*Material Science Research India* Vol. **6**(1), 161-166 (2009)

# Radiation characteristics of rectangular microstrip antenna in weakly ionized plasma medium

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(Received: April 16, 2009; Accepted: May 22, 2009)

**ABSTRACT**

Theoretical investigation has been carried out to evaluate the effect of weakly ionized plasma medium on radiation characteristics of rectangular microstrip antenna. Elemental area has been utilized to obtain the components of radiated fields which further extrapolated to obtain the components of radiation for rectangular patch. Further these expressions are modified for weakly ionized plasma medium. It has been observed that the presence of plasma medium affect the radiation characteristics of microstrip antennas to a great extent. The investigation reveals that in weakly ionized plasma, the level of first side lobe increases with increasing value of $w_p/w$. The effective permittivity is also found to decrease with higher values of $w_p/w$, as a result of which microstrip patches becomes more omnidirectional.

**Key words:** Rectangular, microstrip antenna, Weakly-ionized, radiation, plasma.

## INTRODUCTION

With the advancement of communication engineering the technique of microstrip antennas has been used widely in microwave circuit elements such as transmission line, filter, resonator etc. Recently considerable interest has been devoted to investigate the influence of plasma on the radiation characteristics of microstrip antennas[1-4]. In spite of numerous advantages of microstrip antennas over the conventional microwave antennas, very few definitive data regarding the effect of plasma on the radiation characteristics of such antennas are found. Since during the journey of space of such antennas it has to pass through the ionosphere, consequently the properties of such antennas are modified. Thus it may be mentioned that plasma medium encountered during the voyage of space shuttles or satellites may modified the properties of microstrip antennas. It is therefore thought useful to study the effect of plasma on the various aspects of the antenna, the details of which are given in the following sections of this paper.

### Theoretical consideration

In order to obtain the radiation from rectangular microstrip antenna the mechanism of radiation from an elemental area shown in Figure 1 has been utilized. The elemental area has been excited by both electric and magnetic fields. Thus electric vector potential and magnetic vector potential and magnetic vector potential for elemental area are given by the relation respectively as[5].

$$\mathbf{F} = \frac{\epsilon}{4\pi}\int_s \frac{\mathbf{M}e^{-jkr}}{R}ds \quad ...(1)$$

$$\mathbf{A} = \frac{\mu}{4\pi}\int_s \frac{\mathbf{J}e^{-jkr}}{R}ds \quad ...(2)$$

Where **J** and **M** are the electric and magnetic surface current densities respectively given as

$$\mathbf{J} = \hat{n} \times \mathbf{H} \qquad ...(3)$$

and

$$\mathbf{M} = \hat{n} \times \mathbf{E} \qquad ...(4)$$

Further under far field approximation one has from figure 1

$$R = r - r'\cos\psi \qquad ...(5)$$

Now for such approximation the equations (1) and (2) may be given as

$$\mathbf{F} = \frac{\in e^{-jkr}}{4\pi r}\int_s \mathbf{M} e^{-jkr'\cos\psi} ds \qquad ...(6)$$

$$\mathbf{A} = \frac{\mu e^{-jkr}}{4\pi r}\int_s \mathbf{J} e^{jkr'\cos\psi} ds \qquad ...(7)$$

Now for the simplicity of calculation let us assume

$$\int_s \mathbf{J} e^{jkr'\cos\psi} ds = N \qquad ...(8)$$

$$\int_s \mathbf{M} e^{jkr'\cos\psi} ds = L \qquad ...(9)$$

Then equation (6) and (7) reduce to

$$\mathbf{F} = \frac{\in e^{-jkr}}{4\pi r} L \qquad ...(10)$$

and

$$\mathbf{A} = \frac{\mu e^{-jkr}}{4\pi r} N \qquad ...(11)$$

Now expressing radial vectors in terms of Cartesian co-ordinates one has

$$\mathbf{a}_r = \mathbf{a}_x \sin\theta\cos\phi + \mathbf{a}_y \sin\theta\sin\phi + \mathbf{a}_z \cos\theta \qquad ...(12)$$

$$\mathbf{a}_{r'} = \mathbf{a}_x \sin\theta'\cos\phi' + \mathbf{a}_y \sin\theta'\sin\phi' + \mathbf{a}_z \cos\theta' \qquad ...(13)$$

