Electric field intensity in cross-section of evaporation duct

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Abstract. This paper is devoted to the investigation of an evaporation duct in the context of its impact on microwave links communication stability. The work contains the numerical results for previously developed mathematical model based on using the dyadic Green’s functions. The electric field intensity dependencies on the receiving antenna suspension height and height of evaporation duct have been obtained for two variants of antenna polarization: horizontal and vertical. These results make it possible to formulate recommendations on how to place the transceiver antennas of microwave links to ensure 24-hour radio communication stability.

1. Introduction
The people, operating the microwave retransmission systems, periodically face the problem with the radio communication stability on long-distance intervals, especially spread over the water objects such as lakes and rivers. In this case, the line of sight presence might be insufficient for an acceptable signal level. A perfectly working daytime microwave link is able to malfunction in the morning.

The reason for this is highly likely to be a fog presence over the water surface. The fog density continuously decreases against the altitude, which can be described by the gradient of a moisture and, consequently, by the gradient of an effective permittivity. Therefore, when constructing the electrodynamic model it is possible to divide the above-water space into \( n \) separate layers with their own finite dielectric constant so as the gradient appears when the number of layers \( n \) tends to infinity. This representation makes it possible to clearly imagine why the connection is being lost. Traditionally, the overland propagation is described with a two-ray model. In the other words, the electric field intensity at the reception point is the result of simultaneous contribution of the direct ray and ray reflected from the underlying surface (from the water surface in the current case). However, this complex medium is nonhomogeneous and more optically dense in the bottom part. That is why, returning upward the radio waves reflected from the water surface, under certain conditions, undergo an effect of total internal reflection and turn out to be guided. Taking into account the very nature of the fog, the phenomenon described above was called as an evaporation duct.

If the transceiving antennas at the both ends are located inside the evaporation duct, the signal transmitted can be additionally enhanced in comparison with the free space propagation [1]. However, sometimes one of antennas (for example, transmitting one) is placed above the evaporation duct. In this case, getting in the duct, the wave, direct in daytime conditions, refracts and deviates from the initially right direction, thereby disrupting the connection between two distant ends.

In order to understand whether it is possible to improve the communication stability by means of relatively simple manipulations with transceiving antennas, we have suggested considering the
evaporation duct as a multilayer structure in [2]–[3]. We have also adapted an apparatus of dyadic Green's functions for its analysis. In contrast to the methods of geometrical optics, Green’s functions make it possible to take into account some crucial nuances such as the antenna pattern and multipath propagation without deep understanding a field interaction between the layers of model and without the necessity to know how many times the signal can reflect inside the duct until it reaches the receiver. We made some reasonable approximations, which then were validated with an example of Hertz dipole in a homogeneous medium. The present work is aimed to obtain numerical results for this model and further develop recommendations for the optimal antennas placement.

2. Model of Evaporation Duct

The developed model of the evaporation duct is presented in figure 1.

![Model of the evaporation duct](image)

Figure 1. Model of the evaporation duct. This is the endless sandwich structure, layers of which are parallel to the water surface. Every layer has its own thickness \( d_p \) and permittivity \( \varepsilon_p \). The coordinate axes are chosen as follows: \( z \)-axis is normal to the layers and directed downward; \( x \) and \( y \) lie in the plane parallel to the water surface and form the right system with \( z \)-axis; the origin coincides with the transmitting antenna position.

At the first stage of simulation we have taken as the transmitting antenna an electric dipole with uniform current distribution along its length. We considered two different cases of dipole orientation, which correspond to two orthogonal variants of linear polarization. The dipole placed along the \( x \)-axis is an equivalent of horizontally polarized antenna, whereas along-\( z \)-axis orientation means the vertical polarization. Therefore, in order to find the electric field intensity in arbitrary point of space, it is only necessary to calculate three components of Green’s function per situation: \( \Gamma_{11xx} \), \( \Gamma_{11yx} \), \( \Gamma_{11zx} \) for horizontal polarization, and \( \Gamma_{11xx} \), \( \Gamma_{11yz} \), \( \Gamma_{11zz} \) for vertical one. However, if the receiving and transmitting antennas are perfectly aligned, the components \( \Gamma_{11yx} \), \( \Gamma_{11zx} \) for the first case and \( \Gamma_{11xx} \), \( \Gamma_{11yz} \) for the second case will be equal to zero at the receiver site. Consequently, the vector of electric field intensity is turned out to be completely specified by the component to which the dipole is parallel.

\( \Gamma_{11xx} \)-component is possible to be found from [2]. The calculation of \( \Gamma_{11xx} \)-component is occurred in accordance with much the same sequence of actions. Firstly, to simplify expressions, we introduced

\[
\rho = k_z \left[ (x - x')^2 + (y - y')^2 \right]^{1/2},
\]

where \( k_z \) is a transverse wavenumber defined as a geometric sum of \( k_x \) and \( k_y \), which are the propagation constants along \( x \) and \( y \) axes, respectively. The dashes here mean the coordinates of transmitter; \( x' \) equals to zero for vertically positioned dipole, whereas \( y' \) has zero value in both cases considered. Then we transformed an inner integral in general formula for \( \Gamma_{11xx} \)-component from [4] to zero-order Bessel function of the first kind \( J_0 (\rho) \), and finally used the saddle-point method:

