GLOBAL MAGNETOSPHERIC PERTURBATIONS STIMULATED BY THE PLASMA WAVE DISCHARGE IN THE LOWER IONOSPHERE

G.A.Markov, Yu.V.Chugunov

In this paper we discuss the new method of controlled stimulation of global perturbations and the diagnostics of plasma physical processes in the ionosphere and the magnetosphere of the Earth. The method was realized with the series of rocket experiments by means of excitation of the radio frequency plasma wave discharge in the near field of the dipole antenna [1–4]. The considerable attention we focus on the results obtained in these experiments testifying to a wide choice and diversity of potentialities of this new method.

1. The main idea starts from assumptions that a radio frequency source (antenna) forming the discharge in the nocturnal ionosphere at the altitude $H \geq 150$ km may excite the extensive plasma irregularity which changes significantly the entire geophysical situation within the corresponding geomagnetic tube. This fact is confirmed by model-based experiments in plasma chambers as applied under the conditions of lower ionosphere [5–6]. It is also evident from theoretical assessment that, the proper discharge part of the irregularity is formed by the field of plasma waves radiated by the antenna [7]. Its length is determined by a damping decrement of this waves $L_d \sim \frac{\omega}{\nu_e}\lambda_{\|}$, where ω is the exciting field frequency, ν_e is the effective electron collisions frequency, $\lambda_{\|}$ is the longitudinal length of plasma waves. The longitudinal scale of a diffusion part of irregularity L_D is determined through the relation $L_D \sim \sqrt{D_u/\nu_a}$, where $D_n = E_e/e\,m\,\nu_e$ is the unipolar electron diffusion coefficient along the magnetic field, E_e is electron energy, e and m are the electron charge and the electron mass, respectively, ν_a is the electron attachment frequency for oxygen. When the antenna is supplied with $W \sim 1$ kW power, the plasma density near the source is $N_e \geq 10^7$ cm^{-3}, $E_e \geq 10$ eV, $L_D \geq 10^2$ km. The transversal scale of plasma irregularity is determined by the horizontal component of the source velocity, the structure of the near antenna field and diffusion processes. In rocket experiments [1–3] it is estimated as $L_\perp \sim 100$ m.

Such a plasma cloud may substantialy influence on the physical conditions of the interaction between waves and particles inside the geomagnetic tube in which the cloud is developed. First of all, it is the result of discharge plasma particles pouring into the volume of the tube and the existence of dense plasma at its base. These factors change the conditions of excitation and reflection of whistlers and Alfven electromagnetic waves in the magnetosphere. The inten-

sity of those waves in the given tube controls sporadic physical phenomena to a considerable degree.

The most profound effect is due to the discharge influence exerted upon the amount of the flux of particles (electrons and ions) with different energies, precipitating from the excited magnetic tube. In particular, the amount of the flux of electrons with $E_e \geq 40$ keV changes sufficiently.

That is why modulation of the precipitating particle flux by the plasma-wave discharge in the ionosphere signifies the excitation of alternating current (in accordance with an operation cyclogram of the transmitter) in the magnetic tube bounded by polar regions of the opposite hemispheres. The length of a current string of this type is equal to that of the corresponding L-shell. Due to this fact such a kind of excitation may be regarded as global.

The equipment being fairly simple and not very expensive, the method under discussion provides the optimum local input of electromagnetic energy into plasma. The major part of this energy is redistributed over waves and particles in a narrow magnetic tube throughout the magnetosphere. The method concerned is easily controlled and it has great prospects in future among the active methods of investigating the processes of wave–particle interactions in the system ionosphere–magnetosphere.

2. The experiments were carried out by few flights of meteorological rockets in the northern part of the Norvegian Sea and Kapustin Jahr. As the source of electromagnetic radiation we used the 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 between the body of the rocket and the exciting ring, a high frequency 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 the following devices: Geiger counters, a Langmuir probe, a ELF–VLF 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 in the Norvegian Sea 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.