Then from figure 1 one has

$$\cos\psi = \mathbf{a}_r.\mathbf{a}_{r'} = \sin\theta\sin\theta'\cos(\phi - \phi') + \cos\theta\cos\theta' \qquad ...(14)$$

If the contribution to far fields from electric and magnetic vector potential is isolated then one has

$$\mathbf{E} = \mathbf{E}_A + \mathbf{E}_F \qquad ...(15)$$

Further using spherical Co-ordinates one has

$$\nabla \times \mathbf{F} = -a_\theta \frac{\partial F_\phi}{\partial r} + a_\phi \frac{\partial F_\theta}{\partial r} \qquad ...(16)$$

$$\nabla \times \mathbf{A} = -a_\theta \frac{\partial A_\phi}{\partial r} + a_\phi \frac{\partial A_\theta}{\partial r} \qquad ...(17)$$

Then the values of $E_{A\phi}$, $E_{F\theta}$, and $E_{F\phi}$, are given as

$$E_{A\theta} = \frac{-Jke^{-jkr}}{4\pi r} Z_0 N_\theta \qquad ...(18)$$

$$E_{A\phi} = \frac{-Jke^{-jkr}}{4\pi r} Z_0 N_\phi \qquad ...(19)$$

$$E_{F\theta} = \frac{-Jke^{-jkr}}{4\pi r} L_\phi \qquad ...(20)$$

$$E_{F\phi} = \frac{Jke^{-jkr}}{4\pi r} L_\theta \qquad ....(21)$$

$L_\theta$ and $L_\phi$ are obtained from equation (9). Now combining equations (18), (19), (20) and (21) the components of electric fields are given as

$$E_\theta = E_{A\theta} + E_{F\theta} = \frac{-Jke^{-jkr}}{4\pi \; r}\left(L_\phi + Z_0 N_\theta\right) \quad ...(22)$$

and

$$E_\phi = E_{A\phi} + E_{F\phi} = \frac{Jke^{-jkr}}{4\pi \; r}\left(L_\theta - Z_0 N_\phi\right) \quad ...(23)$$

Further the values of $E_\theta$ and $E_\phi$ can be obtained only when the values of $N_\theta$ and $N_\phi$ are known, which is given as

$$N_\theta = \left(N_x \cos\phi + N_y \sin\phi\right)\cos\theta - N_z \sin\theta \quad ...(24)$$

and

$$N_\phi = \left(-N_x \sin\phi + N_y \cos\phi\right) \quad ...(25)$$

Thus from equations (24) and (25) one has

$$dN_\theta = dN_y \sin\phi\cos\theta = \frac{-E_0 ds \sin\phi\cos\theta}{Z_0}$$

$$dN_\phi = dN_y \cos\phi = \frac{-E_0 ds \cos\phi}{Z_0} \quad ...(26)$$

Also

$$dL_\theta = -dL_z \sin\theta = E_0 ds \sin\theta \quad ...(27)$$

and

$$dL_\phi = 0 \quad ...(28)$$

Now from equations (22) and (23) the θ and ϕ components of far electric field can be obtained as

$$dE_\theta = \frac{-Je^{-jkR} E_0 ds \sin\phi\cos\theta}{2\lambda \; R} \quad ...(29)$$

and

$$= \frac{Je^{-jkR} E_0 ds(\sin\theta + \cos\phi)}{2\lambda \; R} \quad ..(30)$$

Up till now we have developed the equations for the radiations of elemental area. Further these equations are essentially extended and utilized to obtained the field components of rectangular antenna which as follows

**Rectangular micrstrip antenna**

For this purpose, let us consider an aperture of rectangular microstrip antenna figure 2 in x = 0 plane with sides of length *a* and *b* in the y and z directions respectively. Now for uniform illumination of aperture the electric field is constant in amplitude and phase over the aperture, thus in this case equations (30) and (31) integrated over the aperture give the components of electric field of rectangular microstrip antenna[5]. Thus

$$E_\theta = \frac{-Je^{-jkr} E_0 dz\left(\sin\phi\cos\theta\right)}{2\lambda \; r}\iint e^{jkr'\cos\psi} dy'\,dz' \quad ...(31)$$

where

$$r'\cos\psi = \left(y'\sin\theta\sin\phi + z'\cos\theta\right) \quad ...(32)$$

hence

$$E_\theta = \frac{-Je^{-jkr} E_0 dz\left(\sin\phi\cos\theta\right)}{2\lambda \; r}\int_{-b/2}^{b/2}\int_{-a/2}^{a/2} e^{jk(y'\sin\theta\sin\phi + z'\cos\theta)} dy'\,dz' \quad ...(33)$$

