Proceedings of ISAP'04, Sendai, JAPAN

SIMULATION ANALYSIS OF SPACE-TIME CHARACTERISTICS OF THE METEOR BURST COMMUNICATION CHANNEL

Byoung Chul KIM[1], Mikhail V. TININ[1,2], and Sergei N. KOLESNIK[2]
[1]Miryang National University
1025-1, Naei-dong, Miryang, Gyeongsangnam-do, 627-702, Korea,
e-mail: bckim@mnu.ac.kr, mtinin@mnu.ac.kr
[2]Irkutsk State University,
20 Gagarin Blvd, Irkutsk, 664003, Russia
e-mail: mtinin@api.isu.ru

1. Introduction

Every day a great number of meteors intrudes into the Earth atmosphere. These fine particles at an input in the atmosphere burn down, somewhere at altitude of 100-120 kilometers, creating a lot of ionized beams. Ionization of these pencils appears sufficient for a radiowave scatter for horizon and provisions of a radio communication on frequencies higher 50 MHz. In comparison with other ionospheric inhomogeneities meteor inhomogeneities are much more elongated, and the orientation of the big axis (unlike that of the other inhomogeneities - along the magnetic field of the Earth) coincides with the direction of a relative motion of a meteor and the Earth.

Strong elongation of the trail results on the one hand in a higher than for other scatter mechanisms space selectivity, and on the other hand this feature means that the traditional methods of calculation of a scatter here are not applicable. Still no more or less complete simulation analysis of the space-time structure of a meteor burst signal (MBS) has been performed so far. The present paper is devoted to simulation analysis of the time MBS structure. For calculation of a scatter on underdense trails (with linear density less $10^{13} m^{-1}$) we use the theory of the single scattering on the elongated inhomogeneities [1].

2. Scattering on the meteor trail

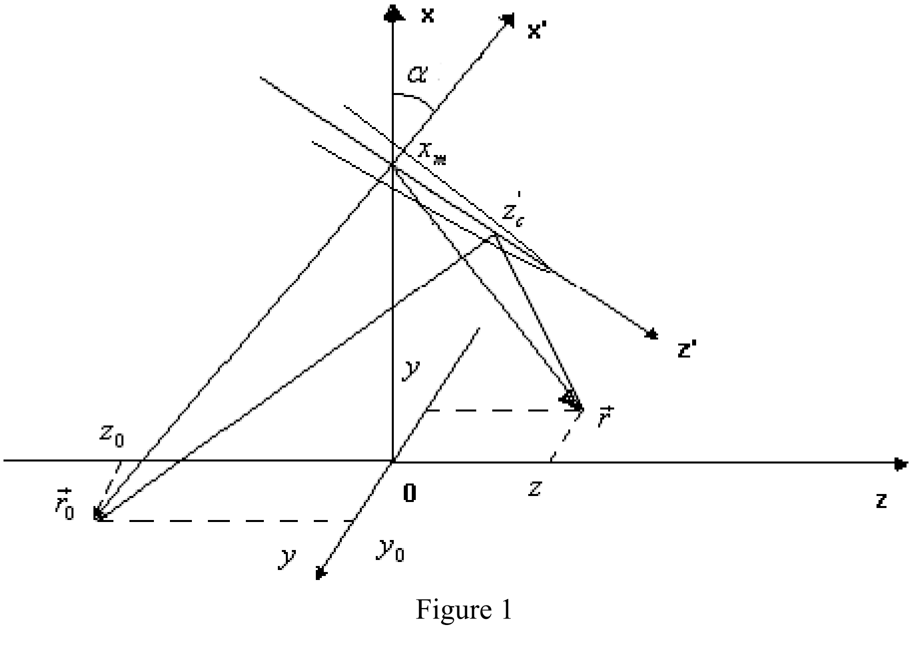

Figure 1

ISBN: 4-88552-206-4 C3055©IEICE

Let's take a prime coordinate system x', y', z' with the origin inside a trail and with an axis z' coinciding with the longer axis of inhomogeneity (see a Figure 1). As a model of the meteor trail electron concentration $N(\vec{r})$ we shall take Gaussian function

$$N(\vec{r}') = N_m \, exp\left\{ -\frac{\rho'^2}{2l_\perp^2} - \frac{z'^2}{2l_\parallel^2} \right\} \tag{1}$$

Here $l_\perp$, $l_\parallel$ are the transversal and the longitudinal sizes of inhomogeneity.