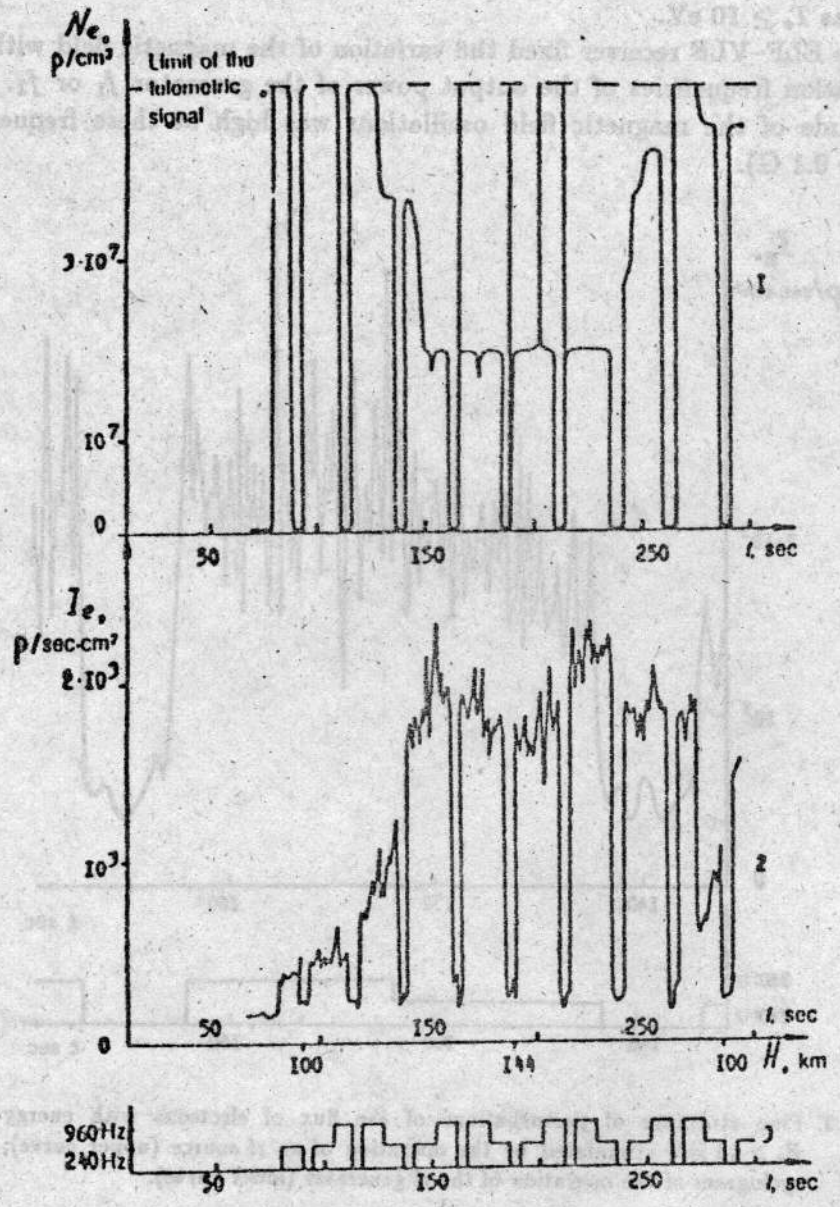

Fig.1. Changes simulated by the action of an rf source in the plasma density N_e near the head of the rocket (1) and in the flux of electrons I_e with energy $E_e \geq 40$ keV (2) as functions of the flight time t. Cyclogram of the operation of the rf generator (3).

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. Such a discharge is a strong local perturbation of the iono-

spheric plasma parameters. The plasma concentration near the head of the rocket was $N_e \geq 10^7$ cm^{-3}, and the electron temperature in the perturbed part was $T_e \geq 10$ eV.

The ELF–VLF receiver fixed the variation of the magnetic field with the modulation frequencies of the output power of the generator f_1 or f_2. The amplitude of the magnetic field oscillations was high at these frequencies ($\triangle B \sim 0.1$ G).

