Modulation of low-frequency waves in the earth's magnetosphere

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The modulation of VLF waves in the earth's magnetosphere was investigated. The dependence of the period and the depth of the modulation on the distance to the point magnetically conjugate to the VLF transmitter is determined. The applicability of different variants of the theoretical interpretation of the experimental results is estimated.

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Observation of the modulation of the amplitude and of the spectrum of signals of a high-power VLF transmitter, with characteristic period $\tau = 0.1-0.3$ sec ($f = 15$ kHz, $L = 2.6$) was reported in[1,2]. Longer periods were difficult to determine, in view of the fact that the work was performed with pulses of duration 0.4 or 0.8 sec. This effect is confirmed in[3], it was noted that there is a large modulation period with $\tau = 0.5 - 0.7$ sec. In this paper we present certain results of a new experiment on the observation of magnetosphere signals of high-power VLF transmitter ($L = 2.47$). In the main, the observation procedure was similar to the preceding one. The work was carried out with pulses of $T = 60$ sec duration at frequencies 15.0, 22.5 or 29.0 kHz and $T = 0.5$ sec at 22.5 kHz during the evening and night time (Janurary 1975). The records were made on the cosmic-service research vessel "Nevel'," which drifted through the magnetically-conjugate region from east to west for approximately ten days. It was observed, just as in[2], that the signal amplitude decreases with distance from the conjugate point like $\sim 1/r$. Figure 1 shows the amplitude of the magneto-

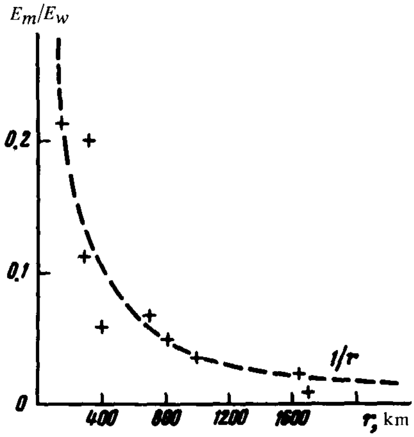

FIG. 1. Ratio of the amplitudes of the magnetosphere signal to the waveguide signal as a function of the distance to the magnetically conjugate point.

phere signals normalized to the wave signals, as functions of the distance to ıe magnetically conjugate point for short pulses $T=0.5$ sec and $f=22.5$ kHz. ıch pulses were easily observed, since they lagged the waveguide signals by ~ 0.4—0.6 sec. We note that E_m/E_w is smaller approximately by a factor of —3 than the values in the first experiment.

It turned out that the period of the amplitude modulation also varies as a ınction of r, namely, the period τ increases from initial values ~ 0.5—1.5 ec to a value ~ 15 sec at large distances. The values of τ as a function of the istance are shown in Fig. 2. It appears that the change of $\tau(r)$ is due to in-

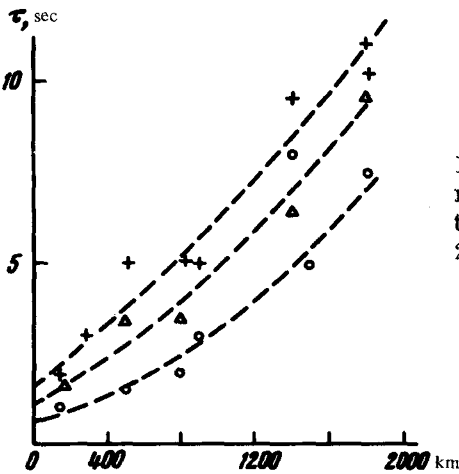

FIG. 2. Average value of the minimal modulation periods vs. the distance to the magnetically conjugate point: ○—29 000 Hz, △—22 500 Hz; ×—15 000 Hz.

rease of $E_m(r)$ on the corresponding magnetosphere trajectories, which in turn eflect the wave-field intensity distribution in the band over the transmitter: $_0(r) \sim r^{-1}$. If this is so, then the $\tau(r)$ dependence reduces to the $\tau(E_m^{-1})$ depenence, which is of interest from the theoretical point of view. As seen from 'ig. 2, $\tau_m \sim E_m^{-\alpha}/f$, where $1 \lesssim \alpha < 2$. We note that tentative values of E_m could e determined from the depth of modulation of long transmissions, which are uperpositions of the magnetosphere signal on the wave signal ($t \ll T$). It was bserved there that $\tau \sim E_m^{-1}$, but the reliability of the values of E_m determined ı this manner is low, owing to the lack of information on the depth of modulaion of the magnetosphere signal itself.

Finally, in this experiment, unlike the first one, we observed only an insigificant broadening of the signal spectrum, with a predominance of high freuencies, and could not observe any trigger radiation. The last fact is apparenty due to the noticeably lower intensity of the magnetosphere signal or to the hort registration time.

Let us estimate the possible variants of the interpretation of the effect of mplitude modulation. The quasilinear mechanism leads to a characteristic onlinear increment $\gamma_n \sim E^{1/2}$ of the process[4,5] and to a modulation period[4] $\sim \gamma_{lin}^{-1}$, where γ_{lin} is the linear increment, which is maximal in the equatorial art of the trajectory, i.e., in the region of minimal values of the electron gyrofrequency $f_{He\,min}$. As shown by theoretical calculations for the real distribution of hot electrons in the magnetosphere,[6] the frequency dependence of γ_{lin} has a maximum at $x=f/f_{He\,min} \sim 0.3$. For our trajectory, $f_{He\,min}=60$ kHz, sc that $x \sim 0.25$—0.5 for the employed frequencies. As seen from Fig. 2, the quasilinear theory does not seem to agree with our data. It is also difficult to attribute the indicated effect to modulation instability ($\gamma_n \sim E^2$), since its growtl rate is positive only at $x < 0.25$ or $\partial v_g/\partial\omega > 0$ (v_g is the group velocity of the VL] whistlers). The onset of modulation may be connected with the mechanisms of nonlinear hydrodynamic scattering of VLF waves by ion-cyclotron waves ($\omega \sim \omega_{Hi}$) or the decay interaction of VLF waves with the ion-cyclotron branch of the electrostatic oscillations ($\omega < \omega_{Hi}$, $k_\perp \gg k_\parallel$),[7] with characteristic growth rates $\gamma_n \sim (\omega E)^{2/3}$ and $\gamma_n \sim eE(1-x)$, respectively. The former mechanism has a large excitation threshold and can be realized only at small heights above the high-power transmitter. As to the latter mechanism, the solution of the problem, with allowance for the limited interaction region ΔS, leads to a relation $\tau \sim (\gamma_n^2 l)^{-1} \sim \omega^{-1}E^{-2}$, where $l=\Delta S/v_g$.[8]

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