Hereafter to research behavior of signal strength in course of time we shall consider, that the meteor moves in a straight line $x' = 0, y' = 0$ with velocity v. Besides assuming that the transversal sizes of inhomogeneity vary in a time $l_\perp^2 = l_{\perp 0}^2 + 4D_\perp t$, we can take into account diffusion of inhomogeneities with the diffusion coefficient $D_\perp$.

The theory of the single scatter is mostly used, when inhomogeneity is in a far-field region, that is its sizes are less than sizes of a Fresnel zone. Meteor trails have a strong elongation (up to 20-30 kilometers) along one axis, and small sizes (0.01-1 meter) along other axes. Therefore inhomogeneity appears both in a near-field region owing to its longitudinal coordinate, and in a far-field region when its transversal coordinates are considered. In this case it is possible to use the mixed approach developed by us [1] and to obtain the following expression for received power P_r

$$P_r = P_t G_t G_r I(\vec{r}, t), \tag{2}$$

where

$$I(\vec{r}, t) = \frac{\left(80{,}6\pi \, q_m / c^2\right)^2 \lambda^3}{\rho' \rho'_0 \sqrt{(\rho' + \rho'_0)^2 + (z' - z'_0)^2}} \, exp\left\{ -\frac{z_c'^2}{l_\parallel^2} - Q_2^2 l_\perp^2 \right\} \tag{3}$$

$$\vec{Q}_2(z_c) = k \left[1 + \left(\frac{z' - z'_0}{\rho' + \rho'_0} \right)^2 \right]^{-1/2} \left[\frac{\vec{\rho}'}{\rho'} + \frac{\vec{\rho}'_0}{\rho'_0} \right], \quad z'_c = \frac{z' \rho'_0 + z'_0 \rho'}{\rho' + \rho'_0},$$

$$\rho' = |\vec{\rho}'| = \sqrt{x'^2 + y'^2}, \quad \rho'_0 = |\vec{\rho}'_0| = \sqrt{x_0'^2 + y_0'^2}$$

Here P_t is a radiated transmitted power; G_r and G_t - gains of the receiving and transmitting antennas; λ - a wave length; $q_m = 2pN_m l_\perp^2$ - a maxima of linear electronic density, that is a maxima of function

$$q(z') = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} N(\vec{\rho}', z') \, d^2\rho' = q_m \, exp\left\{ -\frac{z'^2}{2l_\parallel^2} \right\} \tag{4}$$

Here is used the rotated coordinate system (see Fig. 1) in which the axis z' coincides with the direction of the inhomogeneity elongation. The transition to the initial system is carried out under usual formulas

$$\begin{aligned} x' &= (x - x_m)\cos\alpha + (z - z_m)\sin\alpha \\ z' &= (z - z_m)\cos\alpha - (x - x_m)\sin\alpha \\ y' &= y \end{aligned} \tag{5}$$

3. Some results of simulation analysis of a space-time field structure in the meteor burst communication channel

Let's carry out numerical simulation analysis of a reduced intensity distribution $I(\vec{r},t)$ under the formulas (3). Figures 2-5 show the results of calculation by formula (3) at $\lambda = 6m$, $q_m = 10^{13} m^{-1}$, $l_{\|} = 30km$, $x = x_0 = 0km$. Position of inhomogeneity is in the point $x_{m0} = 100km$, $z_{m0} = 0km$, $y_{m0} = 0km$, $\alpha = 0$.

In the model (1) inhomogeneity width increasing connected with the diffusion of a meteor trail and motion of this trail are taken into account. These two factors effect on the space-time structure of a meteoric signal in different ways. We shall consider over again the effect of meteor trail diffusion.

