VARIATION OF DIRECTIVITY AND QUALITY FACTORS OF CIRCULAR PATCH MICROSTRIP ANTENNA IN PLASMA

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ABSTRACT

Using linearized hydrodynamic theory the radiation properties of a circular patch microstrip antenna in the plasma media are studied. Directivity and quality factors for different plasma-to-source frequencies are calculated and plotted.

INTRODUCTION

Microstrip antennas are replacing old and bulky antennas in modern rockets and satellites[1-4] because of their light weight and better aerodynamic properties. An antenna mounted on space vehicle encounters plasma media and generates electro-acoustic waves in addition to electromagnetic waves. Bhatnagar and Gupta[5] studied the radiation properties of a circular patch antenna in a multicomponent plasma media.

Two widely used mathematical theories describing the plasma state involve the use of hydrodynamic equations and the Boltzmann equations in conjunction with Maxwell's equations. The use of Boltzmann equation requires many assumptions. In this study we use hydrodynamic equations to describe the properties of plasma. The assumptions regarding the state of plasma and the basic equations governing radiations have been mentioned elsewhere[6,7].

RADIATED POWER AND DIRECTIVITY

The circular patch microstrip antenna is shown in figure 1. The fields inside the cavity are obtained by[4]

$$E_z = k_1^2 J_n(k_1 \rho) \cos n\phi. \tag{1}$$

For dominant reflection action at the circular dielectric to plasma boundary at $\rho = a$, the tangential field $H_\phi = j\omega\epsilon_r J_n'(k_1\rho)\cos n\phi$ is very small and the values are given by

$$J_n'(k_1 a) = 0. \tag{2}$$

Following the method adopted by Bhatnagar and Gupta[8] and equations for EM and P mode fields[5], the radiated power is given by

EM mode:

$$P_e = \frac{(hk_1^2 a\beta_e J_n(k_1 a))^2}{1920} I_1, \tag{3}$$

here

$$I_1 = \int_0^\pi [\{J_{n+1}(\beta_e a \sin\theta) - J_{n-1}(\beta_e a \sin\theta)\}^2 + \cos^2\theta \cdot \{J_{n+1}(\beta_e a\sin\theta) + J_{n-1}(\beta_e a \sin\theta)\}^2] \times \sin\theta \, d\theta. \tag{4}$$

β_e is the propagation constant in the EM mode, h the thickness of substrate and a the radius of the patch.

P mode:

$$P_p = \int_0^{2\pi}\int_0^{\pi}\left[\sum_{j=1,2} \frac{K_j J_n^2(\beta_{pj} a \sin\theta)\sin(\beta_{pj} h\cos\theta)}{\sin(\beta_{pj} h \cos\theta)}\right]^2 \sin^2\phi \cdot \sin\theta \, d\theta \cdot d\phi \tag{5}$$

