IRREGULAR TERRAIN EFFECT ON RADIOWAVE PROPAGATION

Vladimir SCHEJBAL, Dušan ČERMÁK

Department of electrical and electronic engineering and signaling in transport

1.Introduction

Propagation of electromagnetic waves over terrain is very challenging for various problems such as communications, radar coverage and antenna far-field measuring range[1]. The geometrical optics and various GTD modifications could be used but GTD fails to predict fields at caustics. An integral equation approach is very slow and neglect backscattering, which plays an important role in field calculations, particularly in deep shadow regions.

This paper describes an improved analysis of electromagnetic wave propagation over irregular terrain using physical optics approximation of vector problem. Numerical simulations are compared with measurement results. That allows more reliable computations for low altitude propagations and diffraction field zone.

2.Propagation over Irregular Terrain

Let us consider the antenna *A* over the earth surface as shown in Fig. 1. The total field everywhere could be calculated as the sum of the incident wave and the scattered field. The resultant electric vector E(P) at the point *P* is given by[1]

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

Where

E_i(P).....................................the incident electric vector,
E_s(P).....................................the scattered electric vector.

The incident field could be considered as a spherical wave at any reflecting point. It could be decomposed into two parts (parallel and perpendicular to the incident plane). According to the equivalence principle, a real scattering object is replaced by the equivalent currents induced on its surface, i.e. a distribution of equivalent sources in free space should be considered, which radiate without restraint in all directions. If these sources were determined correctly that would provide the correct solution to the scattering problem.
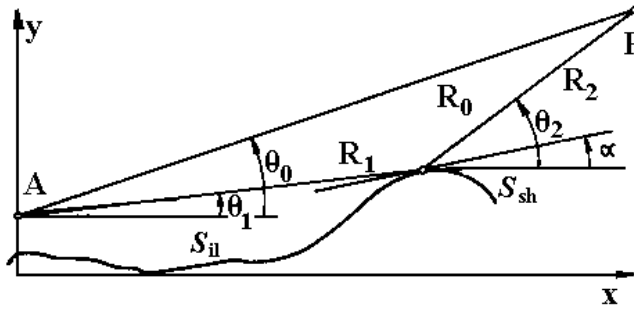

Fig. 1 Propagation geometry

Scattering of electromagnetic waves by arbitrary opaque objects with local reflection coefficient can be determined using physical optics (PO) approximation. The terrain surface could be divided into S_{il} and S_{sh} (illuminated and shadowed parts) with a shadow contour between them, as is shown in Fig. 1.

The propagation over a terrain (the PO approximation of the vector problem with 3-D surface) can be approximated by the propagation over a 2-D surface[1]. The following equation can be derived for the horizontal polarization component $E_{sz}(P)$ and the maximum value of incident electric vector E_0 at a distance R_0

$$\frac{E_{sz}(P)}{|E_0|} = \frac{R_0 e^{j\pi/4}}{2\sqrt{\lambda}} \int_a^b f(\theta_1) \left[(1-\Gamma)\sin(\theta_1 - \alpha)\sin(\theta_2 - \alpha) \frac{e^{-jk(R_1+R_2-R_0)}}{\sqrt{R_1 R_2 (R_1 + R_2)}} \frac{dx}{\cos\alpha} + (1+\Gamma) \right] \quad (2)$$

Where

R_0, R_1, R_2, θ_1, θ_2 and α ....shown in Fig. 1,

$f(\theta_1)$ ....the normalized antenna radiation pattern with phase center at point A at height h_A over the terrain,

Γ the local Fresnel reflection coefficient,

k..$= 2\pi/\lambda$,

λ..the wavelength,

a, b.......................................limits of the illuminated part S_{il}.

Considering Ufimtsev's results a new explanation to analyze propagation over irregular terrain could be used[1]. The scattered field (2) can be divided into two parts, i.e. the reflected radiation component, E_{sz}^{ref}, (with the reflection coefficient Γ terms) and the shadow radiation component, E_{sz}^{sh} (without the reflection coefficient Γ terms).

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A similar equation can be derived for vertical polarization using H_{sz} Therefore, this method takes into account the polarization. Moreover, the reflection coefficient for a surface with random deviations could be calculated.

Numerical simulations, measurements and published solutions have validated individual special cases of the described method (2). That has been extensively used for higher altitude propagation computations of radar coverage, radar site studies and analyses of various antenna far-field measurement ranges[1].

The previous transient zone (TZ) and low altitude computations (LAP) using knife-edge diffraction approximations and Fock's spherical surface solutions, which neglect terrain imperfections, are only approximate solutions. The comparison of the previous solution for higher altitudes (POT) and the new (Improved) methods shows that only small differences exist. Therefore the new approach to analyze propagation over irregular terrain could be much more accurate. The problems of the described method are due to approximations accepted for the surface field. They could be diminished using the 2D physical theory of diffraction (PTD), which is a natural extension of physical optics[1, 2, 3].

