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On radiations from microstrip patch in two component warm ionized plasma medium

Deepak Bhatnagar and K B Sharma*

Microwave Laboratory, Department of Physics, University of Rajasthan, Jaipur-302 004, Rajasthan, India

*Department of Physics, S S Jain Subodh College, Jaipur, Rajasthan, India

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Abstract : Presence of electron-ion plasma medium likely modifies radiation properties of microstrip patch antenna to a great extent. With variation of plasma to source frequency, different radiation properties of patch antenna are observed theoretically by using hydrodynamic theory coupled with vector wave technique

Keywords : Microstrip patch, plasma, radiation conductance, efficiency

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Microstrip antennas are becoming more and more popular in these days due to their light weight, low manufacturing cost and better aerodynamic properties [1,2]. An antenna radiates electroacoustic waves in addition to usual electromagnetic waves during its voyage in ionized plasma media [3]. Presence of electro-acoustic waves is likely to modify the overall radiation properties of antenna structure. Different workers [4,5] have studied radiation properties of linear antennas immersed in ionized plasma medium. The purpose of this paper is to study the effect of ion electron plasma medium on the radiation properties of microstrip rectangular patch antenna fed through a narrow strip. Hydrodynamic theory coupled with vector wave technique is used in the present study.

The geometry and coordinate system of the patch antenna is shown in Figure 1. A microstrip patch of length $l = \lambda_g/2$ (where λ_g is guide wavelength), width b, height h, substrate relative permittivity and permeability of $\varepsilon_r > 1$ and $\mu_r = 1$ respectively, is fed through a narrow strip of very low impedance. The waves guided by the microstrip are assumed to be transverse electromagnetic waves which are concentrated under the strip and incident on each aperture, where some power is radiated and remainder is reflected back as

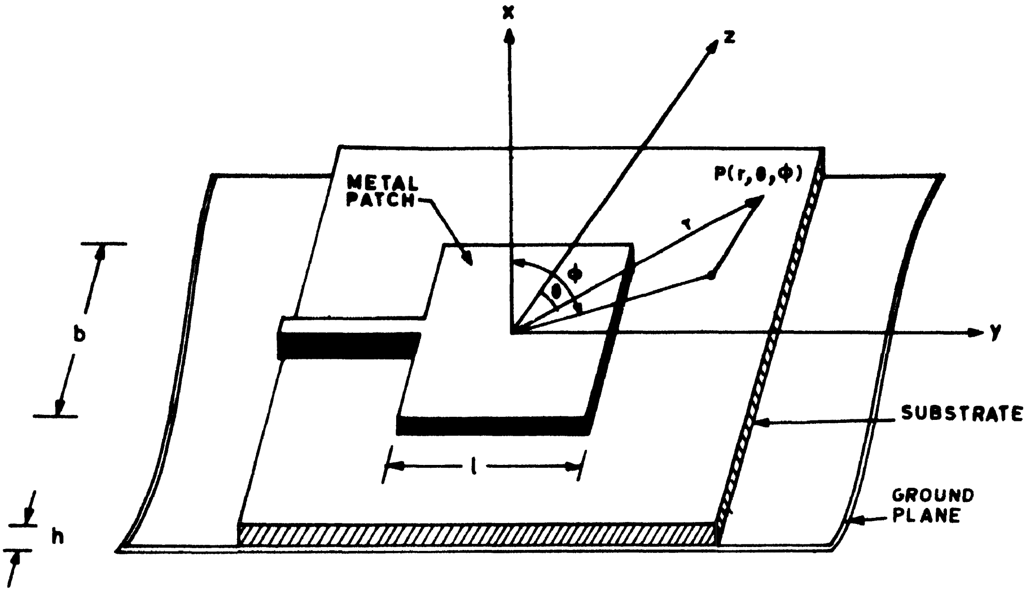

Figure 1. Geometry of microstrip patch.

guided waves. The reflection coefficient $|\Gamma|$ is assumed to be unity. End effects are taken to be negligible for the purpose of simplification [6] because it produces only second order effects in the radiation patterns.

