to the excitation of plasma and ion-acoustic waves into account.

If the disturbing wave is not too strong:

$$\left(\frac{E_1}{E_t}\right)^2 \leqslant 4\cdot10^{-4}\frac{\omega}{\nu_e}, \qquad (1)$$

the instability is of kinetic nature under the conditions of the ionosphere (here ν_e is the effective frequency of collisions between electrons and heavy particles). In this case, oscillations at the principal (first) maximum of the standing wave build up most rapidly, with an increment

$$\gamma_1 = \frac{\nu_e}{2}\left[\left(\frac{E_1}{E_t}\right)^2 - 1\right],$$

where E_1 is the amplitude of the field in the first maximum.

Let t be the time reckoned from the switching on of the field. At $t < t_1$, where $t_1 = \tau_0/\gamma_1$, the oscillations build up exponentially in time: the self-action of the radio wave and the nonlinear interaction between Langmuir waves are insignificant. The parameter τ_0 is determined by the initial noise level; under ionospheric conditions, $\tau_0 \sim 7-10$ at the initial level of thermal noise.

The interaction of the radio wave with Langmuir noise becomes significant at $t > t_1$. Since the disturbances of ϵ are now basically of dissipative nature, the intensity of the wave first drops sharply at $t > t_1$ as a result of its absorption in the first maximum. But the intensity of the reflected wave rises even at $t - t_1 > 1/\gamma_1$ because the field is restructured and the wave begins to be reflected from a region of strongly excited oscillations. A new standing wave is formed. This nonstationary process may then be repeated as a result of excitation of the next maximum, and so forth. The nonlinear interaction between Langmuir waves also results in similar nonstationary effects. Transfer of energy across the Langmuir-wave spectrum is accompanied by strong excitation of oscillations in specific narrow spectral regions—in satellites. Even this process is of oscillatory nature because of the weak damping. Thus, the structure of the disturbed zone is essentially of nonstationary nature during the initial phase of excitation. As a result, the wave reflected from the ionosphere is strongly amplitude- and phase-modulated during the initial stage of plasma excitation. The modulation period $T \sim (1-10)/\gamma_1$. The oscillations that arise are of relaxational nature[3,4]. In the ionosphere, $T \sim 10^{-4}-10^{-2}$ sec.

In the steady state, the disturbances to the dielectric constant of the plasma are proportional to the energy density of the wave: $\Delta\epsilon \sim (E^2 - E_t^2)$. Solution of the wave equation with consideration of this nonlinear disturbance of ϵ indicates that the structure of the field is strongly modified by self-action and that the absorption of the wave in the plasma increases. When the ordinary (linear) absorption is small, the anomalous (nonlinear) absorption due to excitation of the oscillations is the principal factor. The coefficient of reflection of the wave from the plasma then decreases sharply with increasing power of the wave ($\sim W^{-3}$)[5].

Condition (1) is violated at high amplitudes of the disturbing wave, and the instability grows over into its hydrodynamic phase. A characteristic property of hydrodynamic instability under the conditions of the ionosphere is that the maximum of the oscillation increment γ now no longer coincides with the principal maximum of the standing wave, but is shifted downward, approaching the lower boundary of the instability region. As a result, not only is the radio pulse modulated when self-action is taken into account (as in the case of kinetic instability), but part of the pulse may also experience an appreciable delay, undergoing reflection upward from the most strongly disturbed layer at the boundary of the instability region[6].

Analysis of the self-action effects that arise under prolonged continuous action of the radio wave on the ionosphere ($t \gtrsim 10$ sec) indicates that an instability of the self-focusing type may arise when electron heating and the change in plasma concentration in the reflection region of the ordinary wave in the F layer are taken into account, and may result in the formation of an inhomogeneous structure in the ionosphere. The characteristic size of the inhomogeneities in the plane orthogonal to the geomagnetic field **H** is of the order of 0.5—1 km; in the direction along **H**, the inhomogeneity increases with time, reaching sizes ~10 km after ~10 sec. At not very strong fields $E < E_t$, the increment γ of this instability is of the order of $1/\tau_T$, where $\tau_T \sim 1/\delta\nu_e$ is the characteristic electron-heating time (in the F layer of the ionosphere, $\tau_T \sim 20-40$ sec). With increasing field amplitude at $E > E_t$, γ increases sharply, so that it is already an order larger than $1/\tau$ at $E \sim 2E_t$.

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V. V. Belikovich, E. A. Benediktov, G. G. Getmantsev, L. M. Erukhimov, N. A. Zuĭkov, G. P. Komrakov, Yu. S. Korobkov, D. S. Kotik, N. A. Mityakov, V. O. Rapoport, Yu. A. Sazonov, V. Yu. Trakhtengerts, V. L. Frolov, and V. A. Cherepovitskiĭ. Nonlinear Effects in the Upper Ionosphere. The possibility of heating of the upper ionosphere by powerful radio-frequency radiation was indicated in 1960 by Ginzburg and Gurevich[1]. Later, Farley[2] and Gurevich[3] made quantitative estimates of the electron temperature and concentration changes.

