PROPAGATION OVER IRREGULAR TERRAIN

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Abstract

The computer model and computation accuracy for propagation over irregular terrain are presented. Special attention is paid to computation for low altitude propagation and the finite distance between the antenna and the observation point (diffraction field zone). The solution for the transient zone is modified to obtain continuous connection of different methods of calculations.

Keywords

computer model, computation accuracy, propagation of electromagnetic waves, propagation over terrain, low altitudes propagation.

1. Introduction

Irregular terrain reflection computations can be found in [1]. Due to the small storage capacity of the Elliott 503 computer, it was necessary to simplify solution to a great extent. A method, similar to [1], is given in [2] but it is derived from more general assumptions and therefore it offers the other possibilities. Two different programs are described in [3]. The first program is intended for radar coverage pattern calculations, when the observation point P in the infinite distance is considered. The second program calculates a propagation factor over the irregular terrain for the finite distance between the antenna and the observation point P. These programs differ from [1] because they allow to compute propagation over irregular terrain for both horizontal and vertical polarization considering the Fresnel reflection coefficient for terrain with random deviations and refraction (it is possible to enter the effective earth radius). To compute reflections, the contributions from the irregular terrain are integrated. That cannot be used, if the difference between the incident and reflected rays is too small. For the difference less than one third of the wavelength, the electric field is computed using very simplified assumptions (see [3], Eq. (7)).

The computer model and computation accuracy for propagation over irregular terrain are presented. Special attention is paid to computation for low altitude propagation and the finite distance between the antenna and the observation point (diffraction field zone). Comparing with [3] the more accurate solution is described for this case. Various cases of electromagnetic wave propagation have been solved. Computation results and published solutions for individual special cases agree quite well. That demonstrates the usefulness of a given method.

2. Calculation of propagation over irregular terrain

Let us consider the antenna A over the earth surface as shown in Fig. 1. If the difference between the incident and reflected rays is greater than one third of the wavelength, the method described in [3] is used. The vector of electric field E at the point P is given by

$$E(P) = E_i(P) + E_s(P) \tag{1}$$

where E (P) is the resultant electric vector, E_i (P) is the incident electric vector, and E_s(P) is the scattering electric vector.

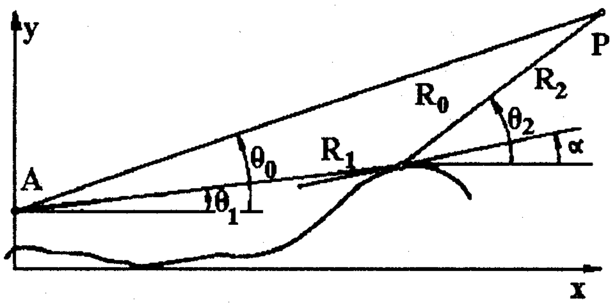

Fig. 1. Propagation geometry

According to [2], the following relationship can be derived

$$\frac{E_s(P)}{|E_0|} = \frac{R_0 e^{j\pi/4}}{\sqrt{\lambda}} \int_{-\infty}^{\infty} f(\theta_1)$$
$$\times \left[\frac{1-\Gamma}{2}\sin(\theta_1-\alpha) + \frac{1+\Gamma}{2}\sin(\theta_2-\alpha)\right]$$
$$\times \frac{e^{-jk(R_1+R_2-R_0)}}{\sqrt{R_1R_2(R_1+R_2)}} \frac{dx}{\cos\alpha} \tag{2}$$

where R_0, R_1, R_2, θ_1, θ_2 and α are shown in Fig. 1, $f(\theta_1)$ is the normalized antenna radiation pattern with phase center in the point A at the height h_A over the earth terrain, Γ is the Fresnel reflection coefficient, $k = 2\pi/\lambda$ and λ is the wavelength. Reflection coefficient for surface with the random deviations is given by

$$\Gamma = \Gamma_0 \exp[-2(2\pi\sigma \sin\gamma_0/\lambda)^2] \tag{3}$$

where σ is the surface standard deviation, Γ_0 is the Fresnel reflection coefficient for the smooth surface and γ_0 is the reflection angle - the angle between the tangent and the incident (reflected) ray.
For calculation, the surface points are read - the length of arc r_B and height h_B according to Fig.2. The coordinates (x_B, y_B) are given by the following expressions

$$x_B = (R_e + h_B)\sin\alpha_z \tag{4}$$

$$y_B = (R_e + h_B)\cos\alpha_z - R_e$$

$$\alpha_z = x_B / R_e$$

where R_e is the effective earth radius (usually R_e = 8500 km).

