NONLINEAR INTERACTION OF ACOUSTIC WAVES WITH PLASMA OF THE IONOSPHERE: THEORY AND EXPERIMENT

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Abstract

This report is devoted to the experimental and theoretical aspects of the nonlinear interaction and influence of the acoustic waves on the ionosphere. This nonlinear phenomenon gives the possibility to simulate the acoustic channel of the lithosphere-atmosphere-ionosphere connection, and to investigate experimentally this channel by means of acoustic generators located on the earth surface. The increase of the transparency of the ionosphere for the cosmic radiowaves caused by a low frequency atmospheric acoustic wave is investigated. Atmospheric acoustic wave creates in the ionosphere a periodic structure of the electron density, like the one created by using two high-power radiowave signals. It is shown that if the length of the acoustic wave is equal or larger than the radiowave length, then a resonant transmission of the radiowaves takes place in the ionosphere.

1. Introduction

In this report we discuss the acoustic channel of the lithosphere-atmosphere-ionosphere connection, which has been established very reliably thanks to the ground and space observations of the earthquakes and volcano explosions. Presently, the use of acoustic generators as the source of very low frequency acoustic signals, and the use of radioelectronical control instruments in the geophysics, for the study of different nonlinear effects in the lithosphere, is possible. The basic difficulty for such investigations is the losses of the acoustic atmospheric waves. Only the low frequency atmospheric acoustic waves (some Hz) reach the ionospheric altitude and interact with the ionospheric plasma. So, as a result we must use the nonlinear interaction of two simultaneously working powerful acoustic generators or one generator with two close frequencies. Due to the hydrodynamical nonlinearity of the atmosphere near the earth's surface it is possible to excite the acoustic wave with differential frequency $\Omega = \Omega_1 - \Omega_2 \prec\prec \Omega_{1,2}$ propagating vertically upwards to the ionosphere and interacting with the ionospheric plasma. Below we show experimentally and theoretically how the low frequency atmospheric acoustic wave creates in the ionosphere a periodical structure of electron density with a period equal to the length of the acoustic wave $\Lambda = 2\pi c_S / \Omega$, where c_s is the sound velocity in the atmosphere. At the cosmic radiation with wave length $\lambda = \Lambda / n$, n=1,2,3..., an increase of the transparency is observed. Moreover, the transmission coefficient of the radiowave might increase many times.

2. Theory

A very important factor is the unique property of the atmospheric acoustic waves [1]. Their amplitude increases exponentially with the altitude z as $V_a \propto e^{z/2H}$, where V_a is the amplitude of the velocity of the acoustic wave, $H = k_B T / m_0 g$, k_B is the Boltzmann's constant and m_0 is the mass of neutral molecules. So, the wave with a certain amplitude at the ground surface of some millimeters per a second will be converted into the wave on the ionospheric altitude ($z \propto 150km$), with an amplitude about the speed of the sound. We take into account the law of the dispersion for vertically spreading atmospheric acoustic waves $\Omega^2 = \Omega_a^2 + K^2 s^2$, where $\Omega_a = s / 2H$ is the cut-off frequency, $s = \sqrt{\gamma P_0 / \rho_0}$ is the speed of the sound. This dispersion is obtained from the hydrodynamic and adiabatic equations in an one dimensional case for the velocity, the density of gas, and the pressure *(V, ρ, P* respectively). In a linear approximation we obtain the acoustic waves velocity described as $V(z) \approx e^{z/2H} e^{i(\Omega t - Kz)}$. It would be noted that the energy flow $\frac{1}{2}\rho_o |V(z)|^2 = const$. The fact that damping of the acoustic waves caused by the viscosity increases with the frequency as Ω^2, shows that the increase of the atmospheric acoustic waves will be essential at the very low frequencies $\Omega \geq \Omega_a \approx 10^{-2} s^{-1}$. The observations confirm this conclusion. One of the difficulties for the experimental investigation of the increase of the transparency is the losses of the acoustic waves [1]. Only a very low frequency acoustic wave can propagate through the atmosphere into the ionosphere. For the generation of very low frequency acoustic wave in the ionosphere, the following technique can be used. We consider the interaction of two powerful acoustic waves with frequencies Ω_1, Ω_2 and wave vectors K_1, K_2 generated with two acoustic generators located at the earth's surface. Due to the nonlinear interaction in the atmosphere a low frequency acoustic wave (the frequency is equal to $\Omega = \Omega_1 - \Omega_2$) can be obtained. The analysis of the nonlinear interaction of two acoustic waves is done by using a nonlinear approach for the velocity of the acoustic atmospheric wave $V = V^{(1)} + V^{(2)}$, where $V^{(1)}, V^{(2)} \propto \cos Kz, K = K_1 - K_2$ are the linear and nonlinear parts of the velocity of acoustic atmospheric wave. The modulation of the ionospheric plasma density is determined by the nonlinear part of the velocity $n_e = n_{eo} + n_n \cos Kz$, where n_n is the modulation caused by the nonlinear low frequency wave. Under the presence of the low frequency atmospheric acoustic wave, the wave vector and wave equation for the electromagnetic wave changes to $k^2 \Rightarrow k^2 + mk^2 \cos(Kz)$ where m is the modulation amplitude determined of the refraction index $N_0 = ck / \omega$, which depends on the specific form of the radiowaves. The wave transmitted into the plasma is analyzed by the wave equation (temporal dependence taken in the form $E \approx e^{i\omega t}$):

