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Effect of ionized plasma medium on Radiation Characteristics of 6×6 Element Planar Array of Circular Patch Microstrip Antenna

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ABSTRACT

The present work deals with the analysis of 6×6 element planar array of circular patch microstrip antenna at 10 GHz in ionized plasma medium by using linearized hydrodynamic theory with vector potential approach at plasma parameter A = 0.5 for plasma medium and at A = 1.0 for free space. The investigation reveals that the effect of plasma on radiation characteristics of the proposed antenna is quite significant and interesting. It is also noted that the shape of the field pattern in $\phi = \pi/2$ and $\phi = 0$ plane for $\beta_I = \pi/2$ phase excitation difference has been modified to a great extent and it redistributed the field intensity considerably.

Keywords: Microstrip Antenna; Planar Array; Ionized Plasma; Radiation Characteristics, Directive gain, Radiation Efficiency.

I. INTRODUCTION

Microstrip antennas have proved their superiority as low drag, low profile and light weight antenna. These are being increasingly used on space shuttles, high speed vehicles, high flying aircraft and satellites [1-4]. The microstrip antennas have a facility for fabricating linear or planar arrays using printed circuit fabricating techniques. In addition to linear arrays, planar arrays provide additional variables which can be used to control and shape the pattern of the array. The planar arrays are more versatile and can provide more symmetrical patterns with lower side lobes. They can also be used to scan the main beam of the antenna towards any point in the space. During the voyage of a space shuttle in space, the antenna mounted on it interacts with the plasma medium. The presence of plasma medium will modify the properties of these antennas. An antenna immersed in plasma medium generates electroacoustic waves in addition to usual electromagnetic waves [5].

The present work deals with the analysis of 6 x 6 element planar array of circular microstrip antenna in ionized plasma medium. The analysis is carried out in plasma mode in which plasma parameter A = 0.5 for plasma medium and A = 1.0 for free space. The far-zone field expression for electromagnetic and plasma mode are obtained by using linearized hydrodynamic theory with vector potential approaches [6-7].

II. ANALYSIS

If the individual radiators can be positioned along a rectangular grid to form a rectangular or planar array and elements are initially placed along the x-axis, then the array factor is given by [8]

$$\text{Array Factor} = \sum_{m=1}^{M} I_{m1} \exp(j(m-1)(\beta_e d_x \sin\theta\cos\phi + \beta_x)) \tag{1}$$

where I_{m1} is the excitation coefficient of each element. The spacing and progressive phase shift between the elements along the x-axis is taken as d_x and β_x. If the elements are placed along y-axis with spacing dy and progressive phase shift β_y. The array factor is given by

$$AF = \sum_{n=1}^{N} I_{n1}\left[\sum_{m=1}^{M} I_{m1} \exp\{j(m-1)(\beta_e d_x \sin\theta\cos\phi + \beta_x)\}\right] \exp\{j(n-1)(\beta_e d_y \sin\theta\sin\phi + \beta_y)\} \tag{2}$$

or

$$AF = S_{xm} S_{yn} \tag{3}$$

where

$$S_{xm} = \sum_{m=1}^{M} I_{m1} \exp\{j(m-1)(\beta_e d_x \sin\theta\cos\phi + \beta_x)\} \tag{4}$$

$$S_{yn} = \sum_{n=1}^{N} \exp\{j(n-1)(\beta_e d_y \sin\theta\cos\phi + \beta_y)\} \tag{5}$$

From equations (2) – (4), it is obvious that the pattern of a rectangular array is the product of the array factors of the arrays in the x- and y- directions. If the amplitude excitation coefficients of the elements of the array in y-direction are proportional to those along x-direction, then amplitude of the $(m, n)^{th}$ element can be written as

$$I_{mn} = I_{m1} I_{n1} \tag{6}$$

If in addition the amplitude excitation of the entire array is uniform, then the array factor is written as

$$AF = I_0 \sum_{m=1}^{M} I_{m1} \exp\{j(m-1)(\beta_e d_x \sin\theta\cos\phi + \beta_x)\} \sum_{n=1}^{N} \exp\{j(n-1)(\beta_e d_y \sin\theta\sin\phi + \beta_y)\} \tag{7}$$

