APPLICATIONS OF BROADBAND RADIO SIGNALS FOR DIAGNOSTICS OF ELECTRON DENSITY PROFILE DYNAMICS AND SPATIAL PLASMA MOTION IN THE HF-PUMPED IONOSPHERE

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Abstract

A technique for studying inhomogeneous structure and motions in the ionosphere by measurements of wideband pulse radio signal amplitude and phase characteristics is developed and tested in investigations of the HF-pumped ionospheric volume above the Sura facility. For the vertical structure (electron density profile) reconstruction with high altitude and temporal resolution, an algorithm of inverse problem solving by using phase sounding data is implemented. Horizontal velocity data are obtained by means of correlation analysis of reflected signals received by diversity technique. Experimental results on electron density profile behavior and on reconstruction of 3D velocity field during HF pumping of the ionosphere are presented.

Electron density profile reconstruction

During the experiments the Sura facility powerful transmitters with specially designed time schedule were used both for radiation the pump wave (at a frequency 4785 kHz) and the probing waves [2]. An additional advantage was obtained due to use of broadband digital receiver with a high dynamic range for data registration. For reconstruction of the temporal evolution of electron density profile in the HF-pumped ionosphere by measurements of the phase for different spectral components of the wideband diagnostic waves [2] we used spectral decomposition of the ionospherically reflected short (<200 μs) powerful (>20 MW) diagnostic pulses over 500 frequencies with a step δf = 1 kHz. The temporal resolution was determined by interpulse period T = 100 ms. Solution of the inverse problem for the electron density profile reconstruction on the base of phase measurements is performed on the base of the Tikhonov regularization method [3]. After data processing it is clearly seen that, on the background of the natural trend, an enhancements of reflection altitudes by 400-800 m during the pumping is observed for the whole range of analyzed frequencies. After the pumping switch off, in contrary, there is a decrease of reflection altitudes. That corresponds to a decrease (expulsion) of plasma density during the pumping and its increase (inflow) after the pump switch off. The characteristic times of development and relaxation of the perturbations are about few tens of seconds. A knowledge of the dependence plasma density over frequency allowed to translate easily a height variations to the perturbations of plasma density. It is also seen that during the heating the most intensive plasma density fluctuations are concentrated near the plasma resonances, are negative, and reach in average about 1.5% from baseline values. Characteristic spatial scales of fluctuations are 200-500 m.

Spatial velocity field for vertical and horizontal plasma motion

A knowledge of the reflection altitude temporal variations for probing waves at different frequencies (spectral components of wideband diagnostic pulses) allows to construct an evolution of vertical velocity field in ionospheric plasma. It was found that velocity perturbations up to ± 40 m/sec are observed already during the first second near the pump wave frequency (i.e. near its reflection point), and occupied a wider frequency range to the second-third seconds. After 2-3 s the plasma expulsion from upper hybrid resonance region began. It is also clearly seen that a chaotic behavior of the vertical velocity field of amplified from session to session.

For calculating horizontal speed and directions of motion of the diffraction pattern by means of diversity technique, the so-called similarity method used in practice [4, 5]. Sharp velocity jump is observed when the pump

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wave switches on. However we do believe that it's spurious, since the simultaneous development of the anomalous absorption of pump wave and probing signals from all three antennas. Magnitude of the horizontal velocity decreased with the reflection altitude (and therefore the ionosphere altitude) increase, for all sounding frequencies in the altitude range about 12 km. In our experiments we found quite weak variation of the regular velocity of the diffraction pattern and a more significant change of velocity direction when the pumping turned on and turned off. In addition, at times 500-800 sec after turn on, approximately in the middle of the all three pumping sessions, a noticeable change of the magnitude and direction of the horizontal drift were observed, which could be a sign to large-scale wave motions in the ionosphere. Also, a correlation between the variations of the horizontal drift and vertical random motion can be pointed during and after heating. Detected variations in the magnitude and direction of the apparent drift depending on the switching on and off the heating do not have an explanation yet.

Discussion

The use of broadband radio receiver and digital processing methods allows to analyze the phase variation of the different spectral components of the pulse signal, reflected at different heights with high frequency (δf) and time (δt) resolution. In this case the time resolution is determined by the interpulse period. In contrast to multi frequency Doppler sounding (MDS) facilities of previous generation [1] with small number (up to 9) of carrier frequencies of the sounding waves, and novel digital ionosondes with time resolutions ~ 10 s, a choice of specific values δf and δt (1 kHz and 0.1 s in our experiments) was determined from the data analysis on the base of characteristic temporal ($>\delta t$) and spatial scales of the processes responsible for the redistribution of the electron density in the ionosphere. The horizontal velocity data are obtained by means of diversity technique and correlation analysis of the received ionospherically reflected signals. Obtained experimental results such as expulsion of ionospheric plasma from the plasma resonance and the UH resonance of the pump wave, observation of characteristic values of the variations of plasma density and the time of their development and relaxation qualitatively correspond to the results obtained by other diagnostic methods of ionospheric plasma such as incoherent and field aligned scattering of radio waves, stimulated electromagnetic emission as well as MDS facilities of previous generation . However, owing to small quantity of sounding waves in these MDS facilities the regions of plasma and UH resonances had been investigated in different experiments. In addition, the spatial and temporal resolution in our measurements and, hence, an accuracy of determining electron density profile is much higher.

The joint application of the phase sounding (MDS technique) and a reception of the reflected sounding wideband pulses with three separated antennas (a diversity technique) allows to analyze both vertical and horizontal motions in the ionosphere by phase and correlation analysis and reconstruct 3D apparent velocity field of the plasma in the perturbed region. Notice, that so far only few successful sessions on investigation of the ionospheric plasma during the HF pumping were performed by the method described. For construction of empirical model of plasma motions in the HF-pumped ionosphere, it's necessary to conduct further experiments under different ionospheric conditions. A work on detailed interpretation of the data obtained is also required.

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