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].

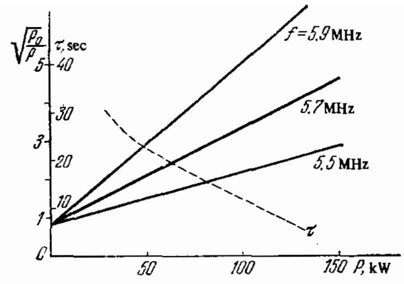

FIG. 1.

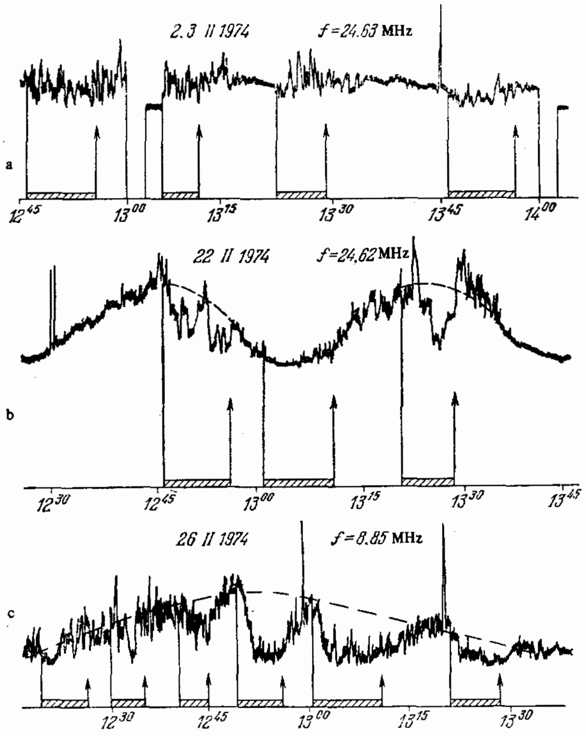

FIG. 2.

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[1] V. L. Ginzburg and A. V. Gurevich, Usp. Fiz. Nauk **70**, 201, 393 (1960) [Sov. Phys.-Uspekhi **3**, 115, 175 (1960)].

[2] D. T. Farley, J. Geophys. Res. **68**, 401 (1963).

[3] A. V. Gurevich, Geomagn. i aeronom. **7**, 291 (1967).

[4] W. F. Utlant and R. Cohen, Science **174**, 245 (1971).

[5] 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)].

[6] C. L. Rufenach, J. Geophys. Res. **78**, 5611 (1973).

[7] S. M. Grach, A. G. Litvak, N. A. Mityakov, V. O. Rapoport, and V. Yu. Trakhtengerts, Usp. Fiz. Nauk **113**, 734 (1974).

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. Experiments in which the ionospheric plasma was subjected to powerful radio-frequency radiation have initiated a whole series of theoretical studies of nonlinear phenomena in the ionosphere.

In many respects, these studies are in the mainstream of investigations in connection with the theory of nonlinear plasma effects. But a range of new problems has already been defined, dictated on the one hand by the specific ionospheric conditions and on the other by the often unexpected results of ionospheric experiments.

An important factor in the F layer of the ionosphere is parametric instability, which, as we know, is manifested in effects in which the incident electromagnetic wave is transformed nonlinearly into plasma oscillations near its reflection point. A comparatively simple theory of parametric instability can be constructed for small energy densities W_t of the pump wave, $W_t/NT_e < (m/M^{1/2}k_e r_D$ (N and T_e are the electron density and temperature, m and M are the masses of the electrons and ions, k is the wave number of the plasma waves, and r_D is the Debye radius). In this case, the plasma-turbulence spectrum is formulated in a process of nonlinear pumping of energy across the spectrum toward large scales as a result of induced scattering by ions[1-4]. Computer calculations[4] indicate that the plasma-wave spectra are highly nonstationary and consist of individual narrow lines.

The strong removal of energy from the pump wave for the plasma oscillations results in self-action effects, which are manifested in amplitude modulation and attenuation of the original signal[4].

The strong removal of energy from the pump wave for the plasma oscillations results in self-action effects, which are manifested in amplitude modulation and attenuation of the original signal[4].

The developed theory accounts satisfactorily for the results of an experiment in the ranging of plasma waves that appeared on irradiation of the ionosphere by a powerful transmitter at Arecibo, Puerto Rico[5].

