Ann. Géophys., t. 36, fasc. 3, 1980, p. 419-422

On the mechanism of whistler-frequency emission in the Araks experiments

by

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ABSTRACT. – *It is shown that the dependence of emission frequency in the whistler range on the rocket potential, as well as the resonant character and amplitude decrease with the distance are in qualitative agreement with the development of diocotron instability around the rocket.*

RESUME. – *On montre dans cet article que la variation de la fréquence d'émission dans la gamme des sifflements avec le potentiel de la fusée, aussi bien que le caractère résonnant et la décroissance de l'amplitude avec la distance sont en accord qualitatif avec le développement de l'instabilité diocotron autour de la fusée.*

As a result of experiments on electron beam injection into the ionosphere, an emission was registered over a wide frequency range (Cartwright and Kellog, 1971, 1974 ; Kellog *et al.*, 1976). The properties of emission at about the Langmuir frequency of the undisturbed ionospheric plasma can be qualitatively explained by the mechanism of coherent Cerenkov radiation from the head front of the beam (Alekhin and Karpman, 1973). The shape of the emission pulse in the whistler frequency range, $\omega < \omega_{He}$, obtained in "Echo-1" experiment can be explained by a similar mechanism (Cartwright and Kellog, 1974). In "Echo-2" experiment (Monson *et al.*, 1976) the emission pulses in this range had practically the shape of electron gun pulses, which cannot be due to radiation at the beam front, for in this case, the received signal should be much shorter than the gun pulse. The received signal amplitude decreased as $\sim 1/R$, where R is the distance from the injector (rocket) to the receiver of emission (ejectable cone). It has led Monson *et al.* (1976) to conclude that the source of whistler-frequency emission during "Echo-2" experiment was the region around the rocket. In fact, as the electron gun operates, the rocket gains a potential of $\varphi_{roc} > 0$. If the rocket axis is nearly collinear with H_0, the drift of ionospheric electrons in the crossed electric field of the rocket ($\vec{E} = -\nabla\varphi_{roc}$) and geomagnetic field ($\vec{H}_0$) will be directed almost circularly :

$$V_\psi^{(e)} = c\,\frac{\partial\varphi/\partial r}{H_0} \sim c\,\varphi_{roc}/H_0 r_* \qquad (1)$$

where r_* is the circle radius, $\vec{r} = (r, \psi, z)$, and Oz axis is directed along the geomagnetic field, $\vec{H}_0$. If $\varphi_{roc} \simeq 100$ V and $r_* \simeq 1$ m, the rotation frequency is $f_0 = V_\psi^{(e)}/2\pi r_* \approx 300$ kHz, i.e. fits the frequency range under discussion.

In this paper, we shall analyse the dynamics of whistler-frequency emission using the data obtained during the Araks experiments with the help of "Spectrum" device (Gouseev *et al.*, 1975 ; Gusev *et al.*, 1978). Only the data from Northward flight (26.01.75), for which the rocket potential measurements are available (Gringauz and Shutte, 1976 ; Managadze, 1979). have been included.

The shape of the received signal and a telemetry record of electron gun current are represented in Figures 1 (a) and (b) respectively. Note the emission to have the same shape as the gun current, in accordance with Monson *et al.* (1976).

Figure 2 shows the spectrum of emission during (a) and after (b) the plasma injection. In both cases, the spectrum distribution has a pronouncedly resonant character, f_0 being about 160 kHz with operating plasma generator, and about 630 kHz when it is switched off. It should be stressed that the measurements of the rocket potential have revealed its increase after the plasma generator was switched off.

Figure 3 shows the amplitude variations of the received signal at 150 kHz and $\theta_0 \sim 70°$ from the beginning

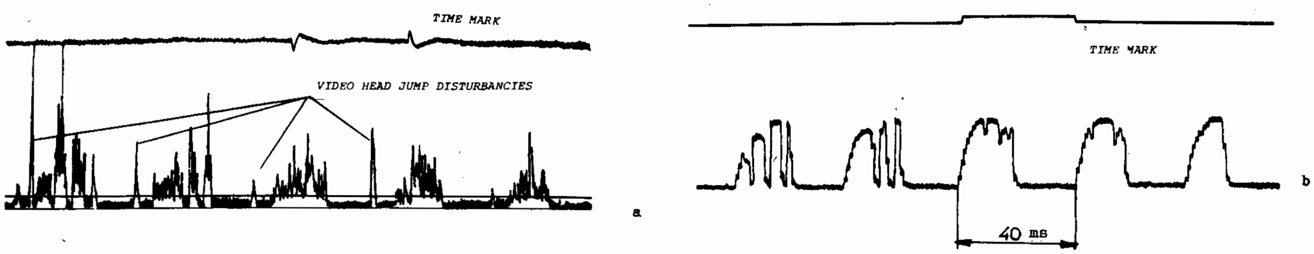

Fig. 1

Comparison between the envelope of whistler mode signal on the frequency 150 kHz (a) and the telemetry of injected current (b).

