WAVE EMISSION FROM A VLF PLASMA-WAVEGUIDE ANTENNA SYSTEM UNDER IONOSPHERIC CONDITIONS

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We study a VLF plasma-waveguide antenna system having the form of a field-aligned quasicylindrical enhancement of plasma density, which relaxes gradually to the background magnetoplasma with distance from the given source. A model enabling one to calculate both the total radiated power and the power distribution over the spatial spectrum of radiated waves is proposed. It is shown that this plasma antenna is useful for increasing the power going to the long-wave part of the spatial spectrum of whistler waves excited in the ambient plasma. Concrete estimates for terrestrial ionospheric conditions are given.

1. INTRODUCTION

In this paper, we continue the investigations performed in [1-4] and consider the excitation of VLF waves by artificial plasma-waveguide radiating systems in the ionosphere. Such systems, which are formed in a self-consistent way in the magnetoplasma near the radiators [5-8], seem to be promising for efficient control of VLF wave characteristics. We restrict ourselves to considering only the frequencies

$$\omega_{LH} < \omega \ll \omega_H < \omega_p$$

(1)

($\omega_{LH}$ is the lower-hybrid frequency, and $\omega_H$ and $\omega_p$ are the cyclotron and plasma frequencies of electrons, respectively) in the VLF range. These frequencies correspond to whistler waves, the methods of effective excitation of which have recently been discussed widely in the literature.

It is well known that only one of the two normal modes of cold magnetoplasma propagates in the frequency region (1). The surface of the refractive index of this mode is shown in Fig. 1 in the form of the dependence $p = p(q)$, where $p$ and $q$ are the longitudinal and transverse components of the wave vector, respectively, which are normalized to the wavenumber $k_0 = \omega/c$ in free space. Efficiency enhancement in the excitation of the long-wave part of the spatial spectrum of radiated whistlers is of particular interest for many applications (see [9]). Conventionally, this long-wave part of the spectrum can be specified as $0 \leq q \leq q_s$, where $q_s$ is the value corresponding to the Story cone, $p''(q_s) = 0$). On the one hand, the increase of interest in this problem is explained by the fact that only in this section of the spatial spectrum can the waves be emitted to the Earth-ionospheric waveguide and reach the Earth's surface when the radiator is located in the midlatitude or polar ionosphere [10]. On the other hand, the waves of this section undergo a considerably weaker collisional damping in the ionosphere than the waves belonging to the intermediate interval $q_s \leq q \leq q_c$, and than the small-scale quasielectrostatic waves belonging to the region $q > q_c$ in particular ($q_c$ is the transverse wavenumber corresponding to conic refraction, $p'(q_c) = 0$). Hence, the excitation of long-wave whistlers is of interest for long-distance transportation of VLF emissions in the near Earth space.

Obviously, the total radiated power and its relative portion going to the long-wave part of the spatial spectrum can be increased either by increasing the dimensions of the radiator itself [1] or by increasing the plasma density in the vicinity of the radiator [2]. In particular, experimental and theoretical studies [2, 11]...
show that the formation of a plasma duct with increased density near the radiator leads to a noticeable increase in the total radiated power in the region (1). When a loop antenna with ring electrical current is used as the radiator, the major portion of this power is spent for the waveguided quasilocalized (improper) modes, which are then re-emitted from the waveguide ends to the ambient plasma medium [2, 3]. Of course, the structure of the radiated field in the plasma environment is strongly dependent on the mode composition as well as on the amplitude and phase relationships between the modes at the waveguide output [4]. Obviously, these factors are determined, in turn, by the conditions of mode excitation and the character of mode transportation in the duct. The study of the influence of these basic factors on the radiated power distribution over the spatial spectrum of waves excited by a plasma-waveguide antenna system in the ionospheric plasma is the main goal of this paper.

2. BASIC EQUATIONS

Consider an emitting system which consists of a cylindrical plasma waveguide aligned with an external magnetic field \( \vec{H}_0 = H_0 \hat{z}_0 \) and an electromagnetic source inside of it with a given time-harmonic \( \sim \exp(i\omega t) \) ring electrical current,

\[
\vec{j}(\vec{r}) = \varphi_0 /0 \delta(\rho - b) \delta(z). \tag{2}
\]

Here \( \rho, \varphi, \) and \( z \) are the cylindrical coordinates and \( \delta(\xi) \) is the Dirac delta function. It is assumed that the plasma density \( \bar{N}(\rho, z) \) in the duct relaxes gradually to the background value \( N \) with distance from the source (see Fig. 2). Since our further analysis is based on the results reported in our previous papers [2-4], we shall recall some of the necessary data given there.

First of all, we recall that for description of the field in the plasma duct we can make use of the well-known method of cross-sections developed for shielded and open isotropic dielectric waveguides [12, 13]. This method is generalized to the case of open guiding systems with gyrotropic filling in [3]. According to [3], complex field amplitudes \( \vec{E}(\rho, z), \vec{H}(\rho, z) \) in a duct with increased plasma density \( \bar{N} > N \), where the existence of only quasilocalized modes [14] in the range (1) is allowed, can be represented in the form*

\[
\vec{E}(\rho, z) = \sum_{\pm \nu} d_{\nu}(z) \vec{E}_{\nu} + \sum_{s, \alpha} \int_{\Gamma_{\gamma}} d_{s, \alpha}(z, q) \vec{E}_{s, \alpha}(q) dq,
\]

\[
\vec{H}(\rho, z) = \sum_{\pm \nu} d_{\nu}(z) \vec{H}_{\nu} + \sum_{s, \alpha} \int_{\Gamma_{\gamma}} d_{s, \alpha}(z, q) \vec{H}_{s, \alpha}(q) dq. \tag{3}
\]

*Hereinafter we give expressions related to the half-space \( z > 0 \), since the field excited by the current (2) is symmetric with respect to the source plane \( (z = 0) \).

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