The normalized form of array can be written as

$$AF_n(\theta,\phi) = \left\{\frac{1}{M}\frac{\sin\left(\frac{M}{2}\psi_x\right)}{\sin\left(\frac{\psi_x}{2}\right)}\right\}\left\{\frac{1}{N}\frac{\sin\left(\frac{N}{2}\psi_y\right)}{\sin\left(\frac{\psi_y}{2}\right)}\right\} \tag{8}$$

where

$$\psi_x = \beta_e d_x \sin\theta\cos\phi + \beta_x$$

$$\psi_y = \beta_e d_y \sin\theta\sin\phi + \beta_y$$

For 6 x 6 element planar array, the array factor can be written as

$$AF(\theta,\phi)=\left\{\frac{1}{6}\frac{\sin 3(\beta_e d_x \sin\theta\cos\phi+\beta_x)}{\sin 0.5(\beta_e d_y \sin\theta\cos\phi+\beta_y)}\right\}\left\{\frac{1}{6}\frac{\sin 3(\beta_e d_y \sin\theta\sin\phi+\beta_y)}{\sin 0.5(\beta_e d_y \sin\theta\sin\phi+\beta_y)}\right\} \quad (9)$$

The array factor of the planar array has been derived by assuming that each element is an isotropic source.

The geometry and coordinate system of 6 x 6 element planar array of circular microstrip antenna are shown in Figure 1. It consists of six identical elements each of radius ‘a’ on a dielectric substrate of thickness ‘h’ and permittivity ε_r = 3.55. The array elements which are positioned along x-axis are separated by a distance d_x and those along y-direction are separated by a distance d_y. Each patch can be excited by a microstrip transmission line connected to the edge or by a coaxial line from the back at the plane ϕ = 0. In such a geometry TM_{nm} mode with respect to z-axis are excited. The subscripts n and m are the mode numbers associated with x- and y-directions respectively. Using the analysis of single element and two elements array [9] and following linearized hydrodynamic theory of plasma, the far-zone field expressions for 6 x 6 elements planar array of circular microstrip antenna are obtained in the present study.

In electromagnetic mode the far-zone field expression is given by

$$\begin{aligned} E_{\theta t} &= j^n V_0 a\,\beta_e \frac{\exp(-j\beta_e r)}{2r}\cos(n\phi).\frac{\sin(\beta_e h\cos\theta)}{(\beta_e h\cos\theta)} \\ &\text{x } \{J_{n+1}(\beta_e a\sin\theta)-J_{n-1}(\beta_e a\sin\theta)\} \\ &\text{x } \frac{1}{36}\left\{\frac{\sin 3(\beta_e d_x \sin\theta\cos\phi+\beta_x)}{\sin 0.5(\beta_e d_x \sin\theta\cos\phi+\beta_x)}\right\}\left\{\frac{\sin 3(\beta_e d_y \sin\theta\sin\phi+\beta_y)}{\sin 0.5(\beta_e d_y \sin\theta\sin\phi+\beta_y)}\right\} \end{aligned} \quad (10)$$

Similarly

$$\begin{aligned} E_{\phi t} &= j^n V_0 a\,\beta_e \frac{\exp(-j\beta_e r)}{2r}.\sin(n\phi)\cos\theta.\frac{\sin(\beta_e h\cos\theta)}{(\beta_e h\cos\theta)} \\ &\text{x } \{J_{n+1}(\beta_e a\sin\theta)+J_{n-1}(\beta_e a\sin\theta)\} \\ &\text{x } \frac{1}{36}\left\{\frac{\sin 3(\beta_e d_x \sin\theta\cos\phi+\beta_x)}{\sin 0.5(\beta_e d_x \sin\theta\cos\phi+\beta_x)}\right\}\left\{\frac{\sin 3(\beta_e d_y \sin\theta\sin\phi+\beta_y)}{\sin 0.5(\beta_e d_y \sin\theta\sin\phi+\beta_y)}\right\} \end{aligned} \quad (11)$$