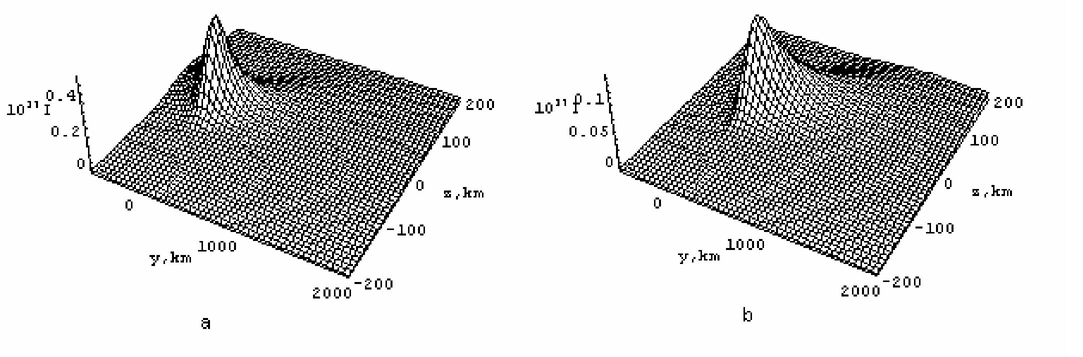

Figure 2

Figure 2 gives the results of simulation analysis at $D_{\perp} = 0.1\, m^2/sec$ (Fig. 2a) and $D_{\perp} = 1\, m^2/sec$ (Fig. 2b), $v = 0$ when the transmitter is at a point $y_0 = -500km$, $z_0 = -50km$. In this case the direction from inhomogeneity to a transmitter is almost transversal to the axis of inhomogeneity. It is visible, that the intensity is localized in some area which slightly grows with the width of a trail.

Now we shall change orientation of a path. Let $y_0 = -500km$, $z_0 = -500km$. It means that the angle between the direction to the transmitter and the axis of inhomogeneity is equal to 45°.

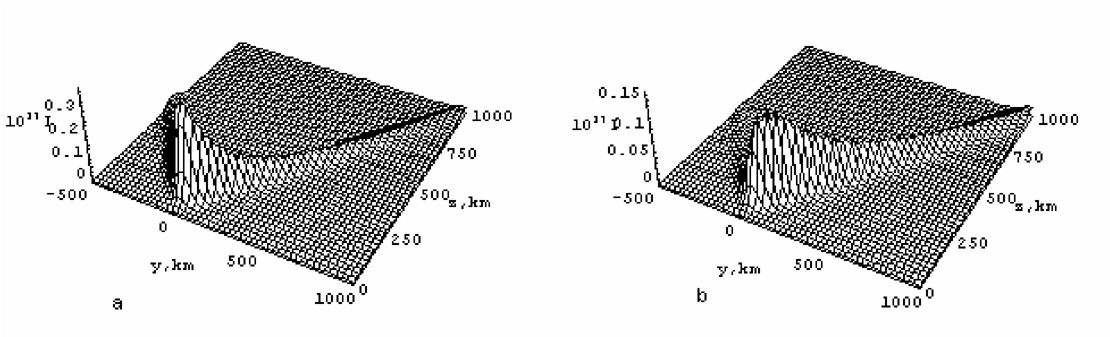

Figure 3

For this case in Fig.3a ($D_{\perp} = 0.1\, m^2/sec$) and Fig.3b ($D_{\perp} = 1\, m^2/sec$) the results of calculation of the reduced intensity distribution are shown. As is seen from figures 3a and 3b in comparison with the previous case, in this case the intensity distribution has a greater extent in some directions and depends on the transversal size of inhomogeneity that is on the degree of diffusion. The corresponding time dependence at the receiver point $y = 30km$, $z = 100km$ is shown in fig. 4a. Simulation analysis showed that the character of this dependence hardly depends on coordinates of the receiver.