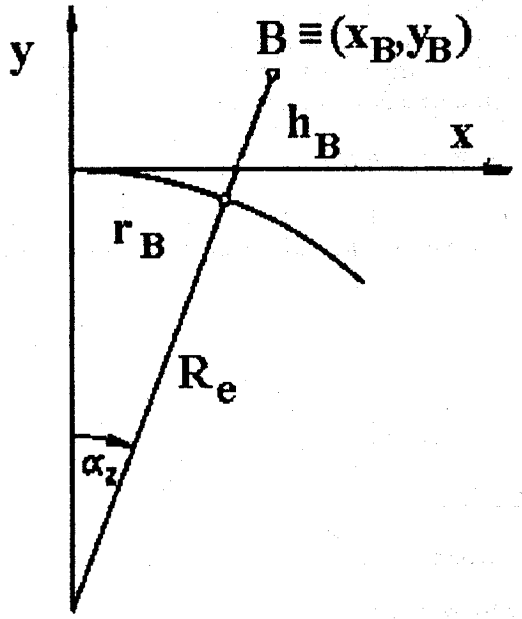

Fig. 2. Curvature correction

The shadow (non-illuminated earth) is considered according to Fig. 3. For the first type of shadow (point x_k), the following expression is obviously valid

$$\theta_k < \theta_z \qquad \text{for} \qquad x_k > x_z \tag{5}$$

For the second type of shadow (point x_k), the following expression is held

$$y_m > y_n + (x_m - x_n)\tan\theta_m \tag{6}$$

The accuracy for this case is considered in [1] and [3].

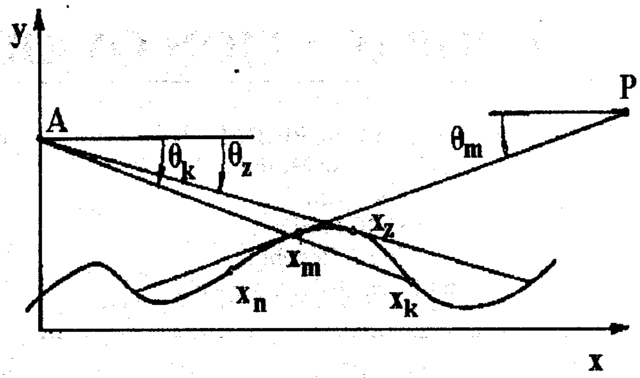

Fig. 3. Shadow areas

3. Low altitudes propagation

For the smaller difference, a very simplified relationship, given in [3], can be used to calculate the coverage pattern but its application for more accurate computations (such as electromagnetic compatibility) is questionable.

If the surface change is stepped (such as obstacle with the sharp edge on the plane surface), the attenuation of electric field is computed using the relationship for electric field calculation over infinite half-plane when the function $F(x)$ is computed using the complex Fresnel integral as described in [2], paragraph 17.1

$$F(v) = \frac{e^{j\pi/4}}{\sqrt{\pi}} \int_{-\infty}^{v} e^{-jt^2}\,dt\,, \tag{7}$$

where v is the square root of phase difference of rays R_1, R_2 and R_0. That can approximately be given by

$$v = h\sqrt{\frac{\pi(R_1 + R_2)}{\lambda R_1 R_i}}$$

h, R_1 and R_2 are shown in Fig. 4, λ is a wavelength.