Present analysis is carried out by assuming plasma as warm, homogeneous, lossless, non-drifting continuum of electrons and equal number of singly charged ions. Collisions of electrons with neutral particles, effect of sheath formation around the antenna and the presence of an external magnetic field are disregarded to make derivation simpler. It is also assumed that only aperture portion of the antenna encounters the plasma. This is possible by covering the remaining portion of structure by protective layer like beryllium oxide, polystyrene and ice. When antenna is covered with a protective layer, alteration in resonant frequency takes place. This causes detuning which may seriously degrade performance of the system. For thin protective layers ($d \leq 1$ mm), fractional change in resonant frequency is only about 0.7% at resonant frequency 1.2 GHz which will not make any serious change in results [7].

The electric field at the aperture is assumed to be

$$\bar{E} = E_x \hat{x} \qquad \begin{matrix} -h \leq x \leq h \\ -b/2 \leq z \leq b/2 \end{matrix} \tag{1}$$

Following image theory and an established method [8] expressions for far zone field pattern factors are derived.

(i) Field pattern factor in electromagnetic mode :

$$F_{e\phi} = \left[\frac{\beta_e hb}{240\pi} \sin\theta \cos\left(\beta_e \frac{l}{2} \sin\theta \sin\phi\right)\right] \frac{\sin X}{X} \cdot \frac{\sin Y}{Y} \tag{2}$$

here $X = \left(\beta_e\, h \sin\theta \cos\phi\right),$

$Y = \left(\beta_e\, b \cos\theta\right)/2$

and $F_{e\theta} = 0.$

(ii) Field pattern factor in electroacoustic mode :

$$F_p = \frac{h\, b(1-\alpha_1)(\beta_{p1})\,(\alpha_2 + M)\,\cos\left(\beta_{p1} \frac{l}{2} \sin\theta \sin\phi\right)}{120\pi\, w\, \varepsilon_0 \left(\alpha_1 - \alpha_2\right)\left(Q^2 - 1 - M\right)}$$

$$+ \frac{h\, b(1-\alpha_2)(\beta_{p2})\,(\alpha_1 + M)\,\cos\left(\beta_{p2} \frac{l}{2} \sin\theta \sin\phi\right)}{120\pi\, w\, \varepsilon_0 \left(\alpha_1 - \alpha_2\right)\left(Q^2 - 1 - M\right)}, \tag{3}$$

here

$$X_j = \frac{\sin\left(\beta_{pj}\, h \sin\theta \cos\phi\right)}{\left(\beta_{pj}\, h \sin\theta \cos\phi\right)} \cdot \frac{\sin\left(\beta_{pj}\, \frac{b}{2} \cos\theta\right)}{\left(\beta_{pj} \times \frac{b}{2} \cos\theta\right)} \tag{4}$$

$j = 1, 2$

$Q = w/w_{pe},\ M = m_e/m_i$ and $\beta_e = \beta_0 A,$

β_0 and β_e are propagation constants of E.M. wave in free space and plasma respectively while w_{pe} and w_{pi} are angular plasma frequency of electrons and ions respectively. A is known as plasma parameter which can be defined as

$$A = \left|1 - \frac{w_{pe}^2}{w^2} - \frac{w_{pi}^2}{w^2}\right|^{1/2}$$

The wave numbers β_{p1} and β_{p2} of eq. (4) are the roots of the equation

$$\beta_{pj}^4 - \left(T_{11} + T_{22}\right)\beta_{pj}^2 + \left(T_{11}T_{22} - T_{12}T_{21}\right) = 0 \tag{5}$$

and are related to α_j by

$$\beta_{pj}^2 = T_{11} + T_{21}\,\alpha_j, \tag{6}$$

where α_j are the roots of equation

$$T_{21}\,\alpha_j^2 + \left(T_{11} - T_{22}\right)\alpha_j - T_{12} = 0, \tag{7}$$

here

$$T_{11} = \frac{w^2}{u_e^2}\left|1 - \frac{w_{pe}^2}{w^2}\right|, \quad T_{12} = \frac{w_{pi}^2}{u_i^2},$$

$$T_{21} = \frac{w_{pe}^2}{u_e^2}, \quad T_{22} = \frac{w^2}{u_i^2}\left|1 - \frac{w_{pi}^2}{w^2}\right|.$$

