Scientific Session of the Division of General Physics and Astronomy, USSR Academy of Sciences (20-21 March, 1974)

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A scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held on March 20 and 21 at the conference hall of the Academy of Sciences Institute of Physics Problems. The following papers were delivered:

1. A. V. Gurevich, Nonlinear Effects in the Propagation of High-Power Radio Waves in the Ionosphere.
2. I. S. Shlyuger, An Experimental Study of Nonlinear Effects in the E and F Layers of the Ionosphere.
3. V. V. Vas'kov and A. V. Gurevich, Excitation of Instability of the F Region of the Ionosphere in a Powerful Radio-Wave Field.
4. 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.
5. S. M. Grach, A. G. Litvak, N. A. Mityakov, V. O. Rapoport, and V. Yu. Trakhtengerts, Toward a Theory of Nonlinear Effects in the Ionosphere.
6. A. B. Shvartsburg, Reflection of Strong Radio Waves from the Ionosphere.

We publish below brief contents of the papers.

A. V. Gurevich. Nonlinear Effects in the Propagation of High-Power Radio Waves in the Ionosphere. The present state of the problem is briefly reviewed. The Luxemburg effect, or cross modulation of radio waves that interact in the lower ionosphere (at heights $z \sim 80$–100 km) and do not strongly disturb the ionospheric plasma, was investigated systematically back in the 1940's[1]. Recently, with the increasing power and directivity attained in radio, very strong heating of electrons in the lower ionosphere has become possible: electron temperatures can be increased by an order of magnitude under the action of the wave's electric field. Nonlinear effects are decisive in the propagation of such "strong" radio waves. A theory of these effects was set forth in[2], and they were investigated experimentally in detail in[3].

It has also become possible to bring about strong disturbances of the upper ionosphere at the heights of the F-layer maximum (250—300 km). The effect is strongest in the vicinity of the reflection point of the radio waves. Here the electrons are not only heated, but their concentration distribution is also affected, so that the manner in which the radio waves propagate is strongly distorted. Excitation of parametric instability is of special importance here. The phenomena that arise are generally of complex nature. They are now being investigated intensively, both theoretically and experimentally[3,4].

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[1] L. Huxley and J. Ratcliffe, Proc. Electr. Eng. 96 (pt. II), 443 (1949).

[2] V. L. Ginzburg and A. V. Gurevich, Usp. Fiz. Nauk **70**, 201, 393 (1960) [Sov. Phys.-Uspekhi **3**, 115, 175 (1970)]; A. V. Gurevich and A. B. Shvartsburg. Nelineynaya teoriya rasprostraneniya radiovoln v ionosfere (Nonlinear Theory of Radio-Wave Propagation in the Ionosphere), Nauka, Moscow, 1973.

[3] I. S. Shlyuger, Usp. Fiz. Nauk **113**, 729 (1974) [Sov. Phys.-Uspekhi **17**, 613 (1975) (follows immediately below).

[4] W. F. Utlaut and R. Cohen, Science **174**, 245 (1971); G. G. Getmantsev, G. P. Komrakov, Yu. S. Korobkov, L. F. Mironenko, N. A. Mityakov, V. O. Rapoport, V. Yu. Trakhtengerts, V. L. Frolov, and V. A. Cherepovitskiĭ, ZhETF Pis. Red. 18, 621 (1973) [JETP Lett. 18, 364 (1973)]; I. S. Shlyuger, ibid. 19, 274 (1974) [19, 162 (1974)].

I. S. Shlyuger. An Experimental Study of Nonlinear Effects in the E and F Layers of the Ionosphere. The results of a study of nonlinear effects that arise when the ionosphere is sounded with powerful radio pulses are set forth. The measurements date from 1961—1968. The pulses were nearly rectangular in shape and $5\cdot10^{-4}$ second wide. The repetition frequency was 25 Hz. The filling frequency of the pulses was $\omega = 8.5\cdot10^{6}$ Hz, which is near the local electron gyromagnetic frequency. The polarization of the wave was strictly fixed: ordinary or extraordinary. The radiated power could be varied continuously within 15—20 sec from the minimum −20 dB to the maximum 0 dB. At the maximum effective power of the radiator, the amplitude of the ordinary-wave field at heights on the order of 100 km exceeded the characteristic value of the plasma field E_p[1] by factors of 5 to 6.

The self-action of the powerful pulse in the ionosphere and its interaction with other radio waves, pulsed and continuous, were investigated. The self-action was manifested in strong distortion of the pulse reflected from the ionosphere. This was because the initial part of the pulse propagates in an undisturbed or weakly disturbed ionosphere (the ionosphere cannot change strongly within a time shorter than 10^{-4} sec). At $t \gtrsim 10^{-4}$ sec, the reflected-pulse amplitude changes rapidly with time due to the changes that occur in the ionosphere, and it arrives at a near-stationary level after $t \sim 2\times10^{-4}$ sec. This change in the amplitude of the reflected pulse is a result of its self-action in the ionosphere. With increasing radiated power, the self-action effects become stronger. In the case of an ordinary wave during the day, the stationary level of the signal reflected from the ionosphere did not increase with increasing radiated power ("saturation" effect). The additional nonlinear absorption reached ~20 dB during the day in this case and 4—5 dB at night. On the other hand, the absorption of the extraordinary wave at powers that were not too high (smaller than −10 dB) decreased with increasing radiated power (plasma "transillumination" effect).

The interaction of the powerful pulse with continuously radiated radio waves at frequencies $f^{(1)} = 254$ kHz and $f^{(2)} = 394$ kHz was studied. A sharp change in the amplitudes 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 $\bar{\mu}$ of the cross-modulation percentage and its fluctuations $\sqrt{\overline{(\mu - \bar{\mu})^2}}$ 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 ~ 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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[2] I. S. Shlyuger, ZhETF Pis. Red. 19, 274 (1974) [JETP Lett. 19, 162 (1974)].

[3] V. V. Vas'kov and A. V. Gurevich, Zh. Eksp. Teor. Fiz. 64, 1272 (1973) [Sov. Phys.-JETP 37, 646 (1973)]; Ya. I. Al'ber, Z. N. Krotova, N. A. Mityakov, V. O. Rapoport, and V. Yu. Trakhtengerts, ibid., 66, 574 (1974) [69, No. 2 (1974)].

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