where $E_{\theta t}$, $E_{\phi t}$ are the components of total electric field vector for electromagnetic mode, β_e is propagation constant in electromagnetic mode given by $2\pi A/\lambda_0$, λ_0 is the free space wavelength and A is plasma parameter given by

$$A=\left[1-\left(\frac{\omega_p}{\omega_0}\right)^2\right]^{1/2} \quad (12)$$

where ω_0 and ω_p are angular source frequency and angular plasma frequency. The feed point location V_o is given by

$$V_0 = hk_1^2 J_n(k_1 a) \quad (13)$$

where k_1 is the propagation constant in free space and is given by

$$k_1 = \omega_0 (\mu_0 \varepsilon_0 \varepsilon_r)^{1/2} \tag{14}$$

where μ_0, ε_0 are absolute permeability and permittivity in free space and

ε_r is relative permittivity of dielectric substrates.

In plasma mode the far-zone field expression is given by

$$E_{pt} = (-j)^{n+2} \ x \ \frac{60\pi(1-A^2)}{A} \ x \left(\frac{c}{v}\right) k_1^2 n J_n(k_1 a) \ x \ \frac{\exp(-j\beta_p r)}{2r}$$
$$\frac{\sin(\beta_p h\cos\theta)}{(\beta_p h\cos\theta)} \ x \ J_n(\beta_p a\sin\theta)\sin(n\phi) \ x \tag{15}$$
$$\frac{1}{6}\left\{\frac{\sin 3(\beta d_x \sin\theta\cos\phi + \beta_x)}{\sin 0.5(\beta d_x \sin\theta\cos\phi + \beta_x)}\right\}\left\{\frac{\sin 3(\beta_p d_y \sin\theta\sin\phi + \beta_y)}{\sin 0.5(\beta_p d_y \sin\theta\sin\phi + \beta_y)}\right\}$$

where E_{pt} is the total electric field vector in plasma mode and β_p is the plasma mode propagation constant given by $\beta_e c/v$, c is the velocity of electromagnetic wave and v is the rms thermal velocity of electrons in plasma.

The total field patterns R(θ, ϕ) is obtained from the relation

$$R(\theta,\phi) = |E_\theta|^2 + |E_{\phi t}|^2 \tag{16}$$

The values of R (θ, ϕ) are computed for a case taking source frequency f_r = 10 GHz, a = 0.47 cm, ε_r = 3.55 and n = 1. For the sake of simplicity, it is imperative to take element separation $d_x = d_y = 0.5\lambda_0$ and phase shifts $\beta_x = \beta_y = \pi/2$. The results are plotted in Figures 2 and Figure 3 respectively for two different planes (i.e. ϕ = π/2 and ϕ = 0) for A = 0.5 i.e. in plasma and A = 1.0, i.e. in free space. The plasma mode fields are computed for A = 0.5 in the plane ϕ = π/2 at θ = 0.5° increment in a small interval of 10° and are plotted between 50° to 60° in Figure 4. It is found that field patterns shows innumerable maxima and minima.

By integrating the poynting vector over a large sphere the expressions for radiated power in electromagnetic and electroacoustic modes are obtained.

The radiated power in electromagnetic mode is given by

$$P_e = \frac{(\beta_e a)^2 V_o^2}{960\pi} I_1 \tag{17}$$

where

$$I_1 = \int_0^{2\pi}\int_0^{\pi}\left[\frac{\sin^2(\beta_e h\cos\theta)}{(\beta_e h\cos\theta)^2}\left\{\frac{\sin^2 3(\beta d_x \sin\theta\cos\phi + \beta_x)}{\sin^2 0.5(\beta d_x \sin\theta\cos\phi + \beta_x)}\right\}\left\{\frac{\sin^2 3(\beta d_y \sin\theta\sin\phi + \beta_y)}{\sin^2 0.5(\beta d_y \sin\theta\sin\phi + \beta_y)}\right\}\right.$$
$$x\{\cos^2 n\phi[(J_{n+1}(\beta_e a\sin\theta) - J_{n-1}(\beta_e a\sin\theta)]^2 \tag{18}$$
$$+ \cos^2\theta\sin^2 n\phi[(J_{n+1}(\beta_e a\sin\theta) - J_{n-1}(\beta_e a\sin\theta)]^2 \sin\theta d\theta d\phi$$