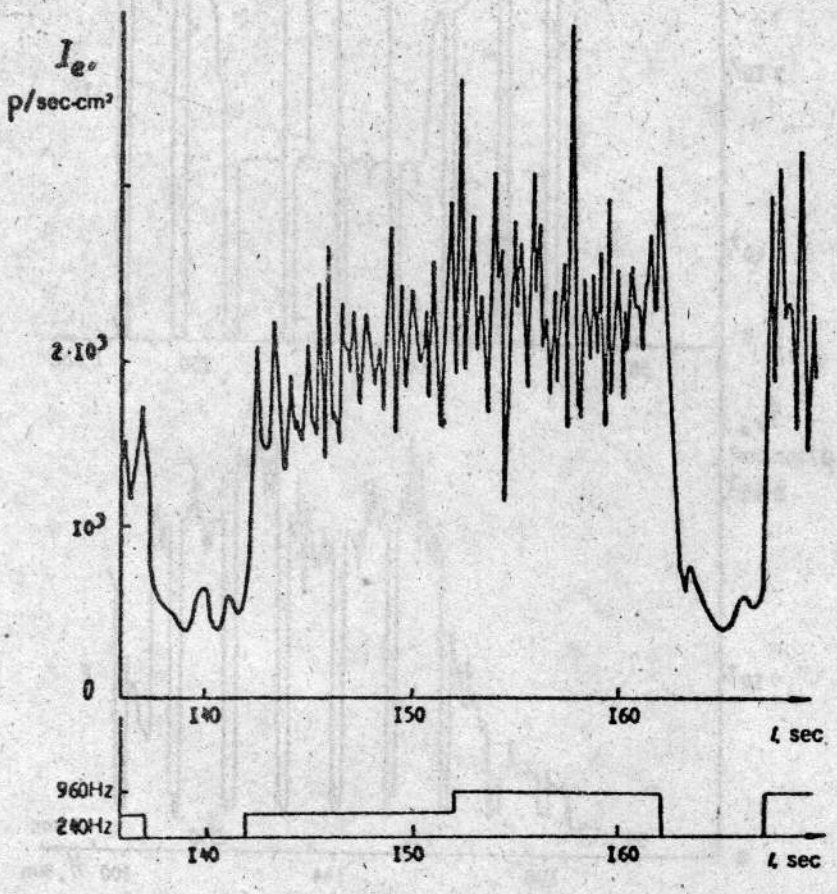

Fig.2. Fine structure of perturbations of the flux of electrons with energy $E_e \geq 40$ keV stimulated by the operation of an rf source (upper curve); cyclogram of the operation of the rf generator (lower curve).

The most important result of the experiment is the demonstration that a plasma–wave discharge in the ionosphere can modulate the flux of precipitated fast electrons of energy ≥ 40 keV. The next Fig.2 shows a fragment of the dependence of the fast electron flux density on the flight time, wich shows the small–scale time structure of the flux. We see from Figs.1 and 2 that there are several characteristic times. First of all, there is the time for the variations to reach a quasistationary state $\tau_1 \sim 80$ sec. Then there are the characteristic times $\tau_2 \sim 2$ sec and $\tau_3 \sim 0.3$ sec reflecting the fine structure of the flux

variation. Finally, $\tau_4 \sim 1$ sec is the time characterizing the relaxation process or the growth of the flux when the transmitter is switched off and on.

The considerable changes of the flux of fast electrons with the energy $E_e \geq 40$ keV were determined in the rocket experiment in the same point of the Norvegian Sea under conditions when the magnetosphere was more perturbed (k_p index was $k_p = 4$). Under these conditions the level of the background electron flux was higher by the order of magnitude, and gradual reaching the stationary level during the time $\tau \sim 1 - 1.5$ min and the increase of the flux were observed when the transmitter was switched on. But in contrast with quiet conditions, the level of the fast electron flux during a pause of the operation of the transmitter did not fall to the background value. Therefore, the modulation of the flux in accordance with the operation cyclogram was more weak (the level of the flux modulation was of the order of 30%). These results testify to the considerable influence of the discharge plasma on the processes of wave–particle interactions in geomagnetic tube within which the discharge is excited.