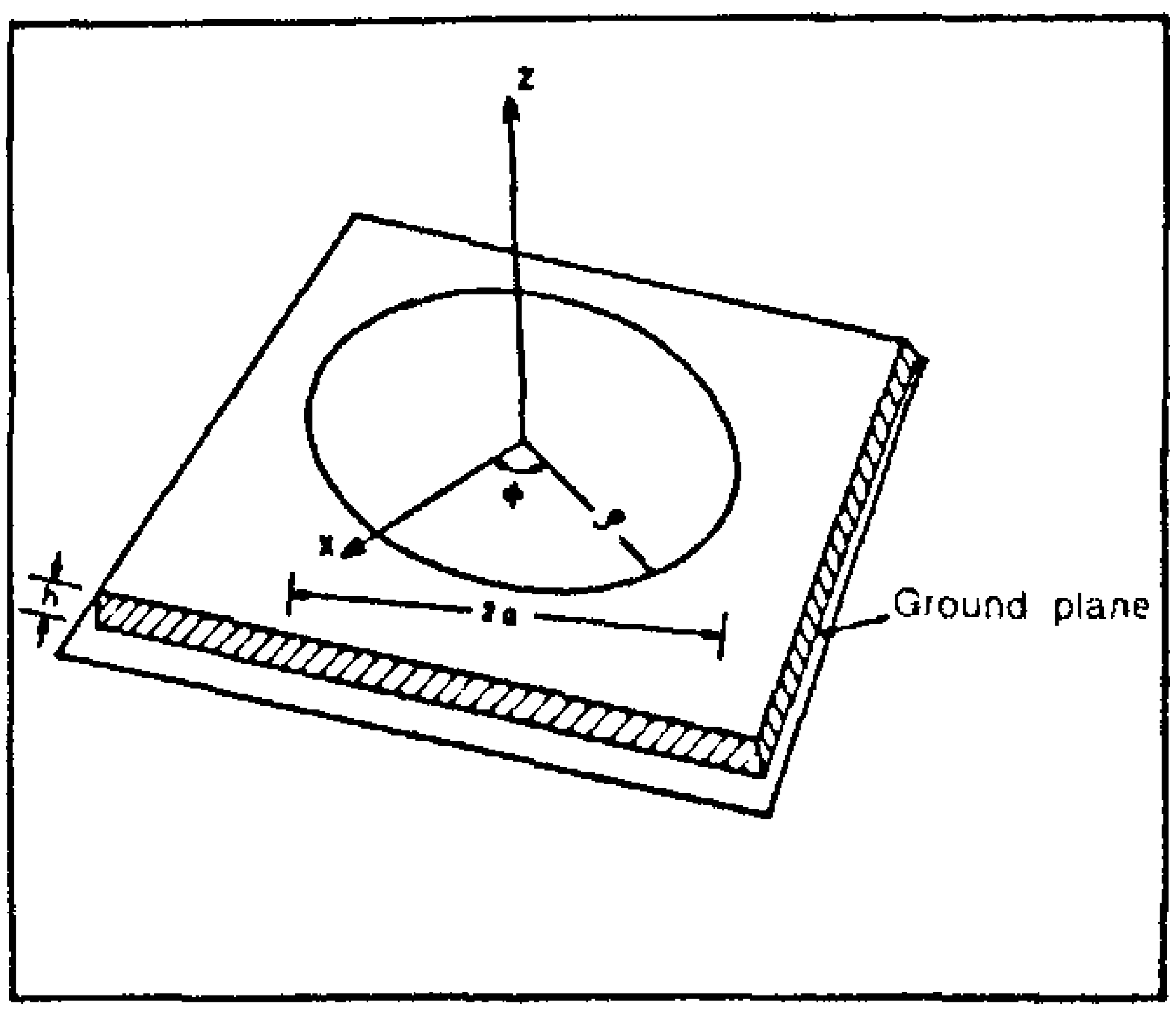

Figure 1. Geometry of circular patch microstrip antenna.

here

$$K_j = \frac{(1-\alpha_j)^2 \omega_{pe}^2 k_1^4 h^2 J_n^2(k_1 a)}{16 \beta_{pj} \varepsilon_0 (1+\tau \alpha_j^2) \omega u_e^2},$$

$$k_1 = \omega(\mu_0 \varepsilon_0 \varepsilon_r)^{1/2} \quad \text{and} \quad \tau = m_i u_i^2 / m_e u_e^2$$

α_1 and α_2 are the roots of the equation

$$T_{21}\alpha_j^2 + (T_{11} - T_{22})\alpha_j - T_{12} = 0, \tag{6}$$

$$\left.\begin{aligned} T_{11} &= \frac{\omega^2}{u_e^2}\left[1 - \frac{\omega_{pe}^2}{\omega^2}\right], & T_{12} &= \omega_{pi}^2/u_i^2 \\ T_{21} &= \omega_{pe}^2/u_e^2, & T_{22} &= \frac{\omega^2}{u_i^2}\left[1 - \frac{\omega_{pi}^2}{\omega^2}\right]. \end{aligned}\right\} \tag{7}$$

The wave number β_{pj} is given by the roots of the equation

$$\beta_{pj}^4 - \beta_{pj}^2(T_{11} + T_{22}) + (T_{11}T_{22} - T_{12}T_{21}) = 0 \tag{8}$$

and is related to α_j by

$$\beta_{pj}^2 = T_{11} + T_{21}\alpha_j, \tag{9}$$

ω_{pe} is the angular plasma frequency of electron, ω the angular frequency, u_e and u_i are r.m.s. thermal velocities of electron and ion respectively.

