METEOR RADIO ECHO SIMULATION

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1. Introduction

During many years in the process of interpretation of oblique radiowave scattered on a meteor trail the formulas [1-4] obtained in 50th years by generalization of radar formulas (when the transmitter and the receiver are located in one point) on oblique propagation of radio waves are used. The theory of wave scattering for the period since 50th years has considerably moved ahead [5-6]. Using its results, it is possible now to obtain corresponding formulas directly from the wave equation, avoiding not always correct generalization of an expression in case of backscattering on the common case of any arrangement of the receiver and the transmitter. In [7-9], using formulas of the single scattering theory expressions for intensity of a wave, oblique scattered on a underdense meteor trail have been obtained. In the present report we compare these expressions with the former results, carry out numerical simulation of dependence of intensity and burst duration on orientation of a meteor trail, its extent and also the coordinates of the receiver and the transmitter.

2. Intensity of oblique meteor radio echo

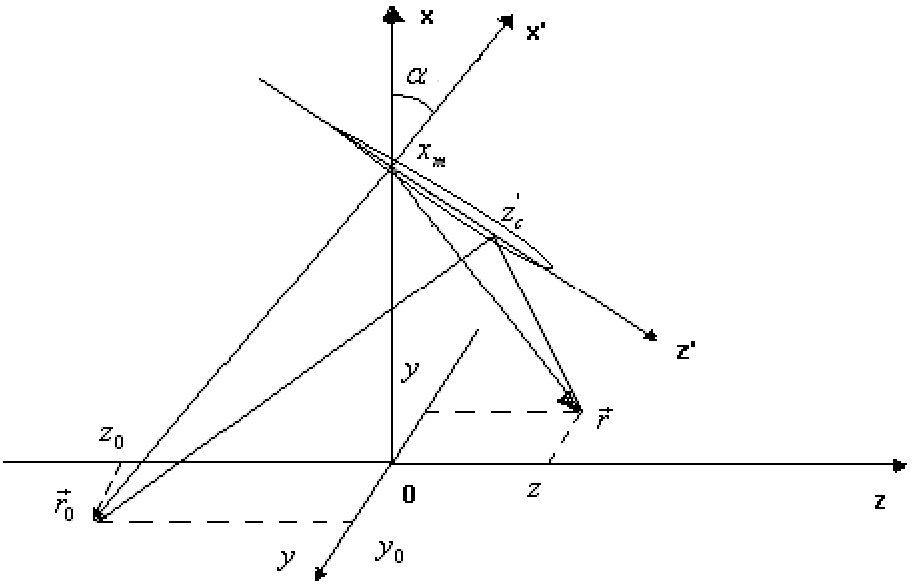

Figure 1

Let's choose a system of coordinates x', y', z' with the origin inside a trail at the height x_m and with an axis z' coinciding with the longer axis of the meteor trail (see. Figure 1). Let the transmitter and the receiver be located in points $\vec{r}_0^{\,'} = \{\vec{\rho}_0^{\,'}, z_0^{'}\} = \{x_0^{'}, y_0^{'}, z_0^{'}\}$ and $\vec{r}\,' = \{\vec{\rho}\,', z'\} = \{x', y', z'\}$ correspondingly. The transmitter radiates a spherical radiowave with amplitude A determined by power of the transmitter and the transmitting antenna gain. Then a field of radiowave scattered on a meteor trail has a form [7-8]:

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$$U_1(\vec{r}) \simeq \frac{A\sqrt{2}\,(\pi k)^{3/2}}{\sqrt{\rho'\rho'_0\sqrt{(\rho'+\rho'_0)^2+(z'-z'_0)}}}\Phi_{\varepsilon 2}\left(\vec{Q}_2\left(z'_c\right), z'_c\right)\exp\left\{ik\Psi_c + i\pi/4\right\} \qquad (1)$$

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

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

and $\Phi_{\varepsilon 2}\left(\vec{Q}_2\right) = -\frac{80.6}{f^2}(2\pi)^{-2}\int N(\vec{r})\exp\left\{-i\vec{\rho}\,'\vec{Q}_2\right\}d^2\rho'$ is a two-dimensional spectrum of a meteor trail on cross-section coordinates; $N(\vec{r})$ is an electron density is in m^{-3}, f is frequency is in hertz; $k = 2\pi f/c$ is a wave number, c is a speed of the light in free space. As a model of a trail, in accordance with [3], we shall take the Gauss function

$$N(\vec{r}\,') = \frac{q(z')}{\pi\left(l_\perp^2 + 4Dt\right)}\exp\left\{-\frac{\rho'^2}{l_\perp^2 + 4Dt}\right\}, \qquad (2)$$

where $l_\perp$ is the initial cross-section size of a meteor trail; D is a diffusion coefficient; $q(z') = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} N(\vec{\rho}\,', z')d^2\rho'$ is a linear electronic density.