In these expressions, u_0 and u_i are the r.m.s. thermal velocity of electrons and ions respectively. The values of $F_{e\phi}$ (E-plane patterns with $\theta = \pi/2$) and F_p are calculated using $b = 0.081$ m, $l = 0.125$ m, $h = 0.00158$ m and resonant frequency $f_r = 1.2$ GHz to compare results with some other structures working at the same frequency [9,10].

Values of b and h are very small ($b < \lambda_0$, $h << \lambda_0$) to a good approximation $\frac{\sin X}{X}$ and $\frac{\sin Y}{Y}$ reduces to 1 in eq. (2). On the other hand, $l \approx \lambda_0/2$ makes $\cos(\beta_e \frac{l}{2} \sin\theta \sin\phi)$ as

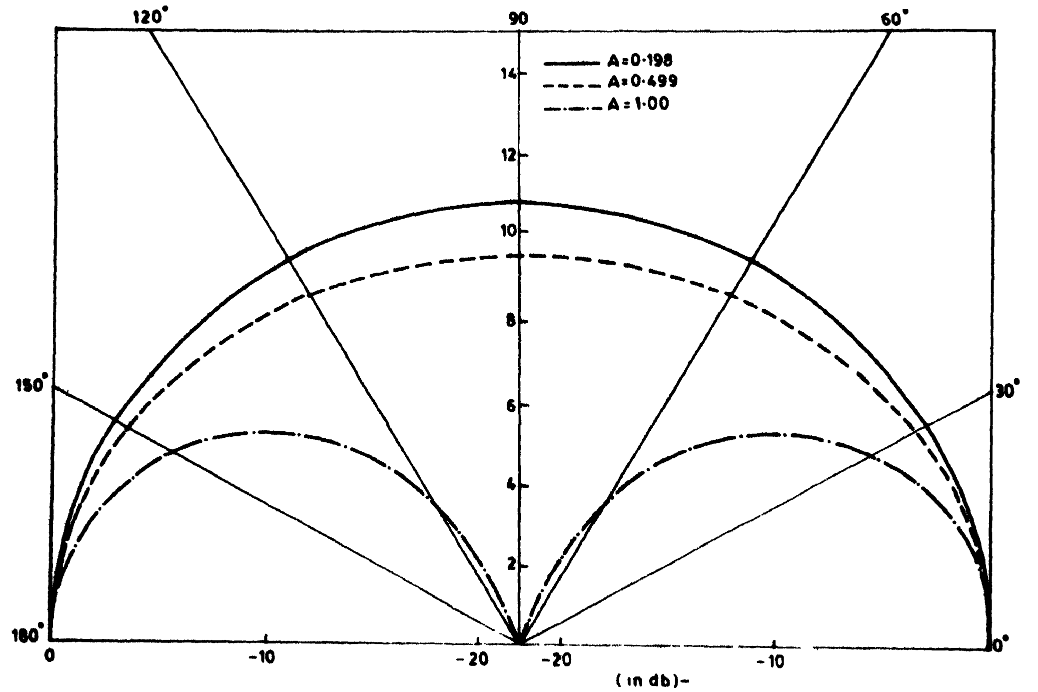

Figure 2. Variation of $F_{e\phi}$ with plasma parameter A.

dominant term in the equation. Due to the presence of this factor, a two lobe pattern appears in free space which reduces to a single lobe on increasing plasma to source frequency.

