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DYNAMIC CHARACTERISTICS OF SIGNALS SCATTERED BY ARTIFICIAL IONOSPHERIC TURBULENCE

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Experimental results are presented of an investigation of the characteristics of backscattered signals (BSS) from a region of artificially generated disturbances in the upper ionosphere, simultaneously studied using two paths of inverse-oblique probing over different path lengths. Data are examined for BSS development during short periods of ionospheric heating, considering fluctuations of the measured signal's Doppler frequency.

Investigations of parameters of signals scattered by artificial ionospheric inhomogeneities, created due to the influence of high-power decameter radiation on the ionosphere, have made it possible to determine the main properties of the artificial region of upper ionospheric disturbance (see, for example, [1, 2]). In that event, inverse-oblique probing is one of the prospective techniques [3, 4].

1. Experimental Procedure. Experimental investigations of the properties of signals backscattered from a region of artificial disturbance of the upper ionosphere were conducted from 1987 to 1989 during the day and evening hours. In order to generate the disturbance region, the Sura heating facility was used [5], operated at $f_{dis} = 4.785$ MHz with an equivalent power $PG = P_e = 50$-75 MW with cycles of different lengths from 5 sec to 5 min. The ordinary magnetoionic polarization was radiated.

Diagnostics of BSS were performed simultaneously from two points, 1300 km away from the Sura facility (P1), and 110 km away (P2). At P1, a test wave transmitter radiated pulsed signals 100 μsec long in the range $f_t = 15$-25 MHz, and at P2, pulsed signals 50 μsec long in the range $f_t = 2.9$-6.5 MHz were used. When receiving at P1 signals backscattered from the disturbance region, quadrature components of those signals were detected. Using an analyzer with parallel filters (analysis band 10 Hz, pass band of a unit filter 0.1 Hz), the BSS spectrum was investigated; the maximum of spectral density (corresponding to the signal Doppler frequency) was detected, and the signal amplitude was calculated. At P2, an amplitude detector was used for recording signal amplitude, and a phase detector for separation of phase fluctuations which were studied using a SK4-72 spectrum analyzer, over a frequency range of 5 Hz with a frequency resolution of $2.5 \cdot 10^{-2}$ Hz.

2. Experimental Results. Let us first discuss the dynamic characteristics of BSS over short heating intervals. Recently studies of that type have become of great interest due to the discovery of certain properties compared to stationary heating (when the time of heating is substantially longer than the time of development of artificial irregularities) (see, for example, [6, 7]).

In Fig. 1a the amplitudes of BSS measured at P1 over 5-second heating of the ionosphere on 02.11.88 ($t_h = 17{:}56$) are presented simultaneously at three frequencies. As seen in the figure, the BSS level from artificial ionospheric irregularities begins to exceed the noise level (0 dB) approximately 2 sec after switching on of the heating (heating time is marked with hatching on the time axis). The effect of BSS maximum amplitude after a short heating time (in that case 5 sec) is most clearly seen in Fig. 1b, where the heating time is also

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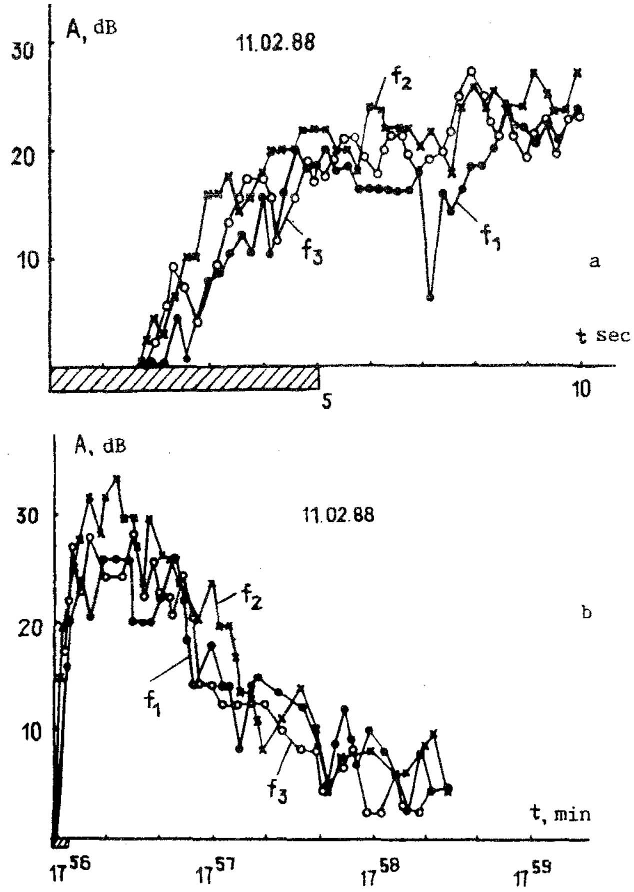

Fig. 1

marked with hatching. During the first five seconds of the pause, the BSS level continues to increase by 5-7 dB. In the next 30-40 sec of the pause, BSS fluctuates in the range of 5 dB. Then, over 100 sec after switching off of the heating facility, the level of BSS decreases by approximately 20 dB and approaches the noise level.

