Stimulated emission of energetic particles by plasma-wave discharge in the polar ionosphere

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A method is developed for the deep modulation of the flux of emitted high-energy particles ($E_e \gtrsim 40$ keV) in plasma wave discharge excited by an edge electromagnetic source in the polar ionosphere at altitudes of 100–150 km. A discharge-perturbed flux of fast electrons, which is an order of magnitude larger than the background in the quiet nocturnal ionosphere, is obtained.

The experiment was carried out by two flights of MR-12 meteorological rockets in early October 1989 in the northern part of the Norwegian Sea. As the edge source of electromagnetic radiation we used a dipole antenna in the form of a wire ring of diameter 2 m, held by an axial telescoping rod at a height of 2 m above the head of the rocket (the rocket diameter was 0.4 m and its length was 10 m). The plane of the ring was perpendicular to the rocket axis. To excite a discharge in the plasma wave field[1] between the body of the rocket and the exciting ring, a high frequency (rf) potential of amplitude ~ 1 kV and frequency $f_0 = 480$ kHz was supplied. The rf signal was modulated in the telegraph regime by the frequencies $f_1 = 960$ Hz and $f_2 = 240$ Hz according to a special cyclogram. The diagnostics were performed using edge devices: Geiger counters, a Langmuir probe, a ULF receiver for the modulation frequencies f_1 and f_2, a photometer, magnetic field detectors, and other hardware.

The results of processing the telemetric information for startup at 18:31 UT on 9 October 1989 are shown in Fig. 1, where the flight time and the corresponding values of the altitude H of the rocket above the Earth's surface are shown on the horizontal axis. On the vertical axis are the values of the plasma concentration N_e near the head of the rocket (curve 1) and the flux density of electrons I_e with energy $E_e > 40$ KeV (curve 2). Curve 3 in Fig. 1 shows the cyclogram of the operation of the electromagnetic radiation generator; the upper level corresponds to the operating mode with modulation at the frequency $f_1 = 960$ Hz, the middle level corresponds to modulation at $f_2 = 240$ Hz, and the zero level corresponds to a pause in the operation of the generator.

The experimental data confirm the conclusion that it is possible to form and support a plasma-wave discharge in the ionosphere in the near field of a dipole emitter.[2] Such a discharge is a strong local perturbation of the ionospheric plasma parameters. The plasma concentration near the head of the rocket was $N_e \gtrsim 10^7$ cm^{-3}, and the electron temperature in the perturbed part was $T_e \gtrsim 10$ eV. The form of the plasma perturbation is determined by several factors. The longitudinal scale (along the direction of the geomagnetic field) depends on the size of the damping constant of the plasma waves excited by the antenna in the discharge plasma and in this parameter