3. Conclusions

One example of the terrain profile of the antenna far-field measurement range is shown in Fig. 2.
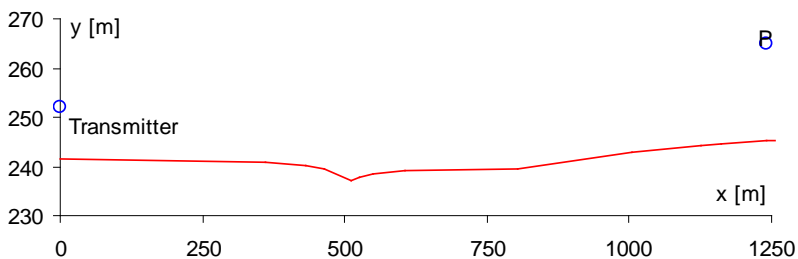

Fig. 2 *Terrain profile of antenna far-field measurement range*

Measured and various calculated values of $A = 20 \log |E(P)/E_0|$, where E(P) is the resultant electric vector, are shown in Fig. 3 for antenna far-field measurement range (the value of $h = 0$ corresponds to a origin of measurement scanner). The field was measured by a small horn to diminish a directivity effect of used horn with vertical scanning movement of 5 m. The transmitting antenna was on a tower with height of 10 m and a receiving antenna (horn) was placed on tower with height of 16 m at distance of 1 240 m. In this case, a shadowing object does not exist, and therefore the terrain between both antennas forms illuminated part. Two examples of calculations for antenna range (with terrain profile shown in Fig. 2) are shown in Fig. 3 for very dry surface (relative permittivity of $\varepsilon_r = 3.2\text{-}0.015\text{j}$) with random deviations $\sigma = 0.2$ m and very wet surface ($\varepsilon_r = 30\text{-}2.5\text{j}$) along with the normalized incident field. It could be noted that the measurements were performed several times and changes due to various terrain conditions (summer, winter,

snow or vegetation) were comparable with numerical simulations. Similarly, the measurements for vertical polarization have been done with comparable results.

It can be seen that the measurement values are in agreement with the calculation. The differences could be explained by reflections from objects in the neighborhood of the horn such as a tower structure and guard rails and by reflection coefficient changes. That depends on terrain conditions (e.g. the earth surface could be covered by snow, plowed or overgrown by vegetation). It affects both reflected and total field but it is not usually substantial as the local reflection coefficient $\Gamma \approx -1$ for a low grazing angle regardless of polarization and surface standard deviation.
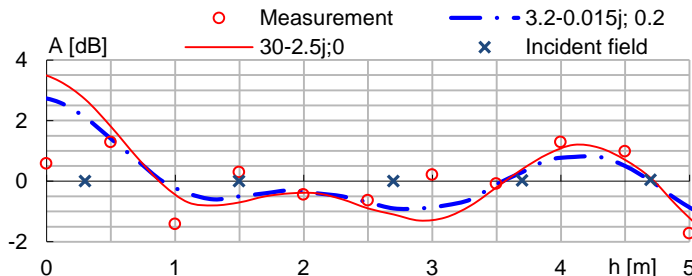
Fig. 3 *Measurement of antenna far-field range and calculations of $A = 20 \log |E(P)/E_0|$ with $\sigma = 0.2$ m and $\varepsilon_r = 3.2 - 0.015j$ and $\sigma = 0$ and $\varepsilon_r = 30 - 2.5j$ along with normalized incident field*

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References

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Resumé

VLIV NEROVNÉHO TERÉNU NA ŠÍŘENÍ RADIOVÝCH VLN

Vladimir SCHEJBAL, Dušan ČERMÁK

V článku se studuje zlepšená analýza šíření radiových vln nad nerovným terénem s použitím fyzikální optiky pro vektorový problém. Metoda nabízí spolehlivé numerické simulace pro šíření v nízkých výškách a difrakční zóně bez dalších pomocných procedur. Numerické simulace se srovnávají s výsledky měření.

SUMMARY

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An improved analysis of propagation over irregular terrain using physical optics approximation of vector problem is presented. It offers more reliable numerical simulations for low altitude propagation and diffraction field zone without any auxiliary procedures. Numerical simulations are compared with measurement results.

Zusammenfassung

EINFLUSS EINES UNEBENEN TERRAINS AUF DIE AUSBREITUNG ELEKTROMAGNETISCHER WELLEN

Vladimir SCHEJBAL, Dušan ČERMÁK

Im Artikel wird die verbesserte Analyse der Ausbreitung elektromagnetischer Wellen über einem unebenen Terrain mit der Verwendung der physikalischen Optik für das Vektorproblem untersucht. Die Methode bietet eine zuverlässige numerische Simulation für die Ausbreitung in niedrigen Höhen und in der Diffraktionszone ohne andere zusätzliche Hilfsprozeduren. Die numerischen Simulationen werden mit den Ergebnissen der Messungen verglichen.