PROPAGATION OF LINEARLY POLARIZED ELECTROMAGNETIC WAVES IN DENSE MAGNETO-PLASMAS

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The theoretical problem discussed here is best illustrated by Figure 1. We wish to find the propagation constant of electromagnetic waves down a parallel-plane waveguide filled with a plasma magnetized parallel to the conducting planes and perpendicular to the direction of propagation. The geometry of this problem is shown in this figure along with the relationship of the components of the dielectric constant K, K , and K_o to the plasma parameters. If the boundary value problem for this case is solved under the assumption of no variation of the fields in the "x" direction, three solutions are obtained. Two of these solutions can be shown to be related to the well known "ordinary" and "extraordinary" waves in an infinite plasma. The third solution has no counterpart in an infinite medium.

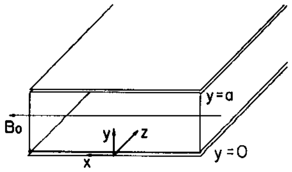
The electric field of the third solution has only a y component and the amplitude grows (or decays) exponentially in this direction while propagating in the plus (or minus) Z direction. The detailed description of this third solution is shown in Figure 2. In the limit of large plate separation, the wave is bound to either the top or bottom plane depending upon the sign of and the direction of propagation. The dependence of the propagation constant upon the magnetic field and plasma density is also shown in Figure 2. The pertinent feature here is that wave motion can take place irrespective of electron density provided Y is greater than 1.

The dependence of the transverse displacement constant, Γ, on plasma parameters is shown in Figure 3. The effect of a small value of Z is to bring the factor Γ back through zero toward its positive value. At this unique point, the field is uniform throughout the plasma. Note that this crossing point always occurs for $Y < 1$.

The physical configuration of the experimental plasma is shown in Figure 4a, and a description of the experimental procedure is shown in Figure 4b. By examining the propagation characteristics of this geometry, one can identify certain features uniquely associated with the surface wave, in spite of the crude experimental approximation to the boundary value problem of Figure 1.

By inserting a low level signal on the antenna located in the middle of the plasma and detecting at the two ends of the guide, one is able to detect the relative coupling to the two directions of propagation, which is a measure of the sign and amplitude of the factor Γ. The results of such an experiment is shown in Figure 5. In Figure 5a, Y is less than 1, and the crossing point is clearly observed. In contrast, Y is greater than 1 in Figure 5b and no crossing is observed.

The propagation of this surface wave through a dense plasma is demonstrated in Figure 6. Here the plasma was created by a high current capacitor discharge and the transmission of a 4.8 Gc signal compared to that of a 70 Gc wave with a constant magnetic field. For the same plasma density conditions, determined by the recombination light, the 4.8 Gc propagates whereas the 70 Gc signal is cut-off.



$$\begin{bmatrix} D_x \\ D_y \\ D_z \end{bmatrix} = \epsilon_0 \begin{bmatrix} K_0 & 0 & 0 \\ 0 & K' & +jK'' \\ 0 & -jK'' & K' \end{bmatrix} \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$

Look for solutions for which $\frac{\partial}{\partial x} \sim 0$, and which propagate as exp.(-jkz)

Notation

where

$K' = 1 + \frac{X(1-jZ)}{(Y^2-1+Z^2)+2jZ}$ $\qquad X = \frac{\omega_p^2}{\omega^2} = \frac{ne^2}{m\epsilon_0}\frac{1}{\omega^2}$ $\qquad$ n = number density

$K'' = \frac{XY}{(Y^2-1+Z^2)+2jZ}$ $\qquad Y = \frac{\omega_c}{\omega} = \frac{eB_0}{m}\frac{1}{\omega}$

$K_0 = 1 - \frac{X}{1-jZ}$ $\qquad Z = \frac{\nu}{\omega}$ $\qquad$ ν = collision frequency for momentum transfer

Solution· Name	Direction of E Field	Propagation Constant
1 Ordinary Wave	$\vec{E} = E_x \hat{a}_y$	$\left[\frac{k}{k_0}\right]^2 = K_0 - \left[\frac{\lambda_0}{2a}\right]^2$
2.Extra-ordinary Wave	$\vec{E} = E_y \hat{a}_y + jE_z \hat{a}_z$	$\left[\frac{k}{k_0}\right]^2 = \frac{K'^2 - K''^2}{K'} - \left[\frac{\lambda_0}{2a}\right]^2$
3.Surface Wave	$\vec{E} = E_y \hat{a}_y$	$\left[\frac{k}{k_0}\right]^2 = K'$

Figure 1. Geometry of the Boundary Value Problem

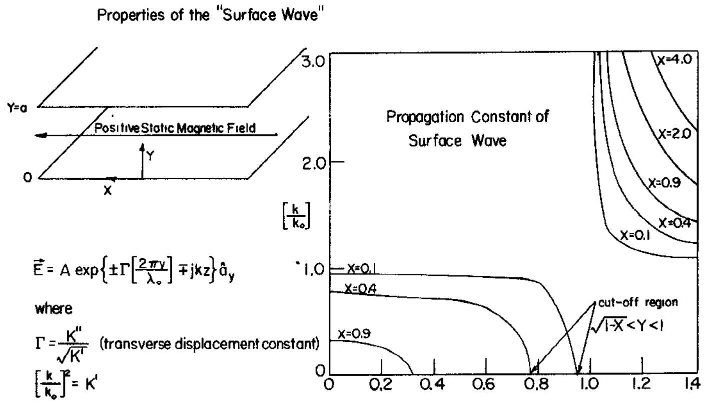


Figure 2. Dependence of the Propagation Constant of the "Surface Wave" on Plasma Parameters