In plasma mode the power radiated is given by

$$P_p = \frac{15\pi(1-A^2)}{A}\left(\frac{C}{\nu}\right)V_0^2 I_2 \tag{19}$$

where

$$I_2 = \int_0^{2\pi}\int_0^{\pi}\left[\frac{\sin^2(\beta_e h\cos\theta)}{(\beta_e h\cos\theta)^2}\left\{\frac{\sin^2 3(\beta d_x \sin\theta\cos\phi+\beta_x)}{\sin^2 0.5(\beta d_x \sin\theta\cos\phi+\beta_x)}\right\}\left\{\frac{\sin^2 3(\beta d_y \sin\theta\sin\phi+\beta_y)}{\sin^2 0.5(\beta d_y \sin\theta\sin\phi+\beta_y)}\right\}\right.$$
$$x\{\cos^2 n\phi[(J_{n+1}(\beta_e a\sin\theta)-J_{n-1}(\beta_e a\sin\theta)]^2 \tag{20}$$
$$+\cos^2\theta\sin^2 n\phi[(J_{n+1}(\beta_e a\sin\theta)-J_{n-1}(\beta_e a\sin\theta)]^2 \sin\theta d\theta d\phi$$

The radiation conductance of microstrip antenna in electromagnetic mode (G_e) and electroacoustic modes (G_p) are obtained by using the power radiated.

In electromagnetic mode the radiation conductance is given by

$$G_e = \frac{2P_e}{V_0^2} = \frac{2(\beta_e a)^2}{960\pi} I_1 \tag{21}$$

and in Plasma mode the radiation conductance is

$$G_p = \frac{2P_p}{V_0^2} = \frac{30\pi(1-A^2)}{A}\left(\frac{C}{\nu}\right)I_2 \tag{22}$$

The radiation efficiency of the antenna in plasma medium is now expressed as

$$\eta = \frac{\text{usefulpowerinplasma}}{\text{Totalradiatedpower}} = \frac{G_e}{G_e + G_p} x100\% \tag{23}$$

The directive gain of six elements planar array antenna in electromagnetic mode is given as

$$D_e = \frac{4\pi U_{max}}{P_e} = \frac{4\pi M_e}{I_1} \quad \text{for } \theta = \pi/2,\ \phi = 0 \tag{24}$$

where U_{max} is the maximum radiation intensity in the desired direction.

where

$$M_e = \frac{\sin^2(\beta_e h\cos\theta)}{(\beta_e h\cos\theta)} x\left\{\frac{\sin^2 3(\beta_e d_x \sin\theta\cos\phi+\beta_x)}{\sin^2 0.5(\beta_e d_x \sin\theta\cos\phi+\beta_x)}\right\}\left\{\frac{\sin^2 3(\beta d_y \sin\theta\sin\phi+\beta_y)}{\sin^2 0.5(\beta d_y \sin\theta\sin\phi+\beta_y)}\right\}$$
$$\cos^2 n\phi[J_{n+1}(\beta_e a\sin\theta)-J_{n-1}(\beta_e a\sin\theta)]^2 \tag{25}$$
$$+\cos^2 n\phi\sin^2 n\phi[J_{n+1}(\beta_e a\sin\theta)-J_{n-1}(\beta_e a\sin\theta)]^2$$

The computed value of all the parameters such as radiation conductance, radiation efficiency and directive gain in electromagnetic mode are given in Table I. These radiation parameters are also plotted with different ratio of plasma to source frequency (ω_p/ω_0).

