IONOSPHERIC GENERATION MECHANISM OF THE LOW-FREQUENCY NARROW-BAND ELECTROMAGNETIC RADIATION DUE TO BACKGROUND NOISE OF NATURAL ORIGIN BEFORE EARTHQUAKES

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INTRODUCTION

According to ground based measurements an occurring of the discrete narrow-band spectrum of extra low frequency electromagnetic oscillations was observed during seismic enhancement, volcanic eruptions and spacecraft flights. (Rauscher and Van Bise, 1999). It was found that the spectrum maxima are the 2, 6, 11, 17 Hz approximately. All these processes are accompanied the formation of horizontal irregularities of the ionospheric conductivities. Afraimovich et al. (2002) observed the total electron contents disturbances by GPS technique during rocket starts. The horizontal spatial scale of these disturbances is of the order of 50-100 km. According to satellite data (Chmyrev et al., 1997) irregularities of electron number density with the scale over ten km arise in the ionosphere before an earthquake. An occurrence of ionospheric irregularities over seismic regions was confirmed by Afonin et al. (1999). The irregularities over seismic and volcanic regions caused by both upward acoustic gravity waves propagation (Mareev et al., 2002) and DC electric field enhancement in the ionosphere (Sorokin et al., 1998). Sorokin et al. (2003) found ionospheric generation mechanism of geomagnetic pulsations observed on the Earth surface. The mechanism is based on excitation of gyrotropic waves (GW) (Sorokin and Fedorovich, 1982; Sorokin and Pokhotelov, 2005) by the coherent polarization electric currents located in the irregularities of ionospheric conductivity. These currents are occurred by the background electromagnetic noise. Various sources generate electromagnetic noise in ELF/ULF range. The most powerful are thunderstorms. Oscillating noise electric field forms the polarization currents on the irregularities of ionospheric conductivity. GW are propagated within thin layer of the lower ionosphere along the Earth surface with small attenuation and with phase velocities of the order of tens to hundreds km/s. The present paper is devoted to investigation of the generation and the propagation of GW in the finite thickness conducting layer of the lower ionosphere and the calculation of spectrum of magnetic field oscillations on the Earth surface related to these waves.

CALCULATION OF THE SPECTRUM OF MAGNETIC FIELD OSCILLATIONS ON THE GROUND

Let us consider the generation of GW by irregularities of ionospheric conductivity. We introduce a local Cartezian system of coordinates (x, y, z) with the longitudinal x and latitudinal y coordinates. The z-axis of our system coincides with local vertical direction. A uniform external magnetic field $\mathbf{B}$ lies in the (x, y) plane and directed under the angle α to the x-axis. The ionosphere is assumed to be plane with the electric Hall conductivity σ_H and Pedersen conductivity σ_P. The conductivity tensor is taken in the form:

$$\hat{\sigma}(x,z) = \hat{\sigma}_0(z) + \hat{\sigma}_1(x,z) \tag{1}$$

where the subscripts 0 and 1 correspond to the undisturbed and disturbed values, respectively. We decompose the electric field as $\mathbf{E} = \mathbf{E}_0 + \mathbf{E}_1$, where $\mathbf{E}_0$ stands for the undisturbed electric field $(\hat{\sigma}_1 = 0)$ and $\mathbf{E}_1$ is the disturbances caused by the presence of the ionosphere irregularities. Assuming the disturbances to be small ($\sigma_1 >> \sigma_0$) and neglecting the small terms of the second order from Maxwell equations and Ohm's law one finds:

$$(\nabla\times\nabla\times\mathbf{E}_1)\times\mathbf{B}+\frac{4\pi}{c^2}\frac{\partial}{\partial t}\left(\sigma_{P0}\mathbf{E}_1\times\mathbf{B}-\sigma_{H0}B\mathbf{E}_1\right)=$$
$$=-\frac{4\pi}{c^2}\frac{\partial}{\partial t}\left(\sigma_{P1}\mathbf{E}_0\times\mathbf{B}-\sigma_{H1}B\mathbf{E}_0\right),\quad \nabla\times\mathbf{E}_1=-\frac{1}{c}\frac{\partial\mathbf{b}}{\partial t}, \tag{2}$$

where $\mathbf{b}$ is the magnetic field disturbances. Let us introduce the relative disturbances of Hall and Pedersen conductivities by formulas:

$$H(x)=\sigma_{H1}(x,z)/\sigma_{H0}(z);\ P(x)=\sigma_{P1}(x,z)/\sigma_{P0}(z)\ .$$

