RADIATIONS FROM A LINEARLY POLARISED MICROSTRIP ANTENNA IN A WARM PLASMA

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ABSTRACT

A linearized hydrodynamic theory and vector wavefunction technique is used to deduce expressions for the electromagnetic (EM mode) and electroacoustic (*P* mode) components of the far fields and radiated powers of a linearly polarised microstrip antenna immersed in an isotropic warm plasma. The far field patterns of the EM mode and the *P* mode are computed and shown in the graphical form for various ratios of the plasma-to-source frequency. It is observed that the behaviour of electroacoustic waves generated by the microstrip antenna in plasma is different from that of linear antennas. However the EM mode field patterns remain almost similar to linear antenna for the size of the antenna under investigation. Analytical expressions for the radiated powers are also obtained and their values computed and plotted in the graphical form for two different sizes of the antenna and various ratios of the plasma-to-source frequency.

INTRODUCTION

The need for conformal and low profile antennas in the aerospace and satellite communications has renewed interest in the possible use of microstrip antennas on space vehicles. Recently, Post and Stephenson[1] have designed a microstrip antenna to fly on NASA's space shuttle OFT-4 mission. During the last ten years, several geometries of microstrip antennas have been designed for use on KC-135 aircraft to ATS-6 satellite[2] in the frequency band of 1 to 10 GHz. It is expected that the presence of plasma encountered during the voyage of space shuttle or a satellite, will modify the radiation properties of microstrip antennas installed on them.

The fabrication and testing techniques of microstrip antennas are slightly different from the normal antennas. The effect of warm plasma on several geometries of linear and slot antennas using hydrodynamic approach has been studied[3]. This approach is extended to study the radiation properties of microstrip antenna in a warm plasma. The expressions for electromagnetic and electroacoustic components of fields and radiated power will be derived and computed for different plasma frequencies.

STATEMENT OF THE PROBLEM

The linearly-polarised microstrip radiator as shown in figure 1a consists of two slots of width *b* and height *h*, perpendicular to the feed line and separated by $\lambda_g/2$ long transmission line of very low impedance[4] (λ_g is the guide wavelength). This acts as a transformer. Consequently, the fields in the slots are reversed (figure 1b) and *x* component of the electric field which is parallel to the ground plane adds in phase and gives a maximum radiation normal to the element. The *y* components are out of phase and their contributions cancel out (figure 1c).

The antenna is assumed to be immersed in an isotropic warm plasma of infinite extent. An antenna immersed in an isotropic warm plasma generates an electroacoustic or plasma (*P*) wave in addition to the usual electromagnetic (EM) wave[5-7]. In the absence of an external magnetic field, these two waves are uncoupled and the basic decoupled equations for the EM mode and the P mode together with the basic assumptions for the plasma system are mentioned by Gupta[8].