The development of parametric instability is accompanied by another important effect—the generation of fast electrons by acceleration on the plasma waves. Estimates based on the quasilinear theory indicate that an appreciable flux of fast electrons with energies >10 eV may appear even at the presently available powers. The appearance of the fast electrons was evidently registered indirectly in the American experiments of[6].

The theory is substantially modified on an increase in the amplitude of the pump wave, when $W_t/NT_e > k_e^2 r_D^2$. Numerical calculations have brought out a number of qualitative features of this stage. As the instability develops, strongly nonlinear standing plasma waves with a broad spectrum of spatial scales are formed. This results in strong nonlinear pumping in the direction of small scales, and collisionless dissipation becomes dominant. It is essential that the process is dynamic (quasiperiodic). To make an approach to ionospheric conditions, the regime described above was considered for incidence of an electromagnetic pulse on a finite plasma layer. According to the numerical calculations, plasma waves and low-frequency disturbances accumulate rapidly in the layer, and the pulse emerging from it is amplitude-modulated. The electromagnetic pulse is also elongated as a result of "deexcitation" of the plasma waves that have accumulated in the layer after the pump field is switched off.*

Modulation and lengthening of the pulse have been observed experimentally[8].

The effects examined above characterize fast processes in parametric instability. Their time scales range from 10^{-3} to 1 sec under ionospheric conditions.

At the same time, the experiments of[6,9] indicate that the most significant changes in the ionosphere occur after longer times. It appears that large-scale disturbances accumulate in the ionosphere and drastically change the conditions for radio-wave propagation. Quantitative explanation of these effects is now the prime objective of further theoretical research.

Strong nonlinear effects have been observed in the low-frequency range $f \approx 10-100$ kHz. Some of them are due to interaction with high-energy particles of the radiation belts. At the same time, phenomena similar to the nonlinear effects in the shortwave band are possible at ionospheric heights $h \approx 500-2000$ km. Calculations indicate that the parametric-instability criterion for low-frequency signals is satisfied under the conditions of experiments with low-frequency transmitters[9]. This may result in amplitude modulation and broadening of the frequency spectrum of the original wave, as well as trapping of the signal in artificial waveguides[10].

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[3] Another explanation for the amplitude modulation and lengthening of the pulse in terms of nonlinear stratification effects is also possible [8].

[1] W. L. Kruer and E. J. Valeo, Princeton University Report MATT-919, 1972.

[2] J. A. Fejer and Yu-Yun Kuo, Phys. Fluids **16**, 1490 (1973).

[3] N. A. Mityakov, V. O. Rapoport, and V. Yu. Trakhtengertz, Planet. and Space Sci. **22**, 95 (1974); Geomagn. i Aeronom. **14** (1) (1974).

[4] Ya. I. Al'ber, Z. N. Krotova, N. A. Mityakov, V. O. Rapoport, and V. Yu. Trakhtengerts, Zh. Eksp. Teor. Fiz. **66**, 574 (1974) [Sov. Phys.-JETP **39**, No. 2 (1974)].

[5] A. J. Wong and R. J. Taylor, Phys. Rev. Lett. **27**, 644 (1971); H. C. Carlson, W. E. Gordon, and R. L. Showen, J. Geophys. Res. **77**, 1242 (1972).

[6] W. F. Utlant and R. Cohen, Science **174**, 245 (1971).

[7] V. V. Vas'kov and A. V. Gurevich, ibid., **113**, 730 (1974) [17, 000 (1975)] (see this issue).

[8] I. S. Shlyuger, ibid., p. 729 (see this issue).

[9] V. V. Belikovich, E. A. Benediktov et al., ibid. **113**, 732 (1974) [17, (1975)] (see this issue).

[10] O. A. Molchanov, V. Yu. Trakhtengerts, and V. M. Chmyrev, Izv. Vuzov (Radiofizika) **17** (2) (1974).

A. B. Shvartsburg. Reflection of Strong Radio Waves from the Ionosphere. The region in which radio waves are reflected from the ionosphere attracts special interest in study of the complex of effects in the field of strong radio waves in the ionosphere. This interest is stimulated primarily by the substantial increase in the amplitude of the field near the reflection point. Moreover, refractive-index disturbances develop in the reflection region under the action of the wave field; these disturbances may therefore result in strong distortions of the field of the standing radio wave.