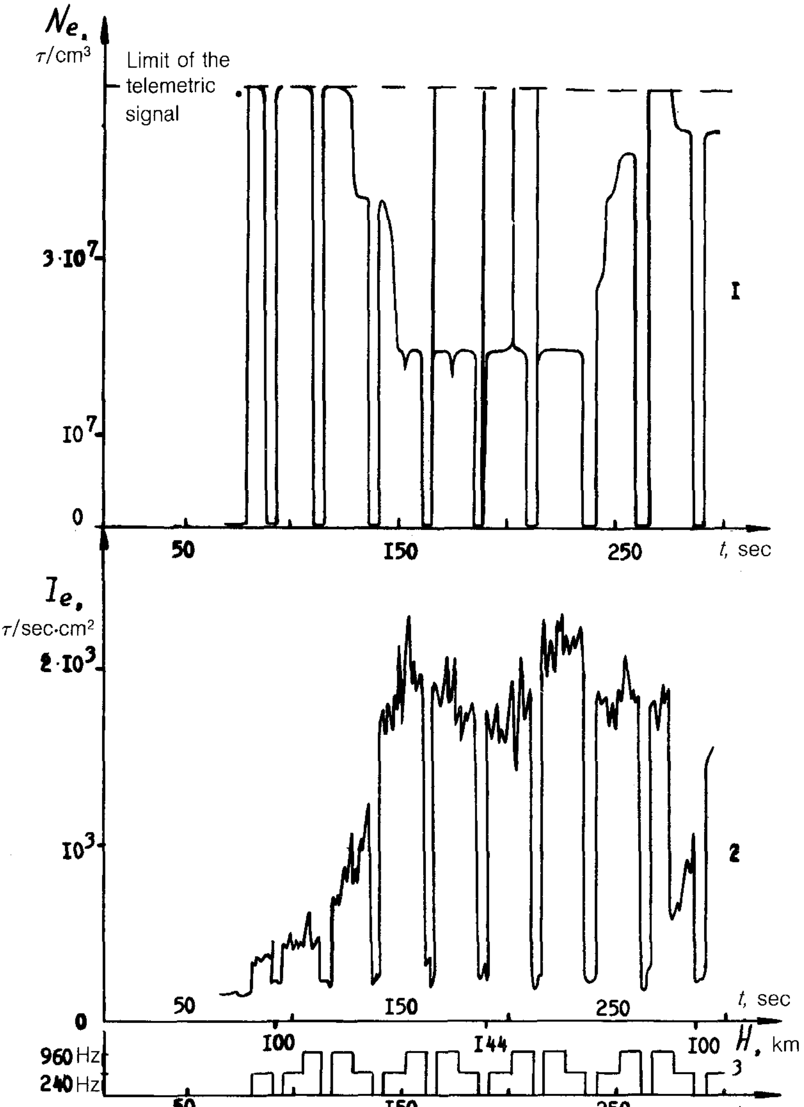

FIG. 1. Changes stimulated by the action of an rf source in the plasma density N_e near the head of the rocket (1) and in the flux of electrons I_e with energy $E_e \gtrsim 40$ keV (2) as functions of the flight time t. Cyclogram of the operation of the rf generator (3).

region can reach $l_\parallel \gtrsim 1$ km (see Ref. 3 for more details). The transverse scale is determined by the horizontal component of the rocket velocity $v_\perp \sim 300$ m/sec and by diffusion processes, and under our conditions it is $L_\perp \sim v_\perp \tau_N \sim 100$ m. The edge ULF receiver fixed the variations of the plasma parameters in the discharge with the modulation frequencies of the output power of the pumping generator f_1 and f_2. Because of diamagnetism of the inhomogeneous plasma, the amplitude of the magnetic field oscil-

