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].

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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.

Two physically different situations can be distinguished in the reflection region:

a) The formation of slow (nonresonant) disturbances resulting from plasma heating and the change in electron density in the disturbed zone, and their action on the wave.

b) The appearance and development of fast (resonant) processes associated with excitation of natural high-frequency oscillations in the ionospheric plasma.

The two types of disturbances differ strongly not only in the characteristic times of their development, but also in the amplitudes of their fields and the spatial structure of the disturbed region.

1. As thermal nonlinearity develops in the reflection region of a vertically incident beam from the E layer, an artificial inhomogeneity may be created as a result of disturbance of the ionization-recombination balance in the plasma heated by the wave. Because of the high collision frequency, the "diffusion length" L_N is short in this region ($L_N \sim 20-40$ m), and the distribution of the disturbance in the horizontal plane basically duplicates the amplitude profile of the beam[1]. This inhomogeneity may result in further scattering of waves incident on the disturbed region.

Effects of particular interest may be related to the development of a thermal disturbance in "resonant" regions of the ionosphere—near the maximum of the layer and at reflection from the region in which the phase velocities of the ordinary and extraordinary waves are nearly equal. For example, the E layer exerts a blocking influence on a wave with a frequency above the critical frequency of the layer as a result of the nonlinear effect. Thus, at $\Delta\omega/\omega_c \lesssim 10^{-3}$ (ω_c is the critical frequency of the layer, $\Delta\omega = \omega_c - \omega$), the fraction of the energy reflected from the layer increases by an order of magnitude as the power is raised to $W \approx 200$ kW. In the region in which loss of the reflected signals is possible in the "linear" theory[2], small changes in the vertical concentration gradient near the reflection point of a powerful radio wave may result in a marked change in the role of the secondary reflected signal.

Slant sounding produces additional "resonant" situations, for example with propagation of the wave in the plane of the magnetic meridian at a near-critical angle[2]. However, analysis of nonlinear effects in this resonance is made difficult by the lack of an appropriate analytic procedure.

2. Development of resonant effects (such as parametric instability) is accompanied by secondary scattering of radio waves on the oscillations that develop. Here the longwave part of the oscillation spectrum ($\lambda \approx 100$ m) may become a source of directional scattering by density perturbations produced by the wave itself[3]. This may result in radio-frequency "flicker" of the scattered-frequency signal and in suppression of "side scattering." On reflection of a powerful wave near the maximum of the F layer, this deflection of the scattered beam from the vertical amounts to 60—80 km. Here, in contrast to the case of thermal nonlinearity, the dimensions of the disturbed region are determined by the excess of field amplitude over the instability threshold during the initial evolution of the oscillations.

3. The geomagnetic field has a strong influence on the development of parametric instability in the ionosphere. The role of this field becomes especially conspicuous when oscillations are excited in the reflection region of the extraordinary wave. In this case, oscillations are excited by vertical sounding only in a sufficiently rarefied plasma[4] ($\Omega_e^2 < 2\omega_H^2$; Ω_e and ω_H are the Langmuir frequency and gyrofrequency of the electrons), i.e., at heights of 150—250 km and preferentially at night. The excitation threshold is 30—60 mV/m. For a given frequency ($\omega \sim 1-3$ MHz), the excitation threshold may be 3—10 times higher for the ordinary than for the extraordinary component, since the ordinary component is reflected in the E layer and the extraordinary component higher up, at the beginning of the F layer.

The range of resonant situations changes in slant sounding. At heights $z < 200$ km, the conditions for instability excitation (proximity of the wave frequency to one of the natural oscillation frequencies) are satisfied basically for ordinary polarization; resonances in the field of the extraordinary wave are also possible at greater heights[5]. These data pertain to the case in which sounding is perpendicular to the plane of the magnetic meridian. In slant sounding in the plane of the meridian, instability excitation would assume special interest, since it could lead to additional wave scattering[2], with possible significant consequences for the reflected-signal-loss effect.

Thus, the range of possible effects broadens considerably with slant sounding and consideration of the geomagnetic field in studies of nonlinear phenomena in the region of reflection of strong radio waves from the ionosphere.

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