The first experiments in which the F layer was irradiated by a powerful shortwave radio transmitter were performed at Boulder and Arecibo in 1970[4]. A similar installation was built in 1972 at the Scientific Research Radiophysics Institute (Gor'kiĭ). The transmitter has an average power output $P \sim 130$ kW and works at 5.75 MHz in either continuous or pulsed operation. Radio waves with right-hand and left-hand circular polarization are emitted vertically upward by an antenna with a gain G ~ 150. An auxiliary ionospheric station and apparatus for registration of discrete-source radio emission at frequencies of 9 and 25 MHz are used to diagnose the state of the F layer. Some of the results obtained in 1973 were described briefly in[5]. When the high-power station is switched on, the intensity of test waves reflected from the ionosphere (with frequencies near that of the high-power transmitter) is observed to decrease by factors of 3 to 10 with characteristic times from 30 to 2 sec, depending on transmitted power. When the high-power transmitter was switched off, the test signals were recovered after approximately the same characteristic times. Figure 1 shows the attenuation of the test waves and the characteristic times of the decrease in test-wave field intensity as functions of transmitter power output. The anomalous-attenuation effect in the test wave became much weaker when the test-wave frequency was moved a few hundred kilohertz away from 5.75 MHz. A whole series of peculiar nonlinear effects was also observed. For example, when the critical frequency was close to 5.75 MHz, there was a sharp increase in the diffuseness of the signals reflected from the ionosphere.

During the experiments described above, the radio emission of the discrete source in Cassiopeia was recorded at frequencies of 25 and 9 MHz while the source was inside the directional pattern of the high-power transmitter's antenna. Figure 2 presents sample records of the source at both frequencies. The vertical line marks the time at which the high-power transmitter was switched on, and the arrow the time at which it was switched off. An increase in the small-scale ionospheric flicker (Fig. 2a) or of the large-scale intensity variations (Fig. 2b) is characteristic for the 25-MHz frequency (see also[6]). A sharp drop in the source intensity is characteristic for the 9-MHz frequency (Fig. 2c). All of these phenomena occurred only when the critical frequency of the F layer was above 5.75 MHz.

In the course of the experiments, we also observed various manifestations of the combination frequencies whose existence was indicated in[1] and which are associated with quadratic nonlinearity. Thus, when the signal from the high-power transmitter was sine-wave-modulated at a frequency $\Omega \ll 5.75$ MHz, we registered signals of ionospheric origin with frequency Ω and an intensity in agreement with the quantitative calculations made jointly by V. Ya. Eĭdman and V. V. Tamoĭkin.

The nature of the observed nonlinear effects forces us to the conclusion that in addition to heating of the ionosphere by powerful radio-frequency radiation, turbulization of the plasma occurs in the disturbed region as a result of the appearance of various types of instabilities. This problem is considered in greater detail in the paper[7].

In 1970, the SRRIF also observed artificial signals at a frequency of 15 kHz in magnetospheric propagation. The receiver and transmitter were at practically the same location with L = 2.6 (L is the McIlwain parameter).

Among the most characteristic features of the return echo, we note substantial (up to 50 Hz) broadening of the spectrum with an asymmetry toward the high-frequency side and amplitude modulation of the signal. In some of the transmissions, the strength of the reflected signal was observed to depend on the length of the transmitted train. Arrival of the main signal was often heralded by a "precursor," whose lag behind the sounding signal varied smoothly in the range 0.2–0.6 sec with a characteristic time of about 2 min (which corresponds to a reflecting region moving at a velocity of ~1000 km/sec). Certain theoretical considerations regarding this experiment are also given in[7].

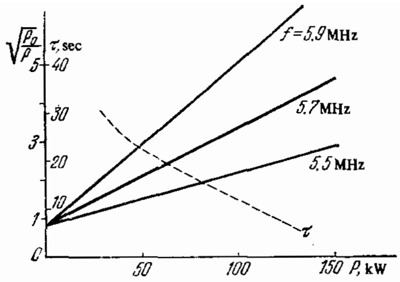

FIG. 1.

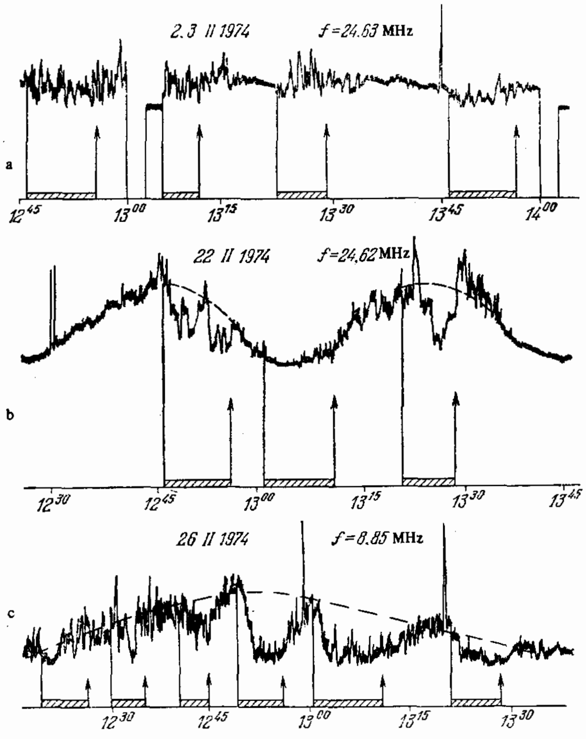

FIG. 2.

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