One of the rocket launches was carried out in the period of the strong magnetic perturbation at the latitude 68° and Grinvich value. In this experiment the energy of plasma–wave RF discharge was evidently sufficient for the stimulation of a wide noise radiation spectrum in the ionosphere. The strong perturbation of a magnetospheric parameters also favored the excitation of noise signals. For example, the data of the telemetric system signals fixed the sharp increase and synchronization of a quantity of telemetric breaches with the operation of the transmitter (the increase of a noise when the transmitter is switched off and a gradual decrease of it in the pause time). The receivers of the Oriel–3 satellite fixed the sharp increase of LF noise at the boundary of a diffuse part of the auroral zone when the discharge was excited on the height $H > 100$ km [2].

The spectrum of the LF electromagnetic oscillations fixed by the equipment of the satellite at the time when discharge is excited at the altitude $H \geq 140$ km, is of special interest. The examples of processing the telemetric information of satellite receivers are shown in Fig.3. On the curve 1 the peaks are seen which can be identified as the modulation frequency $f_1 = 240$ Hz (a), its third harmonic $3f_1 \cong 720$ Hz (c), and the ion cyclotron frequency of ionospheric hydrogen $f_H \cong 600$ Hz (b). In those time the satellite was far enough from the magnetic tube perturbed by a discharge, and the rocket was at the altitude $H \geq 130$ km. The expansion of the excitment band for signals of resonance mentioned above occurs with the growth of the rocket latitude. This is shown in Fig.3 (curves 2–3). These curves correspond to the approach the perturbed tube by the satellite and the rocket altitude $H \geq 150$ km.

During the experiments performed in Kapustin Jahr in 1986 and 1991 the attempts were made to receive LF and RF signals on the ground surface, which were produced by a modulated radio discharge. In the first case radio

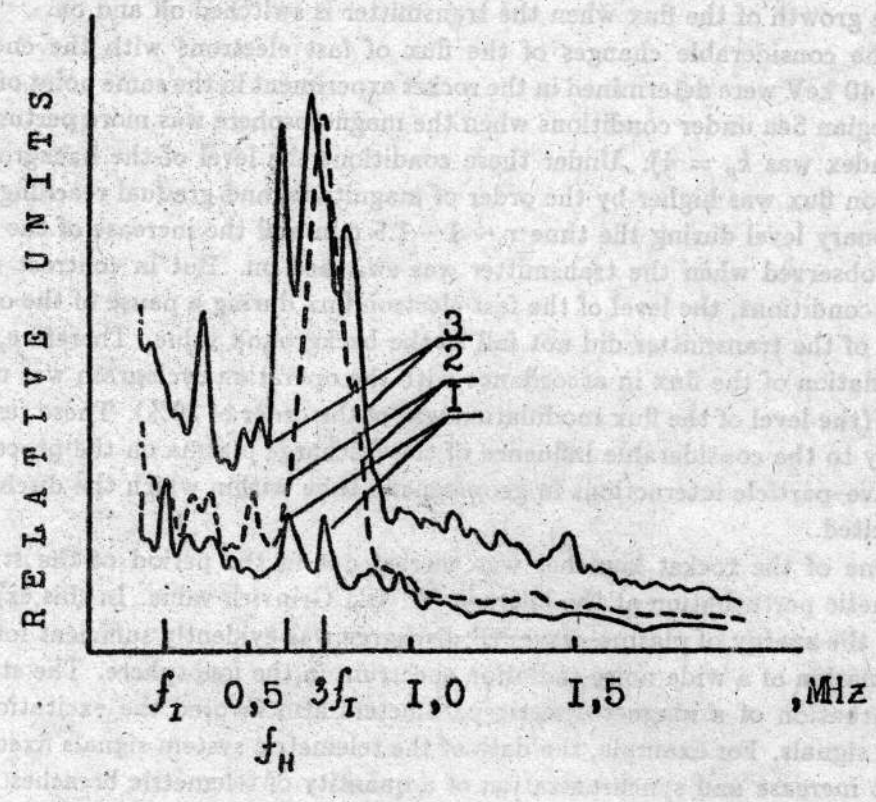

Fig.3. Spektra of LF emissions registered on board of the satellite ORIEL-3 in the course of operating RF generator: 1 — rocket heit H = 130 km, modulation of frequency f_m = 240 Hz; 2 — H = 150 km, f_m = 240 Hz; 3 — H = 155.5 km, f_m = 960 Hz.