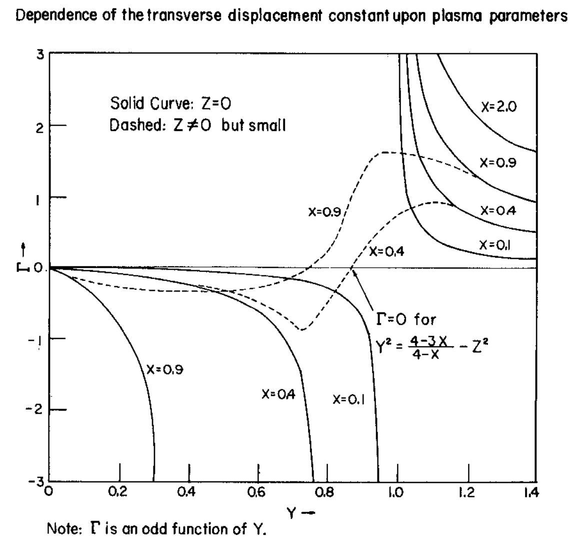


Figure 3. Dependence of the Transverse Displacement Constant on Plasma Parameters

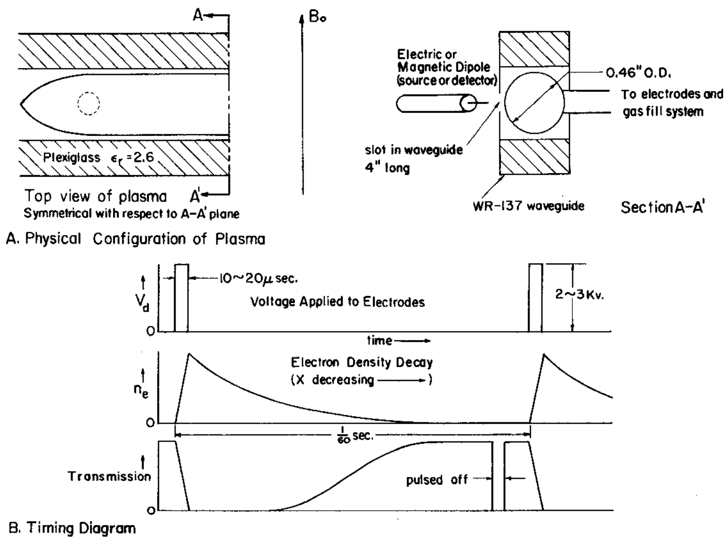


Figure 4. Geometry of the Experiment Plasma

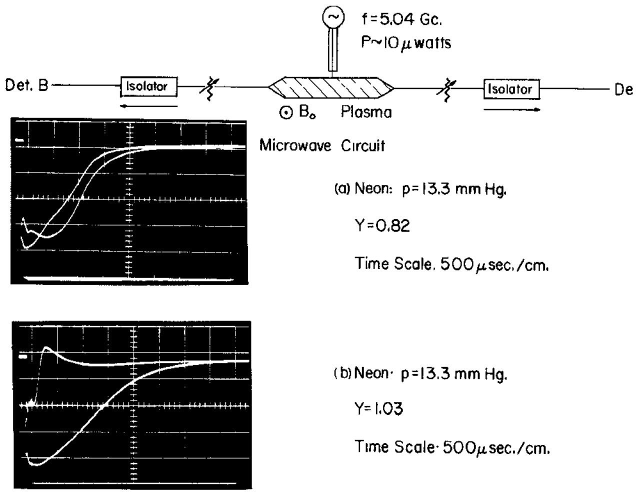


Figure 5. Experiments on the Non-reciprocal Wave Propagation

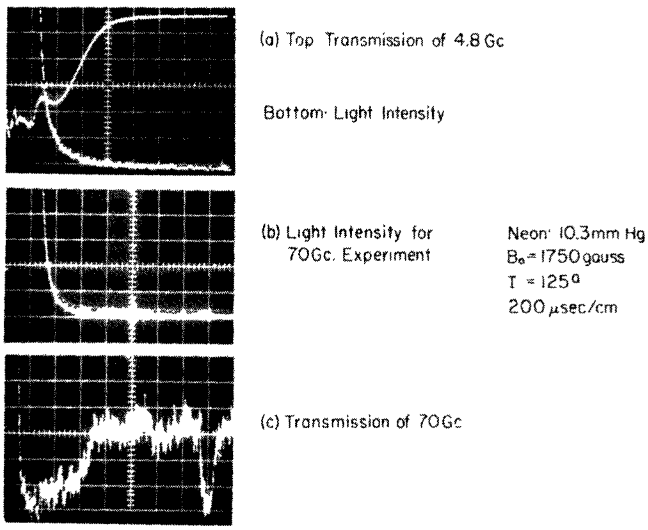


Figure 6. Propagation Through Dense Plasmas

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