The generation of electromagnetic signals due to the interaction of a cosmic X-ray with the Earth's atmosphere is considered. The amplitude and frequency of the radio signal are calculated, and the possibility of its detection at the Earth's surface is shown.

Cosmic explosive phenomena (explosions of galactic nuclei, supernovae and novae, solar flares, etc.) and rotating neutron stars [1, 2] are the nonsteady sources of cosmic ionizing particles (cosmic rays, neutrons, gamma-quanta, X-rays). A narrow beam of ionizing particles is absorbed in the dense layers of the Earth's atmosphere. The longitudinal size of the particle interaction region is determined by the inhomogeneity scale of the atmosphere and is roughly equal to 10 km. As a result of electron–positron pair production, the Compton effect, and the photoeffect, a large number of charged particles is created. They propagate together with the pulse of ionizing radiation. The penetration of a large amount of charged particles through the atmosphere leads to a number of secondary physical phenomena, which can contain information on the initial parameters of the ionizing radiation beam. The relevant processes are Cerenkov radiation, ionization air glow, and radio emission [3].

In penetrating through the atmosphere, the charged particles excite the nitrogen and hydrogen atoms. This leads to the emission of photons in the wavelength range 0.25-0.45 μm during 10⁻⁸ sec. Ionization air flow has an important feature: it is isotropic and therefore can be detected at large distances from the beam axis.

A large amount of charged particles in the beam leads to the generation of radio emission. Various mechanisms of generation of the beam radio emission are possible [3]: Cerenkov radiation of the excess of negative charge and of the electric dipole moment, magneto-bremssstrahlung radiation of charged particles, and classical radiation of the electric dipole moment.

The problem of excitation of electromagnetic fields from a pointlike isotropic cosmic source of gamma-quanta was investigated in [4] within the framework of the quasi-three-dimensional formulation.

It should be noted that the radio emission, as well as the ionization air glow, can be detected at large distances from the beam axis. This is important in developing new methods of detection of ionizing particle beams in the Earth's atmosphere. In this paper we consider the possibility of ground-based detection of the radio signal originating from the interaction of X-ray quanta of energies near 1 keV, and generated by a sharply anisotropic pointlike cosmic source, with the upper layers of the Earth's atmosphere. The structure of the electromagnetic fields is investigated in the high-frequency, small-angle approximation, in the three-dimensional formulation of the problem.

Let us suppose that the source of X-ray quanta is located at altitudes higher than 100 km above the Earth’s surface. Its radiation has the following parameters [5]: wavelength about 1.4 Å, duration of induced radiation τ ≥ 10⁻⁹ sec; energy of the order of 100 kJ, angular divergence of the X-ray beam ΔΩ ∼ 10⁻⁸ sr.

According to [6] the angular distribution of the radiation is highly anisotropic. It is mostly concentrated within angles θ < θ₀ (θ₀ ≈ √ΔΩ), where the angle θ is reckoned from the beam axis. The radiation intensity at θ = 3θ₀ is less than the maximum value by more than an order of magnitude, and rapidly decreases with growing θ.

Below we shall consider an X-ray beam with energies of quanta εₓ = 1 keV, which propagates vertically downward. The absorption length of these quanta in air is equal to λₓ = 0.225 cm at sea level. Therefore the X-rays are absorbed at 84 km altitude (Fig. 1) in an air layer of thickness equal to the characteristic inhomogeneity scale of the atmosphere at this altitude, xₓmax = 5.7 km. Let us suppose that the X-ray quanta are absorbed only within a layer of volume πr²Δξₓmax, and their density...
g is homogeneous (the density of molecules at 84 km altitude is about $10^{14}$ cm$^{-3}$):

$$g = \frac{N_x}{2\pi r^2 \Delta \Omega x_{\text{max}}} = \frac{1}{2} \cdot 10^{12} \text{ cm}^{-3},$$

where $N_x = 6.3 \cdot 10^{20}$ is the number of quanta corresponding to energy 100 kJ, the factor 2 in the denominator is due to the fact that only half of the quanta are emitted vertically downward, and $r$ is the distance from the source to the absorbing layer.

Photoelectrons created by X-rays have a lifetime $\tau_e = 7 \cdot 10^{-8}$ sec at 84 km altitude. During this time, secondary electrons are created with mean energy about 33 keV and corresponding density $n_{e0}[\text{cm}^{-3}] = 5.2 \cdot 10^{13}/r^2 [\text{km}]$ (the maximum natural electron density at 84 km is equal to $3 \cdot 10^3$ cm$^{-3}$).

To find the photoelectron current in the geomagnetic field, we use the result of [7]. For time intervals $\tau > 10^{-9}$ sec ($\tau = t - x/c$ is local time) the temporal variation of the X-ray pulse is described by the $\delta$-function. Then, due to the small values of photoelectron velocities ($\beta = v_x/c = 0.06$), at distances $0 \leq x \leq x_{\text{max}}$ we have the following simplified expressions for the currents $j_{ox}, j_{oy}, j_{oz}$:

$$j_{ox}(\tau, \theta) = -e v_x \cos \theta x \frac{\alpha}{1 + \alpha^2} \left[ \sin \omega_c \tau \left( u(\tau) - K(\tau, \varphi) \right) f(\theta) \right],$$

$$j_{oy}(\tau, \theta) = -e v_x \cos \theta x \frac{\alpha}{1 + \alpha^2} \left[ \sin \omega_c \tau \left( u(\tau) - K(\tau, \varphi) \right) f(\theta) \right],$$

$$j_{oz}(\tau, \theta) = -e v_x \cos \theta x \frac{\alpha}{1 + \alpha^2} \left[ \sin \omega_c \tau \left( u(\tau) - K(\tau, \varphi) \right) f(\theta) \right].$$

In these expressions $f(\theta)$ is the angular distribution of X-ray emission, and $u(\tau)$ is the step-function; the function $K(\tau, \varphi)$ describes the temporal decrease in the number of photoelectrons; the point $x = 0$ corresponds to 87 km altitude; $\cos \theta_x = 0.05$ is the mean cosine of the photoelectron emission angle; the cyclotron frequency $\omega_c$ of the photoelectrons varies within $5.5 \cdot 10^6 \leq \omega_c, \sec^{-1} \leq 1.1 \cdot 10^7$, depending on the geomagnetic latitude of the source; $\alpha = 2 \tan \Phi$, and $\Phi$ is the geomagnetic latitude.

Since the characteristic attachment and recombination times of secondary electrons are many orders of magnitude greater than 1 $\mu$sec, the density of the secondary electrons can be expressed as

$$n_e(\tau, \theta) = n_{e0} f(\theta) \left[ \frac{\tau}{\omega_c} u(\tau') - K(\tau', \varphi) \right] = n_{e0} f(\theta) \left[ \frac{\tau}{\omega_c} u(\tau) - \int_0^\tau \frac{\tau'}{\omega_c} K(\tau', \varphi) \right].$$

In the first approximation $K(\tau, \varphi) = u(\tau - \varphi)$, and for times $\varphi < \tau < 10^{-6}$ sec the density $n_e$ does not change with time.