(signal) reception at the frequency of the field exciting the discharge (f = 480 kc/s) was attained. The point of reception was situated at $L > 1000$ km from the rocket launching site [4]. The reception was registered at the time when the rocket carrying an emitting source was at heights $H - (120 \div 130)$ km. A low frequency spectrum of the received signal proved to be broadened ($\Delta f / f_i \sim 0.02$) as compared to that of the transmitter.

The results of the reception of the signals corresponding to the modulation frequencies of the discharge f_1 = 120 Hz and f_2 = 240 Hz showed the substantial increase of the received noise-signal when the source operated. The low-frequency spectrum of the recieved signals contained the lines at the frequencies f_1 = 2.7 Hz and f_2 = 4.8 Hz (Fig.4).

As a model which is capable of qualitatively explaining the observed variations we used the theory of the Alfven maser developed in [8]. 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

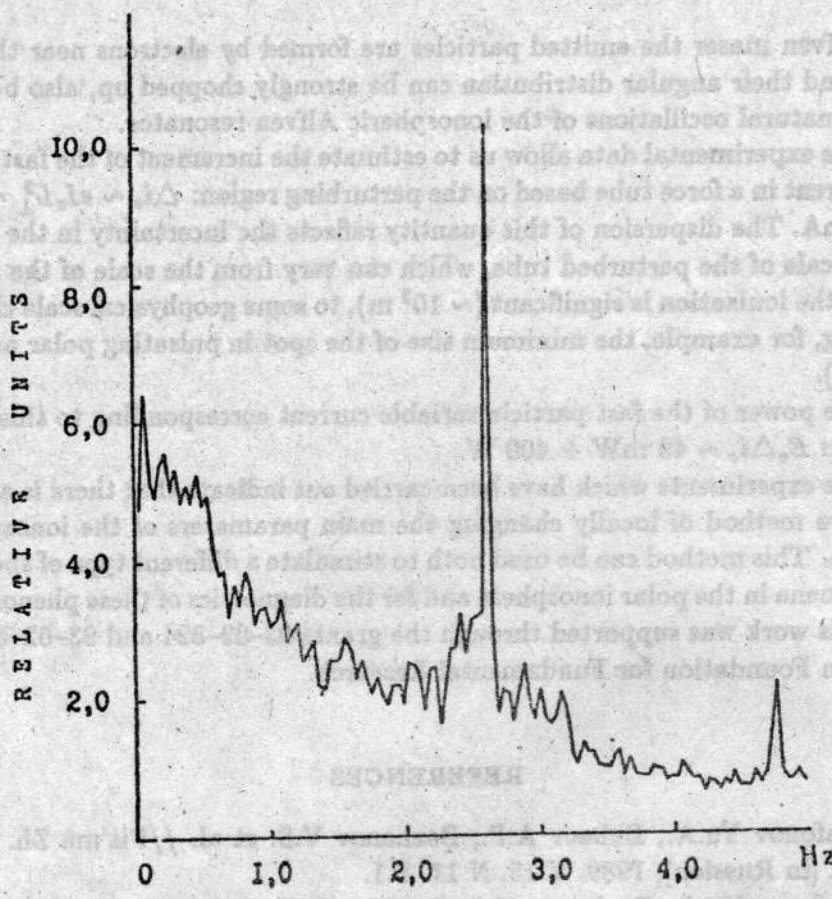

Fig.4. ELF part of the spectrum of detected signal received on the Earth (modulation frequency $f = 240$ Hz, the band of receiving antenna 240 ± 5 Hz).

in neighboring 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 ≥ 10 eV fill the tube. Channeling of the whistling mode is possible in the filament which is formed, and the start of the discharge changes the coefficient of the 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 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 Alfven 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 Alfven resonator.

The experimental data allow us to estimate the increment of the fast particle current in a force tube based on the perturbing region: $\Delta i_e \sim eI_eL_\perp^2 \sim 1\mu A \div 10$ mA. The dispersion of this quantity reflects the incertainty in the transverse scale of the perturbed 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 ($\geq 10^4$).

The power of the fast particle variable current corresponding to this value is $W_e \simeq E_e\Delta i_e \sim 40$ mW $\div$ 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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Nizhny Novgorod University

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