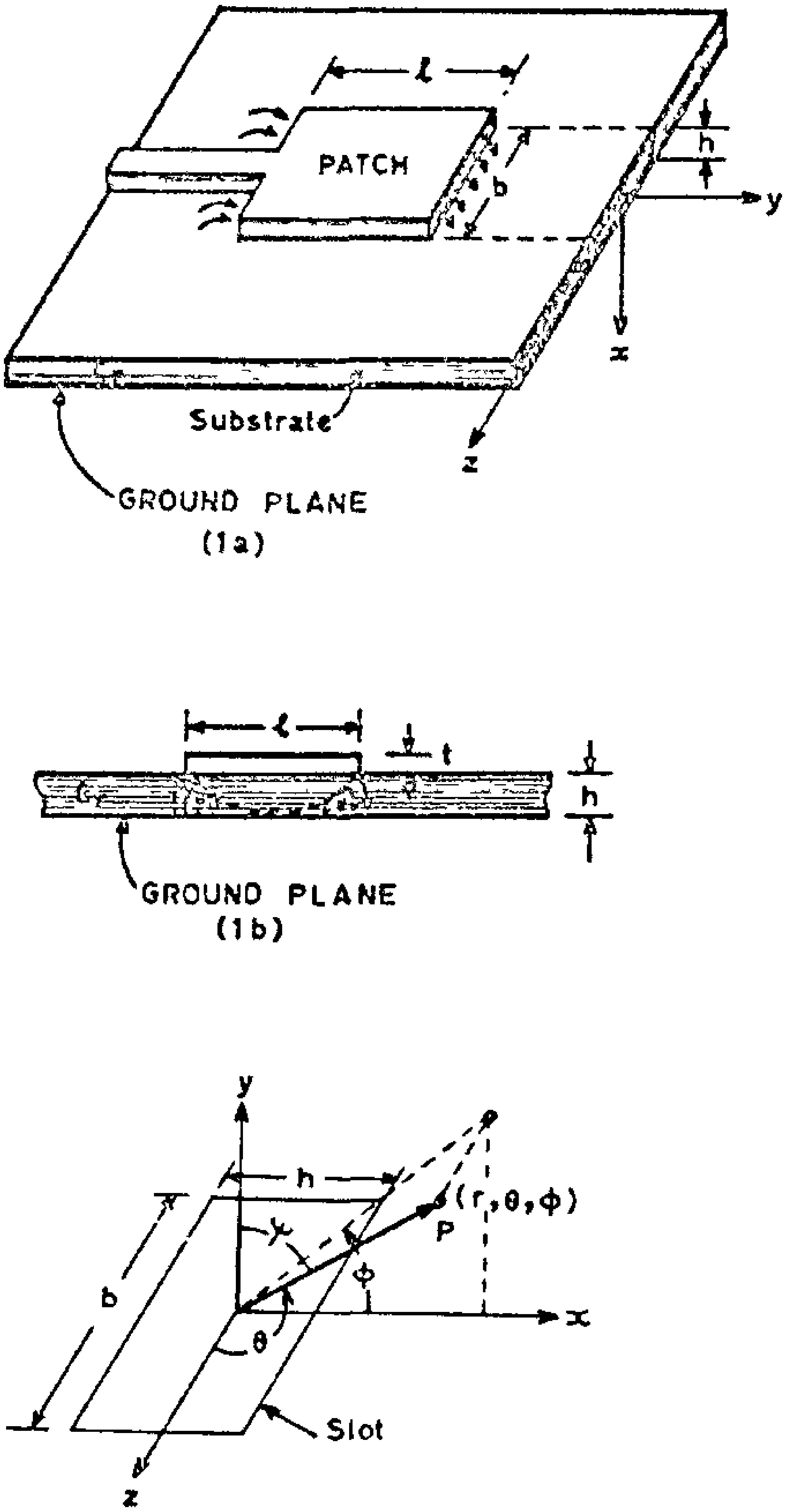
The radiated fields can be found by treating the antenna as an aperture as shown in figure 1c. Since the feed lines are chosen so as to excite only a TEM mode, the *x* component of the electric field at the aperture can be assumed to be constant and equal to[4]

$$\overline{E}_a = \hat{a}_x E_0 \begin{cases} -h/2 \leqslant x' \leqslant h/2 \\ -b/2 \leqslant z' \leqslant b/2. \end{cases} \tag{1}$$

Using equivalence principle[4], it can be shown that each slot will radiate the same fields as a magnetic dipole with magnetic current density

$$I_m = \hat{a}_z 2E_0 \begin{cases} -h/2 \leqslant x' \leqslant h/2 \\ -b/2 \leqslant z' \leqslant b/2 \end{cases} \text{ and} \tag{2}$$
$$= 0 \qquad \text{elsewhere.}$$

The expressions for far zone fields and radiated powers



(1c)

Figures 1[a], [b] and [c]. The microstrip antenna and its fields. Geometry of the basic radiator.

are now derived, using normal procedure followed earlier[3,7,8].

FAR ZONE FIELDS

We now follow the methods of Balanis[4], Derneryd[9] and use the basic equations mentioned by Gupta[8] for deriving electromagnetic and electroacoustic field expression for the antenna.

