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Waves generated in the vicinity of Xenon plasma gun in the APEX-experiment

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Abstract. Wave and plasma observations were made in some neighborhood of a xenon gun, carried at altitudes near 500 km in the APEX-experiment. Wideband noise associated with neutral gas releases and steady beam currents were detected. In modulation regime even and odd harmonics of the beam modulation frequency were observed. Some delay in wave emissions after termination of modulated beam injection was detected as well. This effect was accompanied by the electron temperature and density disturbances as measured by a plasma density and temperature device.

1 Introduction

Active experiments with ions and neutral gas releases have a long history, Starting with the sounding rockets emerging in the sixties. Their purpose included the excitation of artificial aurora and stimulation of plasma turbulence in the ionosphere (Hess et al., 1971, Cambou et al., 1975, Winkler, 1980). In past active experiments significant progress has been made in the study of the generation of electrostatic and electromagnetic waves in the near zone of DC, modulated electron beams, and neutral releases (Shawhan et al., 1984, Neubert and Banks, 1992). Equidistant harmonics within the frequency range from 1 to 5 kHz in some neighborhood of the sounding rocket during argon plasma gun operation were detected (Cahill et al., 1993). Slow variations of the spectrum and intensity of VLF-waves were detected in the process and after neutral xenon and nitrogen releases in the satellite "Active"-experiment (Bankov et al., 1993, Mikhailov et al., 1994). This paper presents the available observations of VLF wave stimulation in a near zone of the xenon plasma gun in the APEX-experiment.

2 Description of the experiment

The satellite Intercosmos-25 (APEX-experiment, IC-25) had been launched on 18 December, 1991 on orbit with apogee 3080 km, perigee 440 km and inclination 82.5°. The satellite attitude is known within an accuracy 1%. On the IC-25 spacecraft we dealt with Xe neutral gas and plasma jet generator as well as scientific instruments for the measurement of the magnetic component of VLF waves by NVC-ONCH receiver (Mikhailov et al. 1994; Mikhailov et al. 1997) and the ion density (Dokoukin, 1992). Hundred second pulses of xenon injection with 2A current and 250 eV energy were realized in two regimes: (i) without modulation and (ii) with current modulation at frequencies 62, 125, 250, 500 and 1000 Hz with square-wave form. These regimes are referred to as PDC for (i) and P62, P125, P250, P500 and P1000 for (ii). Pause between pulses takes place over a period of fifty seconds. The cycle of the gun operation involves the fire up stage, injection of a non-modulated beam, and subsequent injection of a modulated beam. More 70% of injected particles was ionized. The angle between the injection direction and the direction from the Earth's center to the satellite and the direction opposite to the satellite velocity is equal 45°. The density and temperature of plasma have been measured by the KM10 device (Dokoukin, 1992).

