Adv. Space Res. Vol. 1, pp. 89-95.
©COSPAR, 1981. Printed in Great Britain.

0273-1177/81/0201-0089$05.00/0

THE WAVES OBSERVED IN THE ARAKS-NORTH EXPERIMENT

M. Dechambre,* J. Lavergnat,* I. A. Zhulin,** Yu. V. Kushnerevsky,** S. A. Pulinets** and V. V. Selegei**

*Laboratoire de Geophysique Externe, 94100, Saint-Maur, France

**Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, 142092, Troitsk, Moscow Region, USSR

ABSTRACT

Experimental results of the wave measurements over frequency range 0.1 - 5.0 MHz during the first launch of the ARAKS Experiment (26.01.75) are reported. The dynamics of spectra of the whistler mode and plasma mode emission stimulated by high energy electron beam is described.

INTRODUCTION

In the joint French-Soviet experiment ARAKS as well as in "Electron Echo Experiments" [1,2] the processes excited during the injection of energetic electrons, were studied by means of receiving equipment installed on the removable nose cone [3,4]. Fig.1 represents a signal over the whole band of high frequency analysers measured by the sweep frequency analyser (SFA). The lefthand part of the Figure 1 is dark because at the beginning of the flight the sensitivity was redused by 20 dB. Short signals multiple of 600 kHz and parallel to the horizontal axis correspond to the moments of amplitude-frequency calibration of the wave apparatus [3]. At the top righthand side, one can see intensive signals during sequences 20, 22 and 24. They are related neither to the electron gun perfermances nor to the cesium plasma source which is cut off in the middle of sequence 20 but are present only when the broad band telemetry "Spectrum" is ON, that's why we consider it as their cause. The carrier frequency of the transmitter was 164.5 MHz. Such mutual influence was detected only in these cycles. A weak signal is clearly visible around 2.8 MHz near the culmination and its frequency decreases as the plasma frequency. This permanent emission cannot thus be attributed to an hardwave interference even if its origin is difficult to understand. The bottom part of the figure gives a cyclogram of electron gun operation.

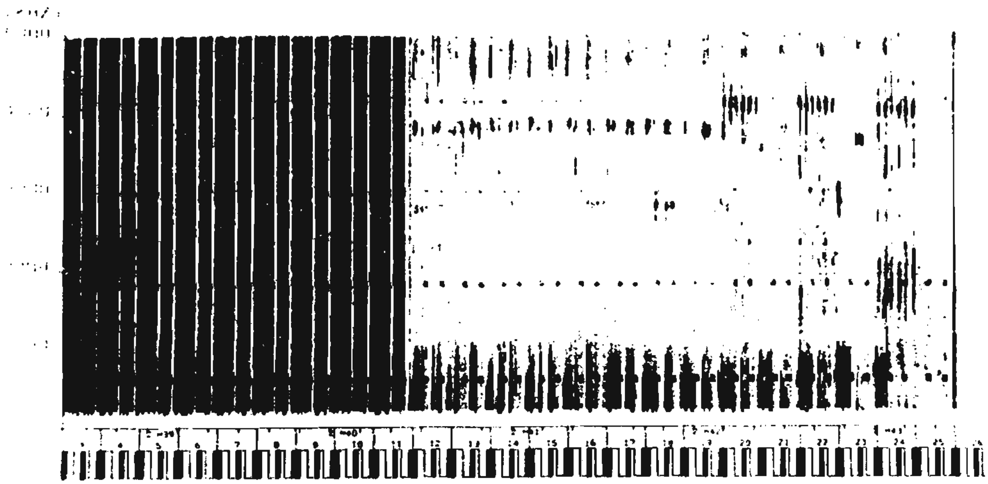

Fig.1 High frequency waves observed during the North flight displayed like a sonagram.

Associated signals may be seen in the following frequency ranges. A large bandwidth emission below electronic gyrofrequency $f_{He} \leq 1.2$ MHz-Whistler mode. It is always correlated with gun injection whatever the pulse duration. A narrow band emission whose frequency is close to 3.8 MHz at the culmination and decreases along the descent of the nose cone. This emission is bounded by the plasma frequency f_P and by the upper hybrid frequency f_{UH} - Plasma mode. This emission is observed only during the beginning of the each pulse of electron gun injection. A narrow band emission, the middle frequency of which is close to the $4f_{He} \sim 4.8$ MHz. It seems to be correlated with the electron beam only during the short pulses but its weak amplitude $\sim 20 \mu V$ makes difficult any temporal study. However, during the short pulses the level is rather constant. We must note that no other harmonic of the electronic gyrofrequency has been recorded except during sequence 23 (pitch-angle 70°) when a moderate signal $\sim 60 \mu V$ near $3f_{He} \sim 3.6$ MHZ was observed. This continuous emission occurs at a time which is remarkable: when the plasma frequency and the double of the electronic gyrofrequency are equal.