\[
\Gamma_{11xx} = \sqrt{2\pi} \cdot f_{zz} (k_{z,0}) \cdot \left[ S_{zz} (k_{z,0}) \right]^{1/2} \cdot \exp \left[ S_{zz} (k_{z,0}) \right],
\]

where \( f_{zz} (k_{z,0}) = J_0 (\rho) \cdot k_z / (2\pi\varepsilon_0) \), \( f \) is an operating frequency; \( S_{zz} (k_{z,0}) = \ln \left[ \tilde{Y}^E (0) / \gamma \tilde{Y}^E (0) \right] - i\gamma z \), \( \tilde{Y}^E (0) \) is input E-plane modal admittance recalculated from the water surface to the origin by the recurrence formulas according to [4], \( \tilde{Y}^E (0) = \tilde{Y}^E (0) + \tilde{Y}^E (0) \), \( \tilde{Y}^E (0) \) is top-side input admittance, which equals to equivalent wave admittance of free space for guided TM-waves if transmitting antenna is placed above the evaporation duct; \( \varepsilon_0 \) and \( \gamma \) are the absolute permittivity and longitudinal (along \( z \)-axis) propagation constant of the model layer closest to the point of observation; \( k_{z,0} \) is the
The use of equation (1) is possible independently on where the antennas are placed in relation to the evaporation duct. However, if the transmitting antenna is inside the duct, the second summand in expression for $S_{zzE}$ gets significantly complicated, since the top-side input admittance is also to be recalculated by the recurrence formulas. Thus, the analysis of equation (1) and all variables composing it allow concluding that in order to find the electric field intensity in arbitrary point of space, it is only necessary to correctly find the recalculated to the reference plane admittances, which are completely defined by the thicknesses and complex permittivities of layers into which the whole model is divided. However, it is obvious that resulting analytical expressions for field intensity are hardly possible to get even for two-layered structure due to their awkwardness. Therefore we used computer calculations.

3. Simulation Results

Rephrasing the words from previous section, we can conclude that, in order to determine the electromagnetic field intensity in the evaporation duct, it is only necessary to substitute the distribution of permittivity with height. In a simulation performed by means of MATLAB software we used the linear profile in the range of real numbers from 1.5 at the water surface to 1 at the upper bound of the duct, as it suggested in [5]. We have omitted the imaginary part of permittivity responsible for the losses in the media because it is extremely small at such super high frequencies as the traditional frequencies of retransmission systems are. For example, the dielectric loss tangent of distilled water approximately equals to $10^{-4}$. Consequently, an attenuation constant for wave propagating inside it is very close to 0.08 dB/m. The loss tangent and attenuation in vapour depend on density (concentration) of the fog, and here they are significantly less. Thus, it can be neglected at the first stage of analysis.

We took $n = 100$ as the number of dielectric layers in the model, and $l = 0.01$ m as the dipole length so as it certainly fits in thickness of single slab for vertically oriented radiator. We considered the situation when the transmitting antenna was strictly above the duct – at an altitude of 25 meters, since in many models this value definitely exceeds the mean of evaporation duct height [6]–[7]. At the same time, the evaporation duct cannot appear and disappear immediately, which means that its height varies with time. Therefore, our task was to find "zones of stability" at a certain height. In the other words, it was necessary to detect such receiving antenna suspension heights at which the observed change in the electric field intensity is negligible regardless of the evaporation duct size.

Figures 2 and 3 show the intensity of horizontally and vertically polarized electric field at the receiver position vs. the receiving antenna suspension height and the height of the evaporation duct. The length of considered microwave link is 13.2 km. We believe that communication quality at the existing microwave links is acceptable during the day by default. That is why we decided to normalize the values obtained to the values of day propagation, i.e. to the case when it is possible to use the conventional two ray model. This way of data presentation lets intuitively understand how much worse or better the signal level is in the morning hours in comparison with an afternoon. Figures 2 and 3 make it clear that these "zones of stability" do exist in cross section of the evaporation duct.

Figure 2. The relation between horizontally polarized electric field intensities at the receiver and transmitter sites, normalized to the same in free space: (a) 8 GHz, (b) 13 GHz, (c) 18 GHz.
Figure 3. The relation between vertically polarized electric field intensities at the receiver and transmitter sites, normalized to the same in free space: (a) 8 GHz, (b) 13 GHz, (c) 18 GHz.

For instance, the optimal suspension height of horizontally polarized receiving antenna is 12.5 m at 8 GHz, 18 m at 13 GHz, and 14.5 or 23.5 m at 18 GHz. At the same time, the vertically polarized antennas have a generally better reception under conditions of evaporation duct, even in comparison with the daytime propagation, probably due to the possible occurrence of pure refraction. Here the best values of suspension height are 23.5 m at 8 and 13 GHz, and 9 m at 18 GHz.

4. Conclusion
The present paper provides the numerical results of evaporation duct digital simulation. The analysis of obtained two-dimensional dependencies made it possible to obtain the optimal position of both horizontally and vertically polarized antennas in order to ensure the minimal fluctuations of electric field intensity at the receiver site. The study undertaken for three standard microwave link frequency bands has shown that in spite of difference in particular situations the use of vertical polarization is generally preferable. The results of research allow concluding that the correct adjustment of the receiving antenna suspension height does reduce the influence of evaporation duct on communication quality at the microwave links. Nevertheless, rigorous formulation of recommendations requires more experiments to be conducted.

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