A similar effect was observed at P2 when studying BSS at f_t = 2.95 MHz (see Fig. 2). Here, as earlier, the heating period is marked on the time axis with hatching. It is seen from the figure that BSS occurs after approximately 2.5 sec after the beginning of heating, and the BSS amplitude reaches its maximum (28 dB) about 5 sec after heating. Then, relaxation of the BSS level begins, lasting 1-3 min. Analysis of experimental data showed that the time of detection of the backscattered signal after switching on the heating facility was 1.5-4 sec.

Let us proceed to the spectral characteristics of the signals scattered by artificial ionospheric irregularities. Experiments at P1 showed a number of features of the dynamics of the maximum of the spectral fluctuation density of BSS (f_d) at longer cycles of ionospheric heating (4-5 min). It is seen in Fig. 3 that, along with cycles in which f is chaotic (Fig. 3a), the dynamics of f_d was often regular, manifested in quasi-regular variations (with period of 20-60 sec) of f_d (Fig. 3b). Note that similar dynamics were observed simultaneously at three test frequencies separated by 2-5 MHz. In Fig. 3 the heating began at 50 min before the hour and ended at 55 min before the hour. After the heating, during the BSS relaxation stage, the regularity of changes in most of the f_d cycles was gone (Fig. 3b), yet in some cycles it continued up until complete BSS relaxation after the heating. No regularity with periods of 20-60 sec was detected in the behavior of the Doppler frequency in the study of dynamics of frequency spectra at P2 at a testing frequency f_t = 2.95 MHz. However, at that location variations with periods of 15-30 min corresponding (in time scale) to the passing of internal gravity waves [8] are clearly observed.

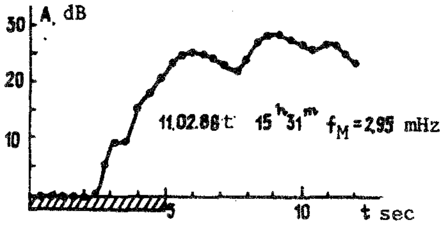

Fig. 2

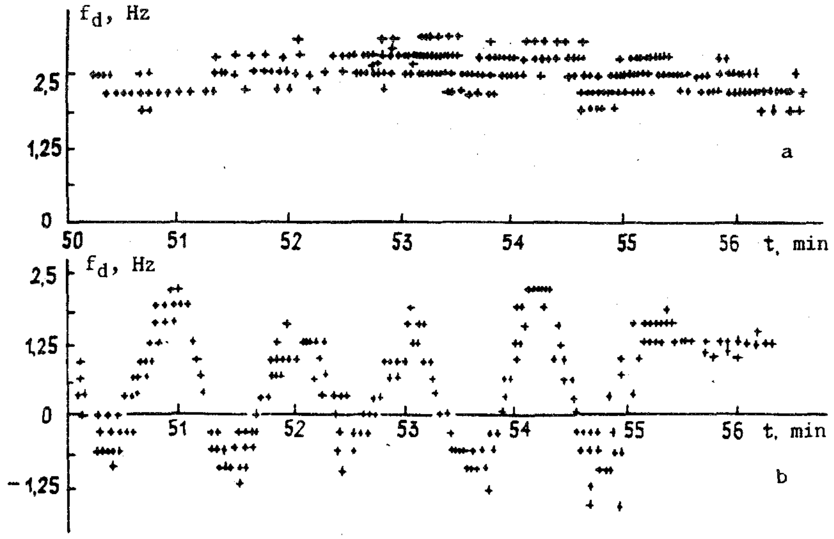

Fig. 3

In February of 1988 simultaneous measurements were performed of Dopoler frequencies from different portions of the BSS (see Fig. 4) with high spatial resolution.* Here the dynamics of the Doppler spectra f_d maxima (star) are shown for the front (Fig. 4a), middle (Fig. 4b), and back (Fig. 4c) profiles of backscattering from the region of artificial disturbance for 5 sec heating cycles. As seen from Fig. 4, in the Dopler spectrum of the front profile of BSS, all absolute maxima have negative Doppler shifts, while for the middle and back BSS profiles, the spectra maxima have positive Doppler shifts.

3. Discussion of Results. Let us first discuss some of the parameters of artificial ionospheric irregularities affecting the backscattered signal. As is known (see, for example, [9]), the main contribution to the intensity of backscattering from anisotropic electron density inhomogeneities in the Born approximation is made by irregularities with cross-section

$$l_\perp \simeq \lambda_0/2n, \tag{1}$$

where n is the index of refraction of the medium at the point of scattering and λ_0 is the wavelength of the test radiowave in vacuum. Therefore, electron density irregularities with $\ell_\perp \simeq$ 7-10 m are responsible for producing BSS based on the observations at P1 at test frequencies $f_t \simeq$ 15-25 MHz (λ_0 = 15-20 m, n ≃ 1).