Solving equation (33) one has

$$E_\theta = \frac{-abE_0 e^{-jkr}\left(\sin\phi\cos\theta\right)}{2\lambda \; r}$$

$$\left[\frac{\sin\left(\frac{ka}{2}\sin\theta\sin\phi\right)}{\left(\frac{ka}{2}\right)\sin\theta\sin\phi}\right]\left[\frac{\sin\left(\frac{kb}{2}\cos\theta\right)}{\left(\frac{kb}{2}\right)\cos\theta}\right] \quad ...(34)$$

In the similar fashion one can write the value of $E_\phi$ as

$$E_\phi = \frac{abE_0 e^{-jkr}\left(\sin\theta + \cos\phi\right)}{2\lambda \;\; r}\left[\frac{\sin\left(\frac{ka}{2}\sin\theta\sin\phi\right)}{\left(\frac{ka}{2}\right)\sin\theta\sin\phi}\right]\left[\frac{\sin\left(\frac{kb}{2}\cos\theta\right)}{\left(\frac{kb}{2}\right)\cos\theta}\right] \quad ...(35)$$

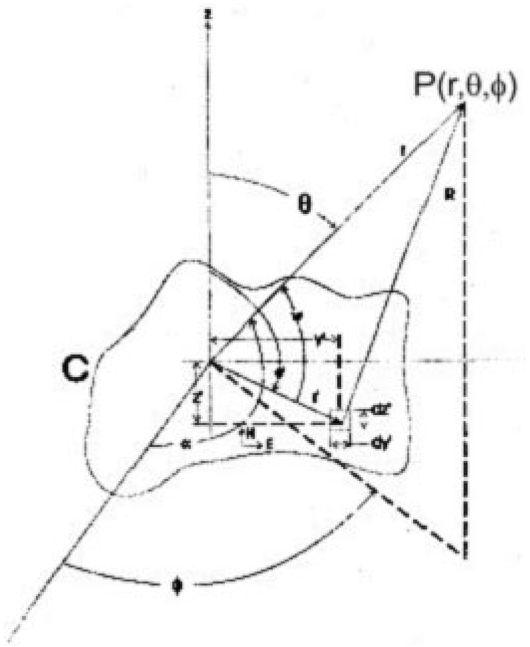


**Fig. 1: Elemental microstrip antenna**

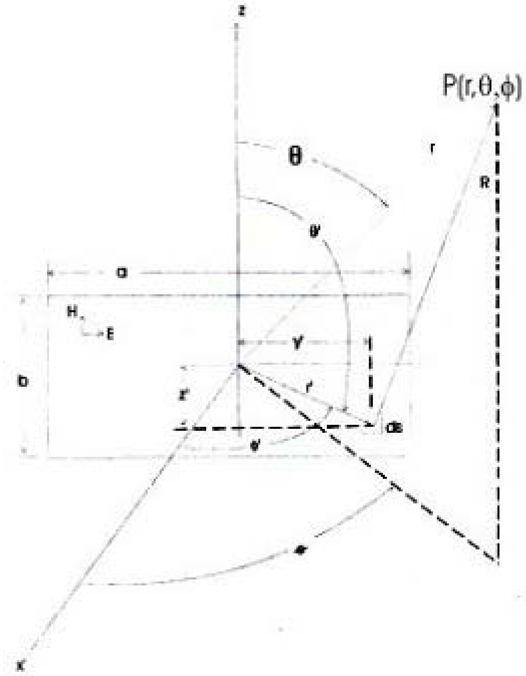


**Fig. 2: Rectangular microstrip antenna**

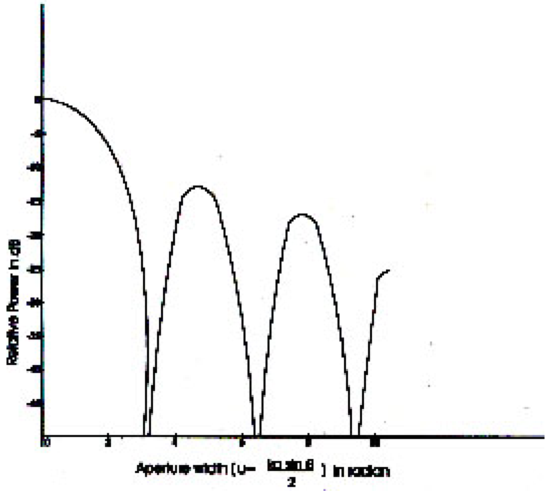


**Fig. 3: Variation of relative power of rectangular microstrip antenna with aperture width (u)**

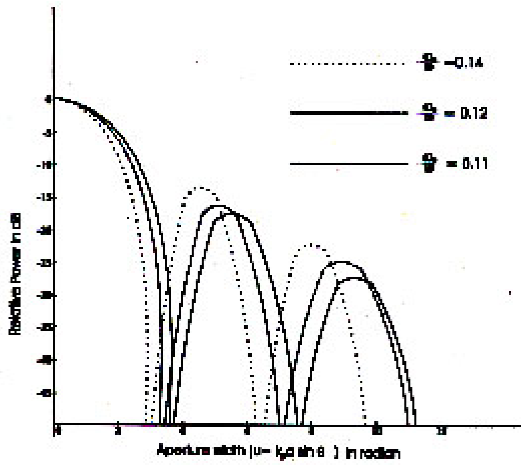


**Fig. 4. Variation of relative power of rectangular microstrip antenna with aperture width (u) in weakly ionized plasma medium for different of $\frac{\omega_p}{\omega}$**

Now the field in z plane is modified as

$$E_\phi\left(r, \pi/2, \phi\right) = \frac{abE_0 e^{-jkr}\left(1+\cos\phi\right)}{2\lambda r}$$

$$\left[\frac{\sin\left(\frac{ka}{2}\sin\phi\right)}{\left(\frac{ka}{2}\right)\sin\phi}\right] = \frac{abE_0 e^{-jkr}\left(1+\cos\phi\right)}{2\lambda\ r}\left[\frac{\sin u}{u}\right] \quad ...(36)$$

