{X}_5) - p/2\sin(0.5a\bar{X}_5)\} \end{aligned} \qquad \ldots(11)$$

$$\bar{X}_1 = \beta_p L_1, \bar{X}_2 = \beta_p L_2, \bar{X}_3 = \beta_p L_3, \bar{X}_4 = \beta_p L_4$$

$$\bar{X}_5 = \beta_p \sin\theta\sin\phi$$

3 Field Patterns

The expression for total field pattern is obtained as usual[6]

$$R(\theta,\phi) = |E_\theta|^2 + |E_\phi|^2 \qquad \ldots(12)$$

By Eq. (4), the field pattern factors for E- and H-plane are:

(i) For E-plane ($\phi = 0$)

$$F_{e\theta} = \eta^2\omega_0^2[|F_y|^2 + |F_x|^2\cos^2\theta] \qquad \ldots(13)$$

(ii) For H-plane ($\phi = \pi/2$)

$$F_{h\theta} = \eta^2\omega_0^2[|F_x|^2 + |F_y|^2\cos^2\theta] \qquad \ldots(14)$$

The field pattern factors $F_{e\theta}$ and $F_{h\theta}$ are computed for a case taking frequency $f = 10$ GHz, $a = 1.1$ cm, and $\varepsilon_r = 3.55$. The results are plotted in Figs 2 and 3 respectively for plasma parameter $A = 0.5$, i.e. in plasma; and $A = 1.0$, i.e. in free space.

The field patterns are also compared with the field patterns of a square-patch microstrip antenna, which are available in the literature[11].

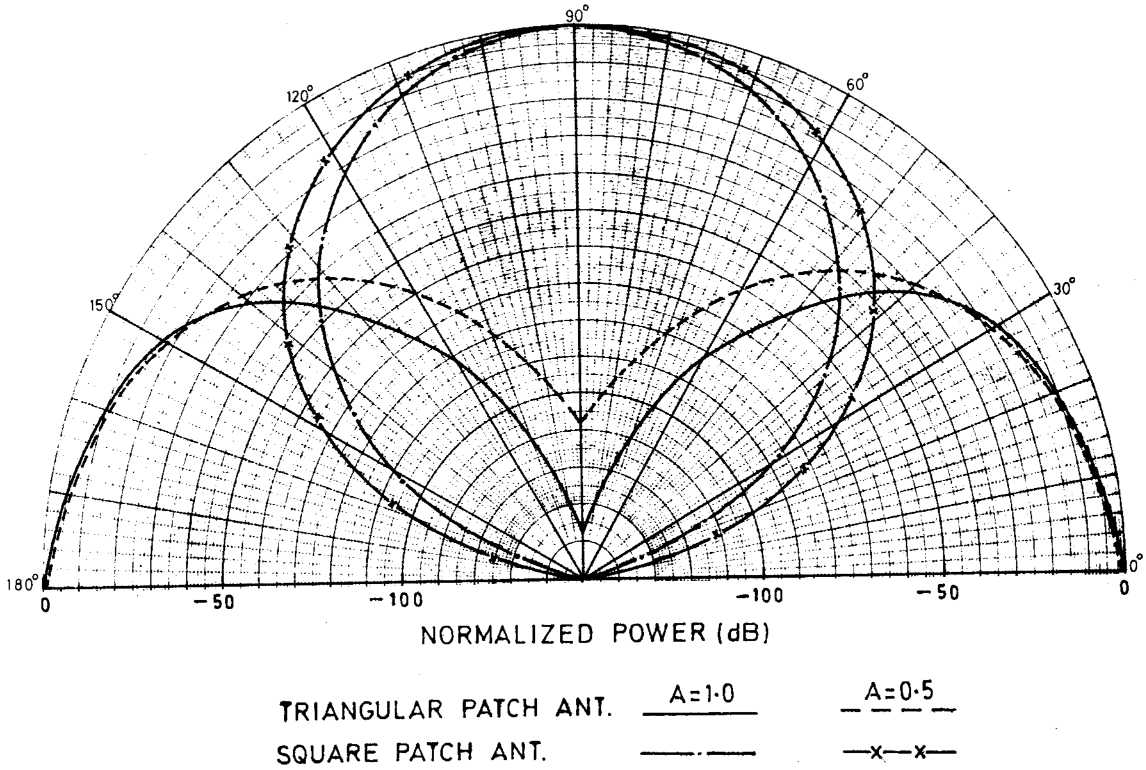

Fig. 2—Variation in theoretical values of field pattern factors of the triangular microstrip antenna and the square-patch microstrip antenna in H-plane