It is rather difficult to estimate the transverse sizes of irregularities producing the BSS observed at P2 at the low test frequency from Eq. (1). This is due to the large angular sizes of the disturbance region occupied by the artificial ionospheric irregularities. In that event, the sizes of the BSS generation region are comparable with the distance from the test waves to that region. The results of numerical modelling [10] showed that the refraction coefficient at the scatter locations varies over the range of $0.1 \leq n \leq 0.5$. Based on (1) and assuming λ_0 = 100 m, we estimate that irregularities $\ell_\perp \simeq$ 100-500 m are responsible for the BSS at P2. It therefore follows from the estimates performed that electron density irregularities producing the signal backscattered from the artificial disturbance region for different path lengths have substantially different sizes. It is also important that different generation mechanisms are responsible for exciting irregularities of various scale

*Duration of strobing pulses was 1-2 μsec.

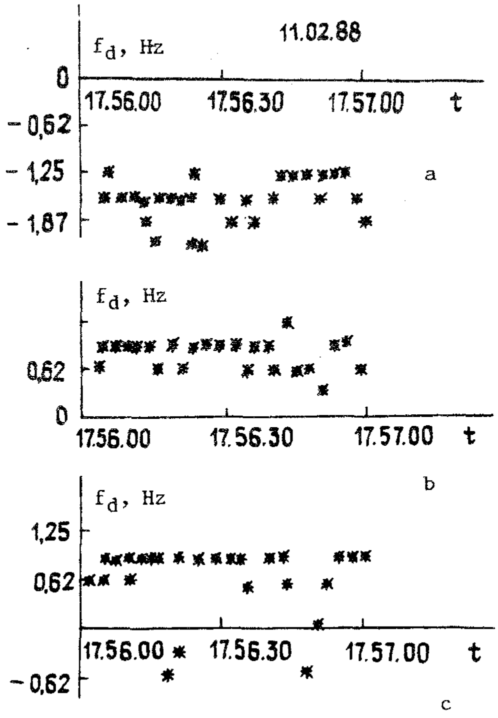

Fig. 4

sizes under the effect of high-power radiation on the ionospheric plasma. It is currently established that generation of artificial ionospheric irregularities with $\ell_\perp \leq 50$ m is due to a thermal parametric instability (see, for example, [11]), and the generation of irregularities with $\ell_\perp \geq 100$ m is due to the self-focussing instability (see, for example, [12]).

Investigations of the dynamics of small-scale ionospheric irregularities with $\ell_\perp \simeq 3$-10 m [1, 7] showed that development of artificial irregularities relative to the switching on of the heating facility is delayed by t_h. It was determined that t_h increases with the increases of $\ell_\perp$, and is the order of seconds for $\ell_\perp \simeq 3$ m. In the case of so-called "overheating" conditions of the ionosphere, when the subsequent period of heating begins during the relaxation stage of irregularities disturbed by the previous heating, the delay time was $t_h \simeq 0.05$-0.1 sec for $\ell_\perp \simeq 3$ m and $t_h \simeq 0.1$-0.2 sec for $\ell_1 \simeq 7$ m (equivalent radiating power of the heating facility was $P_e \simeq 150$ MW). It is seen from a comparison of delay times obtained during observations at P1 [1] that for similar irregularity scale sizes the delay times coincide well.

When analyzing simultaneous observations of the BSS dynamics at P1 and P2, one notices the comparable time scales of the scattered signals. It was noted above that those signals were produced by artificial irregularities significantly different in their scale sizes. Thus, the problem of the initial stage of BSS formation and, therefore, the initial stage of generation of irregularities over a wide range of scale sizes, remains unsolved.

Experimental studies of the dynamics of BSS spectral characteristics are, in our opinion, of greatest importance. It appears that quasiperiodical oscillations of f_d, similar to those shown in Fig. 3b, were detected for the first time for artificial ionospheric irregularities. Such oscillations of BSS Doppler frequency may be due to two causes: passage of acoustic-gravity waves through the disturbance region [8], or generation of such oscillations in the disturbance region itself by the ionospheric radio heating. Since in most observations the regularity of f_d variations vanished in the initial stage of BSS relaxation, one can make conclusions on the artificial origin of the source of generation of those quasiperiodical oscillations f_d. Data shown in Fig. 4 indicate that there are regular and inversely-proportional (in the given case, to the center of the disturbance region) horizontal motions of artificial ionospheric irregularities producing the BSS.* Estimates show that

*Earlier a similar model of radial motions of irregularities was discussed in the paper of Belei, Belenov, et al. (Preprint NIRFI No. 285, Gor'kii, 1989).

the projection of velocity of the irregularity motion relative to the line connecting P1 with the disturbance region is V ≈ 20-30 m/sec.

Based on the discussion of experimental data, we can draw the following main conclusions:

new properties manifested by the quasiperiodic variations of Doppler frequency of the BSS with periods of 20-60 sec, and the regular motions of irregularities with velocities of 20-30 m/sec directed toward the center of the disturbance region, were detected in the dynamics of the artificial disturbance region;

the times of BSS occurrence after the beginning of ionospheric heating along paths of 1300 km (range of test frequencies 15-25 MHz) and about 110 km (test frequency 2.95 MHz) are slightly different, and are respectively approximately 1-2 sec and 1.5-4 sec.

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