The EM mode far zone field for a single slot in plasma is

$$E_{e\Phi} = \frac{jw\mu_0 E_0 h.b}{2\pi r}\exp\{j(wt-\beta_e r)\}\sin\theta[M], \tag{3}$$

where

$$M = \frac{\sin\left(\frac{\beta_e h}{2}\sin\theta\cos\varphi\right)}{\left(\frac{\beta_e h}{2}\sin\theta\cos\varphi\right)}\cdot\frac{\sin\left(\frac{\beta_e b}{2}\cos\theta\right)}{\left(\frac{\beta_e b}{2}\cos\theta\right)}, \tag{4}$$

and β_e is the propagation constant of EM mode in plasma. r, θ and φ are spherical polar coordinates. The total field $E_{Te\Phi}$ will be the sum of two elements array with each element representing one of the slots.

$$E_{Te\Phi} = \frac{j\mu_0 E_0 . hbw}{\pi r}[M]\exp\{j(wt-\beta_e r)\}$$

$$\times\sin\theta.\cos\left(\beta_e\frac{l}{2}\psi\right)\cos(kh\psi),$$

where $\psi = \sin\theta\sin\varphi$ and $k = \beta_0\sqrt{\varepsilon_r}$. (5)

The image factor $\cos(kh\psi)$ is obtained[2,10] by assuming that the slot is imbedded in a half space of dielectric constant ε_r. ($\beta_0 = 2\pi/\lambda_0$) is the wavenumber in free space.

The P mode field for a single slot in plasma is

$$E_{pr} = \frac{w_p^2 E_0 hb}{2\pi wrv_0^2\beta\varepsilon_0}\exp[j(tw-\beta_p r)\}[N], \tag{6}$$

where

$$N = \frac{\sin\left(\frac{\beta_p h}{2}\sin\theta\cos\varphi\right)}{\frac{\beta_p h}{2}\sin\theta\cos\varphi}\cdot\frac{\sin\left(\frac{\beta_p b}{2}\cos\theta\right)}{\frac{\beta_p b}{2}\cos\theta}, \tag{7}$$

w and w_p are source and plasma frequency respectively. The total plasma mode field for both the slots is

$$E_{Tpr} = \frac{w_p^2 E_0 hb}{\pi v_0^2 wr\varepsilon_0\beta_p}[N]\exp[j(wt-\beta_p r)]$$

$$\times\cos\left(\beta_p\frac{l}{2}\psi\right)\cos(kh\psi). \tag{8}$$

FIELD PATTERN FACTORS

The EM and P modes field pattern factor F which is related to electric intensity E_T can be expressed as

$$F = \frac{r}{120\,E_0}|E_T|. \tag{9}$$

In actual practice[11] the h values are very small, the first factor in (4) can be taken equal to 1.

Using (5) and (8), the EM and P mode field pattern factors are obtained as

$$F_e = 2\pi K_1 K_2 \lambda_0 \sin\theta[G]\cos(\pi A K_3 \psi) \times \cos(2\pi K_1 \sqrt{\varepsilon_r}\,\psi), \qquad (10)$$

where

$$G = \frac{\sin(\pi A K_1 \sin\theta\cos\varphi)}{\pi A K_1 \sin\theta\cos\varphi}\cdot\frac{\sin(\pi A K_2 \cos\theta)}{\pi A K_2\cos\theta}, \qquad (11)$$

and $K_1 = h/\lambda_0$, $K_2 = b/\lambda_0$, $K_3 = l/\lambda_0$.

$$F_p = K_1 K_2 \lambda_0^2\left(\frac{1-A^2}{A}\right)(c/v_0)[H] \times \cos\left(\frac{c}{v_0}\pi A K_3 \psi\right)\cos(2\pi K_1 \varepsilon_r \psi) \qquad (12)$$

where

$$H = \frac{\sin\left(\frac{c}{v_0}\pi A K_1 \sin\theta\cos\varphi\right)}{\frac{c}{v_0}\pi A K_1 \sin\theta\cos\varphi}\cdot\frac{\sin\left(\frac{c}{v_0}\pi A K_2\cos\theta\right)}{\frac{c}{v_0}\pi A K_2\cos\theta} \qquad (13)$$

c is the velocity of electromagnetic waves in free space and v_0 is r.m.s. thermal velocity of electrons. The normalized values of $F_{e\Phi}(\theta = \pi/2)$ are computed for $K_2 = 0.25$ and plotted in figure 2 for $A = 0.2$, 0.5 and 1.0. The value of c/v_0 is taken as 10^3 and $A = 1$ gives the free space field pattern factor.

