Theoretical Notes
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On Transient Wave Propagation in a Plasma

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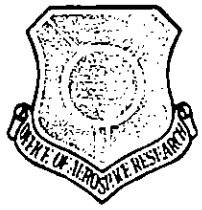

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On Transient Wave Propagation in a Plasma

In the consideration of transient wave propagation in dispersive media, one is generally interested in two aspects of the signal. For communication purposes the shape of the envelope of the signal is most important. In other instances, the initial arrival and buildup of the signal may be of prime importance. The dispersive effect of a plasma or a waveguide on the distortion of the signal envelope has been treated by several authors [1]–[3]. The solutions for the shape of the signal envelope are of an asymptotic nature and are not generally valid in the region of initial arrival of the signal. On the other hand, very little has been reported concerning the initial buildup of a step function carrier propagating in a plasma. Recently Knop [4] has investigated this problem and obtained an exact solution in the form of a convergent infinite series of Bessel functions. Schmitt [5] has experimentally observed the initial transient response of a pulsed carrier propagating through an ionized gas.

It is the purpose of this communication to present a group of curves for the initial buildup of a step sinusoidal carrier propagating in an unbounded, lossless, isotropic plasma. Curves are also presented for the reflection of a sinewave step carrier from a semi-infinite plasma medium. The solution at any point z for the propagation of an input electric field of $E(\tau, 0)=\sin \omega t U(t)$ (where $U(t)$ is the step function operator) is [6]

$$E(\tau,\eta) = \operatorname{Im}\left\{e^{i\tau}\left[1-\frac{\Pi}{\omega}\eta - \int_{\eta}^{\tau}\frac{e^{-iu}J_1\left(\frac{\Pi}{\omega}\sqrt{u^2-\eta^2}\right)du}{\sqrt{u^2-\eta^2}}\right]\right\}U(\tau-\eta) \quad (1)$$

where Π is the angular plasma frequency, $J_1(x)$ is the Bessel function of order one, $\tau=\omega t$, and $\eta=\omega z/c$.

Dispersive effects are also present in reflected signals from plasmas. Consider a half-space of plasma in the region $z>0$, and free space in the region $z<0$. At $z=0$, a signal $E(t)=\sin \omega t U(t)$ is incident on the plasma at $t=0$. The reflected signal is given by [6]

$$E_R = -2\operatorname{Im}\left\{e^{i\tau}\int_0^{\tau}\frac{e^{-iu}J_2\left(\frac{\Pi}{\omega}u\right)du}{u}\right\}U(\tau). \quad (2)$$

Equations (1) and (2) have been evaluated by numerical integration and the results are shown in Figs. 1–5.

An interesting observation is that for a wave propagating in a plasma, the "instantaneous frequency" of the wave is initially very high and decreases approaching the steady-state frequency ω. This corresponds to the high frequencies with group velocities near the speed of light in free space arriving first: the lower frequencies arriving at later times.

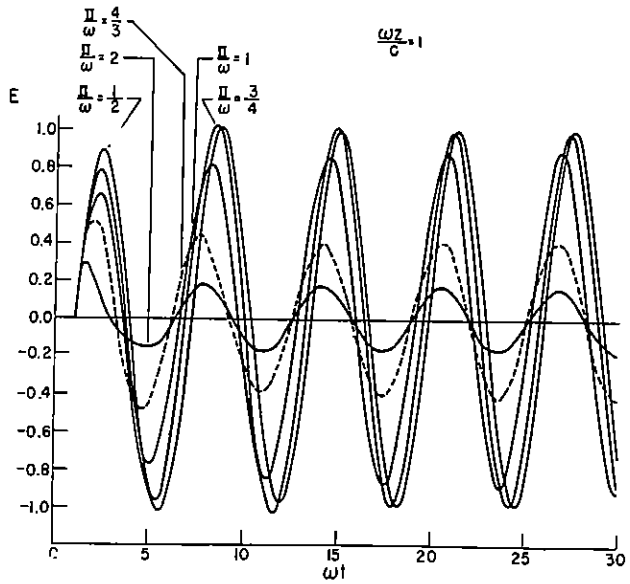

Fig. 1. Electric field intensity as a function of normalized time ωt at the point $\eta=1$ for propagation in an unbounded plasma.

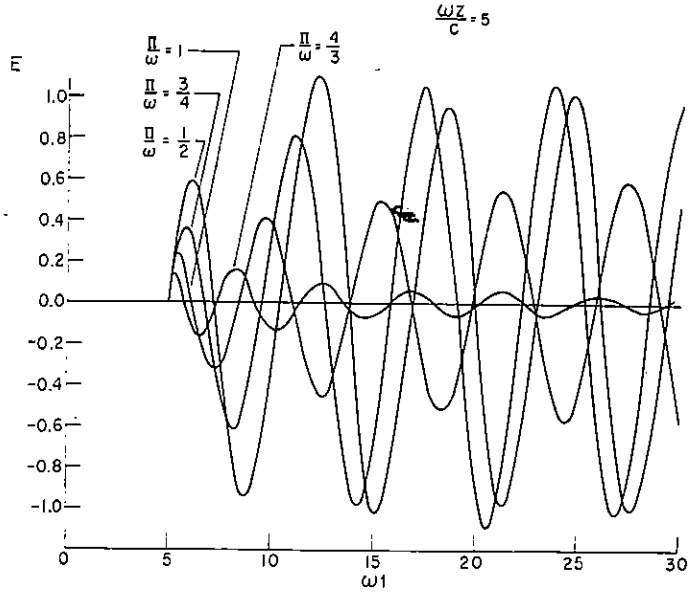

Fig. 2. Electric field intensity as a function of normalized time ωt at the point $\eta=5$ for propagation in an unbounded plasma.