$$\frac{d^2 E}{dz^2} + k^2 E + mk^2 \cos(Kz) E = 0 . \tag{1}$$

This is the Schrödinger equation for a particle in a periodical potential field $V = V_0 \cos Kz$. When $m = 0$ this equation determines the transmitted wave in the plasma $E \approx e^{i(\omega t - kz)}$. At the condition $k = nK$ the resonance is obtained. The resonance condition can also be written in the form $\lambda = \Lambda / n$, $n = 1,2,3,...$ where Λ is the acoustic wave length. Thus, the condition of resonance indicates the length of the acoustic wave must be equal to the whole number of the radiowave lengths. Now we may write down the equations for the Umov-Pointing vector of the transmitted wave S_p as $S_p = S_{p0} + \Delta S_p$, where the value $S_{p0} = \frac{4N_0}{(N_0 + 1)^2} S_0$, where $S_0 = c|E_0|^2 / 4\pi$ is the flow density of the initial wave, and $\Delta S = N_0 m^2 \frac{n^4}{2(4n^2 - 1)^2} S_p$.

This formula is obtained with the conditions $m \prec\prec 1, N_0 \succ\succ 1, m \succ\succ 1/N_0$. As it is seen from this formula the value of ΔS may be comparable and larger than S_p. It should be noted that for the cosmic radiowaves with frequencies $\omega \succ\succ \omega_p, \omega_H$ (ω_p, ω_H are the Langmuir and cyclotron frequencies) the ionospheric plasma is the media with the refraction index $N_0 \succ\succ 1 (N_0 \approx 100)$. By this condition the transparency coefficient for a cosmic radiowave, in the absence of acoustic atmospheric wave, is very small ($\propto 10^{-2}$). So our result $\Delta S \geq S_p$ is not contrary to the energy conservation low.

3. Experimental results

The acoustic generator used in this experiment, built in the Lviv Institute, has the following characteristics: power 150KWt, frequencies 100 Hz and 110Hz, and an efficiency of 20%. For investigation of the cosmic radiation passing through the ionosphere the radiocomplex URAN (a decimetre radiotelescope , the working wavelength is about 100 m) was used .The first experiment was made in Schazk , Volyn, Ukraine.

Technical data of the decimetre radiocomplex [2] are the follows: antenna coordinates are $51^\circ 28' 21{,}2'' \pm 0{,}3''$ North Latitude and $23^\circ 49' 40.1'' \pm 0{,}4''$ East Longitude; working frequencies range (MHz) is 4 - 30; number of polarizations is 2; number of oscillators is 256; sizes of antenna (m) is $240(West-East) \times 60(North-South)$; geometry (in m^2) is 14 400; effective geometry of antenna (in m^2) is 5 700 at the frequency of 16,7 MHz; the width of the beam diagram (Grad) is $3{,}5(West-East) \times 15(North-South)$; radiocomplex has a low noise radiometers with two channels and computer control system for obtaining final results. The registration of cosmic radiation was prepared with the phase method and interferometer measurements