For the model (2) we get from (1) the following expression for received power

$$P_r = P_t G_t G_r I(\vec{r})\sin^2\gamma\ . \qquad (3)$$

Here

$$I(\vec{r}) = \frac{\left(20.15q(z'_c)/c^2\right)^2\lambda^3}{\rho'\rho'_0\sqrt{(\rho'+\rho'_0)^2+(z'-z'_0)}}\exp\left\{-Q_2^2\left(l_\perp^2+4Dt\right)/2\right\} \qquad (4)$$

is a reduced power, that is the received power when the receiving and transmitting antennas are isotropic, and the transmitter radiates a unit power; P_r is the received power of a scattered signal; P_t is the transmitted power; G_r and G_t - the gains of the receiving and transmitting antennas correspondingly; λ - a wavelength; γ is the angle between a vector of the electric field of the incident wave and the direction to the receiver. The Gauss function may also be taken as a dependence of the linear electronic density on z' axis coordinate.

$$q(z') = q_m\exp\left\{-\frac{(z'-z_m)^2}{2l_\parallel^2}\right\}\ . \qquad (5)$$

Here z_m and $l_\parallel$ are the z' coordinate of the maximum and the longitudinal size of the trail correspondingly, q_m is the value of linear electronic density in maximum. After substitution of (5) to (4), we get

$$I(\vec{r}) = \frac{\left(20.15q_m/c^2\right)^2\lambda^3}{\rho'\rho'_0\sqrt{(\rho'+\rho'_0)^2+(z'-z'_0)}}\exp\left\{-\frac{(z'_c-z_m)^2}{l_\parallel^2} - Q_2^2\left(l_\perp^2+4Dt\right)\right\}. \qquad (6)$$

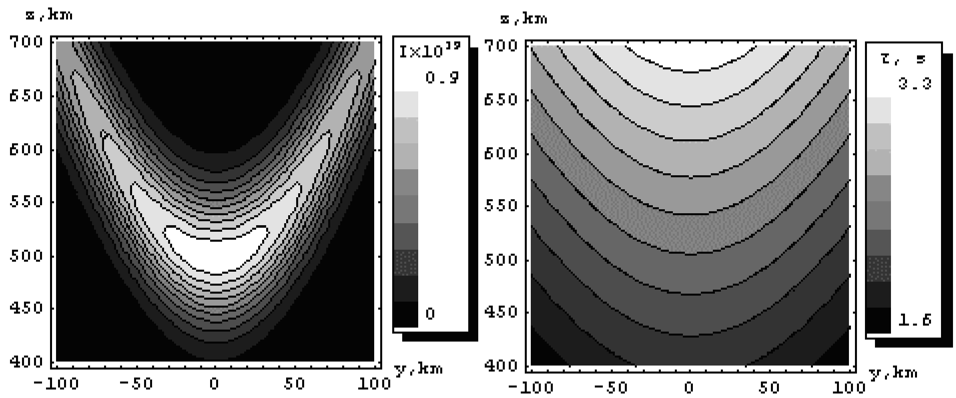
The duration of burst τ may be defined as the time when the burst intensity decreases by e times in comparison with maximum. Then from (6) we get.

$$\tau = 1/\left(4DQ_2^2\right) \qquad (7)$$

It may be shown that for the meteor trail located in the principal Fresnel zone with $l_{\|} = \infty$ the formulas (3), (6)-(7) transform to the known Eshleman formulas [1-4]. Our more common formulas give obvious dependences on coordinates while the formulas in [1-4] include both spatial and angular coordinates that are to be expressed through spatial coordinates. Apart from that, the formulas in [1-4] are usually given for the infinite trail ($l_{\|} = \infty$), while our formulas take into account the finite extent of a trail and its axis variability.