Using Fourier transformation

$$E_{1,x,y,z}(k,z,\omega)=\int_{-\infty}^{\infty}dx\int_{-\infty}^{\infty}dtE_{1,x,y,z}(x,z,t)\exp\left(-ikx+i\omega t\right),$$

from Eq. (2) one finds the equations for the components of electric field:

$$ik\tan\alpha\frac{dE_{y1}}{dz}-k^2E_{z1}-i\frac{4\pi\omega}{c^2}\left(\frac{\sigma_{H0}}{\cos\alpha}E_{y1}-\sigma_{P0}E_{z1}\right)=i\frac{4\pi\omega}{c^2}\frac{\sigma_{H0}}{\cos\alpha}f_H$$
$$\left(\frac{1}{\cos^2\alpha}\frac{d^2}{dz^2}-k^2\right)E_{y1}+ik\tan\alpha\frac{dE_{z1}}{dz}+i\frac{4\pi\omega}{c^2}\left(\frac{\sigma_{P0}}{\cos^2\alpha}E_{y1}+\frac{\sigma_{H0}}{\cos\alpha}E_{z1}\right)=. \tag{3}$$
$$=-i\frac{4\pi\omega}{c^2}\frac{\sigma_{P0}}{\cos^2\alpha}f_P;\quad E_{x1}=-E_{y1}\tan\alpha$$

Here the following abbreviations are:

$$f_P\left(k,\omega\right)=\int_{-\infty}^{\infty}P\left(x\right)E_{0y}\left(x,\omega\right)\exp(ikx)dx;\quad f_H\left(k,\omega\right)=\int_{-\infty}^{\infty}H\left(x\right)E_{0y}\left(x,\omega\right)\exp(ikx)dx\,. \tag{4}$$

The altitude distribution of the ionosphere conductivity shows the variation of σ_P and σ_H conductivities versus altitude. One sees that both conductivities attain the maximum values at different altitudes. The maximum of Hall conductivity lies higher than that for Pedersen conductivity. The maximum value of Hall conductivity exceeds that for Pedersen conductivity by one-two orders in value. At the higher altitudes the Pedersen conductivity substantially exceeds Hall conductivity. Such an altitude profile allows us to represent the ionosphere in the form of two distinct thin layers. Let us assume that in the low layer $\sigma_P = 0$ whereas in the upper layer $\sigma_H = 0$ and their thickness is equal l. Solution of Eqs.(3) for such distribution of the ionosphere conductivity has a form:

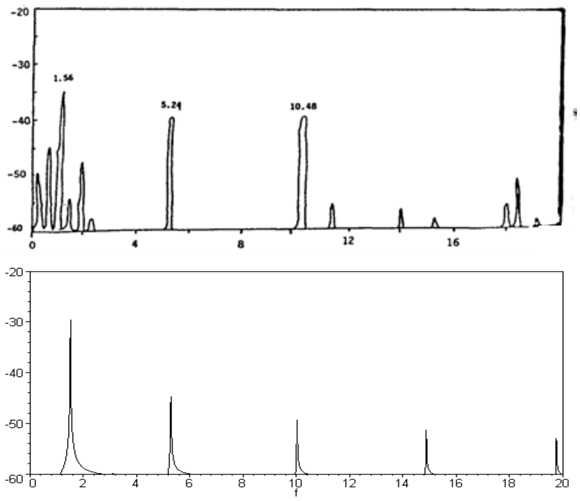
$$E_{y1}\left(k,z=-\frac{l}{2},\omega\right)=-E_{oy}(\omega)\frac{\left(|k|\varsigma_1-\varsigma_2\right)H-\varsigma_3P}{|k|\xi_1+k^2\xi_2+\xi_3+\xi_4}\ . \tag{5}$$

In Eq. (5) the following abbreviation are introduced

$$\xi_1=\cosh(ql)-\frac{\kappa_H\sin\alpha}{q\cos^2\alpha}\sinh(ql);\ \xi_2=\frac{\sinh(ql)}{q};\ \varsigma_1=\left(\frac{\kappa_H}{q\cos\alpha}\right)^2\left[1-\cosh(ql)\right]-\frac{\kappa_H\sin\alpha}{q\cos^2\alpha}\sinh(ql);$$
$$\xi_3=\cosh(ql)+\frac{\kappa_H\sin\alpha-i\kappa_P}{\cos^2\alpha}\frac{\sinh(ql)}{q};\ \xi_4=\left[k^2-\frac{\kappa_H(\kappa_H-i\kappa_P\sin\alpha}{\cos^4\alpha}\right]\frac{\sinh(ql)}{q};\ ,$$
$$\varsigma_2=\frac{\kappa_H(\kappa_H-i\kappa_P\sin\alpha)}{\cos^4\alpha}\frac{\sinh(ql)}{q}-\frac{1-\cosh(ql)}{q^2}\frac{\kappa_H}{\cos^2\alpha}\left(k^2\sin\alpha-i\kappa_P\frac{\kappa_H}{\cos^2\alpha}\right);\ \varsigma_3=\frac{i\kappa_P}{\cos^2\alpha}$$

where $q^2=k^2-\left(k_H/\cos\alpha\right)^2$, $k_H=4\pi\omega\sigma_{H0}/c^2k$, $k_P=4\pi\omega\sigma_{P0}l/c^2$.