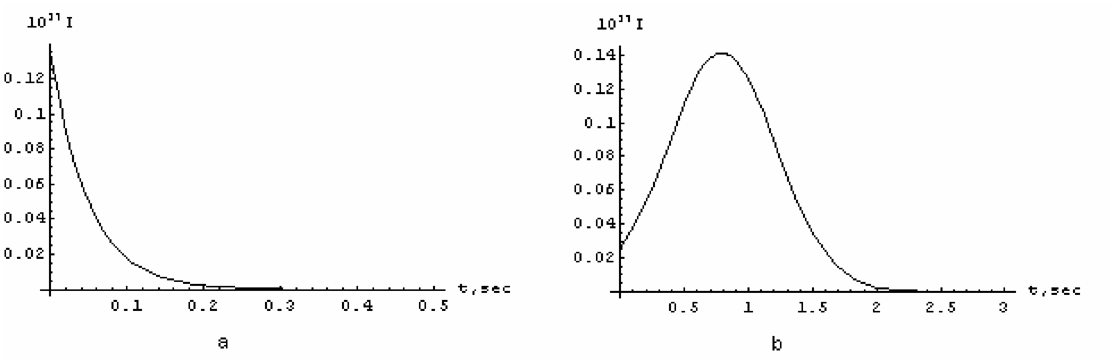

Figure 4

Now we shall consider the effect of a trail motion on the space and time structure of the field. In Fig.5 results of calculation of intensity are instanced at $y_0 = -500km$, $z_0 = -500km$, $z_m = vt$, $v = 50km/\sec$ in various points of time: $t = 0$ (Fig.5a) and $t = 1\sec$ (Fig. 5b). It is visible, that in this case the intensity distribution is moved in space.

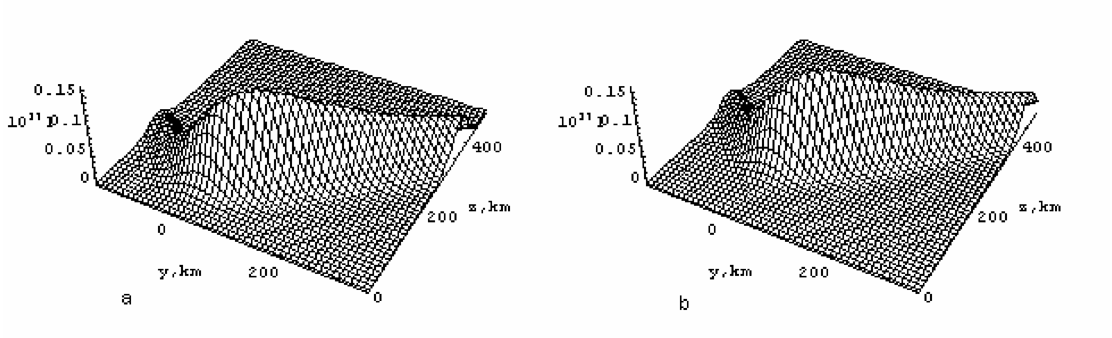

Figure 5

This distribution motion in space becomes apparent in the intensity behavior in a time apparently from a Figure 4b in which results of calculation are instanced at receiver point $y = 30km$, $z = 150km$.

4. The conclusion

The obtained in [1] formulas take into account the fundamental features of meteor radio propagation and allow to simulate space and a time meteor signal structure. The space intensity distribution and the behavior of meteor signal intensity in time appear to depend essentially on parameters of the trail and position of the transmitter. In some cases the space intensity distribution of the kind is possible, in particular when extended areas of the earth surface are «lighted» and these areas move. It should be taken into consideration while designing any secure communication system basing upon meteoric channels.

The formulas (2)-(3) are convenient not only in simulation analysis of separate bursts structure, but also in calculation of statistical characteristics of a meteoric radio channel.

This work was done with partial financial support under Russian Ministry of Education grant № E02-3.5-197.

References:

1. Kim B.-C., Tinin M.V. 2004, Numerical simulation of radio signal characteristics in meteor burst radio channels. The Journal of the Korea Institute of Maritime Information and Communication Sciences. (KIMICS) Feb. 2004 (In Korean, to be published)