III. RESULTS AND DISCUSSION

The study is carried out in plasma medium due to its appreciable effect on 6 x 6 element planar array of circular microstrip antenna, when it is used on space vehicles. The far-zone field expression for electromagnetic mode and plasma mode radiation fields are derived using pattern multiplication approach. Figures 2-3 shows the electromagnetic radiation field patterns of the array antenna in plasma (A = 0.5) and in free space (A = 1.0) in $\phi = \pi/2$ and $\phi = 0$ plane respectively for $\beta_I = \pi/2$ phase excitation difference. From these figures it observed that the field patterns of the present array are greatly affected due to the presence of plasma medium. The shape of the field pattern has been modified to a great extent and it redistributed the field intensity considerably. The figures also shows the symmetric changes in all the four quadrants resulting the unchanged maxima at $\theta = 0^o$ direction. In case of R (θ, ϕ) for $\phi = 0$ plane, the normalized relative power is diversified between $\theta = 30^o$ to 150^o, as a result of which two equal lobes are obtained. It is also noted that the attitudes of the radiation field at A = 1.0 and A = 0.5 have mutually opposite response at $\theta = \pi/2$. The plasma mode field pattern $|E_{pt}|^2$ for A = 0.5 is shown in Figure 4. It is found oscillatory in nature and thus does not play any significant role in communication (or loss of radiant energy). Further, it has been found that when an antenna interacts with a plasma medium, the generation of electroacoustic waves creates detuning in antenna system which in turn changes the radiation properties in such a medium.

The variation of radiation conductance G_e in electromagnetic mode with different ratio of plasma to source frequency (ω_p/ω_0) is plotted in Figure 5. This figure shows that the value of G_e decreases with increase in plasma to source frequency ratio. Variation of radiation efficiency with different ratio of plasma to source frequency is shown in Figure 6. The radiation efficiency decreases with increase in the ratio of plasma to source frequency and becomes zero when plasma frequency (ω_p) approaches to source frequency (ω_0), which in fact a limitation of hydrodynamic theory of plasma employed in the present analysis. Figure 7 represents the variation of directive gain with different ratio of plasma to source frequency (ω_p/ω_0). The directive gain is slightly increases with increase in the ratio of plasma to source frequency and decreases rapidly when plasma to frequency equal to source frequency.

IV. CONCLUSION

From the study of pattern characteristics and antenna parameters, it can be concluded that the effect of plasma medium on the radiation patterns of 6 x 6 elements planar array of circular patch microstrip antenna is quite significant and interesting. The magnitude of fields, radiation conductance and efficiency decreases gradually in the presence of plasma medium. Plasma fields are longitudinal in nature and do not contribute to radiation or reception of electromagnetic waves. Hence energy radiated in plasma fields decreases and efficiency of such a radiating system decreases even though it is higher in free space. An experimental verification of these results in free space as well as in plasma medium at higher frequency is required which may give additional information about the effect of plasma medium on the radiation properties of such an array through simulation of natural plasma medium in laboratory is a very difficult task.

REFERENCES

[1] Roopali Bharadwaj, *Global Journal of Research and Review, Vol. 4(17)*, 2017

[2] Kshatriya bhavna and Anil K. Sisodia, *International Journal of Electronics, Electrical and Computational System, Vol. 6(4)*, 2017

[3] Rajaneesh Ganiger., *International Journal on Recent and Innovation Trends in Computing and Communication, Vol. 5(5*), 2017

[4] U Srinivasa Rao and P Siddaiah, *Journal of Theoretical and Applied Information Technology, Vol. 95(4*), 2017

[5] D Bhatnagar, A M Salem and J M Gandhi, *Indian J. Phys.,Vol.* 71,1957

[6] S Durrani and M E Bialkowski, *Electron Letters, Vol. 38*, 2002

[7] B. Singh, *Indian J. Phys. Vol.70B*,1996

[8] D Bhatnagar and R K Gupta, *Indian J. Radio & Space Phys. Vol.14*, 1985

[9] V K Saxena, A Dinesh and R K Gupta, *Indian J. Radio & Space Phys., Vol.(18)*, 1989

Table-I

Calculated values of radiation conductance (Ge), radiation efficiency (η) and directive gain (De)

Plasma to source frequency ω_p / ω_0	Plasma parameter A	Radiation conductance (Ge) (mho x 10^{-3})	Radiation efficiency (η %)	Directive Gain(De) (dB)
0	1.00	10.40	99.9	2.47
0.1	0.99	9.85	95.6	2.57
0.2	0.97	8.91	90.2	2.92
0.3	0.95	7.63	85.6	2.94
0.4	0.91	9.49	83	2.96
0.5	0.87	6.66	75	3.72
0.6	0.80	5.93	65	4.48
0.7	0.71	4.32	50	5.55
0.8	0.60	1.47	47	10.04
0.9	0.44	0.60	36	9.79
1.0	0.00	0.00	0	0.00

