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ASPECT SCATTERING OF SHORT-WAVE RADIO SIGNALS ON ARTIFICIAL IONOSPHERIC NONUNIFORMITIES

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As shown in [1–5], when the F layer of the ionosphere is acted upon by powerful radio emission, plasma nonuniformities with a wide spectrum of scales arise. Small-scale nonuniformities that are markedly extended along the earth's magnetic field (scales \( l_\parallel \) across the field on the order of 1–30 m) cause scattering of radar signals, with a high degree of aspect sensitivity [2]. In this paper we offer the first results of an investigation of aspect scattering on artificial ionospheric nonuniformities, by means of reception of short-wave signals from remote broadcasting stations.

Perturbation of the ionosphere was created at the Zimenki station (Gor'kii) by using a transmitter with an average power of around 130 kW operating at a frequency of 4.62 MHz into an antenna with a vertical emission pattern (directive gain around 100). The ordinary mode was emitted. The perturbed region (PR) was diagnosed by using the emission (in carrier mode) of remote stations at azimuths of 69° and 75° operating at frequencies of 13.2 and 18.8 MHz. Emissions from these stations were received in the region of Volgograd at a site that approximately satisfied the condition of specular scattering from extended artificial nonuniformities (for quasihorizontal signal trajectories in the vicinity of the perturbed region of the ionosphere). A horizontal rhombic antenna aimed toward Gor'kii was used for reception. Signals scattered by the perturbed region were picked up at the maximum of the antenna pattern (directive gain around 100), while direct signals from the stations were picked up on a side lobe. To calibrate the direct signal level, measurements using horizontal dipoles were made. Experiments were carried out between August 16 and September 7, 1975; the main cycle of continuous measurements was made between August 28 and September 7, 1975. The perturbing transmitter (PT) operated from 0800 to 1200 (Moscow time) and from 1600 to 1900, in 15-min cycles (7 min of


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transmission and 8 min of pause) and 30-min cycles (13 min of transmission and 17 min of pause). When the PT did not operate (or was switched off a few minutes beforehand), only the direct signals of the broadcasting stations were received. Their amplitude $A_0$ was subject to the customary ionospheric fading, the mean value being determined by the propagation conditions on the path. Some 20-60 sec after the PT was switched on, signals scattered by PR nonuniformities arrived at the reception site (in addition to the main signal). Because of the movement of the scattering nonuniformities, the frequency of the scattered signals was shifted by an amount $\Omega_S$ relative to the direct wave. The scattered signal with amplitude $A_S$ was primarily evident, therefore, in the quasinomoidal beats that appeared with characteristic period $\Omega_S^{-1}$ and modulation depth $A_S/A_0$ for $A_S/A_0 < 1$ and $A_0/A_S$ for $A_S/A_0 > 1$. In the latter case the received signal level increased substantially. The modulation disappeared some tens of seconds after the PT was switched off. The characteristics of the signals can be seen from the examples shown in Figs. 1 and 2 (Fig. 1a is for 18.8 MHz, Fig. 1b for the PT signal at $f = 18.8$ MHz; Fig. 2a is for 18.8 MHz, Fig. 2b for the PT, and Fig. 2c for 13.2 MHz). The disappearance of the modulation 10-20 sec after the PT was switched off is particularly evident in Fig. 2; Fig. 1 illustrates the case in which the scattered-signal amplitude $A_S$ was greater than $A_0$.

The mean value of $\Omega_S$ was 2.2-3.2 Hz at 18.8 MHz. The ratio $\eta_S = \Omega_{SF_1}/\Omega_{SF_2}$ for frequencies $f_1 = 18.8$ MHz and $f_2 = 13.2$ MHz was 1.46 on average, this being close to the frequency ratio $f_1/f_2 = 1.42$ and indicating a Doppler mechanism of frequency shift for the scattered waves.*

During the continuous observations, scattered signals were primarily recorded between 0800 and 0900 (Moscow time) and between 1700 and 1900 at $f = 18.8$ MHz and between 0800 and 0900 and between 1600 and 1800 at $f = 13.2$ MHz. This can be seen from the histogram in Fig. 3, which illustrates the frequency of appearance of scattered signals with amplitude $A_S$ equal to or greater than 1/30 of $A_0$. Evidently, the lack of scattered signals during daytime hours is partially the result of strong absorption of the signal (4.62 MHz) in the lower ionosphere, i.e., reduction of the efficiency of heating. But strong variation in $A_S$ was observed from session to session in both the morning and the evening, and this can hardly be associated only with variation of the integral scattering diameter in the PR without allowance for changes in aspect-sensitivity conditions as a result of variation in the angles of incidence of the signals on the scattering region.

At $f = 13.2$ MHz the ratio of the scattered-signal amplitudes in the evening and morning, $A_{S\text{ e}}/A_{S\text{ m}}$, was greater than unity and was on the order of the amplitude ratio for the direct signals $A_{0\text{ e}}/A_{0\text{ m}}$. Thus, at this frequency the evening increase in $A_S$ can be linked primarily to variation in the level of the direct signal $A_{0\text{ e}}$ in the PR as a result of changes in signal absorption over the path. At $f = 18.8$ MHz, $A_{S\text{ e}}/A_{S\text{ m}}$ is greater than $A_{0\text{ e}}/A_{0\text{ m}}$. As estimates showed, the difference can be due in part to the low efficiency of rhombic antennas in receiving signals at angles close to the horizontal, as should be the case during the evening when the MUF was close to the operating frequency on the "last" jump.

*The difference between $\eta_S$ and $f_1/f_2$ is partially related both to the fact that the index of refraction of the medium in the scattering region differs from unity (at the plasma frequency $f_0 = 4.62$ MHz we have $\eta_S \approx 1.44$) and to the fact that the angles of incidence on the perturbed region are different. Taking account of the value of $\Omega_S$ at $f = 18.8$ MHz, we obtain, using the familiar formula $\Omega_S \approx \lambda^{-1} \cos \theta_2 - \cos \theta_1$ ($\lambda$ is the wavelength, while $\theta_1$ and $\theta_2$ are the angles between the velocity vectors of the nonuniformities and the wave vectors of the incident and scattered waves, respectively), that $v \cos \theta_2 - \cos \theta_1 \sim v \gg 35-50$ m/sec, and this is in good agreement with the results of radar observations [2].