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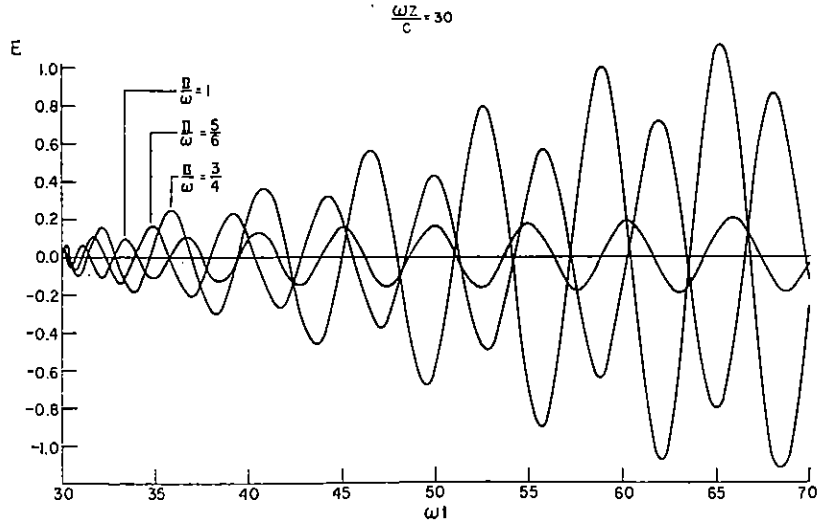

Fig. 3. Electric field intensity as a function of normalized time ωt at the point $\eta = 30$ for propagation in an unbounded plasma.

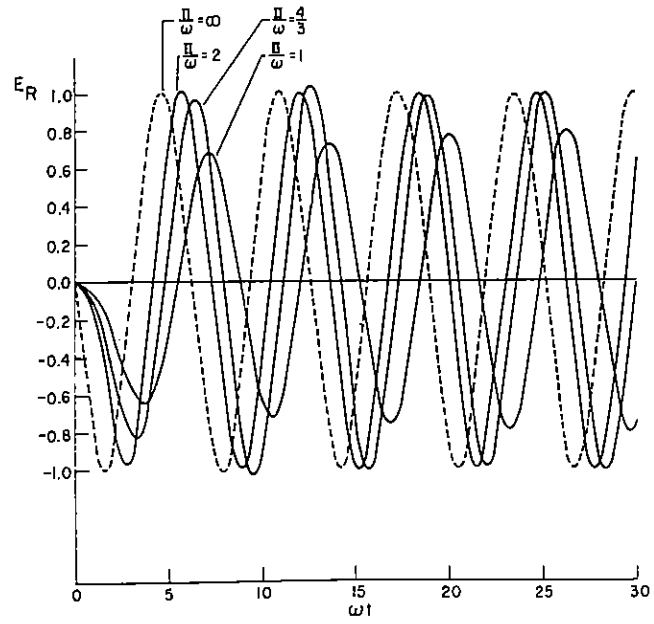

Fig. 4. Electric field intensity as a function of normalized time ωt for a wave reflected from a plasma half space.

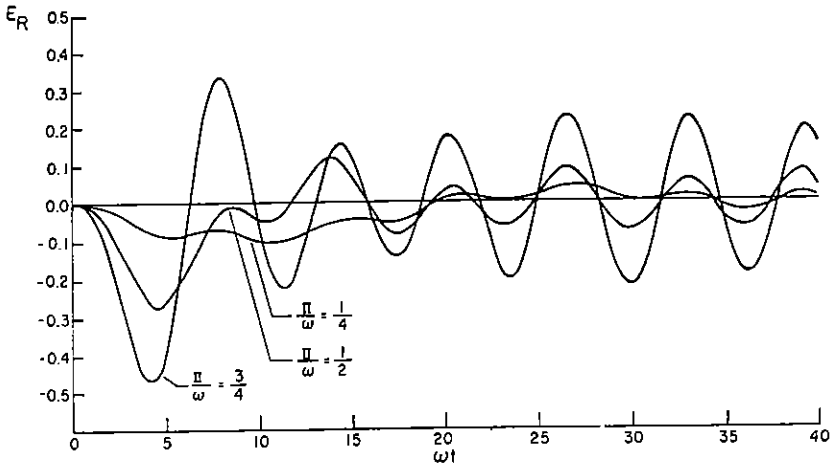

Fig. 5. Electric field intensity as a function of normalized time ωt for a wave reflected from a plasma half space.

The reflected wave for the case $\Pi/\omega > 1$, as in Fig. 4, has an "instantaneous frequency" that is initially relatively low and increases approaching the signal frequency. In the case of the reflected signal for the condition $\Pi/\omega < 1$, as in Fig. 5, two frequencies are predominant. The signal frequency is present, being superimposed on a lower frequency near the plasma frequency.

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