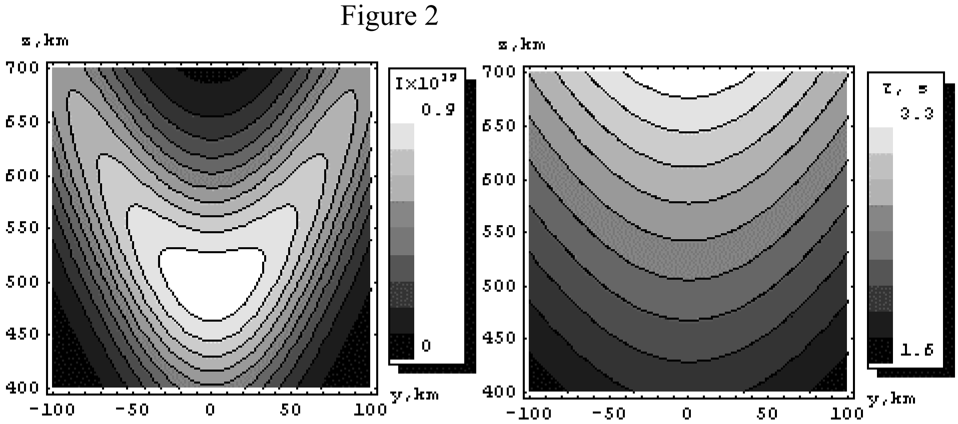
3. Simulation of a space-time structure of an oblique scattered meteor signal.

Figures 2a - 4a provide results of numerical simulation for the reduced intensity distribution $I(\vec{r})$ of a scattered signal on the earth surface (an illumination footprint), and Figures 2b – 4b provide calculations of the meteor burst duration $\tau(y, z)$ as the functions of the receiver coordinates. For all calculations the parameters are taken $\lambda = 6m$, $q_m = 10^{13} m^{-1}$, $D = 1m^2/\sec$, $l_{\perp} = 1m$,



a b

Figure 2



a b

Figure 3

$x = x_0 = 0km$. The center of a meteor trail is located in the point $x_{m0} = 100km$, $z_{m0} = 0km$, $y_{m0} = 0km$, $\alpha = 0$. Let the transmitter be located in the point $y_0 = 0km$, $z_0 = -500km$, $x_0 = 0km$. To show an essential role of a trail extent, Figures 2 provides the results of calculations at $l_{\|} = 30km$, and Figures 3 provides them at $l_{\|} = 60km$. It is clear from pictures 3 to 4 that a double increase of a meteor trail extent has resulted to the essential change of the intensity distribution. It means that the infinite trail model used in [1-4] is unacceptable. These results were obtained in case of coinciding the direction of a meteor trail and the direction from the transmitter to a meteor trail, but Figures 4 at $l_{\|} = 30km$ provides the results of a calculation in case of orthogonality of these directions, namely when the transmitter is located in the point $y_0 = -500km$, $z_0 = 0km$, $x_0 = 0km$. The comparison of

Figure 2 and Figure 4 shows the evident strong dependence of the space-time structure of a field not only on the trail extent, but also on its direction (see also [9]).

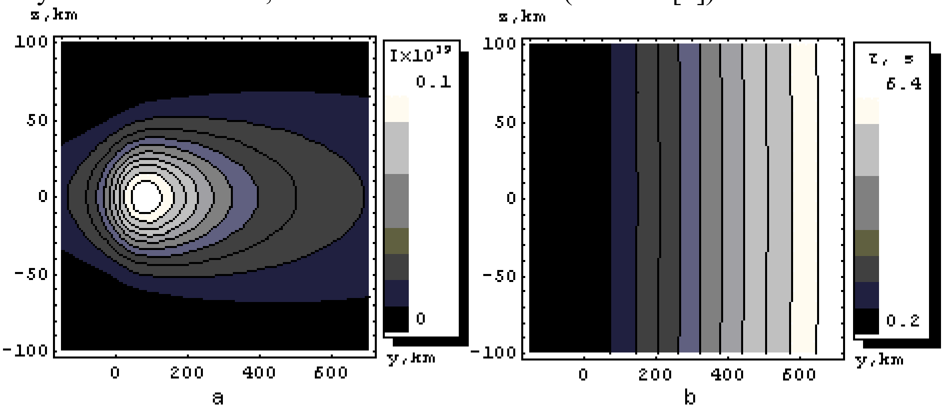


Figure 4

At the analysis of the given results it is necessary to bear in mind that the ratio signal - noise in this case is not taken into account. It follows from the joint analysis of the dependence of the burst intensity and duration that in the area of big burst duration the signal strength goes down and therefore such durations cannot be observed.

4. Conclusion.

Here we provide some results of meteor radio echo simulation on the links of various extents and orientation of a meteor trail. According to the results the trail orientation and its other parameters (an initial diameter, an extent and a diffusion coefficient) substantially affect the space-time distribution of the burst intensity and duration. We have used only the simple model (2) of the cross-section structure of a meteor trail. However, the formula (1) allows considering more complicated models. In this respect the research problem of a meteor trail with radio methods becomes a problem of radio tomography. Such approach is especially vital according to some researches the meteor trail has rather complex cross-section structure.

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