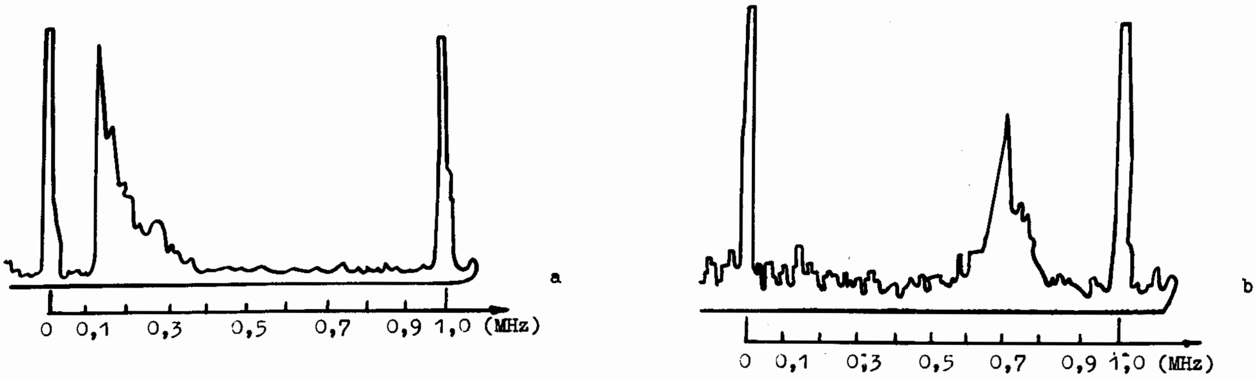

Fig. 2

Representation of the whistler mode spectrums (a) when the plasma source works (plasma on) and (b) after it has been cut off (plasma off).

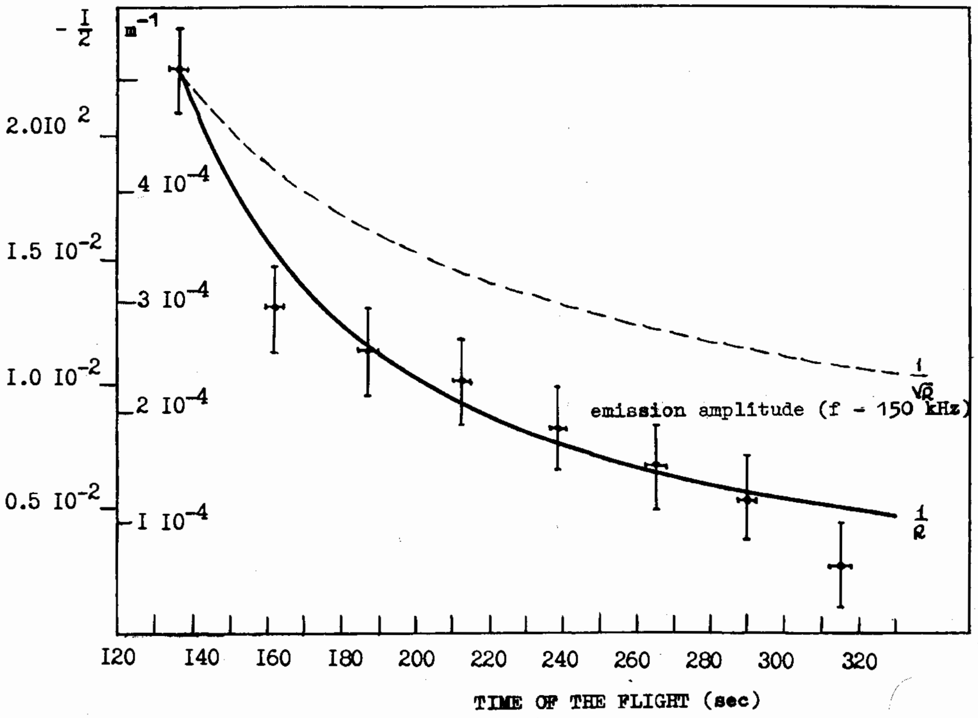

Fig. 3

Variation of the whistler-mode amplitude during the Northward flight, for the series of 70° gun-rocket axis angle injections.

of injection till the plasma generator was switched off (further on, the spectrum of the signal changed) ; $1/R(t)$ and $1/\sqrt{R(t)}$ are plotted herewith. The amplitude dependence on R is far from square root law and closer to $1/R$ or even steeper.

Discussion

The dependence on R suggests the "point" character of the source localized near the rocket. The changes in the signal spectrum observed when the plasma generator is switched off imply some relationship between the emission mechanism and potential of the rocket. And finally, the resonant character of the emission spectrum points to a selectivity of its generation mechanism that may be due to geometry of the emitting region.

One of possible mechanisms seems to be the instability of electron cloud near the rocket in the crossed electric and geomagnetic fields (diocotron instability: Mihajlovskij, 1977 ; Dolgopolov *et al.*, 1973 ; Schuurman, 1967 ; Levy, 1965 ;Knauer, 1966) which develops under the condition (Mihajlovskij, 1977) :

$$V_{\psi}^{(e)} > V_{T_e} \gg V_{\psi}^{(i)}, \left.\frac{\partial n}{\partial r}\right|_{r=r_*} = 0, \qquad \left.\frac{\partial^2 V_{\psi}^{(e)}}{\partial r^2}\right|_{r_*} = 0 \tag{2}$$

Here $V_{T_e} = (2\ T_e/m)^{1/2}$ is the thermal velocity of electrons ; $r_{\min} < r_* < r_{\max}$; $r_{\max}$, $r_{\min}$ are the external and internal boundary of the electron cloud respectively.