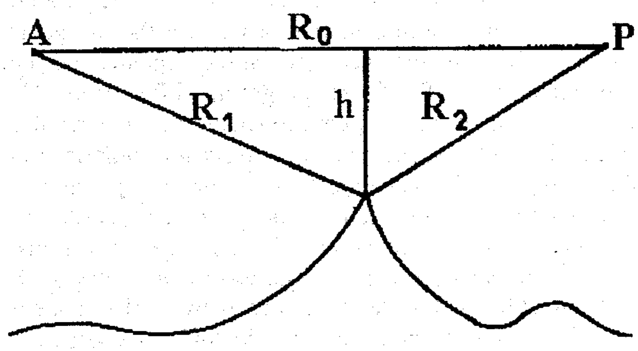

Fig. 4. Propagation over irregular terrain (knife-edge)

Usually, we can consider propagation over the spherical earth or approximate the round obstacle with the spherical surface. Calculation of propagation over the spherical surface was performed by Fok as described in [4], [5]. This accurate solution, given by series, converges very slowly for slightly greater altitudes. If the program [5] is used, the computation for some cases (for various combinations of heights and distances) is very slow and sometimes it fails completely. Therefore, it is better to approximate the attenuation according to [2] or [6] by

$$A_{vx} = 20 \log F(v) + T(x) + Q(v,x), \quad \text{[dB]} \quad (8)$$

where $F(v)$ is given by (7).

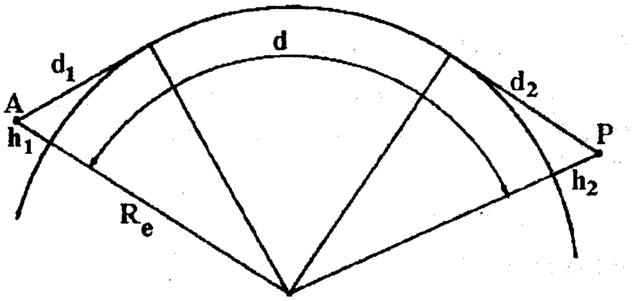

Fig. 5. Propagation over sphere

Functions $T(x)$ and $Q(v,x)$ can be evaluated using the expressions [2] or [6]. As stated in [2], the derivative of expressions [6] is not continuous at $v = 0$. On the other hand, the expressions [6] usually approximate the accurate solution better and therefore the program uses expressions [6]

$$T(x) = -7.2x + 2x^2 - 3.6x^3 + 0.8x^4 \quad \text{[dB]}$$

where

$$x = (R_e)^{1/3} (\lambda / \pi)^{1/6} \sqrt{\frac{d_1 + d_2}{d_1 d_2}},$$

R_e is the effective earth radius (usually $R_e = 8500$ km), d_1, d_2 are shown in Fig. 5,

$$Q(v,x) = 17vx + 6 + 20 \log(-vx) \quad \text{[dB]}$$

for $vx \leq 4$,

$$Q(v,x) = 12.5\, vx$$

for $-4 < vx \leq 0$,

$$Q(v,x) = -T(x)\, v$$

for $0 < v \leq 1$.

For small heights and therefore for small distances d_1 and d_2, it is not possible to use (8) as x is large. In this case, the infinite series can be approximated [4], [7] by

$$A_{LH} = W(d/L) + U(h_1/H) + U(h_2/H). \quad \text{[dB]} \quad (9)$$

According to [7], the following approximation can be used

$$W(d/L) = 10 \log (4\pi d/L) - 17.5455 d/L,$$

where d is shown in Fig. 5,

$$L = \left(\frac{\lambda R_e}{8\pi^2} \right)^{1/3}$$

The following approximation can be derived using the graph [7]

$$U(h_1/H) = 20 u_1 + 0.5$$

for $u_1 < 0$,

$$U(h_1/H) = 20\, u_1 (1 + u_1) + 0.5$$

for $0 \leq u_1 < 1.3$,

$$u_1 = \log (h_1/H),$$

$$H = \left(\frac{\lambda^2 R_e}{8\pi^2} \right)^{1/3}$$

$U(h_2/H)$ can be computed analogously.