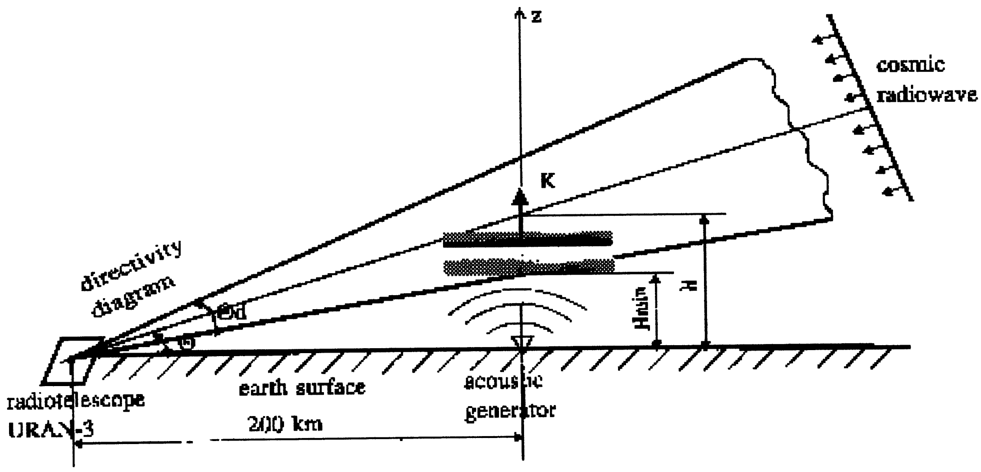

Fig. 1: Geometry of experiment for cosmic radio waves observation by radiotelescope URAN-3.

(Fig.1). The number of registrations equal to 24 were made in the period of November-December 1997. The results are shown in Fig.2. The increase of the transparency cosmic radiation level is shown in curves a) , b), c) of Fig.1 for different acoustic power levels. The initial level obtained in the absence of a low frequency atmospheric wave is shown in curve d). It is possible to see very clearly a big difference of signals obtained at the beginning of the acoustic excitation, and at the time without acoustic excitation. This phenomenon has some analogy with the transparency obtained by a periodical structure generated with two power radio waves [3].

4. Conclusion

It is possible to use an acoustic generator for the generation of the low frequency acoustic wave to be transmitted through the atmosphere into the ionosphere. We observed the increase of the transparency for cosmic radiation caused by a low frequency acoustic atmospheric wave. The increase of the radio signal (cosmic radiation) is experimentally observed during the acoustic excitation by means of the radiotelescopic system. These measurements give the possibility of experimental investigation of the transparency and other phenomena such as the moving of E - and F- layers caused by a low frequency atmospheric acoustic wave.

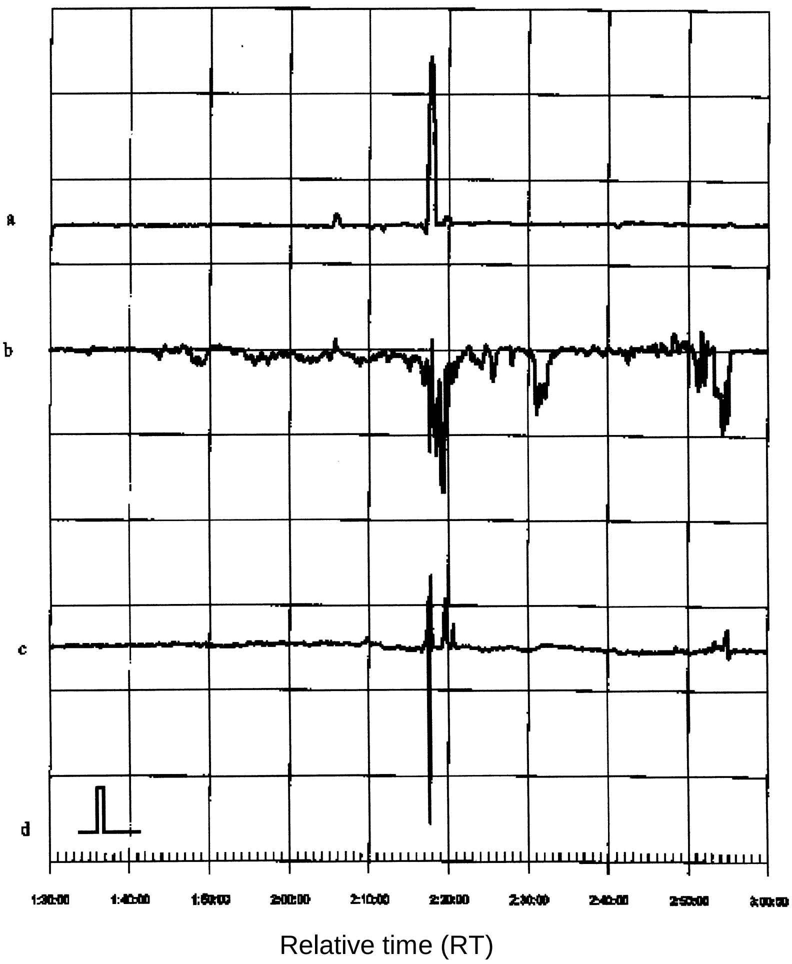

Fig. 2: Result of cosmic radiowaves observation by radiotelescope URAN-3 (02.04.97 year, $\theta = 39^\circ; H = 160km$; records $a) r_{12b}(t); b) - P_A; c) - P_B; d)$ - time model of acoustic excitement beginning-12:41:LT; end-12:42:LT

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