THE WHISTLER MODE

We have established that the signal envelope of whistler mode emission repeats the form of injected current pulses of the electron gun (Fig.2). One can see that the time delay in the whistler range relative to the beginning of injection is negligible; in any case it does not exceed 1-2 ms. The order of magnitude of the input signal within the passband 42.5 kHz of the SFA is between 0.1 and 1 mV, the noise level is close to 2 μV.

Fig.3 shows the evolution of the integrated squared amplitude within 0.1 - 1.0 MHz band versus time. On account of the commutation of the receiver sensitivity we can see the mean level of the noise of about 0.2 mV only in the first part of the flight. The scheme of the gun sequences drawn at the bottom of the figure is a theoreti-

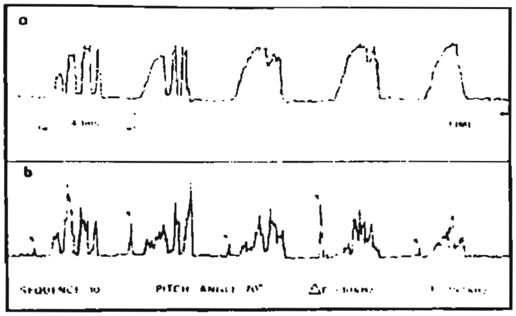

Fig.2 a - telemetry record of the injected current, b - the whistler mode emission filtered from "Spectrum" signal.

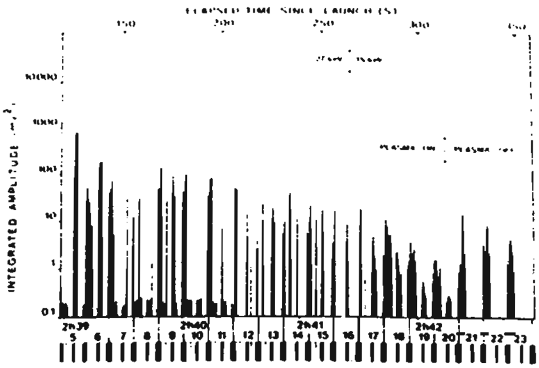

Fig.3 The integrated squared amplitude within 0.1 - 1 MHz band versus time.

cal one. We can see that, during operation of the plasma source (from sequence 5 to middle of sequence 20) the radiated energy is inclined to decrease with time for all configurations of operation of the electron gun. After plasma is switched off there is a moderate level mainly when the pitch-angle is 0°.

We found that the radiated energy is modulated at the double of the spin frequency of the nose cone that is normal and at the spin frequency of the rocket which is unexpected because this effect has the same intensity both in the case of modulation of pitch-angle by rocket spin and in the case of injection exactly along the rocket longitudial axis. The correlation analysis was made for the period when the electron gun works well during the long pulse 2.56 s in the 18-th sequence. The cross-correlation functions were calculated for the signal amplitude E(t) and functions $\cos\alpha(t - \tau)$ and $\cos\beta(t - \tau)$, where α is the angle between the direction of injection and the velocity vector of the rocket if the pitch-angle was 70° and β is the angle between the dipole and Earth magnetic field B_0. The analisis showed that the electric component of the received wave is quasi perpendicular to B_0 and that the emission amplitude is maximal when the electron gun pulses are injected in the direction opposite to the velocity vector of the rocket.