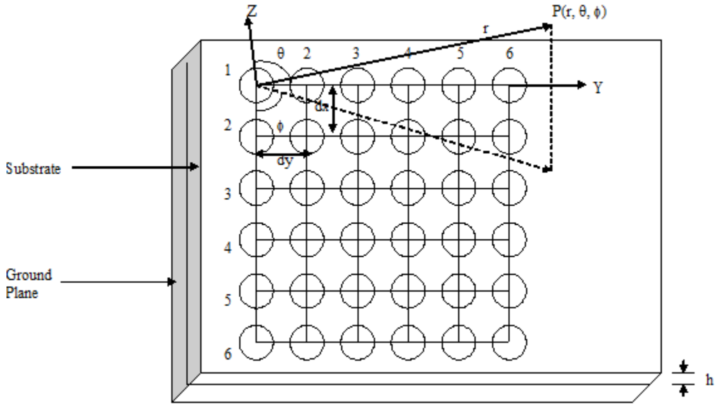

Figure 1. Geometry and coordinate system of 6 x 6 element planar array of circular patch microstrip antenna.

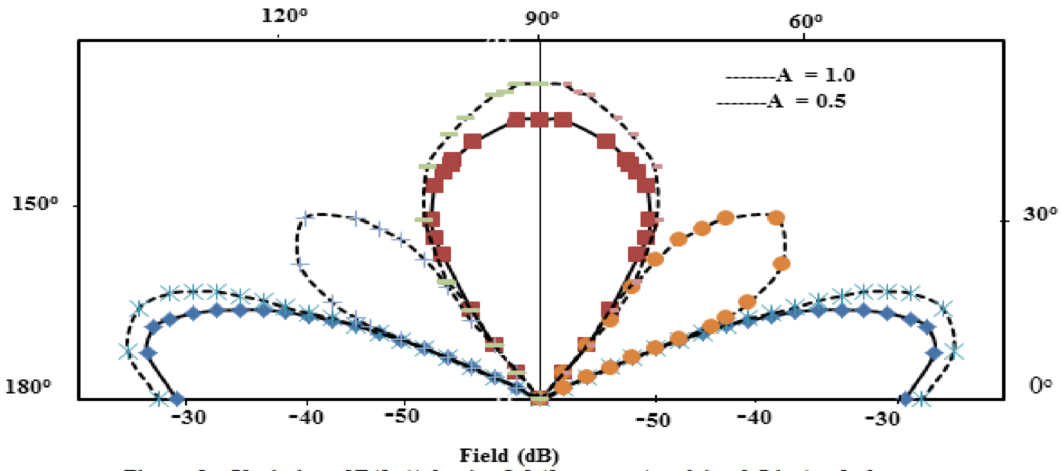

Figure 2: Variation of R(θ, ϕ) for A = 1.0 (free space) and A = 0.5 in ϕ = 0 plane.