The directivity of an antenna is defined as the ratio of maximum power density to average power density. From the previously calculated far fields[5] and the total radiated power, the directivity of circular patch microstrip antenna in plasma excited by $n=1$ mode in the

EM mode:

$$\begin{aligned} D_e &= (\beta_e a)/120\, G_e \\ &= 8/\int_0^{\pi} [\{J_{n+1}(\beta_e a \sin\theta) - J_{n-1}(\beta_e a \sin\theta)\}^2 + \\ &\quad + \cos^2\theta\, \{J_{n-1}(\beta_e a \sin\theta) + \\ &\quad + J_{n+1}(\beta_e a \sin\theta)\}^2] \sin\theta \, d\theta. \end{aligned} \tag{10}$$

P mode:

$$D_p = \frac{4\pi \sum\limits_{j=1,2} \left\{\frac{\sin(\beta_{pj} h \cos\theta)}{(\beta_{pj} h \cos\theta)}\right\}^2 K_j \sin\phi \, J_n^2(\beta_{pj} a \sin\theta)}{\sum\limits_{j=1,2} \pi K_j \int_0^{\pi} \frac{\sin(\beta_{pj} h \cos\theta)}{(\beta_{pj} h \cos\theta)} J_n^2(\beta_{pj} a \sin\theta) \cdot \sin\theta \, d\theta}. \tag{11}$$

The values of D_e and D_p are calculated and plotted for different values of ω_{pe}/ω (figure 2).

