Phys.-JETP 7, 168 (1958)].
[3] G.A. Askar'yan, ibid. 42, 1567 (1962) [15, 1088 (1962)].
[4] G.A. Dawson and R.C. Jones, Pure and Appl. Geophys. 75, 247 (1969).

MODULATION OF SPECTRUM AND AMPLITUDES OF LOW-FREQUENCY SIGNAL IN THE MAGNETOSPHERE PLASMA

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We discuss in this communication certain results of an experiment on the sounding of the magnetosphere of the earth by powerful low-frequency pulses with carrier frequency f_0 = 15 kHz. Since it is known that such frequencies channel themselves in the magnetosphere plasma along the force lines of the earth's magnetic field [1], the signals are received in a region that is magnetically conjugate to the transmitter. Pulses of duration τ = 200, 400, and 800 msec and repetition period T = 3 sec were transmitted. At practically all times, two signals were received: the waveguide signal passing over the earth's surface in the earth-ionosphere waveguide, along a route $S_1 \approx$ 10,000 km long, with a delay $t_1 \approx$ 32 msec, and the magnetosphere signal, with a delay $t_2 \approx$ 500 - 900 msec, which corresponds at a route length $S_2 \approx$ 30,000 km to an average group refractive index along the trajectory $n_g \approx 5 - 10$. An example of the dynamic spectrum of the received signal is shown in Fig. 1. The axes represent the frequency f and the running time t, and the spectral intensity of each instant of time is represented by the blackening of the paper. We see that unlike the waveguide signal A_1 (τ = 400 msec), the dynamic spectrum broadens in a certain region of the magnetosphere signal A_2, and quasimonochromatic induced (called "trigger") radiation A_3 appears. The maximal broadening of the noise spectrum does not exceed the limits $\Delta f_{n\cdot max} \approx$ 100 - 400 Hz. The frequency of the trigger radiation f_T can either increase or decrease, and sometimes the $f_T(t)$ dependence has several extrema and the radiation continues 100 - 300 msec after the cessation of the primary signal at the frequency f_0, $\Delta f_{T\cdot max} = |f_T - f_0|_{max}$ = 1 - 3 kHz. Trigger radiation was already observed earlier [2] and will not be discussed in detail in this paper.

In our experiment we observed the effect of periodic modulation of a quasinoise spectrum of the magnetosphere signal and the associated amplitude modulation. This phenomenon was first observed by us in 1968 [3], but it became manifest most clearly in the described experiment, when the duration of the transmissions was increased. Figure 2 shows the dynamic spectrum (a) and the amplitude plot (b) of the received signal. The duration of the radiated pulse in this case was τ = 800 msec; the waveguide signal was eliminated from the amplitude plot, since the two signals, as can be seen from the spectral plot, partly overlap owing to the insufficiently large delay of the magnetosphere signal (the slow variation of the carrier frequency, seen in Fig. 2a, is due to instability of the recording apparatus and is not connected with the described effect).