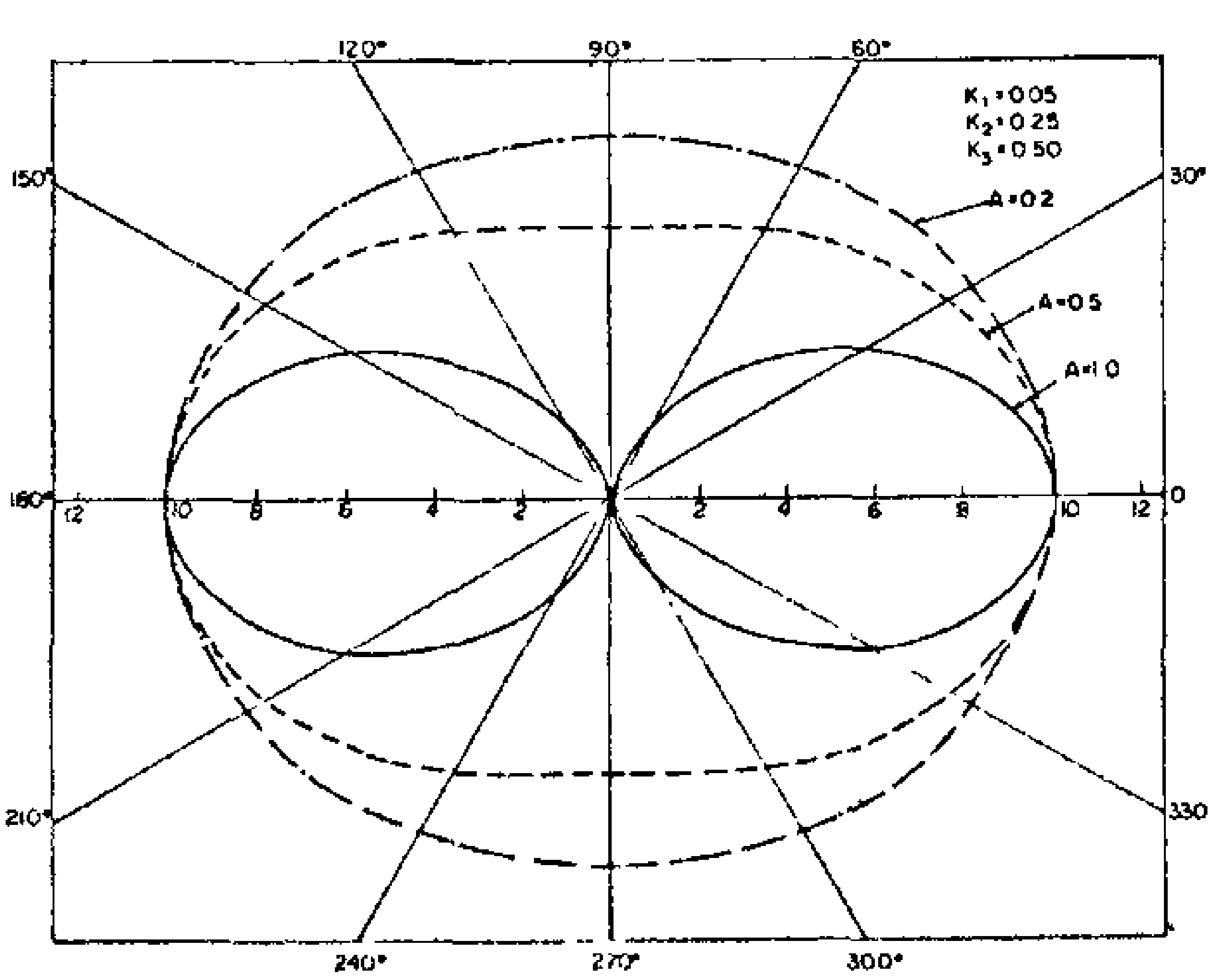


Figure 2. Theoretical EM mode radiation field patterns of the antenna for $K_1 = 0.05$, $K_2 = 0.25$ and $K_3 = 0.5$ for $A = 1$, 0.5 and 0.2.