where

$$u = \frac{ka}{2}\sin\phi$$

and a is the length of side in figure 2.

## Analysis of rectangular microstrip antenna in weakly ionized plasma medium

### Weakly ionized plasma medium

For this purpose the dielectric constant of plasma medium can be given as

$$\epsilon_{rpeff} = 1 - \left(\frac{\omega_p}{\omega}\right)^2 \quad ...(37)$$

where,

$\omega_p$ = electron plasma frequency

and

$\omega$ = angular frequency

Now the propagation constant in plasma medium is defined as

$$k_p = \frac{2\pi}{\lambda_0}\sqrt{\epsilon_{rpeff}} \quad ...(38)$$

Further taking collision effect into account the effective dielectric constant in weakly ionized plasma medium is defined as

$$\epsilon_{rpeff} = 1 - \left(\frac{\omega_p^{\ 2}}{\omega^2\left(1-\frac{j\nu}{\omega}\right)}\right) = 1 - \left(\frac{\omega_p^{\ 2}\omega^2}{\omega^4+\omega^2\nu^2} + \frac{j\nu\omega_p\omega}{\omega^4+\omega^2\nu^2}\right) \quad ...(39)$$

Where v is the collision frequency, which is given by the relation

$$\nu = \nu_0\left[1+\left(\frac{T_e - T}{2T}\right)\right] \quad ...(40)$$

Where $T_e$ is the electronic temperature and T is the electromagnetic temperature putting the value of n in equation (39) one has

$$\epsilon_{eff} = 1 - \left(\frac{\omega_p^{\ 2}\omega^2}{\omega^4+\omega^2\ \nu_0^2\left[1+\left(\frac{T_e-T}{2T}\right)\right]^2} + \frac{j\ \omega_p\omega\ \nu_0\left[1+\left(\frac{T_e-T}{2T}\right)\right]}{\omega^4+\omega^2\ \nu_0^2\left[1+\left(\frac{T_e-T}{2T}\right)\right]^2}\right) \quad ...(41)$$