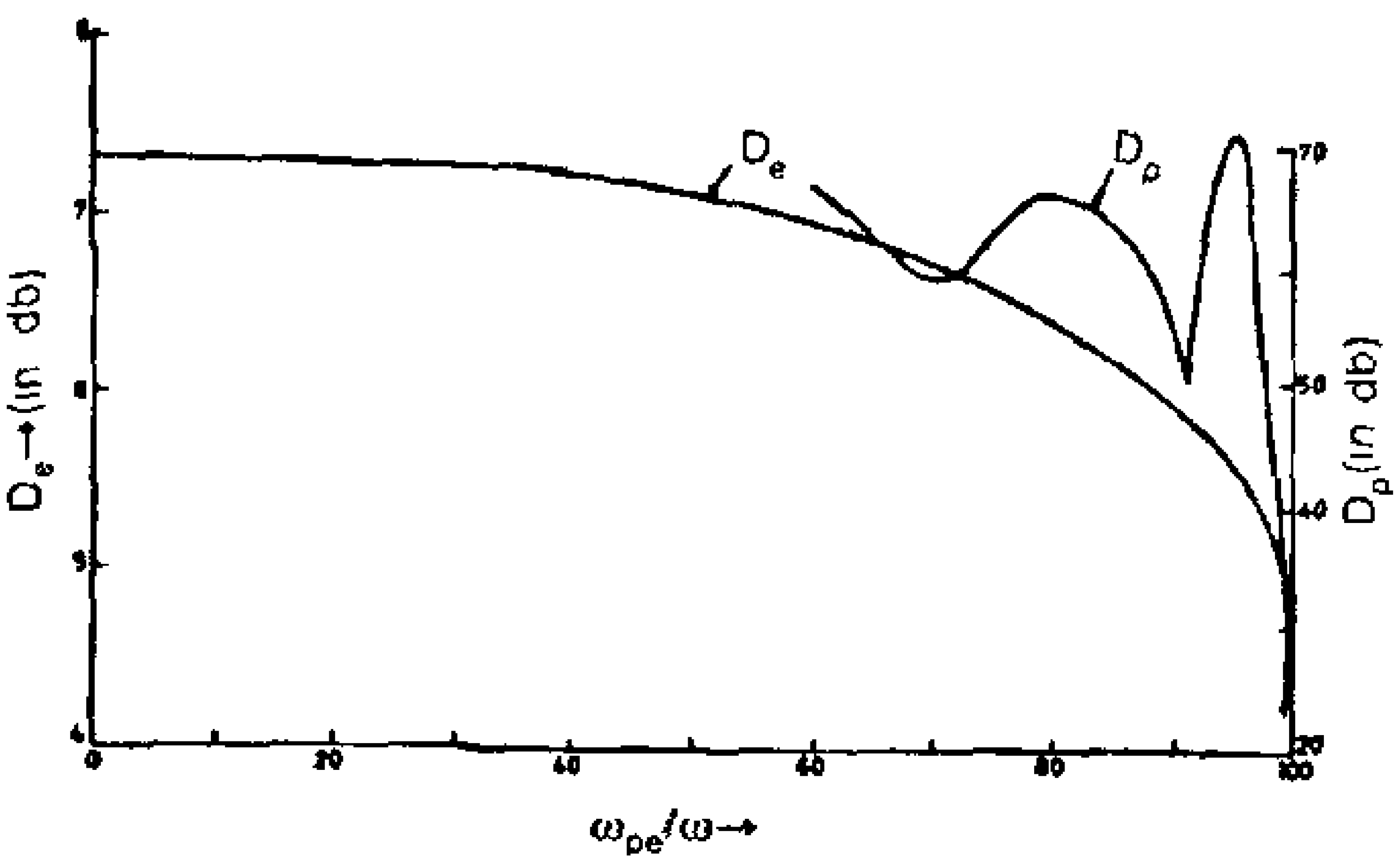

Figure 2. Variation of directivities (D_e and D_p) with plasma frequency.

QUALITY FACTOR

A parameter specifying the frequency selectivity of a resonant circuit is the quality factor. It is defined as the ratio between the energy stored in the system and the energy lost. At resonance, the energy stored can be calculated from either the maximum magnetic field or from the maximum electric field. In the present case, the energy stored is

$$\begin{aligned} W_t &= \tfrac{1}{2}\varepsilon |E|^2 \, dV \\ &= \frac{h k_1^4 J_n^2(k_1 a)}{8\omega f \mu} \{(k_1 a)^2 - n^2\}, \end{aligned} \tag{12}$$

and

$$Q_{\text{rad}} = \omega W_t / P_L. \tag{13}$$

The total power lost P_L, includes the power radiated and the power attenuated. The power attenuated is

$$\begin{aligned} P_A &= \left\{\frac{\pi f \mu}{\sigma}\right\}^{1/2} k_1^4 \frac{J_n^2(k_1 a)}{2(\omega\mu)^2} \cdot \{(k_1 a)^2 - n^2\} + \\ &\quad + \frac{h \tan\delta \, k_1^4 J_n^2(k_1 a)}{8\mu f} \{(k_1 a)^2 - n^2\}. \end{aligned} \tag{14}$$

The quality factor becomes for the

EM mode:

$$Q_e = \left[\frac{1}{h(\pi f \mu \sigma)^{1/2}} + \tan\delta + \frac{h f \mu (\beta_e a)^2 I_1}{240\{(k_1 a)^2 - n^2\}}\right]^{-1}. \tag{15}$$

P mode:

$$Q_p = \left[\frac{1}{h(\pi f \mu \sigma)^{1/2}} + \tan\delta + \frac{\mu f \omega_{pe}^2 h L}{2\varepsilon_0 \omega u_e^2 \{(k_1 a)^2 - n^2\}}\right]^{-1}, \tag{16}$$