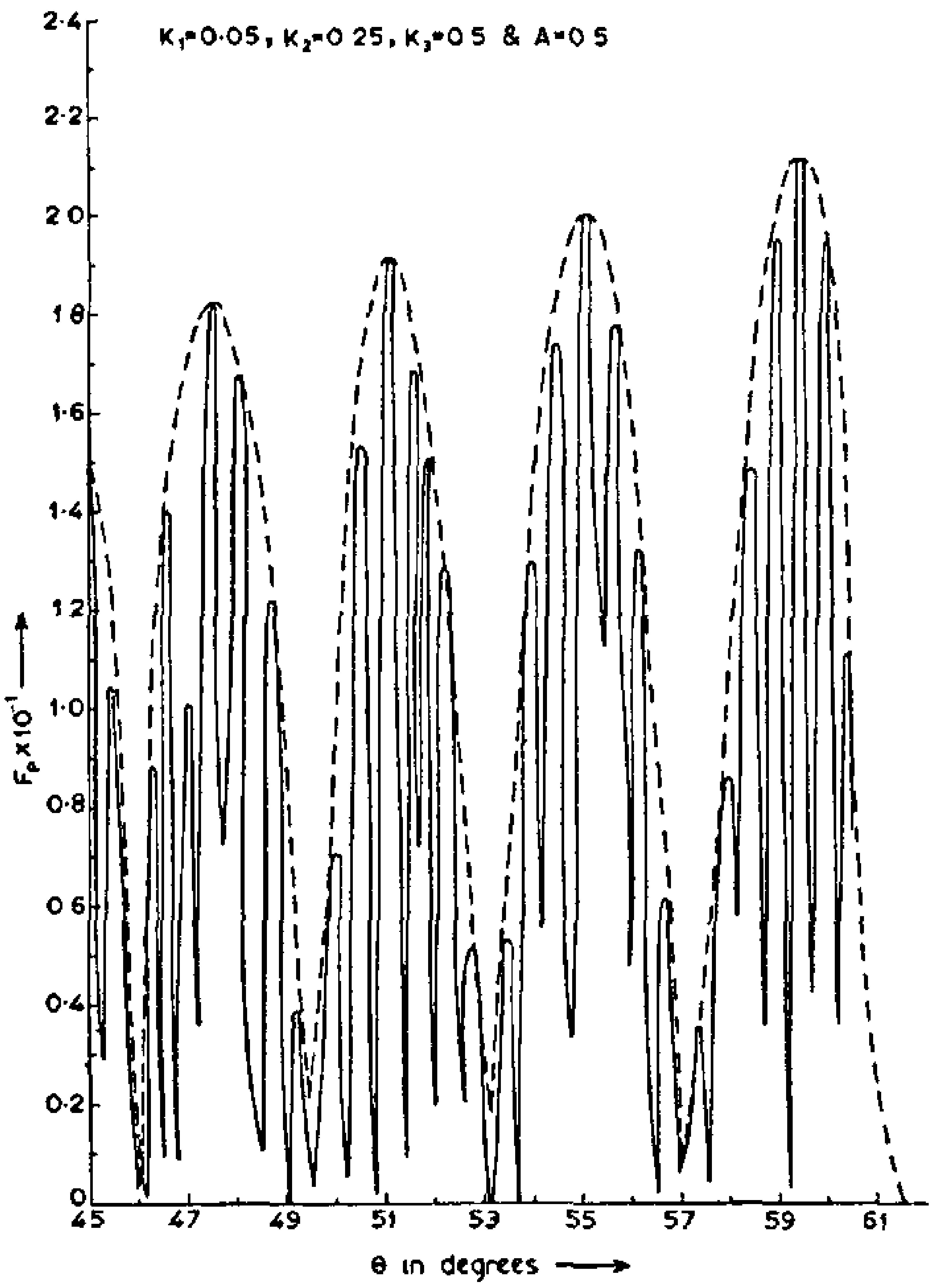


Figure 3. Theoretical plasma mode radiation field patterns of the antenna for $K_1 = 0.05$, $K_2 = 0.25$ and $K_3 = 0.5$ for $A = 0.5$.

The distribution of $F_{pr}(\varphi = 0)$ is shown in figure 3 for $K_1 = 0.05$, $K_2 = 0.25$ and $K_3 = 0.5$ between $\theta = 45$ and 61 degrees for $A = 0.5$. For $A = 1$, F_{pr} vanishes as expected.