The power radiated by an antenna through an upper half space can be obtained by integrating the complex poynting vector over a closed surface [11]. Using above relations, the radiation conductance in two modes reduces to

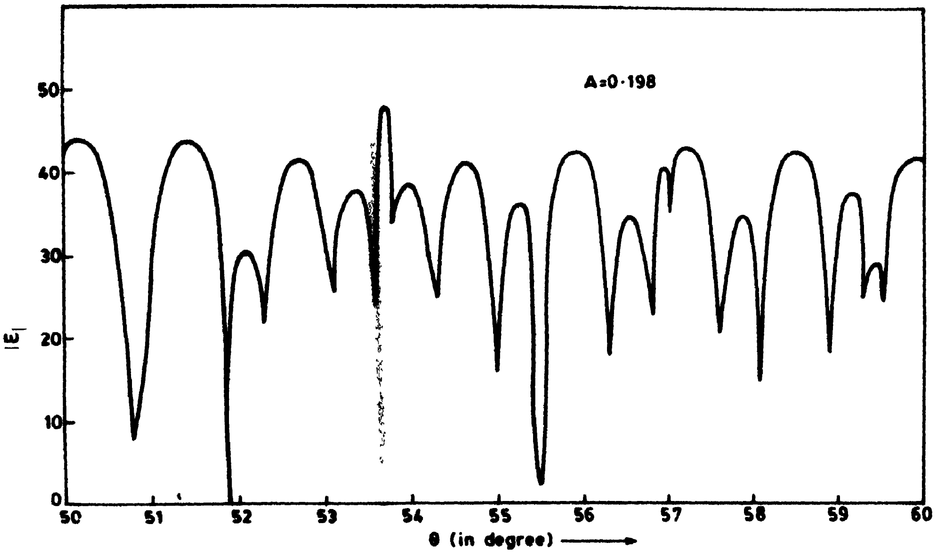

Figure 3. Variation of F_p with angle θ for $A = 0.198$.

(i) In electromagnetic mode :

$$G_e = \frac{P_e}{V_0^2} = \int_0^{2\pi}\int_0^{\pi} \frac{A^3 \beta_0^2 b^2 \sin^3\theta}{120\pi^3} \cos^2\left(\beta_e \frac{l}{2}\sin\theta\sin\phi\right.$$

$$\sin^2 X \quad \sin^2 Y \quad d\theta\, d\phi, \tag{8}$$

here

$$V_0 = E_x \cdot h.$$

(ii) In electroacoustic mode :

$$G_p = \frac{}{V_0^2} = \sum_{j=1,2} \frac{4\, b^2\left(1 - \alpha_j^2\right) w_{pe}^2}{w\, u_e^2\, \beta_{pj}\left(1 + \tau\alpha_j^2\right) \pi^2\, \varepsilon_0}$$

$$\times \int_0^{2\pi}\int_0^{\pi} \cos^2\left(\beta_{pj} \frac{l}{2}\sin\theta\sin\phi\right) X_j^2 \sin\theta \; d\theta\, d\phi, \tag{9}$$

here

$$M = u_i^2 / u_e^2 .$$

Variation of the radiation conductance with plasma parameter A is calculated and tabulated for both electromagnetic mode and electroacoustic mode in Table 1.

Table 1. Variation of radiation conductance and efficiency with plasma parameter A.

Plasma parameter	Radiation conductance (℧)		Efficiency
A	G_e	G_p	(%)
0.1	3.589×10^{-8}	81.0839	—
0.2	2.224×10^{-6}	1.2347	—
0.3	2.403×10^{-5}	6.96×10^{-2}	0.03
0.4	1.2530×10^{-4}	3.37×10^{-2}	0.37
0.5	4.347×10^{-4}	9.50×10^{-4}	31.39
0.6	1.157×10^{-3}	5.83×10^{-4}	66.49
0.7	2.558×10^{-3}	6.10×10^{-4}	80.74
0.8	4.929×10^{-3}	2.57×10^{-4}	95.04
0.9	8.576×10^{-3}	2.50×10^{-5}	99.71
1.0	1.389×10^{-2}	—	100.00

The radiation efficiency of an antenna in plasma medium can be defined as the ratio of useful power output in plasma to the total power input

$$\eta = \frac{\quad}{P_e + P_p} \times 100\ (\%), \qquad (10)$$

here P_e and P_p are the radiated power in electromagnetic mode and electroacoustic mode respectively. Radiation efficiency of some other microstrip structures in plasma medium is also plotted for comparison purpose. Their nomenclatures are tabulated in Table 2.

