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Research Article

STUDY OF DIELECTRIC PERMITTIVITY AND CONDUCTIVITY IN THE IONOSPHERE

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ABSTRACT

The ionosphere is so named because it is a region in the atmosphere where ions exist. In most areas of the atmosphere, molecules are in a combined state and remain electrically neutral. In the ionosphere, however, solar radiation (mainly ultraviolet light) is so intense that when it strikes gas molecules they split-ionize and an electron is set free. What remains is a positive ion (a molecule that is "missing" an electron) and a free electron. Although ions give their name to the region, free electrons actually affect radio waves. The number of electrons starts to increase at an altitude of about 30 km, but the electron density isn't sufficient to affect radio waves until about 60 km. We often think of the ionosphere as having a number of distinct layers.

KEYWORDS

Lonosphere, conductivity, dielectric constant, atmosphere

INTRODUCTION

The ionosphere, like any medium, is characterized by dielectric constant ε, magnetic permeability μ and conductivity σ. The magnetic permeability of the entire atmosphere with a sufficiently high degree of accuracy is assumed to be constant and equal to the magnetic permeability of the vacuum, that is, the relative value μ=1. The remaining two parameters are derived based on the physical processes occurring in the ionosphere and depend on the state of the ionosphere, the frequency of the propagating wave, and other parameters. One very important distinction of the dynamics of the ionospheric plasma below 400 km altitude from the dynamics of the magnetospheric plasma is that the ionospheric plasma is embedded into the dense neutral gas. Collisions between neutral and charged particles significantly affect the electromagnetic processes occurring in the ionosphere. In particular, collisions provide a finite conductivity of the ionospheric plasma, connecting currents and the electric field in the ionosphere.

The field of a propagating wave in the ionosphere induces a displacement current of free space and a current due to the movement of free electrons under the action of the field. The density of these currents is:

$$j = i\omega\varepsilon_0 E + j_e \quad (1)$$

The current density due to the movement of free electrons,

$$j_e = eN_э \acute{\upsilon}_e\ , \quad (2)$$

where $\acute{\upsilon}_e$ is the average speed of the ordered motion of electrons, which is determined from the equation of electron motion:

$$m_e \frac{d\ \acute{\upsilon}_e}{\partial t} + m_e \cdot \nu \cdot \acute{\upsilon}_e = e\,E\ , \quad (3)$$

where m_e is the electron mass; e is the charge of an electron.

The electric force acting on the charge from the side of the field F= eE is balanced by the force

particle inertia $m_e \frac{d\ \acute{\upsilon}_e}{\partial t}$ and friction force $m_e \cdot \nu \cdot \acute{\upsilon}_e$. We seek the solution of equation (3) in the form

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$$\acute{v}_e = \acute{v}_e \exp(i\omega t) \qquad (4)$$

Expression (4) is substituted into (3) and after simple calculations the speed of movement of free electrons and the current density (2) are found. Next, the total current density in the ionosphere (1) is compared with the total current density in a medium with losses

$$j = i\omega(\varepsilon_0\varepsilon - i\sigma/\omega)E$$

The Pedersen conductivity is responsible for the Pedersen currents flowing in the ionosphere in the direction of the electric field (Fig.1). This current is carried mostly by ions. It causes dissipation of the electric field energy in the ionosphere and the ionospheric heating. The Hall conductivity is responsible for the Hall current flowing in the ionosphere in the direction perpendicular to the electric field and mostly carried by electrons.

Both conductivities result from the fact that collisions with neutrals demagnetize ions in the ionosphere, and they start to move in the direction of the electric field instead of participating in the E×B drift. Electrons remain magnetized, and they continue to move perpendicular to E with the velocity of the electric drift. Thus, collisions effectively separate electrons from ions, the ions carry Pedersen current in the direction of the electric field, and the electrons carry Hall currents in the direction perpendicular to E.