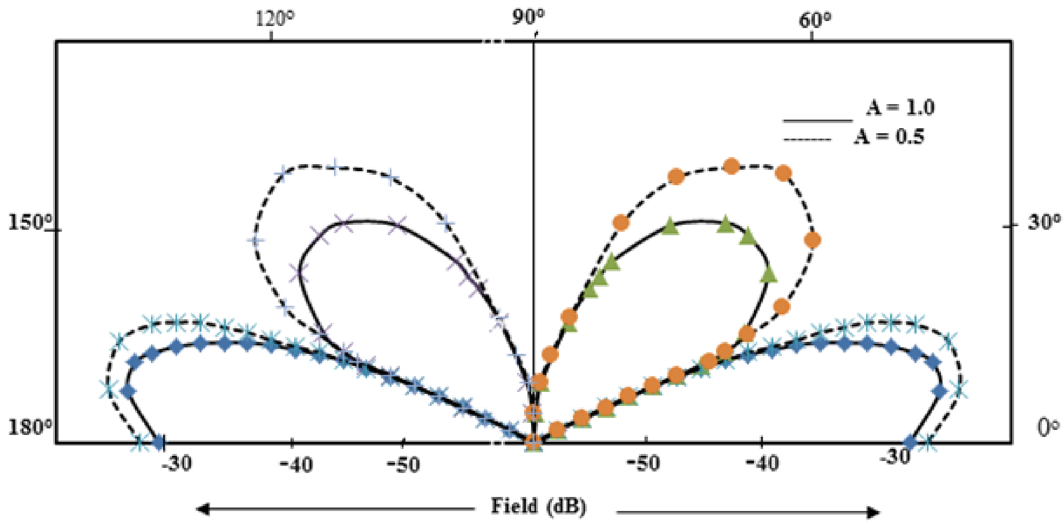

Figure 3: Variation of R(θ, ϕ) for A = 1.0 (free space) and A = 0.5 in ϕ = π/2 plane.

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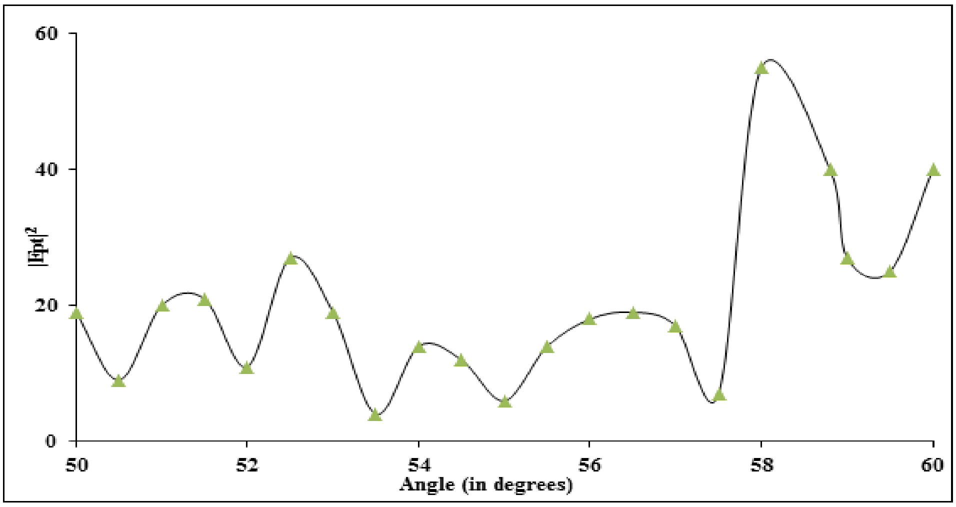

Figure 4: Plasma mode field $|Ept|^2$ pattern for A = 1.0

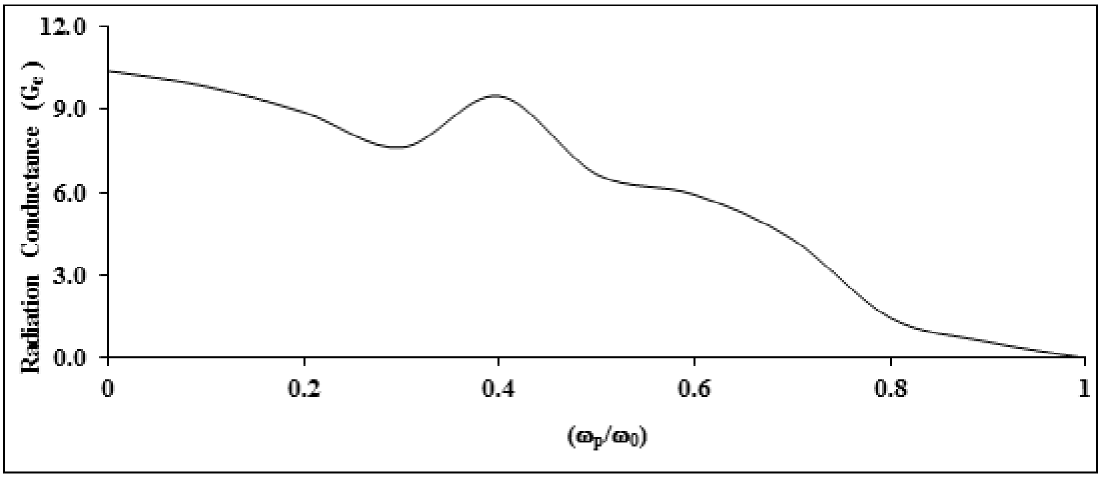

Figure 5: Variation of radiation conductance Ge with plasma to source frequency (ω/ωo)