Approximation (9) assumes that h_1/H is very small. If this condition is not fulfilled and the expression (8) cannot be used, the following approximation is used

$$A_{LH1} = 4.8 + U(h_1/H) - U(h_3/H) \quad \text{[dB]} \quad (10)$$

for $U(h_1/H) > 60$ or $U(h_1/H) + W(d/L) > -20$, where h_3 is such a height of point P when the difference between the reflected and incident rays is one third of the wavelength i.e. the phase difference is $2\pi/3$.

The first condition follows from $u_1 < 1.3$. The second condition follows from the requirement that the remainder of the infinite series could be neglected. This approximation assumes that the electric field for the height $h_2 = h_3$ is the same as the electric field for reflection from the plane surface when $2 \sin (\pi/3)$ is obtained that corresponds 4.8dB.

If h_2/H is not very small and (8) cannot be used, the following approximation is used

$$A_{LH2} = A_{LH} + b(h_2 - h_4)/(h_3 - h_4) \quad \text{[dB]} \quad (11)$$

for $U(h_2/H) > 60$ or $U(h_2/H) + W(d/L) > -20$, where $b = 4.8 - U(h_1/H) - U(h_3/H) - W(d/L)$ and h_4 is such a height of the point P when the condition given above is just not fulfilled.

Described methods are used for various antenna and observation point heights. If the surface change is stepped, the expression (8) can be evaluated using $x = 0$ and therefore it is not necessary to treat this case specially. The local roughness is not considered for expressions (6) to (10) as they are replaced by the mean value.

4. Transient zone

The solution for the transient zone is modified to obtain continuous connection of different methods of calculations (the similar approach is used in [8]).

If the difference between the incident and reflected rays $R_1+R_2-R_0$ is greater than one third of the wavelength i.e. $v>\sqrt{(2\pi/3)}$, the reflections from the irregular terrain are integrated using (2). For the transient zone, the resulting attenuation is computed using

$$A=\left(A_s(v-1)+A_k\left(\sqrt{(2\pi/3)}-v\right)\right)/\left(\sqrt{(2\pi/3)}-1\right) \tag{12}$$

for $1<v\leq\sqrt{(2\pi/3)}$

$=A_k$

for $v\leq 1$, where $A_s=A_i(v-1)/(\sqrt{(2\pi/3)}-1)$, A_i is obtained by integration for point P where $v=\sqrt{(2\pi/3)}$,

$A_k=A_{vx}$

for $x<1$,

$=(A_{vx}(1.5-x)+A_{LH}(x-1))/0.5$

for $1\leq x<1.5$,

$=A_{LH}$

for $x\geq 1.5$.

5. Conclusions

The computer model and computation accuracy for propagation over irregular terrain are presented. The program differs from [1] because it allows to compute propagation over irregular terrain for both horizontal and vertical polarization considering the Fresnel reflection coefficient for terrain with random deviations and refraction (it is possible to enter the effective earth radius). To compute reflections, the contributions from the irregular terrain are integrated. That cannot be used, if the difference between the incident and reflected rays is too small. Special attention is paid to computation for low altitude propagation and the finite distance between an antenna and an observation point. The program uses various relations for this special case. The solution for the transient zone is modified to obtain continuous connection of different methods of calculations.

Computation results obtained by described program agree quite well with the calculations of special cases such as two obstacles with the sharp edges or the spherical earth when the computations have been compared with calculations [5] or with calculations using reflections from the infinity plane earth. The relevant paper is under preparation. That demonstrates the usefulness of a given method.

Some problems arise for the transient zone. The transition between the integration over irregular terrain and low altitude propagation is continuous due to expression (12) but it is not smooth. This is caused by various calculation methods. Of cause, it would be possible to smooth the transition but this problem cannot be solved generally.

The modification of the expression (9) by the relationship (10) is not optimum but that is rather exception. This modification is only used for great heights h_1 and small h_2 as for greater h_2 the expression (8) is used.

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