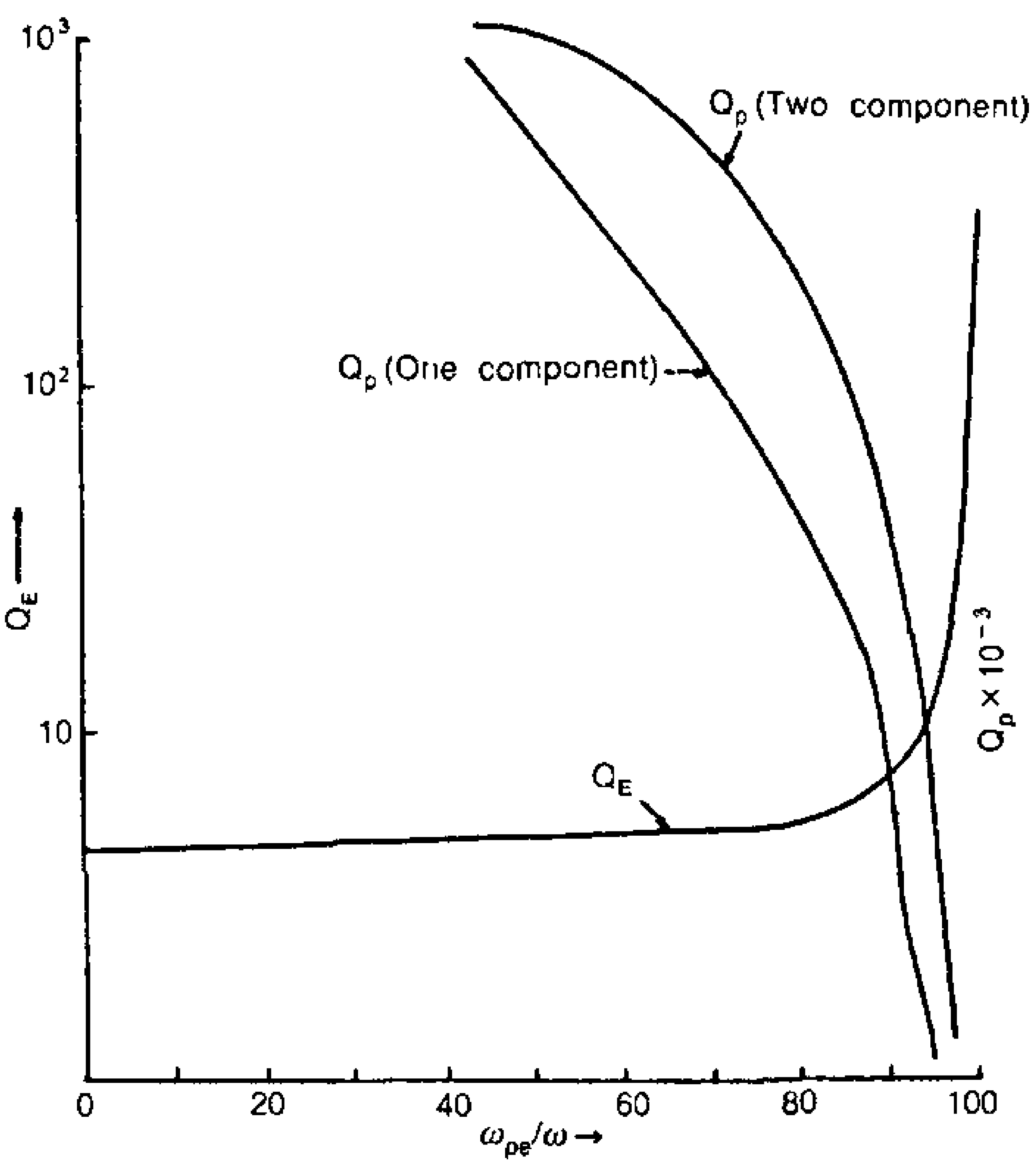

Figure 3. Variation of quality factor (Q_e and Q_p) with plasma frequency.

here

$$L=\int_0^{2\pi}\int_0^{\pi}\left\{\sum_{j=1,2}\frac{(1-\alpha_j)^2 J_n^2(\beta_{pj}a\sin\theta)\sin(\beta_{pj}h\cos\theta)}{\beta_{pj}(1+\tau\alpha_j^2)\beta_{pj}h\cos\theta}\right\}^2$$

$$\sin^2\phi\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\phi, \tag{17}$$

σ is the conductivity of the metallization, μ the permeability of the medium, $\tan\delta$ the loss tangent of the dielectric and ε_0 the free space permittivity.

Figure 3 shows the variation of the quality factor for both EM and P modes with different ω_{pe}/ω values. Quality factor Q_p in electron ion model is compared with Q_p of the electron plasma model.

Values of D_e, D_p, Q_e and Q_p are obtained using $h=0.158$ cm, $a=2.1$ cm, $f=2.75$ GHz, $\varepsilon_r=2.31$, $n=1$ and $k_1a=1.84118$.

DISCUSSION AND CONCLUSION

The present study of different parameters indicates that the presence of plasma media affects the radiation properties to a great extent. Variation of directivity in the EM mode indicates that maximum radiation intensity in a particular direction ($\theta=0°$) decreases with increase in the plasma-to-source frequency. It is maximum in free space ($\omega_{pe}/\omega=0$). In the P mode, the variation of directivity is not uniform. The quality factor curve of EM mode indicates that energy loss decreases for higher ω_{pe}/ω values. For lower values, the quality factor remains almost unchanged. Energy loss in P mode increases with ω_{pe}/ω and becomes infinite at $\omega_{pe}/\omega=1$, making the quality factor zero. The overall conclusion about circular patch antenna is that it is better suited for operation in plasma compared to the linear antennas. However this theory is valid for the range where plasma frequency is lower than the source frequency.

ACKNOWLEDGEMENT

The author thanks Dr Rajkumar Gupta and Mrs Charulata for help.

25 May 1988; Revised 27 February 1989

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