As shown under laboratory conditions (Vlasov *et al.*, 1975), the realization of (2) in cylindrically symmetrical plasma placed in the crossed fields leads to oscillations with a frequency of $\omega_0 \approx V_{\psi}^{(e)}/r$ localized in radial direction at about r_*, so that $\Delta\omega/\omega_0 \lesssim 0.3$. Besides, the emitted frequency, ω_0, was found to increase with increasing potential at the cylindric anode. The laboratory conditions and the results of Vlasov *et al.* (1975) seem to be analogous to those in the rocket environment, particularly during the Northward launch in the Araks experiments, when the angle between the axis of the rocket and H_0 was ~ 6°. In fact, the rocket length (~ 8 m) is much more than its radius (~ 0.3 m), so that the electric field may be approximated as the field of a cylinder. It is known (Galeev *et al.*, 1976) that only the discharge ignition near the rocket is able to neutralize the injection current of ~ 0.5 A. In such a case, the density profile is to have a maximum, because the density near the rocket will decrease due to death of electrons on the rocket body, whereas in the distance it is close to the ionospheric electron density. The radial extension of the cloud seems to be determined by the zone of high potential, whose dimensions do not exceed several meters (see Galeev *et al.*, 1976). Thus, $r_{\min} > 0.3$ m, 1 m $< r_{\max} < 10$ m.

The distance from the rocket, at which the instability can form, may be derived from the condition $V_{\psi}^{(e)} \sim c\varphi_{\text{roc}}/H_0 r_{\text{in}} > V_{Te}$ where $V_{Te} \approx 2\ 10^8$ cm/sec (the electron temperature in discharge as it was estimated by Galeev *et al.*, (1976) is ~ 10 eV). Hence, $r_{\text{in}} \leqslant 10\ \tilde{\varphi}_{\text{roc}}$ m, where $\tilde{\varphi}_{\text{roc}} = \varphi_{\text{roc}}$ (kV). The emission source with a given frequency, f_0, can be localized at:

$$r_* \simeq 50\ [\tilde{\varphi}_{\text{roc}}/f_0\,(\text{kHz})]^{1/2}\ m \tag{3}$$

For $f_0 \approx 150$ kHz, $r_* \approx 4\ \tilde{\varphi}_{\text{roc}}^{1/2}$ m ; for $f_0 = 630$ kHz, $r_* \approx 2\ \tilde{\varphi}_{\text{roc}}^{1/2}$ m. If $\tilde{\varphi}_{\text{roc}} = 0.2 \div 1$ (see Gringauz and Schutte, 1976 ; Managadze, 1979), (3) will give $r_* \lesssim 2 \div 5$ m and $1 \div 2.5$ m respectively, which doesn't contradict the estimate for $r_{\text{in}} \lesssim 2 \div 10$ m.

Finally, let us estimate the emission intensity assuming the electron emission in a cloud to be coherent as a result of phase bunching associated with diocotron instability. Using the expressions for the emission intensity of a circularly rotating particle (Landau and Livshitz, 1973) we obtain :

$$E \sim \frac{1}{R}\left(\frac{1}{c}\,\frac{\sqrt{\omega_0\omega_{He}}}{\omega_{pe}}\cdot\frac{\omega_0^4 e^2 r_*^2}{3\,c^3}\,N^2\right)^{1/2} \sim \\ \sim N\frac{r_*}{R}\,\frac{e\omega_0^2}{c^2}\left(\frac{\omega_0\omega_{He}}{\omega_{pe}^2}\right)^{1/4} \tag{4}$$

Here N is the number of emitting electrons, R is the distance between the receiver and the rocket ;

$$\omega_{pe} = (4\,\pi\, n\, e^2/m)^{1/2}$$

$\omega_{He} = \dfrac{eH_0}{mc}$. N can be given by

$$N \sim n\,2\pi r_*\,\Delta r\,\Delta Z \sim n\,2\pi r_*^2\left(\frac{\Delta f}{f_0}\right)\Delta Z$$

where $\Delta Z \sim 10$ m, i.e. the order of the rocket length; $n \approx 10^6$ cm^{-3} is the discharge plasma density (Galeev *et al.*, 1976), $\Delta f/f_0 \simeq 0.2$-0.3 (see Fig. 2). As a result, (4) will give $E \simeq (3 \div 30)\ R^{-1}$ (km) (mV/m) for $f_0 = 150$ kHz, which doesn't contradict the experimental results. The arm of the receiving dipole being 4 m, the whistler-range signal with the frequency of 150 kHz and the bandwidth of 3 kHz will reach several mV/m at the receiver output located at ~ 1 km from the rocket.

Thus, it may be concluded that the diocotron instability seems to have play an important role in generating the whistler-range emission during the Araks Northward flight.

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