The Hall and Pedersen currents arise from the peculiarities of the electric drift motion in the collisional media. They both depend on the orientation of the background magnetic and electric field relative to each other. These fields are oriented differently at high and low latitudes. At high latitudes, the magnetic field has a large angle with the ionosphere and with the electric field produced in the ionosphere. At low latitudes, the magnetic field in the south–north direction is parallel to the ionosphere and, if there is an electric field in the east–west direction in the ionosphere, then the E×B drift pushes electrons in the vertical direction and creates a vertical component of the electric field. Comparison makes it possible to determine the dielectric permittivity and conductivity of the ionosphere [1, 2, 3].

$$\varepsilon = 1 - \frac{e^2 N_e}{\varepsilon_0 m_e} \times \frac{1}{\omega^2 + \nu^2} = 3{,}19 \cdot 10^{-9} \frac{N_e}{\omega^2 + \nu^2} \qquad (5)$$

$$\sigma = \frac{e^2 N_e^2}{m_e} \times \frac{\nu}{\omega^2 + \nu^2} = 2{,}82 \times 10^{-2} \frac{N_e \nu}{\omega^2 + \nu^2} \qquad (6)$$

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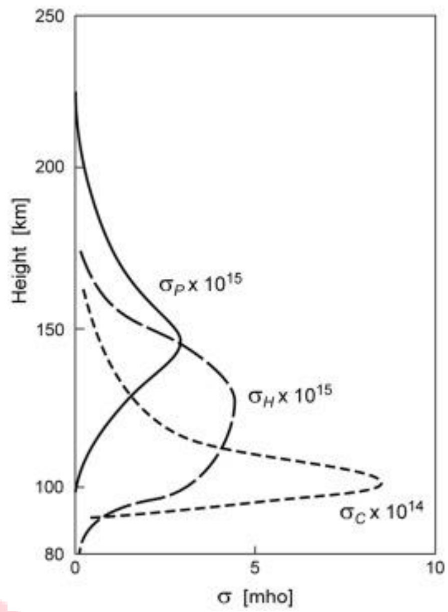

Fig.1. Example of distribution of Pedersen (σP), Hall (σH), and Cowling (σC) conductivities with altitude.

Expressions (5) and (6) are substituted with numerical values e, ε_0, m_e and; ω frequency of the propagating wave, N_e (el/cm^3) - concentration of free electrons, ν (1/sec) - frequency of collision of electrons with heavy particles.

The resulting formula (5) for the permittivity allows us to draw the following conclusions.

RESULTS AND DISCUSSION

The presence of free electrons leads to the fact that the dielectric constant of the ionosphere is always less than the dielectric constant of free space. Free electrons have a negative charge and, moving against the field, they create an opposite polarization and thereby reduce the total field [4, 5]. The permittivity depends on the electron concentration, which has a main maximum at altitudes of 300–400 km. Consequently, ε first decreases, and then, above the ionization maximum, increases with height, and the ionosphere is an electrically inhomogeneous medium (Fig. 2).

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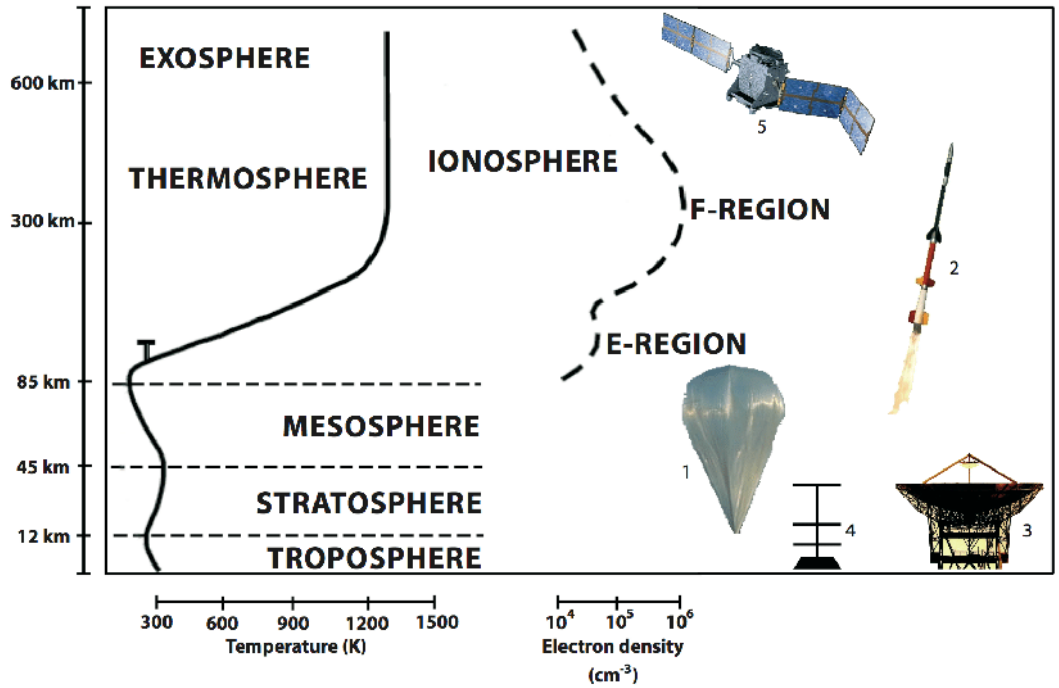