The whistler spectra for different pitch-angles and for regimes of plasma source ON and OFF obtained by two methods (SFA and "Spectrum") are shown on Fig.4 and Fig.5. One can see that the emission amplitude is maximal near the lower boundary of the receivers passband during the operation of plasma source. So we must be careful in the interpretation of the left edge of the spectra represented on Fig.5 a, b, c. We can equally talk about the subsequent growth of emission amplitude with decreasing of frequency lower than 100 kHz (the wave measurements in the frequency band 10-100 kHz make possible such conclusion) and about the resonant form of the spectra (the results of wave measurements in the East launch [5] showed that whistler emission is resonant with maximum of spectra located at 650 kHz). The "Spectrum" results show that the spectra become wider under large pitch-angles, the separate maximum appears at 300 kHz when Θ = 140° (Fig.5c). It may be seen on Fig.4c too. The

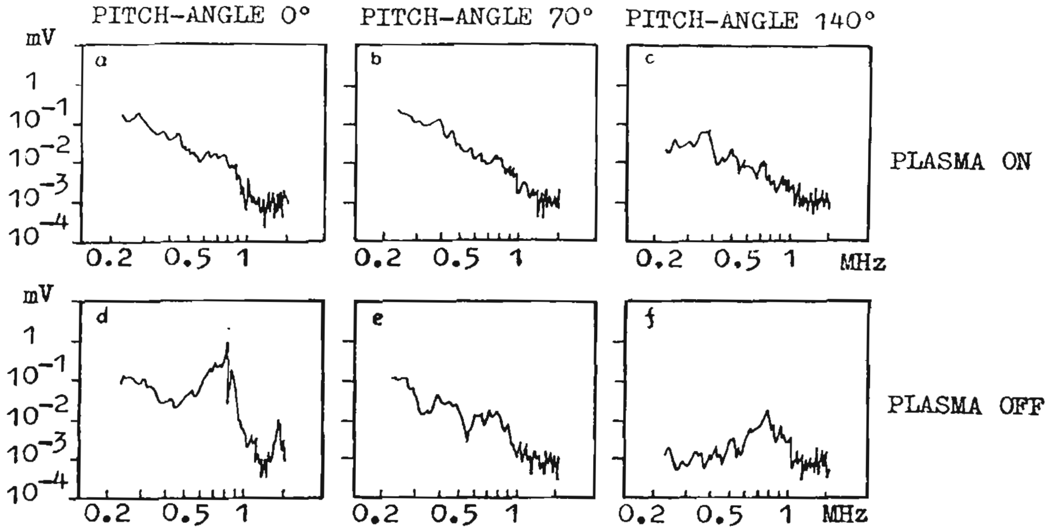

Fig.4 The whistler spectra obtained by the SFA.

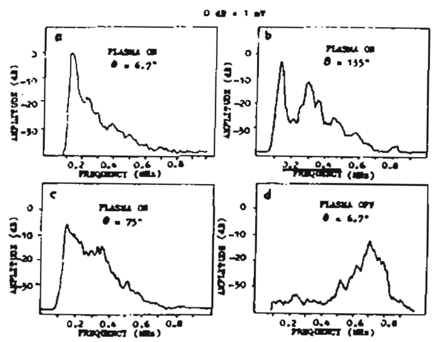

Fig.5 The whistler spectra obtained by the "Spectrum".

effect of modulation of whistler spectrum by rocket spin makes dynamics of it more involved [6]. The emission spectrum widens periodically with the rocket spin.

After the source of plasma operation has stopped there are changes in the temporal evolution of the spectra in several ways: sometimes the separate peak appears at 700 kHz frequency (Fig.5d), sometimes it superposed on the previously detailed form (Fig.4d). This pictures change chaotically in 22 sequence but in the 24 sequence mainly the emission on 700 kHz is observed. The changes in the spectral dynamics after the plasma source was off indicates the essential influence of the rocket body neutralisation processes and the rocket region environment on the generation and propagation of waves in the whistler band [7, 8]. The modulation of whistler spectrum by the rocket spin is once more confirmation of this thesis.

THE PLASMA MODE

In this range, the emission pulses appear at the beginning of each injection pulse with a delay of the order of several hundreds of microseconds. In some cases the delay is imperceptible (Fig.6). The maximum amplitude of emission is reached in about 1-2 ms after the beginning of an electron pulse and then decreases continuously to a backgound value. Its average value did not exceed 200 μV over the flight. However, Fig.6 represents the statistical means. Fig.7 shows the development of individual pulses for the injection angles of 0° and 70° during the 18-th cyle of electron gun operation. Of special interest is the case of the pulse injected at a small angle to the magnetic field ($\theta \sim 7°$). From Fig.7a it is evident that at higher frequencies of the dynamic spectrum, the emission pulse seems to extend in time. For the dynamic spectrum at the angle $\theta \sim 71°$ (Fig.7b) at central frequencies of the spectrum two isolated maxima of emission can be noted, though the telemetric record of the gun current, given at the top, does not reveal any conspicuous discontinuity of pulses. However, common for all signals is the fact that they do not follow the shape of the gun current, being associated only with the beginning of the pulse. Note that the pulse duration is of no importance, for the plasma mode is also emitted at the front of pulses of 2.56 s duration.

