A DUAL MODEL OF THE FOREST AS A RADIO WAVE PROPAGATION MEDIUM

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1. Introduction

Extensive application of radio communication systems and aerospace remote sensing systems causes the invariable interest to problems of radiowave propagation through a forest.

The mechanism of radio wave propagation through a forest includes multiple scattering, diffraction, absorption of radiation by forest constituents. As a result, complicated interference structure of field strength is formed. It is impossible to take into account all factors influencing process of radio wave propagation through forest. Hence, some suppositions about basic mechanism of radio wave propagation should be done. Criterion of choice of the basic mechanism has to be its predominate contribution into intensity of signal being received. We investigate the attenuation of average intensity, when there is a transmitter and a receiver in the forest. Another goal of the investigation is to establish the connection between the specific forest stand parameters and the average characteristics of electromagnetic field propagating through the forest. Verification of the obtained results are carried by means of comparison with experimental data [1, 2].

2. The model of radiowave propagation through forest at short distances

The forest as a radio wave propagation medium is a random layer. The bottom of this layer is the ground. The upper boundary is rough and formed by tree crowns. The description of radio wave propagation is carried with the help of the multiple scattering theory [3]. Measurements show that the coherent part (average field strength) is sufficiently great. We obtain that the average field strength at short distances (x) is

$$U(x) = \exp\left\{ ikx\left[1 - \frac{\nu(1-T)}{ik} \right] \right\}. \qquad (1)$$

This relationship takes into consideration the effects of multiple interaction of radiation with obstacles, namely, field attenuation because of scattering and absorption by great number of trees. The value T depends on tree sizes and complex permittivity distributions as well as on correlation tree diameter with wavelength $\lambda = 2\pi/k$. The value T may be defined from experiments. Another method for estimation T is simulation of electromagnetic scattering from trees. Our calculations give $\mathrm{Re}(T) = 0.7 \pm 0.1$.

The multiple scattering theory allows the characterizing the average field strength in random medium by effective complex permittivity [3]. As a result we obtain the estimation for effective complex permittivity of forest medium: $\varepsilon_l = 1 + \Delta\varepsilon_l$, where $\varepsilon_l = 1 + i \cdot \frac{2\nu(1-T)}{k}$. Effective conductivity of forest is $\sigma_l = \frac{k\,\mathrm{Im}(\varepsilon_l)\sqrt{\mu_0}}{\sqrt{\varepsilon_0}} = \frac{\nu(1-\mathrm{Re}(T))}{60\pi}$. In this equation ν is the trees' average density, T is the "transmission coefficient" for an "average" tree (obstacle).

Measured values of attenuation due to forest depending on distance [1] are shown in Figure 1. Data are obtained for vertical polarization. Hollow circles show attenuation at frequency f_1=110 MHz, solid circles — at f_2=330 MHz. The sections show the typical range of experimental values. The attenuation, calculated by (1) is shown by straight line. Specific attenuation of forest is the tangent of slope angle of this straight line. It is clear, that experimental and theoretical data are in a good

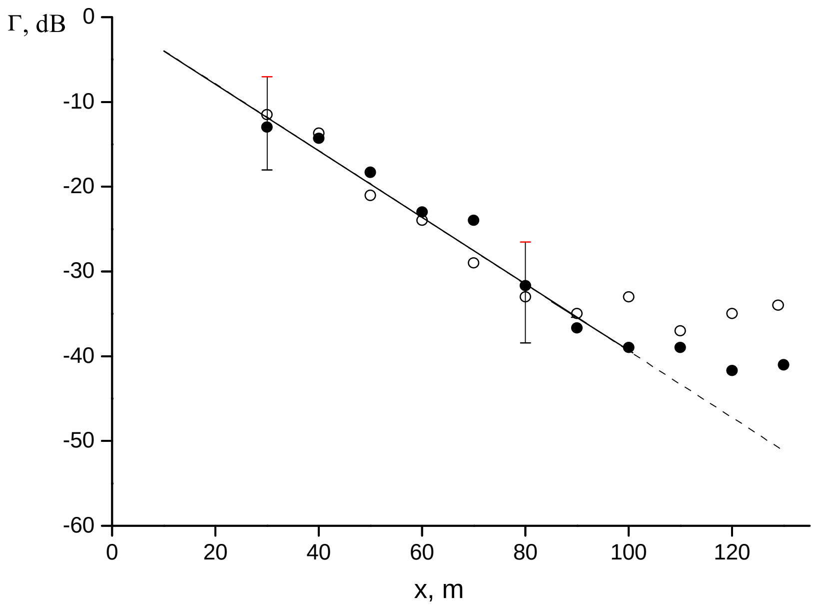

Figure 1 Attenuation due to forest at short distances

agreement for distances less than as x ≤ 100 m. As follows from (1) frequency dependence of specific attenuation is defined by dependence of conductivity with frequency and for frequencies f_1, f_2 is not found.

3. The model of radiowave propagation through forest at large distances

Exponential attenuation of radiowave is observed at short distances, approximately for x <100 m. At grater distances (x >100 m) field strength decreases slowly, it is likely to be degree (power) of distance.