The patterns are found to have a number of well-defined maxima and minima. All these are shown enveloped within regular oscillating dotted curves.

POWER CONSIDERATIONS

The total power radiated by the antenna is the sum of the powers radiated in the EM mode (P_e) and the P mode (P_p), separately[3].

For the antenna under discussion, power radiated in the electromagnetic mode P_e for the single slot is given by

$$P_e = \frac{A V_0^2 w^2 \mu_0^2}{240\pi^2\beta_e^2}\int_0^{\pi}\frac{\sin^2(\pi K_2 A\cos\theta)}{\cos^2\theta}\sin^3\theta\,d\theta, \qquad (14)$$

$V_0 = hE_0$, V_0 is the voltage across the slot. On evaluation, one gets:

$$P_e = \frac{60 V_0^2}{A}\left[-2+\cos(2\pi K_2 A)+\frac{\sin(2\pi K_2 A)}{2\pi K_2 A} - 2\pi K_2 A\,\mathrm{si}(x)\right], \tag{15}$$

where

$$\mathrm{si}(x) = \int_0^x \frac{\sin v}{v}\,\mathrm{d}v \text{ and } x = 2\pi K_2 A. \tag{16}$$

The value of P_e/V_0^2 is plotted in figure 4 for different values of w_p/w for $K_2 = 0.15$ and 0.25.

The free space value is obtained by putting $A = 1$ The power radiated in the plasma mode for the single slot is given by

$$P_p = \tfrac{1}{4} R_e \int_0^\pi \int_0^{2\pi} \frac{m w_p^4 V_0^2 b^2}{4\pi^2 n_0 w \beta_p e^2 r^2 v_0^2} \times [N]^2 r^2 \sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi. \tag{17}$$

The value of the integral in (17) can only be obtained by numerical computation. However, for a typical case when $h = 1$ mm, and operation is in 1 GHz range[11],

$$\sin\left(\frac{c}{v_0}\pi A K_1 \sin\theta\cos\varphi\right)\Big/\left(\frac{c}{v_0}\pi A K_1 \sin\theta\cos\varphi\right)$$

can be taken equal to 1. The integral then can be solved analytically and the following expression is obtained

$$P_p = 60 V_0^2\left(\frac{1-A^2}{A}\right)\frac{c}{v_0}\frac{1}{\left(\frac{c}{v_0}\pi A K_2\right)^2} \times\left[1-\cos\left(\frac{c}{v_0}2\pi A K_2\right) + \frac{c}{v_0}2\pi A K_2 \cos\left(\frac{c}{v_0}2\pi A K_2\right) + \frac{c}{v_0}4\pi A K_2 \sin\left(\frac{c}{v_0}2\pi A K_2\right)\right]. \tag{18}$$

In the absence of plasma ($w_p = 0$), P_p is also zero. The variation of P_p/V_0^2 with different ratio of w_p/w is plotted in figure 5, for $K_2 = 0.15$ and 0.25.