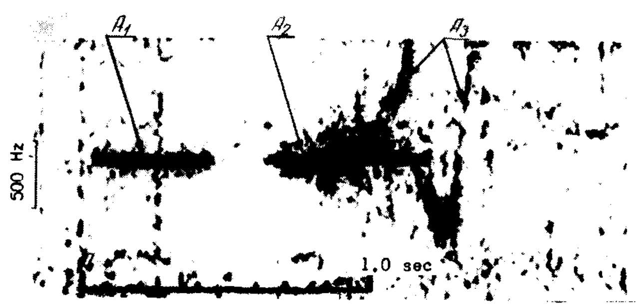

Fig. 1

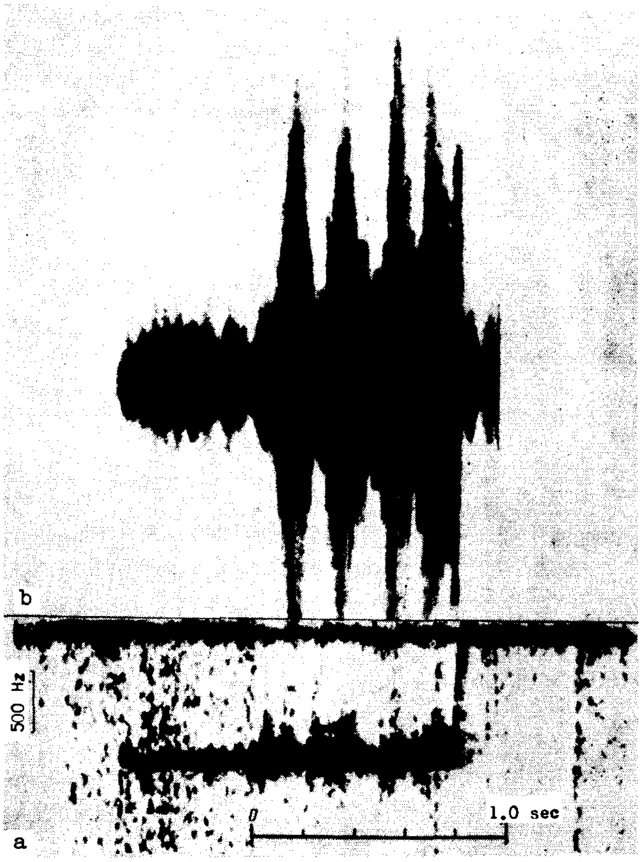

Fig. 2

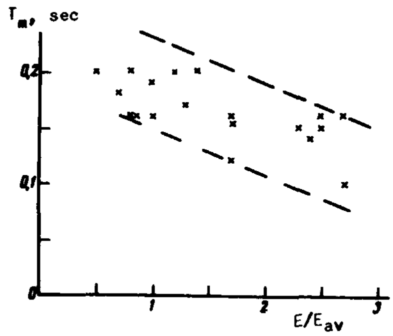

Fig. 3

A characteristic fact is that the maxima of the spectrum broadening coincides with the maxima of the signal amplitude. The amplitude modulation of the signal is almost complete. It is interesting that the quasinoise spectrum is asymmetrical with respect to f_0, the higher frequencies predominating. Figure 2 contains also the trigger radiation. In this as well as in other cases it appears predominantly at the end of the signal and begins, as a rule, near the maxima of the quasinoise spectrum. The trigger radiation is hardly visible on the amplitude plot, owing to the fact that the amplitude was recorded in a relatively narrow band $2\Delta f$ = 500 Hz. Distinct modulation of the magnetospheric signal was registered in approximately 20% of the sessions; the modulation period varied from session to session in the range $T_m \simeq 100 - 200$ msec, but during the same session it remained approximately constant. At the end of several sessions we were able to receive long transmissions ($\tau > 10$ sec), which were modulated throughout their length with the same period as during the session. These facts apparently indicate that the modulation was stable. The variation of the modulation period from session to session is connected with the variation of the amplitude E of the received signal, which is determined by the wave propagation condition in the magnetosphere. This relation is illustrated in Fig. 3. To exclude the amplitude variation connected with absorption in the ionosphere, we normalized E to the mean value with allowance for the time of the day in each session. Owing to the lack of enough experimental data, it is difficult to determine the detailed $T_m(E)$ determination, but the tendency of T_m to decrease with increasing E is quite well discerned. This is evidence of an essentially nonlinear nature of the described effect.

Modulation occurs apparently in quasilongitudinal propagation of a pulse in the upper sections of the trajectory, which are located $\sim 10^4$ km away from the earth's surface. In this region of the magnetosphere there is present, besides the cold electrons ($T_e \sim 1$ eV), also a small amount of hot electrons ($T_e \simeq 10 - 100$ keV) with an anisotropic velocity distribution ($T'_{\perp e}/T'_e > 1$) [4], and consequently effective cyclotron resonance is possible, with capture of the electrons in a potential well owing to the longitudinal force

$ec^{-1}[v_\perp \times H]$ (H is the magnetic component of the wave [5]. The estimated mean frequency of the electron oscillations in the potential well is $\sim 10^2$ Hz. Thus, we can explain the occurrence of a quasinoise broadening of the magnetophonon-signal spectrum. Modulation of the quasinoise spectrum and of the signal amplitude may be due to the presence of an intense extraneous ion-acoustic wave, particularly a quasimonochromatic one ($f_s \sim 5$ Hz) in the corresponding regions of the magnetosphere [6].

On the other hand, it is quite possible that the modulation is connected with the motion of resonant particles between mirror points in the geomagnetic field. The period of such a motion as estimated by us (200 - 300 msec) is close to the period of the modulation. Another possibility of explaining the observed effect is described in [7].

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[1] R.A. Helliwell, Whistlers and Related Ionospheric Phenomena, Stanford, California, 1965.
[2] R.A. Helliwell, J. Katsufrakis, M. Trimpi, and N. Brice, J. Geophys. Res. 69, 2391 (1964).
[3] Yu.V. Kiselev, Ya.I. Likhter, and O.A. Molchanov, in: Nizkochastotnye izlucheniya vo vneshnei inosfere (Low-frequency Radiation in the Outer Ionosphere), Nauka, 1972 (in press).
[4] B.A. Tverskoi, Dinamika radiatsionnykh poyasov Zemli (Dynamics of the Earth's Radiation Belts), Nauka, 1968.
[5] T. Stix, Theory of Plasma Waves, McGraw, 1962.
[6] V.M. Chmyrev, op. cit. in [3].
[7] N.I. Bud'ko, V.I. Karpman, O.A. Pokhotelov, ZhETF Pis. Red. 14, 469 (1971) [this issue, p. 320].

E R R A T U M

In the article by A. I. Pil'shchikov and N. E. Syr'ev, Vol. 14, No. 4, on page 160, third line of the text from the top, read "....with equal volumes [2]." and not "... with different volumes [2]."