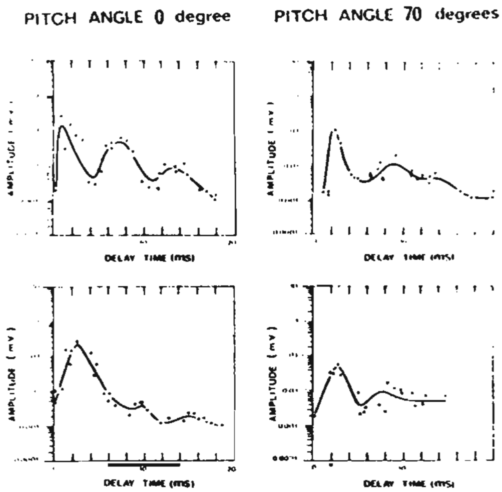

Fig.6 Plasma mode amplitude as a function of time since start of gun pulse (SFA).

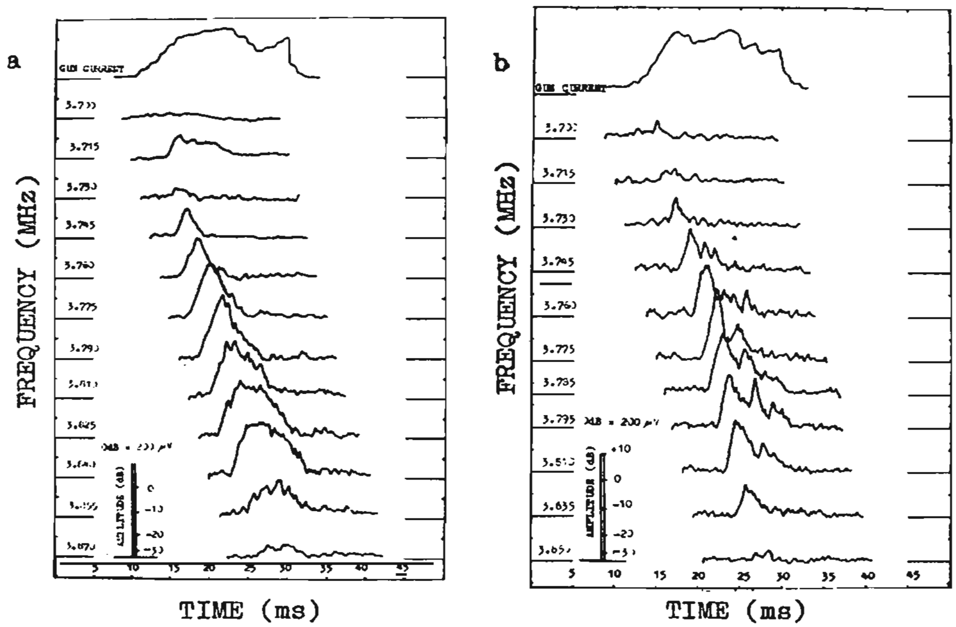

Fig.7 The development of individual pulses, 18 sequence, 15 keV; a - 0° series 17 pulse, b - 70° series, 13 pulse.

As shown by the first launch data, the plasma mode emission is observed at the pitch angles of 0° and 70° and is absent when the beam is injected at 140° to the magnetic field. In the range of 0°-70° no pronounced pitch-angle dependence of the emission amplitude has been discovered. In average, the emission amplitude at $\theta = 70°$ is something smaller than at $\theta = 0°$ (Fig.6). This dependence is, however, considerably disguised by the effect of deep modulation of the plasma mode emission due to the rocket spinning (Fig.8). This modulation has nothing to do with the pitch-angle variation as a result of spinning. It may be seen from the following: in the first launch at $\theta = 0°$, the electron beam was injected strictly along the rocket's vertical axis, so that its spinning could not tell on the injection pitch angle. Nevertheles, the amplitude of plasma mode emission was modulated with the spinning period much deeper than it is when the pitch angle changes from 0° to 70°. As seen from the Fig.8, the amplitude modulation depth was more than 30 dB. At the same time, the average emission amplitude at $\theta = 70°$ was by 5-10 dB smaller than at $\theta = 0°$.