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2 Experimental results

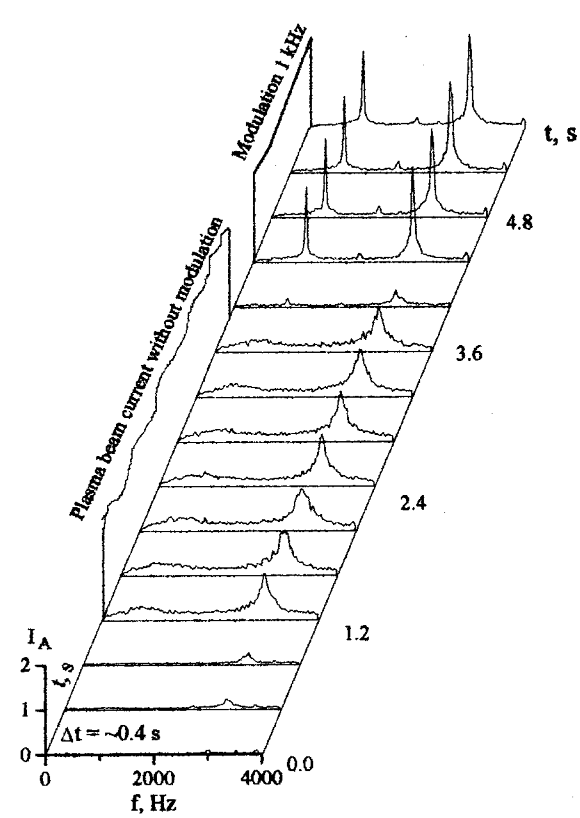


Fig. 1 Spectra of VLF-waves in different modes of Xe-gun operation

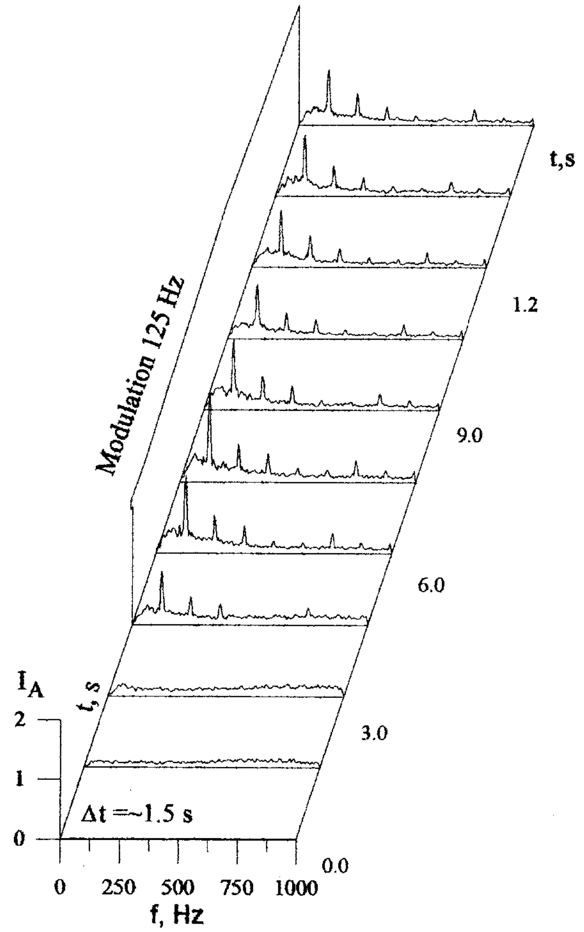
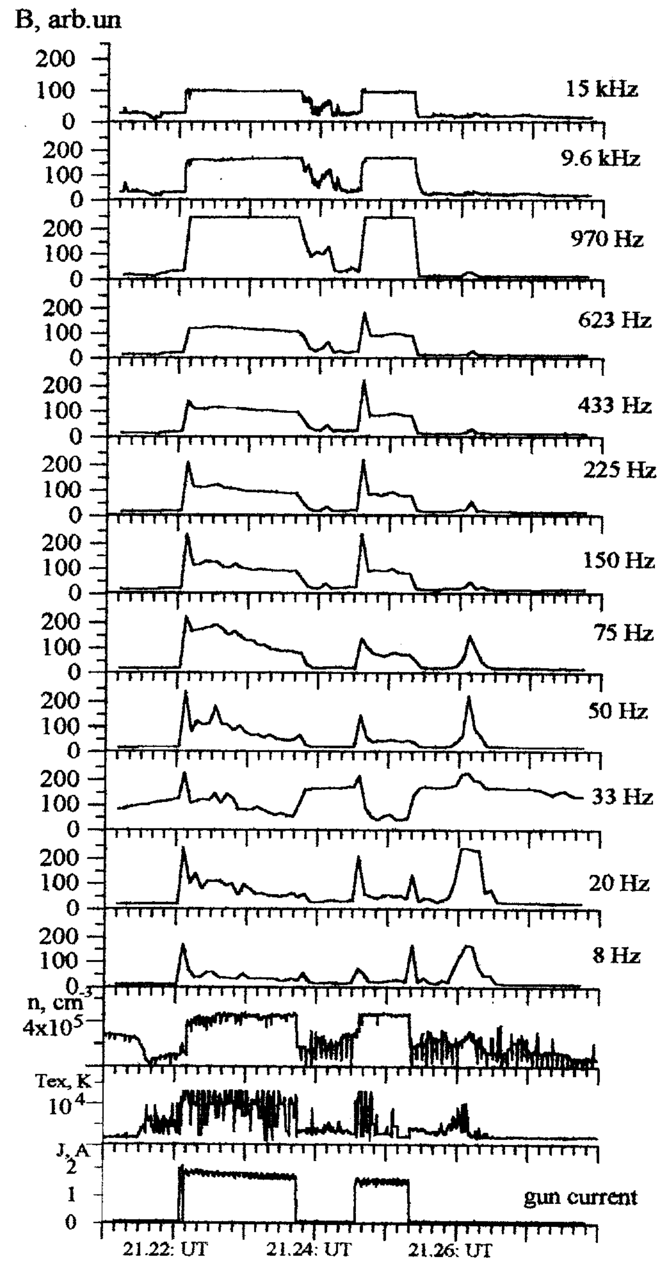