Table 2. Nomenclatures of some microstrip antennas.

	Rectangular patch antenna	Open circuit rectangular microstrip resonator	Circular patch microstrip antenna
Dimensions			
(i) length (l)	0.125 m and 0.12 42 m*	0.048 m	—
(ii) radius (a)	—	—	0.021 m and 0.022 m*
(iii) width (b)	0.08 lm	0.047 m	—
(iv) thickness (h)	0.00158 m	0.00158 m	0.00158 m
Resonant frequency (fr)	1.2 GHz	1.2 GHz	1.2 GHz
ε_r of substrate	2.31	2.31	2.31

*considering end effects.

Radiation patterns of a rectangular patch antenna indicates that the presence of plasma medium affects them to a great extent. Electromagnetic mode pattern indicates that with the increase of plasma to source frequency ratio, directivity of antenna decreases while 3 db beamwidth increases. Plasma mode radiation pattern shows discrete multilobe pattern, which

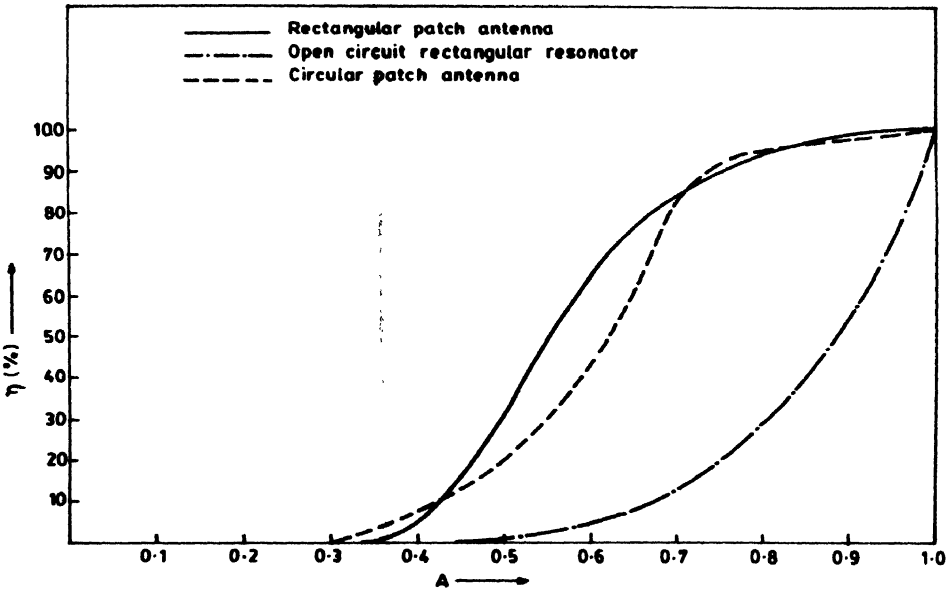

Figure 4. Variation of radiation efficiency with plasma parameter A for different radiators.

is different from that of linear antenna [12,13]. Radiation conductance of present antenna structure in E.M. mode is maximum in free space and becomes negligible for lower A values. On the other hand, plasma mode radiation conductance shows a reverse behaviour. The net result of these two is a continuous decrease in radiation efficiency with decreasing A values although it is still higher than the radiation efficiency of two other antennas working at the same frequency. An interesting feature regarding efficiency is that it becomes almost zero for all antennas under consideration for values of A lower than 0.3.

The effect of plasma medium on radiation properties is quite significant and needs experimental verification though simulation of plasma medium in laboratory is difficult.

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