Fig.2. Height relation of the atmosphere and ionosphere.

The permittivity also depends on the frequency of the propagating electromagnetic wave, and the ionosphere is a dispersed medium. The ionosphere has an unequal influence on the propagation of radio waves of different ranges. The frequency dependence is explained by the fact that an electron, having a finite mass, manifests its inertial properties in different ways. At high frequencies, due to inertia, the average velocity of electrons decreases, and the properties of the ionosphere at high frequencies approach the properties of free space, this occurs at frequencies f > 100 MHz The ionosphere practically has the main influence on radio waves of frequencies

f < 100 MHz (λ > 3m) [6, 7].

At frequencies f > 3 MHz, condition $\omega^2 >> \nu^2$ is satisfied and in expression (5) one can neglect ν^2 compared to ω^2. The permittivity (5) of the ionosphere takes on a simpler form

$$\varepsilon \approx 1 - 81 \frac{N_e (el/cm^3)}{f\,(kHz)} \quad (7)$$

Simplified formula (7) can be used at frequencies above 3 MHz, i.e. in the HF and VHF bands. Depending on the frequency, the permittivity varies over a wide range, taking both zero and negative values. For a given electron density N_e, we find the frequency at which $\varepsilon = 0$

$$f_0(kHz) = 9\sqrt{N_e(el/cm^3)} \qquad (8)$$

The frequency at which $\varepsilon = 0$ is called the natural frequency of the ionosphere or the Langmuir frequency. Taking into account (8), the permittivity takes the following form:

$$\varepsilon = 1 - \frac{f_0^2}{f^2} \qquad (9)$$

At frequencies $f < f_0$, the permittivity takes negative values $\varepsilon < 0$. Propagation of radio waves of the indicated frequencies is impossible. Figure 2 shows the case when for some frequency f_3 at heights from h_1 to h_2 $\varepsilon < 0$. A wave with frequency f_3 cannot propagate in the indicated region of the ionosphere [8, 9, 10].

This is explained by the fact that the propagation constant $k = \omega\sqrt{\varepsilon_a \mu_a}$ at $\varepsilon_a < 0$ and the absence of losses becomes the imaginary value $k = -i\alpha$ and the field amplitude decreases exponentially $E = E_0 e^{-\frac{2\pi}{\lambda_0}\sqrt{|\varepsilon|}r}$, and there is no energy transfer.

Without taking into account losses for a wave propagating in the ionosphere, one can use the known calculation formulas.

$$\upsilon_{ph} = \frac{c}{\sqrt{\varepsilon}} , \quad \upsilon_{gr} = c\sqrt{\varepsilon} \qquad (10)$$

CONCLUSIONS

The phase velocity is considered in matters of reflection, refraction of waves, determining the shape of the trajectory of the wave propagation path. The group velocity determines the speed of energy propagation, it is necessary in the evaluation of signal distortion, when measuring the delay time of radio waves reflected in the ionosphere. Pulse distortion is

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significant if the carrier frequency is close to the natural frequency of the ionosphere.

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