We consider that for explanation of attenuation behavior at large distances it is necessary to take into account ground influence. The reflections from upper boundary of forest may be neglected, as air-forest interface is rough and gradual. It follows from the theory of radio wave propagation along earth surface [4], small terminals around transmitting and receiving antennas give main contribution to field attenuation. Radio wave propagates from transmitter to receiver through upper halfspace, situated between these terminals, some distance above the interface. In this case, the ground terminals cause the field attenuation. If field attenuation into the ground increases, the size of terminals decreases respectively. We consider that similar mechanism of radio wave propagation is valid in the presence of forest covering the ground. Influence of forest layer may be taken into account by correction factor. For determining average (mean) field strength we use Huygens' principle. As a result, the estimation of the average (mean) field strength is

$$U(x) \approx \frac{2i\varepsilon}{kx^2}(1-\delta)\exp\left(1+\delta^{3/2}\right), \qquad (2)$$

where $\delta = \left(\Delta\varepsilon_l\, h/x\right)^{2/3}$. In this equation h is the average forest height, ε is effective complex permittivity of the ground, ε_l — the effective complex permittivity of the forest. The equation (2) takes into account the presence of forest over the ground. When $\delta = 0$ the forest is absent. Hence, average field strength of the wave, propagated over the forest, is attenuated as an inverse square of distance. Similar dependence field strength with distance is obtained for radio wave propagation along earth surface. The presence of forest over the ground would be considered with the help of correction factor for dielectric constant of ground ε . Effective dielectric constant for ground together with forest layer is $\varepsilon_e = \varepsilon(1-\delta)$.

The forest influence increases with the increase of average forest height and effective dielectric constant of forest layer. The forest influence decreases with increase x and when $x \to \infty$ forest influence may be neglected.

Attenuation due to forest obtained from (2) depending on distance is shown in Figure 2 by the straight lines. In Figure 2 experimental data [2] at frequency f_1 =50 MHz are shown by solid circles, at f_2 =200 MHz— by crosses, at f_3 =500 MHz — by hollow circles, at f_4 =800 MHz — by up triangles. The sections show typical range of experimental values. The curve 1 shows attenuation at frequency f_1, the curve 2 — at f_2., the curve 3 — at f_3. , the curve 4 — at f_4. One can see that for x >300 m the proposed model is valid. At shorter distances we observe the influence both mechanisms of radiowave propagation. The experimental data shows that the frequency dependence as inverse square of frequency is valid at frequencies f_1 and f_2. We can't talk about the frequency dependence at f_3 and f_4 , because we don't now the normalization of experimental data.

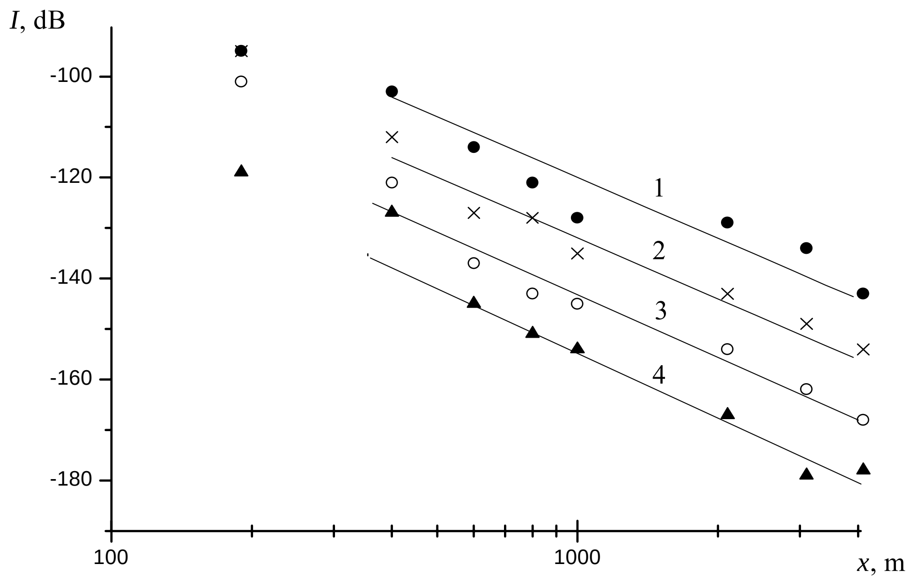

Figure 2. Signal Intensity in the forest at large distances

The good agreement of theory and experiment confirm proposed mechanism of radio wave propagation at large distances.

4. Conclusion

Our investigation shows that radio wave propagation through forest is characterized by dual model. At short distances field strength is determined by direct wave, propagated through the forest and attenuated due to forest vegetation. At large distances the mechanism of propagation is similar to radio wave propagation along earth surface. There are some distances (between "short" and "large") where both mechanisms are valid. The presence of forest causes a little decrease of effective dielectric constant of the ground. At large distances the forest influence may be neglected.

Reference

1. B.C. Dorgiev, V.I. Pletnev and E.M. Khomyak, "Specific Attenuation of Metric Waves Propagating in Forest Medium," in Propagation Electromagnetic Waves, Ulan-Ude BB SB SA USSR, 1987, pp.87-103.
2. R.K. Tewari, S. Swarup, and M.N. Roy, "Radiowave Propagation Through Rain Forest of India," IEEE Trans. Antennas Propagat., Vol. 38, No. 4, 1990, pp.433-449.
3. A. Ishimaru, Wave Propagation and Scattering in Random Media, Academic Press, New York, 1978
4. M. Dolukhanov, Propagation of Radio Waves, Mir Publishers, Moscow, 1971.