Fig. 2. Spectra of ELF-waves in P125 mode of Xe-gun operation on orbit 756 19.02.92. Time interval 21.02:03 ÷ :18, coordinates: h=560 km, lat =48.2°N, long = 8.3°E.

At the orbit 767 on 20.02.92 the plasma generator was operating with the modulation frequency 1000 Hz. Figure 1 presents spectra of the VLF magnetic field within the band up 4 kHz. The vertical axis were the jet generator current and the operating modes, the horizontal is the frequency, the third axis is the time interval between 21.22:05÷21.22:11 UT and curves are spectral power density of magnetic induction B in arbitrary units. In the specified interval the following effects were revealed: (i) the noise levels increased in the non-modulated beam mode, some increasing of spectrum amplitudes on frequency near 3.0 kHz was related to the board system influence, (ii) P1000 - excitation of even and odd harmonics of modulation frequency of 1000 Hz. In Figure 2 the dynamic spectra of VLF signals received on orbit 756 when the plasma jet generator operated with the modulation frequency 125 Hz are presented. In this figure one can see during the first 3 s the noise related to the gun operation in the DC mode. After the modulation is on, some harmonics of the modulation frequency are seen, the most intensive being the first, second and third ones. In Figure 3 the results obtained on the orbit 767 are presented. Abscissa presents time and orbital parameters, ordinates (from bottom to top) show gun current I in A, electron temperature Te_X (K), where X is coordinate along the velocity of satellite, ion density in cm^{-3} and magnetic induction B in arbitrary units for filters at frequencies shown in the figure. In the considered interval there are two gun pulses.

During the first impulse an increase in the noise inten-



h, km	632	723	825
lat,°N	54.1	61.7	68.8
long,°E	33.8	37.0	42.1
L	2.636	3.886	6.078
MLT	0.19	0.71	1.39
SZA	136.2	129.0	122.1

Fig. 3. B_{VLF}, B_{ELF} in relative units, density of ions *n*, T_e and gun current *I*. Frequencies are given on the right of the Figure. Coordinates include h - height, MLT - magnitude local time and SZA - solar zenith angle.

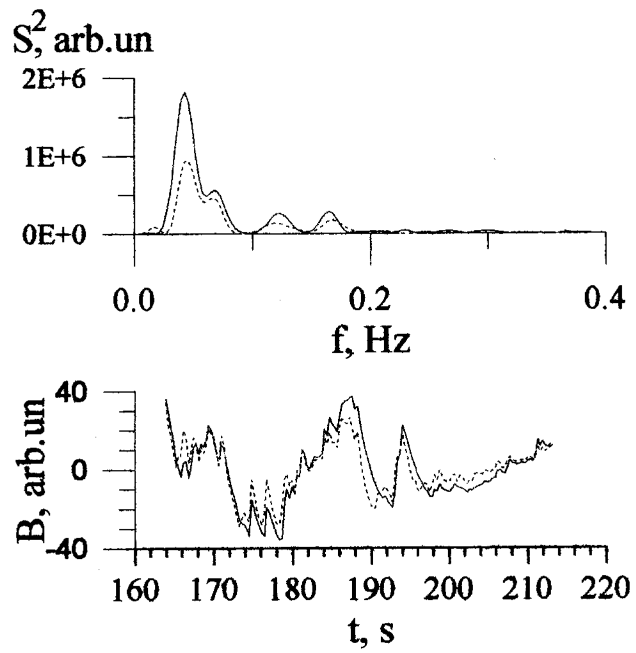


Fig. 4 Spectra (upper panel) and time dependencies (lower panel) of envelop curves for channels 9.6 (solid lines) and 15.0 kHz (dashed lines) between Xe-gun pulses in interval 21.23:40 to 21.24:34.