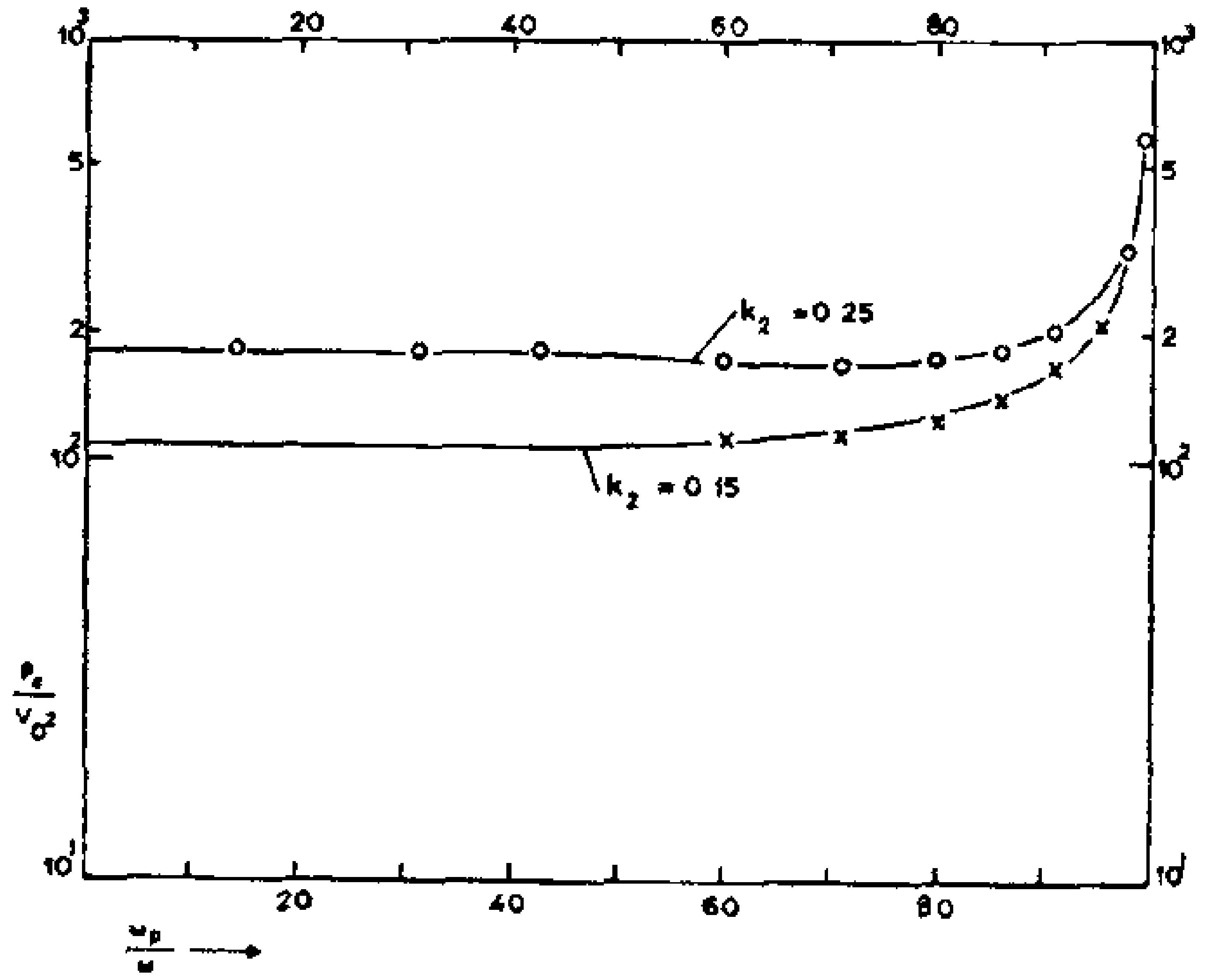


Figure 4. Electromagnetic component of the radiated power P_e for $K_2 = 0.15$ and 0.25 as a function of w_p/w.