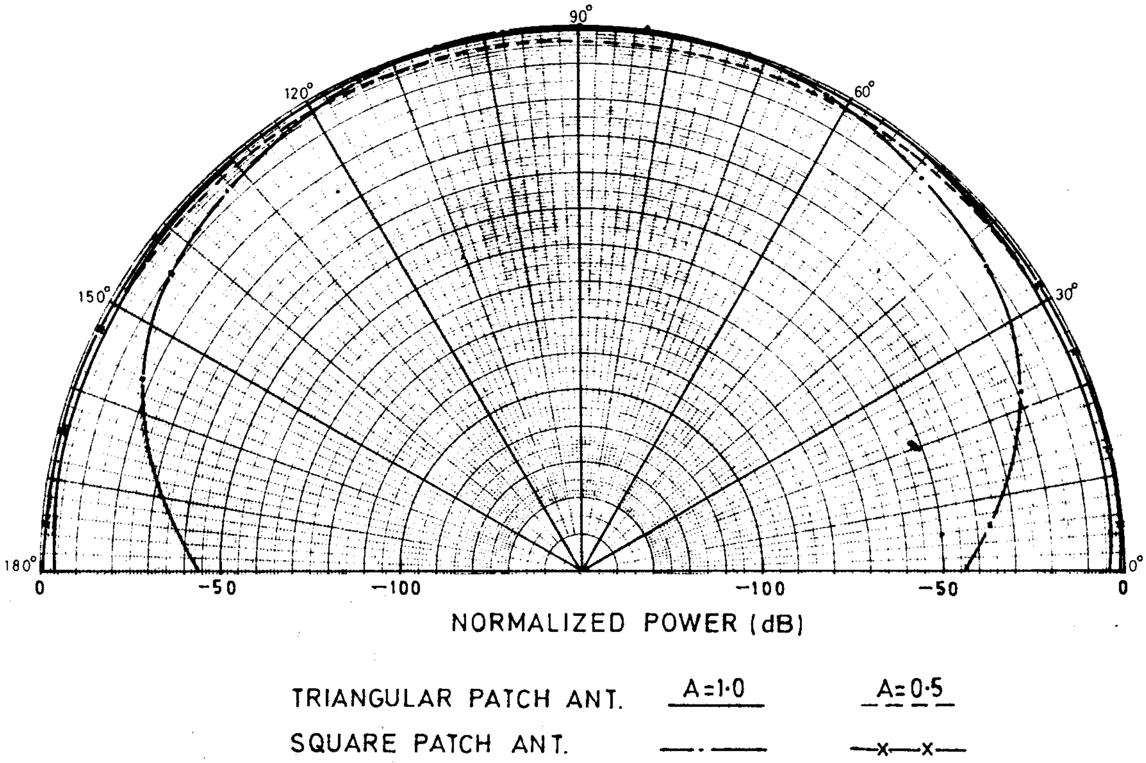

Fig. 3—Variation in theoretical values of field pattern factors of the triangular microstrip antenna and the square-patch microstrip antenna in E-plane

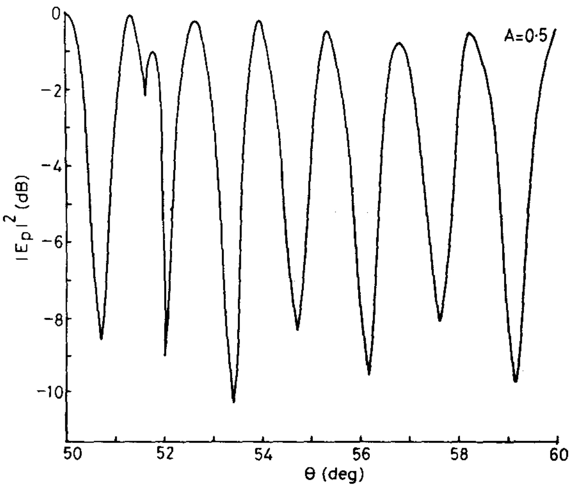

Fig. 4—Plasma mode field pattern, $|E_p|^2$, of the triangular microstrip antenna for plasma parameter $A = 0.5$

The P-mode fields are plotted in Fig. 4 taking $A = 0.5$ for a limited range of 10 degrees (50°-60°).

4 Discussion and Conclusion

From the present study it is found that the presence of plasma modifies the radiation characteristics of the triangular microstrip antenna. The H-plane plot (Fig. 2) shows that null direction is less prominent in plasma medium, whereas the E-plane (Fig. 3) field patterns remain almost omnidirectional.

The P-mode field patterns (Fig. 4) are similar to those for microstrip and conventional antennas, with innumerable maxima and minima.

While comparing the radiation properties with a square -patch microstrip antenna, it is found that

(a) In the H-plane, the maximum radiations occur in the plane of antenna for the square-patch antenna; whereas in the case of triangular microstrip antenna, it is in the normal plane. However, the effect of plasma is identical for both the antennas.

(b) In the E-plane, the patterns are almost similar in broadside direction ($\theta = 0$), but the beam is narrower in the end-fire direction ($\theta = \pi/2$) in the case of square-patch antenna.

From the present study it can be concluded that the power distribution is symmetrical in every direction for a triangular microstrip antenna, and as such it may be suitable for hemispherical coverage even in the plasma medium.

Nomenclature

$A_{1,0,-1}$	An arbitrary amplitude constant.
$A=$	$[1-(\omega_p^2/\omega_0^2)]^{1/2}$, Plasma frequency parameter
a	Length of a side of triangle
$b=4\pi/3aK$	
$\beta_e = 2\pi A/\lambda_0$,	Phase propagation constant of EM-mode
β_p	Phase propagation constant of P-mode
ε_r	Relative permittivity of subtrate material
η	Wave impedance in plasma media
E_θ, E_ϕ	Components of electric vector for EM-mode
E_p	Electric field vector for P-mode
$F_{e\theta}$	Field pattern factor in E-plane
$F_{h\theta}$	Field pattern factor in H-plane
h	Thickness of the subtrate
$K=[3]^{1/2}$	
λ_0	Free space wavelength
μ	Permeability of subtrate material
ω_0	Angular source frequency
ω_p	Angular plasma frequency
$p=4\pi/3a$	
r	Radial distance of observation point
$\hat{r}$	Unit vector along radial direction

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