sity up to the maximal level of the receiving scale at frequency from 75 Hz to 15 kHz is detected. At frequencies from 8 to 75 Hz the noise level is about ¼ of the scale. Simultaneous increases of ion density and strong fluctuations of Te_X are registered. When the first pulse is off, the noise at frequencies 9.6 and 15.0 kHz remains and at the same time electron temperature fluctuations are detected. During this time oscillations with periods about 8 and 5 s on envelope curves $B_{9.6}$ and $B_{15.0}$ were detected. Spectral analysis with subtracting of line trend of $B_{9.6}$ and $B_{15.0}$ of envelope curves, which is presented in Figure 4, shows that noticeable peaks occur at frequencies 0.04-0.08 Hz and weaker ones at 0.125 and 0.17 Hz. According to Figure 3 the second pulse produces another reaction, namely, a significant increase in B_{970}, $B_{9.6}$ and $B_{15.0}$ filters without any delay after turning off the gun. In contrast to this, at frequencies 8 to 75 Hz and in Te long lasting and intensive variations are observed. The peak B coincides with an electron temperature peak. May be, this is effect caused by the different nature of the excited waves in the different conditions of the ambient plasma. The interval between some elements of the pulses is about 130 s or near 1000 km, thus causing a significant change in the excitation conditions especially in the angle between the beam and magnetic field direction.

In Fig.5 there are presented magnetometer data on 767 Orbit. The upper curve is a gun current, the same as a lower curve in Fig.3, the second curve is B_y magnetometer data, from which ? variations, stipulated by change of Earth magnetic field, has been excluded, but there are shown variations, related with longitudinal currents. The next curves are fast variations of B_x, B_y and B_z components respectively. The largest variations are registered on B_y component curve. The initial stage of variations coincides with injection on, but the very end is differs from the injection off.

Just for this reason a possibility that these variations are related to straight injector influence on magnetometer is out of the question. It seems more probable, that the interaction between gun currents and longitudinal currents takes place. It is confirmed by envelope curves of B_x, B_y and B_z components. But this supposition is need in additional studying.

Variations of H_y component of magnetic field were observed on 756 orbit too (Fig.6). Start and end of these variations coincide with injection on and off. We suppose that in this case variations of H_y did not related with longitudinal currents.

3 Discussion

Analysis of Figures 1-4 shows that both during and after the injection process a complicate picture is formed. It is suggested that during the injection time different wave modes are excited. Although the direction of injection is opposite to the satellite velocity, excited waves propagate along the magnetic field lines and some of them may travel in the same direction as the satellite velocity. The time of the joint movement is defined by the wave packet dimensions. By the law of charge conservation applied to the charge injected by Xe-gun, we may estimate the linear dimensions