Let us take the disturbances of the Hall and Pedersen conductivities in the form $H(x)=P(x)=A\exp\left(-x^2/4x_0\right)\cos\left(k_0x\right)$, where $x_0>>\lambda=2\pi/k_0$. Applying the inverse Fourier transform over k to Eq. (5) with the help of Faradey's law one obtains the expression for relative spectrum of magnetic field oscillations $\beta(x,\omega)=\left|b_{x1}(x,\omega)/b_{x0}(0,\omega)\right|$:



$$\beta(x,\omega) = \frac{A_0}{2}\exp\left(-\frac{x^2}{4x_0^2}\right)\left| F\left(k_0 + i\frac{x}{2x_0^2},\omega\right)\exp(ik_0x) + F\left(k_0 - i\frac{x}{2x_0^2},\omega\right)\exp(-ik_0x)\right|;$$

$$F(k,\omega) = \frac{g_1 q\sinh(ql) - g_2\left[1-\cosh(ql)\right] + g_3 q^2}{G_1 q\sinh(ql) + G_2 q^2\cosh(ql)} \qquad . \qquad (6)$$

In Eq. (6) the following abbreviation are introduced

$$g_1 = \frac{\kappa_H^2}{\cos^4\alpha} + \frac{\kappa_H\sin\alpha}{\cos^2\alpha}\left(|k| - i\frac{\kappa_P}{\cos^2\alpha}\right);\ g_2 = \frac{\kappa_H^2}{\cos^2\alpha}\left(|k| - i\frac{\kappa_P}{\cos^2\alpha}\right) + \frac{k^2\kappa_H\sin\alpha}{\cos^2\alpha};\ g_3 = i\frac{\kappa_P}{\cos^2\alpha};$$

$$G_1 = \frac{\kappa_H^2}{\cos^4\alpha} - 2k^2 + i\frac{\kappa_P}{\cos^2\alpha}\left(|k| + \frac{\kappa_H\sin\alpha}{\cos^2\alpha}\right);\ G_2 = -2|k| + i\frac{\kappa_P}{\cos^2\alpha}$$

Setting $l \to 0$ and $\sigma_0 \to \infty$ at $\sigma_0^2 l = \int_{-\infty}^{\infty}\sigma_{H0}^2(z)dz = const$ in Eq. (6) one finds that this expression transforms to the formula which was obtained by Sergeev and Sorokin (2004).

The experimental dependence of magnetic field oscillations on frequency obtained by Rauscher and Van Bise (1999) during space shuttle Columbia landing at January 20, 1989 is depicted in Fig.1a. We can see a few discrete spectrum lines. Fig.1b shows the dependence of

$$U(f) = 20\lg\left\{\frac{b_{x0}}{b_*}\left[1+\beta(f)\right]\right\}$$

versus frequency $f = \omega/2\pi$ calculated by Eq. (6). In this formula b_{x0} is the level of background electromagnetic noise, which is defined by experimental data presented in Fig.1a. Calculated characteristics of spectrum are in agreement with ground based data.

CONCLUSION

The formation of the ionospheric horizontal periodic irregularities of the conductivity leads to the appearance of magnetic field oscillations on the Earth's surface. These oscillations are associated with the gyrotropic waves. Spectrum lines of oscillations are formed by the coherent propagation of gyrotropic wave discrete modes in the finite thickness conducting layer of the lower ionosphere. The waves are generated by the electric current that arises in the irregularities of the ionospheric conductivity under the action of the external electric field from the atmospheric sources. The spectrum of oscillations possesses the maximums in the ELF/ULF frequency range. The irregularities can arise, for example, during propagation of gravitational waves or DC electric field enhancement in the ionosphere from seismic sources, typhoons, volcanoes, rocket flights. If the irregularities are elongated in the latitudinal direction and their horizontal scale is of the order of 10-100 km the spectrum lines frequency lies in the range 1-20 Hz. Note that type and frequency of these lines depend essentially on the volume of Hall and Pedersen ionospheric conductivity, angle of magnetic field inclination, azimuth of direction of the wave propagation, and spatial scale of conductivity irregularities. The variations of theses parameters lead to the change of the spectrum maximum frequency over a wide range. The spectrum lines frequency decreases with the increase in spatial scale of the irregularities. The horizontal phase velocity of these oscillations constitutes the values 10-100 km/s. The features of the gyrotropic waves can be used for the interpretation of the electromagnetic effects that arise in the course of natural and man made action on the ionosphere.

Acknowledgments - This work was partly supported by Russian Fund for Basic Research through the Grant No. 03-05-64553.

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