tudes of the $f^{(1,2)}$ waves was observed under the action of the disturbing pulse. Thus, the amplitude of the $f^{(2)}$ wave decreased by factors of 10–20 at maximum disturbing-pulse power, which corresponds to a nonlinear absorption of 20–25 dB ("suppression" effect). On the other hand, amplification of the reflected wave under the action of the powerful pulse ("bleaching" of the plasma) was observed under certain conditions at frequency $f^{(1)}$. We note that even when two continuously radiated waves interacted, strong cross modulation (up to 7%) was observed and was accompanied by strong distortion of the form of the cross modulation and even doubling of the modulation frequency ("overmodulation" effect).

Cross modulation of short pulses, i.e., the interaction of a strong pulse with another pulse f of duration 10^{-4} sec, was studied in a broad range of frequencies f from 0.5 to 6 MHz. At frequencies $f \lesssim 1–2$ MHz, the percentage cross modulation reached 90% during the day and in the evening, dropping to 10–30% after midnight. The percentage cross modulation increased with increasing frequency f, but it reached 30–40% during the day even at the highest frequencies, $f \sim 5–6$ MHz. The cross modulation percentage was found to be a strongly nonlinear function of the power of the disturbing station and varied substantially and irregularly in time. The hourly, daily, and seasonal average values $\overline{\mu}$ of the cross-modulation percentage and its fluctuations $\sqrt{\overline{(\mu - \overline{\mu})^2}}$ were plotted for various frequencies f and various disturbing-pulse powers.

The observed self-action and interaction effects of the high-power radio waves, including the qualitative effects ("saturation," "bleaching," "suppression," "overmodulation"), agree closely with the results of theoretical calculations [1] that take account of the change in the electron-collision frequency in the ionosphere as a result of heating of the electrons in the field of the powerful pulse. Study of the time variations of field amplitude in self-action and interaction of the waves makes it possible to investigate nonstationary heating and temperature relaxation of electrons in the ionosphere. A detailed comparison with theory indicates that the electron temperature rose by factors of $\sim 10–20$ under the action of the strong pulse at heights of 80–100 km in the lower ionosphere in these experiments.

A marked variation of electron density in the E layer was also established: during the time for which the powerful station acted, the frequency of appearance of the sporadic E_s layer increased, and the maximum frequency of the E_s layer was, on the average, 10–20% higher.

A singular phenomenon was observed at night on reflection of the ordinary wave from the F layer of the ionosphere [2]. In this case, beginning at a certain critical power (on the order of −5 dB), the reflected-pulse amplitude decreased sharply with increasing radiated power, with the simultaneous appearance and subsequent rapid development of strong distortions of pulse-envelope shape, i.e., deep amplitude modulation of the reflected signal with a frequency $f_m \sim 5$ kHz was observed. These pulse-shape distortions were of irregular character and oscillated rapidly in time. These nonstationary effects are evidently related to parametric excitation of Langmuir plasma oscillations in the region in the F layer of the ionosphere in which the pulses are reflected [3].

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V. V. Vas'kov and A. V. Gurevich. Excitation of Instability of the F Region of the Ionosphere in a Powerful Radio-Wave Field. The problem of buildup of oscillations and waves in the ionospheric plasma is of considerable interest in connection with experimental study of excitation of the upper ionosphere by powerful radio waves [1]. Instability is excited most effectively in the plasma-resonance ranges, where the frequency of the radio wave is close to one of the natural frequencies of the plasma. Thus, with normal incidence of an ordinary wave on the plasma, the frequency ω of the wave near the reflection point is close to the Langmuir frequency ω_0 of the electronic plasma oscillations. Parametric buildup of plasma and ion-acoustic waves is possible in this region [2].

To excite instability, it is necessary that the amplitudes E of the wave electric field exceed a threshold field E_t [2]. Under the conditions of the ionosphere, the field E_t for an ordinary wave is smallest at heights $h \sim 200–250$ km: during the day, $E_{t\,min} \sim 300$ mV/m and $\omega_{min} \sim 3 \times 10^7$ Hz; at night, $E_{t\,min} \sim 30$ mV/m and $\omega_{min} \sim 6 \times 10^6$ Hz. At the height of the F-layer maximum, the field E_t is 3–4 times larger than $E_{t\,min}$; it also increases rapidly with decreasing height in the E layer. Instability is excited at the maxima of the radio-wave field, i.e., at the maxima of the standing wave formed near the reflection point. The instability region occupies 1–5 km downward from the reflection point, and 10 to 100 maxima are excited. The generated plasma waves have wavelengths from 0.2 to 1 meter.

The propagation conditions in the plasma for the radio wave that caused the disturbance change when instability is excited. This gives rise to the wave's self-action. It is important that self-action effects are also resonantly amplified in the neighborhood of the reflection point. In fact, even small disturbances of the plasma in the region where $\epsilon_0 \to 0$ result in a substantial change in ϵ and hence also in the structure of the radio-wave field. In turn, this strongly influences the development of the instability [3].

Disturbances of ϵ may be related either directly to excitation of plasma oscillations or to the over-all change in plasma density caused by expulsion of plasma from the heated region or by the change in the ionization-recombination balance. In the ionospheric F layer, however, the latter process is characterized by a substantial time $\tau_N \sim 10–100$ sec, and can therefore be neglected in treatment of the initial stage of instability development, i.e., we may take only the disturbance of ϵ due to the excitation of plasma and ion-acoustic waves into account.

If the disturbing wave is not too strong:

$$\left(\frac{E_1}{E_t}\right)^2 \leqslant 4\cdot 10^{-4}\frac{\omega}{\nu_e}, \quad (1)$$

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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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