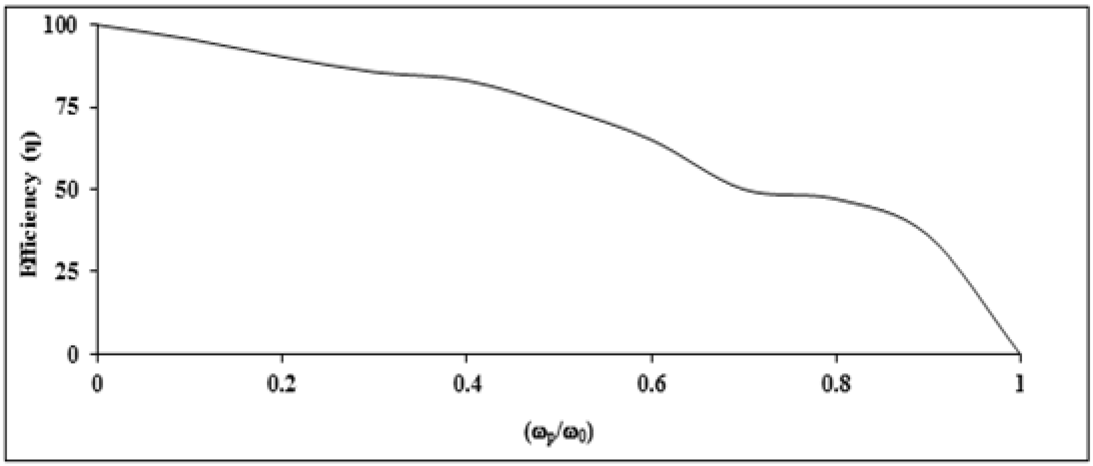

Figure 6: Variation of radiation efficiency η with plasma to source frequency (ω/ωo)

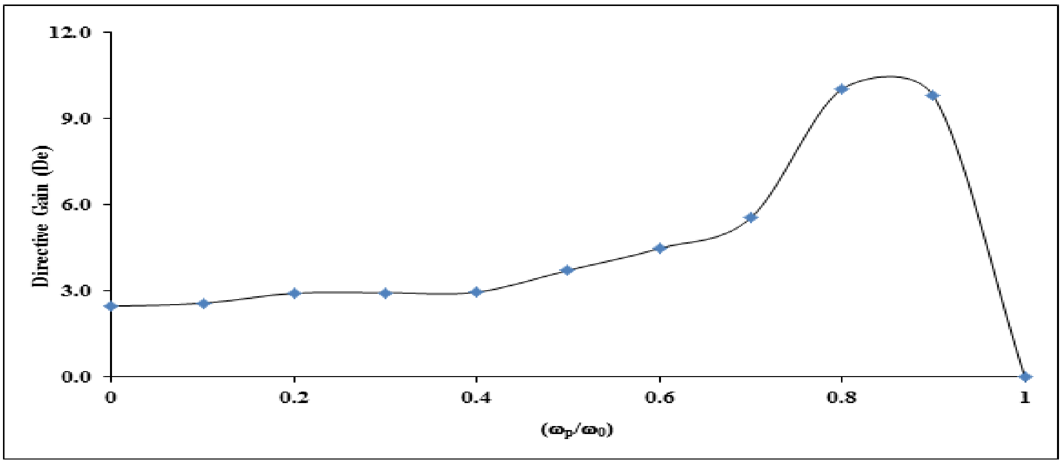

Figure 7: Variation of directive gain D_e with plasma to source frequency (ω/ω_0)