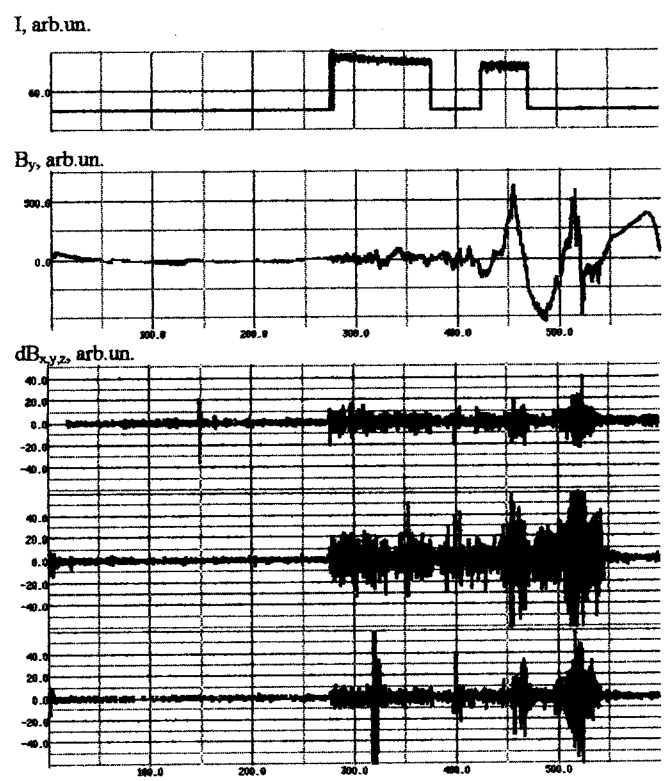


Fig.5 Data on 767 Orbit. The upper curve is a gun current, second curve is B_y, magnetometer data; the next curves are fast variations of B_x, B_y and B_z components

of the beam. The total charge is equal to $I \cdot t$, where t is the duration of the injection. This charge diffuses in a cylindrical volume $S \times l \times \Delta n$, where S and l are the cross section and length of beam respectively and Δn is the density above that of the ambient plasma. Such estimations, if we assume radius of beam 500 m (Volokitin and Drozdov, 1992), give a length of beam ~1 km. The relation between length of a beam and wave packet dimension must be given in future work. The time of joint movement is equal to $\Delta l/\Delta v$, where Δl is the projection of wave packet dimension on X-axis, and Δv is difference between velocities of wave and satellite along the same axis. The situation may be different in high latitudes where the Earth's magnetic field is near to a vertical one.

The total intensity of magnetic field in the near zone of about 1 nT is consistent with Cahill's data for electric field ~0,1 V/m, taking into account differences between the experiments (Cahill et al.,1993).Using theory of linear antennas in a plasma and that the field decreases as r^{-2} for VLF propagation perpendicular to magnetic field, we find, that the field in the far zone at a distance of ~250 km may be near $1.5.10^{-2}$ pT, which is at the limit of sensitivity of the receiver on subsatellite (Oraevsky et al.,1994) but is still detectable.

Observations of time delays are consistent with theoretical calculations of impact-generated plasma clouds and excitation in these clouds of Alfven waves (Volokitin and Drozdov,1992). One of the fundamental frequency of modulation, 0.17 Hz (Fig.4) is near to 0.33 Hz, which coincides with the frequency of the magnetic energy density integral $(B^2/4\pi)$ dz variations, allowing for the approximate character of the estimations.

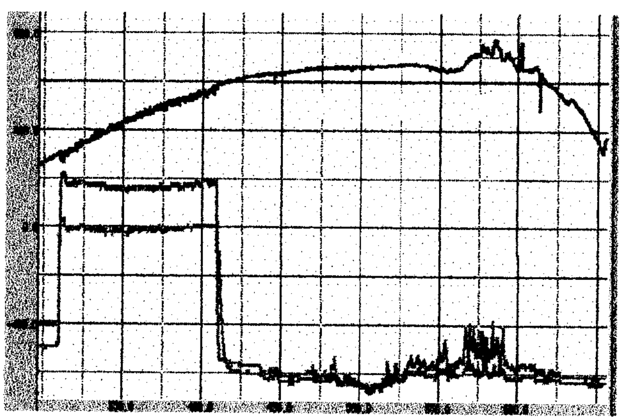


Fig.6. H_y-variations of magnetic field on 756 orbit (upper curve). Lower curves are intensity of 15.0 and 9.6 kHz electric components of VLF.

Careful analysis of three components magnetic variations (Fig.5) allows to estimate approximately of wave normal direction for ULF waves. This vector coincides with the direction of injection.

4 Conclusion

Wide range variations of spectra and amplitudes of waves in xenon gun operation time are represented. These data give us an introduction to the dynamics of wave phenomena in near zone of the satellite and estimate the general picture of wave propagation in near and far zones during the xenon gun operation.

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