CYLINDRICAL ANTENNA IN A RESONANT MAGNETOPLASMA

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ABSTRACT

A study is made of the current distribution and the input impedance of a perfectly conducting cylindrical antenna in a resonant magnetoplasma. The antenna is aligned with an external magnetic field and is excited by a given time-harmonic slice voltage generator. A rigorous representation is obtained for the current distribution on an infinitely long antenna in the cases where it is either uninsulated or insulated from the surrounding magnetoplasma by a thin concentric dielectric sheath. Based on these results, generalized transmission-line theory suitable for finding the characteristics of finite-length antennas is developed.

ANALYSIS AND RESULTS

We first consider an infinitely long, magnetic-field-aligned cylindrical antenna of radius a_0 which is insulated from the surrounding magnetoplasma by a dielectric sheath of radius a and dielectric permittivity $\epsilon_0\tilde{\varepsilon}$. The plasma is described by the dielectric tensor $\hat{\boldsymbol{\varepsilon}} = \epsilon_0(\varepsilon\hat{\rho}\hat{\rho} - ig\hat{\rho}\hat{\phi} + ig\hat{\phi}\hat{\rho} + \varepsilon\hat{\phi}\hat{\phi} + \eta\hat{z}\hat{z})$. The emphasis is placed on frequencies lying in the resonant interval of the whistler band where $\varepsilon > 0$ and $\eta < 0$. The antenna is excited by a time-harmonic voltage supplied across a narrow circumferential gap. This voltage creates the field $E_z^{ext} = V\delta(z)$ at $\rho = a_0 + 0$.

To determine the current distribution on the antenna, we use the Fourier transform technique. The detailed analysis of the integral representation for the current on a perfectly conducting uninsulated cylinder and a cylinder with a narrow insulating sheath ($a - a_0 \ll k_0^{-1}\tilde{\varepsilon}^{-1/2}$) shows that at the chosen frequencies, the total current through the cross-section $z = \mathrm{const}$ can be expressed as $I(z) = \alpha_0 \exp(-ik_0 p_0|z|) + \Delta I(z)$, where $k_0 = \omega(\epsilon_0\mu_0)^{1/2}$, p_0 and α_0 are, respectively, the normalized axial wavenumber and the amplitude of the eigenmode guided by the antenna surface in the whistler band, and ΔI is the continuous-spectrum part of the current. The axial wavenumber p_0, which is real, and the amplitude α_0 are shown in Figs. 1 and 2 as functions of the normalized sheath thickness $\delta = (a - a_0)/a_0$. A close examination reveals that $\alpha_0 \gg |\Delta I(z)|$ everywhere on the antenna, except for the very small region near the feedpoint. Moreover, the presence of a dielectric sheath whose parameters are chosen so as to model the ion sheath around the cylindrical conductor in plasma leads to an increase in the relative contribution of the eigenmode to the total current.

Next, taking into account the dominant role of the eigenmode, we determine approximately the current distribution of a finite-length antenna with the help of the concept of multiple reflections of the current eigenmode between two antenna terminals. For an antenna with a half-length L ($L \lesssim (k_0 p_0)^{-1}$), the axial and azimuthal components of the surface-current density are then approximated by $J_z(z) = \mathcal{J}_z \sin[k_0 p_0(L - |z|)]$ and $J_\phi(z) = \mathcal{J}_\phi \mathrm{sgn}(z)\cos[k_0 p_0(L - |z|)]$, where $\mathcal{J}_z$ and $\mathcal{J}_\phi$ are constants. Note that for a sufficiently thin antenna, $|J_\phi| \ll |J_z|$. We can thus conclude that since the axial wavenumber p_0 depends significantly on the sheath thickness δ, even a rather narrow sheath can significantly affect the current distribution on the antenna.

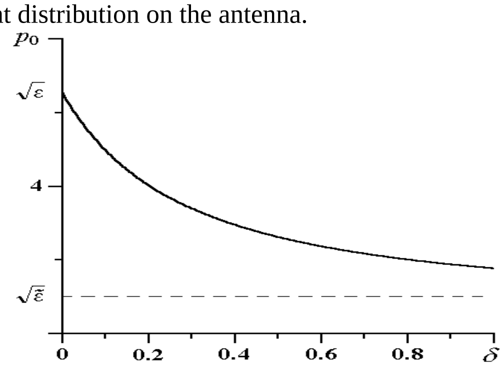

Fig. 1. Eigenmode axial wavenumber as a function of δ for $X = \omega_{\mathrm{p}}^2/\omega^2 = 9 \times 10^4$, $Y = \omega_{\mathrm{H}}/\omega = 46.6$, $k_0 a_0 = 6.2 \times 10^{-6}$, and $a_0 = 1$ cm

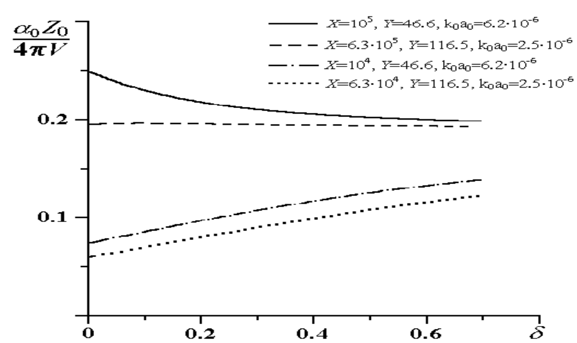

Fig. 2. Normalized amplitude α_0 as a function of δ for $a_0 = 1$ cm and a variety of plasma parameters