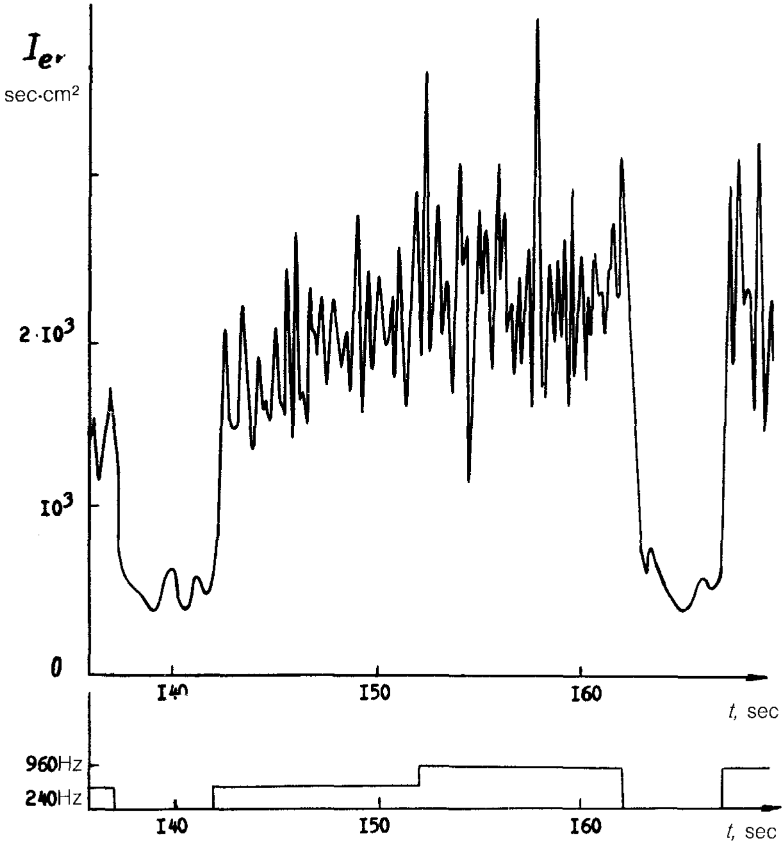

FIG. 2. Fine structure of perturbations of the flux of electrons with energy $E_e \gtrsim 40$ keV stimulated by the operation of an rf source (upper curve); cyclogram of the operation of the rf generator (lower curve).

lations was fairly high at these frequencies, $\Delta H_0 \lesssim 10^{-2}$ Oe.

The most important result of the experiment is the demonstration that a plasma-wave discharge in the ionosphere can modulate the flux of emitted electrons of energy $E_e \gtrsim 40$ keV. In Fig. 2 we show a fragment of the dependence of the fast electron flux density on the flight time, which shows the small-scale time structure of the flux. We see from Figs. 1 and 2 that there are several characteristic times determining the nature of the flux variation. First of all, there is the time for the variations to reach a quasistationary state $\tau_1 \sim 1$–1.5 min. Then there are the characteristic times $\tau_2 \sim 2$ sec and $\tau_3 \sim 0.3$–0.5 sec reflecting the fine structure of the flux variations. Finally, $\tau_4 \sim 1$ sec is the time characterizing the relaxation process or the growth of the flux when the generator is switched off and on. The power contained in the discharge varied in the range $W \lesssim 700$ W.

As a model which is capable of qualitatively explaining the observed variations we used the theory of the Alfvén maser developed in Ref. 4. First of all, this maser is a distributed system in the form of a set of magnetic force tubes based on the ionosphere at conjugate points. Second, the generation regimes in neighboring force tubes differ significantly, which is indicated, for example, by pulsating spots in polar auroras. If we use this mechanism for the activity variation as the basis, the stimulated emission of fast particles can be represented as follows. First, during the course of several cycles of operation of the pumping generator overflow of the plasma from the ionization region to the magnetospheric force tube occurs. This time interval corresponds to the time required to reach the quasistationary state τ_1, during which epithermal particles in the discharge with energy $\gtrsim 10$ eV fill the force tube. Channeling of the whistling mode is possible in the filament which is formed, and the start of the discharge changes the coefficient of reflection of this mode from the resonator wall, causing the emitted particle flux level to rise. The quantity τ_4 corresponds to the time for the whistler to propagate the length of the force tube. The characteristic time τ_2 coincides with the "bounce-oscillation" period of 40-keV electrons. This modulation of the flux also occurs during a pause, but its depth is increased considerably in the operation of the perturbing transmitter. The modulation with the characteristic time scale $\tau_3 \sim 0.3$–0.5 sec is attributable to the fact that for a weak perturbation of the operating state of the Alfvén maser the emitted particles are formed by electrons near the loss cone and their angular distribution can be strongly chopped up, also because of the natural oscillations of the ionospheric Alfvén resonator.[5]

The experimental data allow us to estimate the increment of the fast particle current in a force tube based on the perturbing region: $\Delta i_e \sim e I_e L_1^2 \sim 1$ μA–10 mA. The dispersion of this quantity reflects the uncertainty in the transverse scale of the perturbed force tube, which can vary from the scale of the region where the ionization is significant ($\sim 10^2$ m), to some geophysical scale characterizing, for example, the minimum size of the spot in pulsating polar auroras ($\gtrsim 10^4$ m).

The power of the fast particle variable current corresponding to this value is $W_e \simeq E_e \Delta i_e \sim 40$ mW–400 W.

The experiments which have been carried out indicate that there is a fairly effective method of locally changing the main parameters of the ionospheric plasma. This method can be used both to stimulate a different type of sporadic phenomena in the polar ionosphere and for the diagnostics of these phenomena.

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