Combining equation (37) and (40) the propagation constant in weakly ionized plasma medium can be obtained as

$$k_p = \frac{2\pi}{\lambda_0}\left[1-\left\{\frac{\omega_p^{\ 2}\omega^2}{\omega^4+\omega^2\nu_0^{\ 2}\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}^2} + \frac{j\omega_p\omega\nu_0\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}}{\omega^4+\omega^2\nu_0^{\ 2}\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}^2}\right\}\right]^{\frac{1}{2}} \quad ...(42)$$

Further let

$$Y = \frac{\omega_p^{\ 2}\omega^{\ 2}}{\omega^4+\omega^2\nu_0^{\ 2}\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}^2} \quad ...(43)$$

and

$$Z = \frac{j\omega_p\omega\nu_0\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}^2}{\omega^4+\omega^2\nu_0^{\ 2}\left\{1+\left(\frac{T_e-T}{2T}\right)\right\}^2} \quad ...(44)$$

Then $k_p$ can be written as

$$k_p = \frac{2\pi}{\lambda_0}\left(1-Y-Z\right)^{\frac{1}{2}} \quad ...(45)$$

**Rectangular microstrip Antenna**

Now the value of $E_\theta$ and $E_\phi$ for rectangular microstrip antenna in weakly ionized plasma medium can be obtained by replacing $K_p$ in equations (34) and (36) respectively as

$$E_\theta = \frac{-abE_0 e^{-jk_p r}\left(\sin\phi\cos\theta\right)}{2\lambda r}$$

$$\left[\frac{\sin\left(\frac{k_p a}{2}\sin\theta\sin\phi\right)}{\left(\frac{k_p a}{2}\right)\sin\theta\sin\phi}\right]\left[\frac{\sin\left(\frac{k_p b}{2}\cos\theta\right)}{\left(\frac{k_p b}{2}\right)\cos\theta}\right] \quad \text{...(46)}$$

and

$$E_\phi\left(r, \pi/2, \phi\right) = \frac{abE_0 e^{-jk_p r}\left(1+\cos\phi\right)}{2\lambda r}\left[\frac{\sin u}{u}\right] \quad \text{...(47)}$$

Putting the value of $K_p$ from equation (45) in equation (46) and (47) one has

$$\left[\frac{\sin\left\{\frac{\pi}{\lambda_0}(1-Y-Z)^{1/2} a\sin\theta\sin\phi\right\}}{\left\{\frac{\pi}{\lambda_0}(1-Y-Z)^{1/2} a\right\}\sin\theta\sin\phi}\right]\left[\frac{\sin\left\{\frac{\pi}{\lambda_0}(1-Y-Z)^{1/2} b\cos\theta\right\}}{\left\{\frac{\pi}{\lambda_0}(1-Y-Z)^{1/2} b\right\}\cos\theta}\right] \quad \text{...(48)}$$

and

$$E_\phi\left(r, \pi/2, \phi\right) = \frac{abE_0 e^{-j\frac{2\pi}{\lambda_0}(1-Y-Z)^{\frac{1}{2}} r}\left(1+\cos\phi\right)}{2\lambda r}\left[\frac{\sin u}{u}\right] \quad \text{...(49)}$$

**Numerical Computation**

In order to obtain the value of E-plane radiation pattern of rectangular, circular and annular microstrip antennas in weakly ionized plasma media, the computational works were done using equations (48) and (49) for $\theta = 60°$, a = 2.5 cm, $\frac{\omega_p}{\omega} = 0.11, 0.12, 0.14, 0.16$ and 0.20. The data thus obtained are shown plotted in the form of graphs in Figures 3 & 4.

## RESULTS AND DISCUSSION

It is found from Figures 3 and 4 that the relative power decreases sinusoidally with increasing aperture width (u) for all patches such as rectangular. The first sidelobe in free space for the rectangular patch is obtained at u = 3.14 having value -13.2 dB. This is due to the fact that the effective area of the uniformly illuminated rectangular patch approaches to the geometrical area. It is also found that relative power decreases with increasing aperture width (u) for different values of $\omega_p/\omega$, Figure 4. This is also corroborated with the fact that the increasing number of ions in plasma medium, increases the values of $\omega_p/\omega$, as a result of which for the particular value of operational frequency, the ratio of $\omega_p/\omega$ increases, which further enhances the relative power of microstrip antenna for rectangular patch.

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