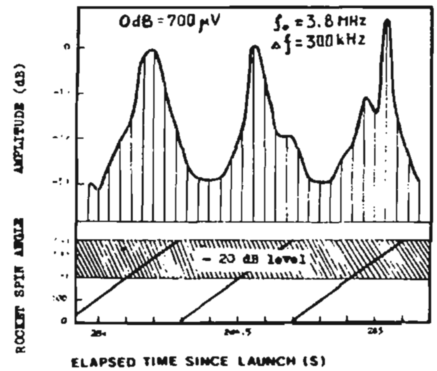

Fig.8 The modulation of plasma mode emission by the rocket spinning.

The emission mechanisms may be discriminated by using such parameters as the effectivity of plasma-beam interactions (injected current-emission amplitude), the shape of emitted pulses, the delay of emission relative to the injection beginning, the pitch-angle dependence of the emission amplitude, the shape of electron gun current and voltage pulses. In particular, the authors of [9] believe that the ratio of $dU/dt > 0$ (where U is the accelerating voltage) to be indicative of the beam emission coherence. The question of how the experimental amplitude of emission corresponds to theoretical estimates [9, 10, 11] is a quite complicated one. The results presented above may also be interpreted as Cherenkov emission from the leading edge of the beam.

Let us note that though the beam current in ARAKS experiment (0.5A) was about an order larger than in the "Electron Echo Experiment" (70 mA) and more efficient receiving antennas were used, the measured amplitude of the plasma mode emission was much lower than in EEE-2 and of the same order as in EEE-1 experiment [2] . The smaller emission amplitude at $\theta = 70°$ than at $\theta = 0°$ and the shape of accelerating voltage during the pulsed injection suggest that the emission registered in ARAKS is the incoherent Cherenkov radiation of the beam [9] . However some facts as, for example, the emission pulses that don't follow the shape of electron gun current, still need explanation. It should be mentioned that nominal current 0.5A was reached in 5-6 ms after beginning of the injection pulse (Fig.7) By this moment the plasma mode emission pulse was almost finished. So it is necessary take the effective current for calculation of the emission amplitude less than 0.5A. Besides, it should be noted that in some cases (mostly at electron gun breakdowns) one could observe the emission pulses with an amplitude exceeding by an order the maximum mean statistical value.

CONCLUSIONS

The authors have not made their objective to accomplish a discussion of data on wave emissions obtained during ARAKS experiment. Some results still are under procession and will be published later. However, the data discussed above allow us to make certain conclusions. One of the most unexpected and interesting phenomena is the deep modulation of all emissions by the rocket spinning at practically constant pitch angle of injection. This experimental fact allow us to speak about the important role which the rocket region environment plays in the beam-plasma interaction.

New results concerning to whistler and plasma modes spectral dynamics bring us closer to exact indentification of the generation mechanisms, but the involved character of the experimental results makes clear the necessity of determination of the received waves polarisation and receiving antennas impedance in the future experiments with the artificial injection of electron beam in the ionosphere.

REFERENCES

1. F. Cambou, R. Z. Sagdeev, I. A. Zhulin, Space Science Instrumentation 4, 117 (1978).
2. P. J. Kellogg, D. G. Cartwright, R. A. Hendrickson, S. J. Monson, J. R. Winckler, Space Research XVI, 589 (1976).
3. J. Y. Delaye, J. Lavergnat, R. Ney, I. F. Karczewski, Space Science Instrumentation 4, 143 (1978).
4. G. A. Gusev, I. A. Zhulin, Yu. V. Kushnerevsky, V. V. Migulin and S. A. Pulinets, Space Science Instrumentation 4, 171 (1978).
5. Yu. V. Kushnerevsky and S. A. Pulinets, this volume.
6. S. A. Pulinets, Ph. D. Thesis, IZMIRAN, Moscow, 1980.
7. S. A. Pulinets, in: Fizika ionosphery i magnitosphery, IZMIRAN, Moscow, 1976, p. 144.
8. A. A. Galeev, E. V. Mishin, R. Z. Sagdeev, V. D. Shapiro, V. I. Shevchenko, Doklady Akademii Nauk USSR 231, 71 (1976).
9. J. Lavergnat, R. Pellat, Journal of Geophysical Research 84, 7223 (1979).
10. V. I. Karpman, Planetary and Space Science 22, 1597 (1974).
11. J. W. Jones, P. J. Kellogg, Journal of Geophysical Research 78, 2166 (1973).