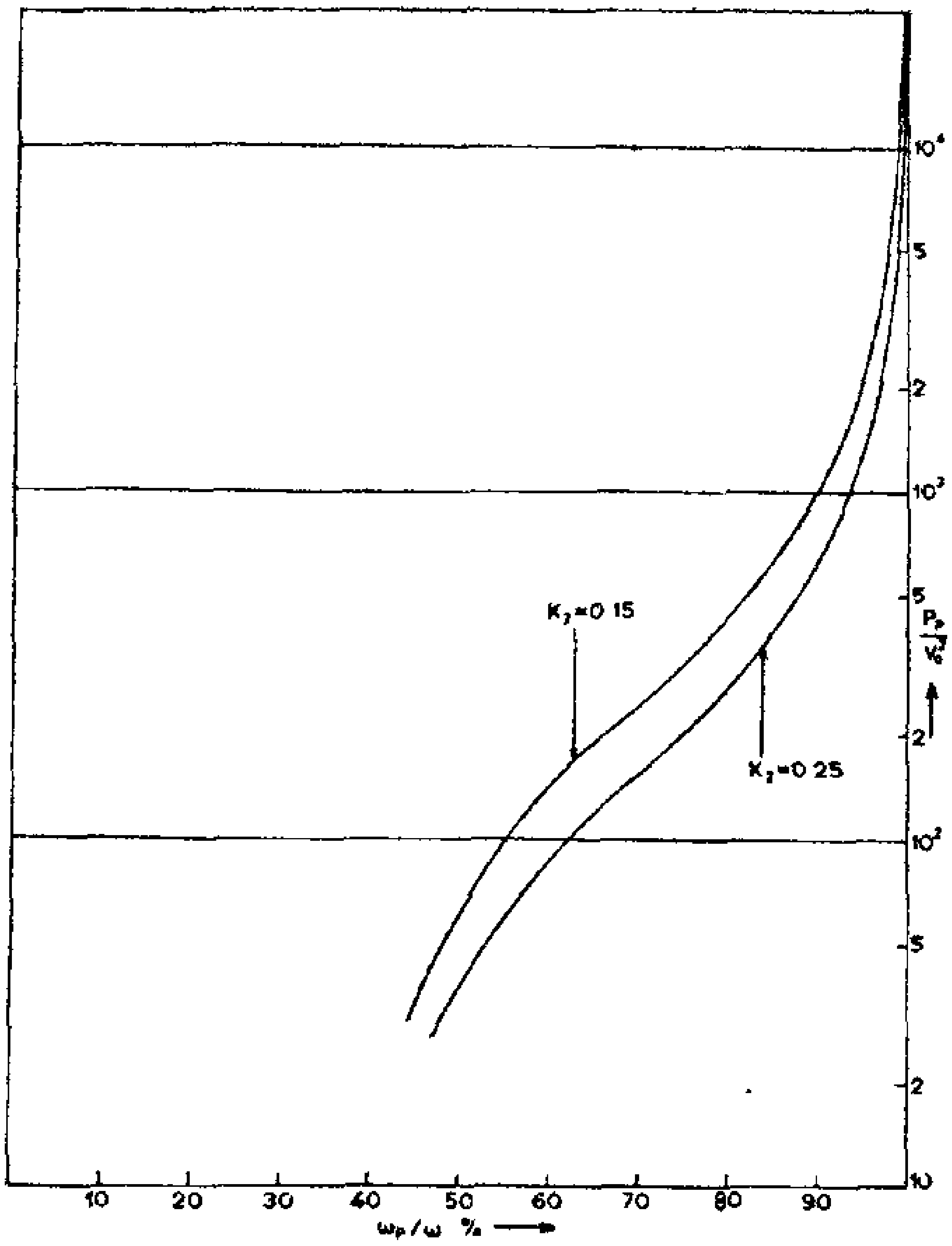


Figure 5. Electroacoustic component of the radiated poser P_p for $K_2 = 0.15$ and 0.25 as a function of w_p/w.

DISCUSSION AND CONCLUSION

The present results show that the microstrip antenna immersed in isotropic plasma also generates electroacoustic waves as in conventional linear antennas. The plasma mode patterns have a large number of maxima and minima. However, unlike conventional antenna, they observe a periodic variation as indicated by dotted envelopes shown in figure 3. It is suggested that experimental varification of the electroacoustic waves generated by microstrip antenna should also be undertaken on the lines similar to those of linear antennas[13].

The effect of plasma on electromagnetic waves generated by microstrip antenna is similar to that on linear antennas as shown by representative field patterns drawn in figure 2.

The magnitude of P mode power is comparable to that of EM mode power and both increases with increase in plasma frequency. Since the power radiated in plasma mode cannot be used for communication purposes, the presence of plasma would decrease the net efficiency of the microstrip antenna.

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ANNOUNCEMENT

FIFTH ASEAN ORCHID CONGRESS, SINGAPORE

The Fifth Asean Orchid Congress will be held at Singapore during 1–7 August, 1984.

As a part of the Congress, there will be a Seminar organised to discuss the following aspects of orchid industry: Orchid Research; Cooperation and coordination; Ecology and Conservation; Breeding and Quality Improvement Towards Export; Commercial Orchid Production and Orchid Improvement in ASEAN Countries.

Papers will be presented in English language and the proceedings will be published.

Further particulars may be had from: Professor A. N. Rao, Chairman, Seminar Organising Committee, Fifth Asean Orchid Congress, Department of Botany, National University of Singapore, Lower Kent Ridge Road, Singapore 0511.